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ORIGINAL SCIENTIFIC PAPERS

Confining a non-negative solution between a lower and upper solution for a sixth-degree boundary value problem

Zouaoui Bekri[a], *Nicola* Fabiano[b], *Mohammad Esmael* Samei[c], *Stojan* Radenović[d]

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FIELD: mathematics
ARTICLE TYPE: original scientific paper

Abstract:

Introduction/purpose: The aim of the paper is to prove the existence of solutions for a special case of the sixth-order boundary value problem.

Methods: The Leray-Schauder fixed point theorem is used in order to determine lower and upper bound solutions.

Results: Lower and upper bound solutions have been found.

Conclusions: The sixth-order boundary value problem admits solutions.

Key words: Leray-Schauder nonlinear alternative, Green's function, fixed point theorem, lower and upper solutions, boundary value problem.

Introduction

Many modern mathematical studies are based on modeling phenomena in various applied branches, and simulating the results. Often, it is important to evaluate the obtained results at least with approximate solutions. One of these cases concerns BVPs related to sixth-degree differential equations derived mostly from physical phenomena and applied mathematics.

Some authors have addressed the problem of obtaining positive solutions to a sixth-degree BVP by employing multiple methods, such as the spectral operator theory, the general bifurcation theorem, the minimization theorem, and the fixed point theory in the cone, see references (Möller & Zinsou, 2013; Tersian & Chaparova, 2002; Li, 2012; Agarwal et al., 2013; Ji et al., 2012; Kovács & Guedda, 2014; Zhang & An, 2010; Mirzaei, 2016; Yang, 2019). Not a long time ago, the authors of this paper analyzed sixth-order BVPs with different boundary conditions at two points (Bekri & Benaicha, 2018, 2020). In 2018, see reference (Bekri & Benaicha, 2018), the same authors formed the conditions for finding the existence of solutions for a sixth-degree BVP:

$$\begin{cases} -\xi^{(6)}(\varepsilon) + \hbar\left(\varepsilon, \xi(\varepsilon), \xi^{''}(\varepsilon)\right) = 0, \quad 0 \leq \varepsilon \leq 1, \\ \xi(0) = \omega^{'}(0) = \xi^{''}(0) = 0, \\ \xi^{'''}(1) = \xi^{(4)}(1) = \xi^{(5)}(1) = 0, \end{cases}$$

where $\hbar \in C([0,1] \times \mathbb{R}^2)$. Suitable operators are employed in the proof of the nonlinear Leray-Schauder alternative. Also, in 2020, (Bekri & Benaicha, 2020), created all the necessary factors to prove the existence of non-negative solutions for a BVP of the sixth-order

$$\begin{cases} -\xi^{(6)}(\varepsilon) + z(\varepsilon)\hbar\left(\varepsilon, \xi(\varepsilon), \xi^{'}(\varepsilon), \xi^{''}(\varepsilon), \xi^{'''}(\varepsilon), \xi^{(4)}(\varepsilon), \xi^{(5)}(\varepsilon)\right) = 0, \\ 0 \leq \varepsilon \leq 1, \\ \xi(0) = \xi^{'}(1) = \xi^{''}(0) = 0, \\ \xi^{'''}(1) = \xi^{(4)}(0) = \xi^{(5)}(1) = 0, \end{cases}$$

where $\hbar \in C([0,1] \times [0,+\infty) \times [0,+\infty) \times (-\infty,0] \times (-\infty,0] \times [0,+\infty) \times [0,+\infty) \longrightarrow [0,+\infty))$. The authors focused on the fixed point theorem

of Leray-Schauder and on a nonlinear version of the theorems of Leray-Schauder type. For more examples, see (Chabanea et al., 2022; Fabiano & Parvaneh, 2021; Samei et al., 2021b; Fabiano et al., 2020; Samei et al., 2021a; Boutiara et al., 2021; Santra et al., 2023; Houas & Samei, 2023; Hammad et al., 2022; Amiri & Samei, 2022; Boutiara et al., 2023).

This work demonstrates the existence of a solution for sixth-degree six-point BVPs

$$\begin{cases} -\xi^{(6)}(\varepsilon) + \hbar\left(\varepsilon, \xi(\varepsilon), \xi^{(5)}(\varepsilon)\right) = 0, \quad 0 < \varepsilon < 1, \\ \xi(0) = \xi^{'}(0) = \xi^{''}(0) = 0, \\ \xi^{'''}(1) = \xi^{(4)}(1) = \xi^{(5)}(0) = 0, \end{cases} \tag{1}$$

where $\hbar \in C([0,1] \times \mathbb{R}^2)$, and

$$\begin{cases} -\xi^{(6)}(\varepsilon) + \hbar\left(\varepsilon, \xi(\varepsilon), \xi^{'}(\varepsilon), \xi^{(5)}(\varepsilon)\right) = 0, \quad 0 < \varepsilon < 1, \\ \xi(0) = \xi^{'}(0) = \xi^{''}(0) = 0, \\ \xi^{'''}(1) = \xi^{(4)}(1) = \xi^{(5)}(0) = 0, \end{cases} \tag{2}$$

where $\hbar \in C([0,1] \times \mathbb{R}^3)$.

This article is structured as follows. The section on the basic concepts reviews the definition and three lemmas to realize the analysis. Then, the part on the main results presents some desired results because there are solutions for two nonlinear sixth-order BVPs. The methodology used here is based on the Schauder fixed point theorem and the lower and upper solution method by creating the aforementioned estimates. The fourth, final part, Application, offers a few similar examples to demonstrate the findings.

Basic concepts

Within this section, a BVP (1) with the condition $\hbar \in C([0,1] \times \mathbb{R}^2, \mathbb{R})$, and $A = C^6[0,1]$ is put forward. Some lemmas that define the role of the nonlinear term are summarized and lower or upper solutions are generated.

DEFINITION 1. *Assume* $\zeta, \eta \in C^2[0,1] \cap A$ *lower and upper solution of the BVP* (1)*, respectively, if for* $0 < \varepsilon < 1$*,*

$$-\zeta^{(6)}(\varepsilon) + \hbar(\varepsilon, \zeta(\varepsilon), \zeta^{(5)}(\varepsilon)) \geq 0,$$

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$$\zeta(0)=\zeta^{'}(0)=\zeta^{''}(0)=\zeta^{'''}(1)=\zeta^{(4)}(1)=0, \qquad \zeta^{(5)}(0)\geq 0,$$
$$-\eta^{(6)}(\varepsilon)+\hbar(\varepsilon,\eta(\varepsilon),\eta^{(5)}(\varepsilon))\leq 0,$$
$$\eta(0)=\eta^{'}(0)=\eta^{''}(0)=\eta^{'''}(1)=\eta^{(4)}(1)=0, \qquad \eta^{(5)}(0)\leq 0.$$

LEMMA 1. *Let it be $k\in C([0,1])$. So the five-point BVP*

$$\begin{cases} \xi^{(5)}(\varepsilon)=k(\varepsilon), & 0<\varepsilon<1,\\ \xi(0)=\xi^{'}(0)=\xi^{''}(0)=0, \quad \xi^{'''}(1)=\xi^{(4)}(1)=0, \end{cases} \tag{3}$$

is simulated by the integral equation

$$\xi(\varepsilon)=\int_0^1 \chi(\varepsilon,\varrho)k(\varrho)\,\mathrm{d}\varrho,$$

where $\chi:[0,1]\times[0,1]\to[0,+\infty)$ is the Green's function defined by

$$\chi(\varepsilon,\varrho)=\frac{1}{24}\begin{cases} \varepsilon^3(4\varrho-\varepsilon), & 0\leq\varepsilon\leq\varrho\leq 1,\\ \varrho^2(\varrho^2+6\varepsilon^2-4\varepsilon\varrho), & 0\leq\varrho\leq\varepsilon\leq 1. \end{cases} \tag{4}$$

Define the integral operator $P:A\to A$ by

$$P\xi(\varepsilon)=\tfrac{1}{24}\int_0^{\varepsilon}\varrho^2\left(\varrho^2+6\varepsilon^2-4\varepsilon\varrho\right)k(\varrho)\,\mathrm{d}\varrho+\tfrac{1}{24}\int_{\varepsilon}^1\varepsilon^3(4\varrho-\varepsilon)k(\varrho)\,\mathrm{d}\varrho.$$

According to Lemma 1, if the operator P admits a fixed point in A, it implies that the BVP (1) has a solution. Thus, one found a fixed point of P in A. Using the theorem of Ascoli-Arzelà, one checks that P is an operator which is completely continuous. Therefore, a nonlinear alternative of Leray-Schauder is given.

LEMMA 2. *(Deimling, 1985) Let A be a Banach space of and Ψ be a subset that is open and bounded of A, $0\in\Psi$. Let $P:\overline{\Psi}\to A$ be a completely continuous operator. Therefore, either*

(i) $\exists\,\xi\in\partial\Psi$ *and* $\nu>1$ *in which* $P(\xi)=\nu\xi$, *or*

(ii) $\exists\,\xi^*$ *a fixed point such that* $\xi^*\in\overline{\Psi}$.

LEMMA 3. *By $\chi(\varepsilon,\varrho)$ given by (4), the following holds*

$$(J1)\quad \frac{\chi(\varepsilon,\varrho)}{\chi(\varrho,\varrho)}\leq 1 \quad for \quad \varepsilon,\varrho\in(0,1),$$

$$(J2)\quad \frac{\chi(\varepsilon,\varrho)}{\chi(\varrho,\varrho)} \geq V > 0 \quad for \quad \varepsilon,\varrho \in (0,1),$$

$$(J3)\ \varsigma = \int_0^1 \chi(\varrho,\varrho)\varrho d\varrho, \quad such\ that\ \ \varsigma > 0.$$

Main results

This section introduces some concepts in the form of lemmas indicating some bounds on the nonlinear term and the construction of lower or upper solutions. Consider that $\hbar \in C([0,1]\times\mathbb{R}^2)$, and $\hbar \in C([0,1]\times\mathbb{R}^3)$.

LEMMA 4. *Let there be a real $\varpi \geq 0$ in which*

$$\hbar(\varepsilon,\mu,\nu) \leq \varpi, \quad for \quad 0 \leq \varepsilon \leq 1, \quad \varsigma\varpi V \leq \mu \leq \varsigma\varpi, \quad -\varpi \leq \nu \leq 0,$$

so the BVP (1) admits an upper solution.

Proof. We put $\Sigma(\varepsilon) = \xi^{(5)}(\varepsilon)$, so problem (1) is parallel to the equivalent problem

$$\begin{cases} \Sigma'(\varepsilon) = \hbar\left(\varepsilon,(\vartheta\Sigma)(\varepsilon),\Sigma(\varepsilon)\right), \quad 0<\varepsilon<1, \\ \Sigma(0) = 0, \end{cases} \tag{5}$$

where $(\vartheta\Sigma)(\varepsilon) = \int_0^1 \chi(\varepsilon,\varrho)\Sigma(\varrho)\,\mathrm{d}\varrho$ and $\chi(\varepsilon,\varrho)$ is given by (4). It is obvious that the bound on $\hbar$ ensures that $\Xi(\varepsilon) = \varpi\varepsilon$ realizes the inequality

$$\begin{cases} \Xi'(\varepsilon) - \hbar\left(\varepsilon,(\vartheta\Xi)(\varepsilon),\vartheta(\varepsilon)\right) \geq 0, \quad 0<\varepsilon<1, \\ \Xi(0) \geq 0. \end{cases} \tag{6}$$

From this, it holds that $\eta(\varepsilon) = (\vartheta\Xi)(\varepsilon)$ is an upper solution of the BVP (1). □

LEMMA 5. *Let there be a real number $\kappa \leq 0$ such that*

$$\hbar(\varepsilon,\mu,\nu) \geq \kappa, \quad for \quad 0 \leq \varepsilon \leq 1, \quad \varsigma\kappa \leq \mu \leq \varsigma\kappa V, \quad 0 \leq \nu \leq -\kappa,$$

so the BVP (1) has a lower solution.

Proof. Suppose that $\Gamma(\varepsilon) = \kappa\varepsilon$. Then, it is obvious that the bound on $\hbar$ ensures that $\Gamma(\varepsilon) = \kappa\varepsilon$ provides

$$\begin{cases} \Gamma^{'}(\varepsilon) - \hbar\left(\varepsilon, (\vartheta\Gamma)(\varepsilon), \Gamma(\varepsilon)\right) \leq 0, \quad 0 < \varepsilon < 1, \\ \Gamma(0) \leq 0, \end{cases} \tag{7}$$

this inequality proves that $\zeta(\varepsilon) = (\vartheta\Gamma)(\varepsilon)$ is a lower solution of the BVP (1). □

COROLLARY 1. *The upper solution $\eta(\varepsilon)$ and the lower solution $\zeta(\varepsilon)$ of the BVP (1) can be written in a simple manner:*

$$\eta(\varepsilon) = \frac{\varpi}{720}\varepsilon^6 - \frac{\varpi}{48}\varepsilon^4 + \frac{\varpi}{18}\varepsilon^3,$$

$$\zeta(\varepsilon) = \frac{\kappa}{720}\varepsilon^6 - \frac{\kappa}{48}\varepsilon^4 + \frac{\kappa}{18}\varepsilon^3.$$

THEOREM 1. *Let there be two real numbers $\varpi \geq 0 \geq \kappa$, $\varpi \geq |\kappa|$ such that*

$$\hbar(\varepsilon, \mu, \nu) \leq \varpi, \qquad 0 \leq \varepsilon \leq 1, \quad \varsigma\varpi V \leq \mu \leq \varsigma\varpi, \quad -\varpi \leq \nu \leq 0, \tag{8}$$

$$\hbar(\varepsilon, \mu, \nu) \geq \kappa, \qquad 0 \leq \varepsilon \leq 1, \quad \varsigma\kappa \leq \mu \leq \varsigma\kappa V, \quad 0 \leq \nu \leq -\kappa. \tag{9}$$

If $\hbar(\varepsilon, \mu, \nu)$ is nondecreasing in μ, so the BVP (1) admits a solution $\xi(\varepsilon)$ for which

$$\zeta(\varepsilon) \leq \xi(\varepsilon) \leq \eta(\varepsilon), \quad \zeta^{(5)}(\varepsilon) \leq \xi^{(5)}(\varepsilon) \leq \eta^{(5)}(\varepsilon), \qquad \varepsilon \in [0, 1],$$

where

$$\zeta(\varepsilon) = \kappa \int_0^1 \chi(\varepsilon, \varrho)\varrho \, \mathrm{d}\varrho, \quad \eta(\varepsilon) = \varpi \int_0^1 \chi(\varepsilon, \varrho)\varrho \, \mathrm{d}\varrho, \qquad \varsigma = \tfrac{1}{48}.$$

Proof. According to formulas (8) and (9), Lemmas 4 and 5 together produce the result that the BVP (1) accepts an upper solution $\eta(\varepsilon)$ and a lower solution $\zeta(\varepsilon)$. Define $\Gamma = \zeta^{(5)}$, $\Xi = \eta^{(5)}$, therefore $\Gamma^{'}(\varepsilon) = \kappa \leq \varpi = \Xi^{'}$. In another way, $\varpi \geq 0 \geq \kappa$ implies $\zeta^{(5)}(\varepsilon) \leq \eta^{(5)}(\varepsilon)$. This implies that $\chi(\varepsilon, \varrho) \geq 0$ and, depending on the boundary condition, $\zeta(\varepsilon) \leq \eta(\varepsilon)$, for $0 \leq \varepsilon \leq 1$. Now, introduce the following operators Δ, Θ, where $\Delta : \operatorname{dom}\Delta = \left\{\Sigma \in C^1(0,1) \cap C[0,1] \to C[0,1] : \Sigma(0) = 0\right\}$ is a derivative operator such that $(\Delta\Sigma)(\varepsilon) = \Sigma^{'}(\varepsilon)$, $\varepsilon \in (0,1)$, and $\Theta : C[0,1] \to C[0,1]$ is

a continuous operator for which

$$\Delta\Sigma = \Theta\Sigma, \qquad \Sigma \in \mathrm{dom}(\Delta), \tag{10}$$

where Θ is given by

$$(\Theta\Sigma)(\varepsilon) = \hbar\left(\varepsilon, \vartheta\left(\min\left\{\Xi, \max\left\{\Sigma, \Gamma\right\}\right\}\right), \min\left\{\Xi, \max\left\{\Sigma, \Gamma\right\}\right\}\right). \tag{11}$$

This shows that if Σ^* is a solution of (10), then $\Gamma(\varepsilon) \leq \Sigma^*(\varepsilon) \leq \Xi(\varepsilon)$, $\varepsilon \in [0,1]$. Therefore, $\Sigma^*(\varepsilon)$ is a solution of (7). In addition $\xi^*(\varepsilon) = (\vartheta\Sigma^*)(\varepsilon)$ is a solution of the BVP (1) realizing $\zeta(\varepsilon) \leq \xi^*(\varepsilon) \leq \eta(\varepsilon)$. If $\Gamma(\varepsilon) > \Sigma^*(\varepsilon)$, there exists $\varepsilon_1 \in [0,1]$ such that $\Gamma(\varepsilon_1) > \Sigma^*(\varepsilon_1)$. Also, $\Sigma^*(0) = 0 = \zeta^{(5)}(0) = \Gamma(0) = 0$, as Σ^* and Γ are continuous, so we have an interval $(\varepsilon_2, \varepsilon_3)$ in which $\Gamma(\varepsilon_2) = \Sigma^*(\varepsilon_2)$ and $\Gamma(\varepsilon) > \Sigma^*(\varepsilon)$, for $\varepsilon \in (\varepsilon_2, \varepsilon_3)$. Then, for $\varepsilon \in [\varepsilon_2, \varepsilon_3]$,

$$\begin{aligned}(\Theta\Sigma^*)(\varepsilon) &= \hbar\left(\varepsilon, \vartheta\left(\min\left\{\Xi, \max\left\{\Sigma^*, \Gamma\right\}\right\}\right), \min\left\{\Xi, \max\left\{\Sigma^*, \Gamma\right\}\right\}\right)\\ &= \hbar\left(\varepsilon, \vartheta\left(\min\left\{\Xi, \max\left\{\Sigma^*, \Gamma\right\}\right\}\right), \Gamma\right).\end{aligned}$$

There exists $\Upsilon(\varepsilon) = \Sigma^*(\varepsilon) - \Gamma(\varepsilon)$, $\hbar$ and ϑ are monotonic, and one has

$$\begin{aligned}\Gamma'(\varepsilon) = \zeta^{(6)}(\varepsilon) &\leq \hbar\left(\varepsilon, \zeta(\varepsilon), \zeta^{(5)}(\varepsilon)\right) = \hbar\left(\varepsilon, \vartheta\Gamma(\varepsilon), \Gamma(\varepsilon)\right), \qquad \varepsilon \in [0,1],\\ \Sigma^{*\prime} &= \hbar\left(\varepsilon, \vartheta\left(\min\left\{\Xi, \max\left\{\Sigma^*, \Gamma\right\}\right\}\right), \phi\right),\end{aligned}$$

so $\Upsilon'(\varepsilon) \geq 0$, $\varepsilon \in [\varepsilon_2, \varepsilon_3]$. Consequently, $\Upsilon(\varepsilon_2) = 0$ implies $\Upsilon(\varepsilon) \geq 0$, $\varepsilon \in [\varepsilon_2, \varepsilon_3]$. From the relation $\Gamma(\varepsilon) \leq \Sigma^*(\varepsilon)$, $\varepsilon \in [\varepsilon_2, \varepsilon_3]$. This contradicts the given hypothesis. So, $\Gamma(\varepsilon) \leq \Sigma^*(\varepsilon)$, $\varepsilon \in [0,1]$. The proof of $\Xi(\varepsilon) \geq \Sigma^*(\varepsilon)$, $\varepsilon \in [0,1]$, is analogous to $\Gamma(\varepsilon) \leq \Sigma^*(\varepsilon)$.

One will now introduce $\Omega : C[0,1] \to [0,1]$, given by

$$(\Omega\Sigma)(\varepsilon) = \int_0^\varepsilon (\Theta\Sigma)(\varrho)\,\mathrm{d}\varrho, \qquad \varepsilon \in [0,1].$$

It is obvious that the operator is continuous and a fixed point of Ω is a solution of the BVP (10). Let there be a set $\Psi_\varpi = \{\rho \in C[0,1] : \|\rho\| \leq \varpi\}$, and is easy to observe that $\Xi, \Gamma \in \Psi_\varpi$. Now, one demonstrates that $\Omega : \Psi_\varpi \to \Psi_\varpi$ is a completely continuous operator. By formula (9), one

obtains

$$\Big|(\Omega\Sigma)(\varepsilon)-(\Omega\Sigma)(\varrho)\Big| = \left|\int_0^{\varepsilon}(\Theta\Sigma)(\tau)\,\mathrm{d}\tau\right| \leq \varpi|\varepsilon-\varrho|.$$

That is, $\{\Omega(\Psi_{\varpi})\}$ is bounded uniformly and equi-continuous. According to the theorem of Arzelà-Ascoli, it is affirmed that $\Omega : \Psi_{\varpi} \to \Psi_{\varpi}$ is a completely continuous operator, and the Schauder fixed point theorem ensures that Ω admits a fixed point $\Sigma^* \in \Psi_{\varpi}$. Hence,

$$\xi^*(\varepsilon) = \int_0^1 \chi(\varepsilon,\varrho)\Sigma^*(\varrho)\,\mathrm{d}\varrho,$$

is a solution of problem (1) such that $\zeta(\varepsilon) \leq \xi(\varepsilon) \leq \eta(\varepsilon)$, $\zeta^{(5)}(\varepsilon) \leq \xi^{(5)}(\varepsilon) \leq \eta^{(5)}(\varepsilon)$, $\varepsilon \in [0,1]$. □

Now, let us consider problem (2). Suppose that $\hbar \in C([0,1]\times\mathbb{R}^3)$ is a continuous function. It is possible to obtain lemmas analogue to Lemmas 4 and 5. This is evident by observing that the equation of problem (2) is parallel to

$$\begin{cases} \Sigma^{'}(\varepsilon) = \hbar(\varepsilon,(\vartheta\Sigma)(\varepsilon),(\Pi\Sigma)(\varepsilon),\Sigma(\varepsilon)), & 0<\varepsilon<1,\\ \Sigma(0)=0, \end{cases}$$

where

$$(\vartheta\Sigma)(\varepsilon) = \int_0^1 \chi(\varepsilon,\varrho)\Sigma(\varrho)\,\mathrm{d}\varrho, \qquad (\Pi\Sigma)(\varepsilon) = \int_0^1 \Sigma(\varrho)\,\mathrm{d}\varrho.$$

LEMMA 6. *Let there be a real number $\varpi \geq 0$ such that*

$$\hbar(\varepsilon,\mu,\nu,\tau) \leq \varpi, \text{ for } 0\leq\varepsilon\leq 1, \quad \frac{\mu}{\varsigma}, 2\nu \in [0,\varpi], \quad \tau\in[-\varpi,0].$$

So the BVP (2) accepts an upper solution.

LEMMA 7. *Let there be a real number $\kappa \leq 0$ such that*

$$\hbar(\varepsilon,\mu,\nu,\tau) \geq \kappa, \text{ for } 0\leq\varepsilon\leq 1, \quad \mu\in[\varsigma\kappa,0], \quad 2\nu,\tau\in[0,-\kappa].$$

So the BVP (2) admits a lower solution.

In an analogous fashion, we can write the same proof for Lemmas 6 and 7 in the same way, as formulated in Lemmas 4 and 5. The similarity in Theorem 1 allows obtaining the following results of problem (2).

THEOREM 2. *Let there be two real numbers* $\varpi \geq 0 \geq \kappa$, $\varpi \geq |\kappa|$ *such that*

$$\hbar(\varepsilon, \mu, \nu, \tau) \leq \varpi, \qquad 0 \leq \varepsilon \leq 1, \ \tfrac{\mu}{\varsigma}, \ 2\nu \in [0, \varpi], \ \tau \in [-\varpi, 0], \tag{12}$$

$$\hbar(\varepsilon, \mu, \nu, \tau) \geq \kappa, \qquad 0 \leq \varepsilon \leq 1, \ \mu \in [\varsigma\kappa, 0], \ 2\nu, \tau \in [0, -\kappa]. \tag{13}$$

If $\hbar(\varepsilon, \mu, \nu, \tau)$ *is nondecreasing in each* μ *and* ν, *then problem* (2) *admits a solution* $\xi(\varepsilon)$ *such that*

$$\zeta(\varepsilon) \leq \xi(\varepsilon) \leq \eta(\varepsilon), \quad \zeta^{(5)}(\varepsilon) \leq \xi^{(5)}(\varepsilon) \leq \eta^{(5)}(\varepsilon), \qquad \varepsilon \in [0, 1],$$

where

$$\zeta(\varepsilon) = \kappa \int_0^1 \chi(\varepsilon, \varrho)\varrho \, \mathrm{d}\varrho, \quad \eta(\varepsilon) = \varpi \int_0^1 \chi(\varepsilon, \varrho)\varrho \, \mathrm{d}\varrho, \qquad \varsigma = \tfrac{1}{48}.$$

Application

Some examples are given in order to illustrate the results obtained above.

EXAMPLE 1. Extrapolate the following application of the BVP

$$\begin{cases} -\xi^{(6)} + \frac{1}{48}\left[\varepsilon + \cos\xi(\varepsilon) + \xi^{(5)}(\varepsilon)\right] = 0, \quad 0 < \varepsilon < 1, \\ \xi(0) = \xi'(0) = \xi''(0) = 0, \\ \xi'''(1) = \xi^{(4)}(1) = \xi^{(5)}(0) = 0. \end{cases} \tag{14}$$

There is $\hbar(\varepsilon, \mu, \nu) = \frac{1}{48}\left[\varepsilon + \cos\mu + \nu\right]$. It is not difficult to verify that the values of $\varpi = 24$, $\kappa = 0$ meet conditions (8) and (9), respectively; hence,

$$\zeta(\varepsilon) = 0, \qquad \eta(\varepsilon) = 24 \int_0^1 \chi(\varepsilon, \varrho)\varrho \, \mathrm{d}\varrho,$$

represented by the lower and upper solutions of (14). According to Theorem 1, problem (14) admits a positive solution ξ^* such that

$$0 \leq \xi^*(\varepsilon) \leq 24 \int_0^1 \chi(\varepsilon, \varrho)\varrho \, \mathrm{d}\varrho.$$

Figure (1) shows the search for a result of the comparison of the numerical solution to (14) and its estimate given by the Green's function.

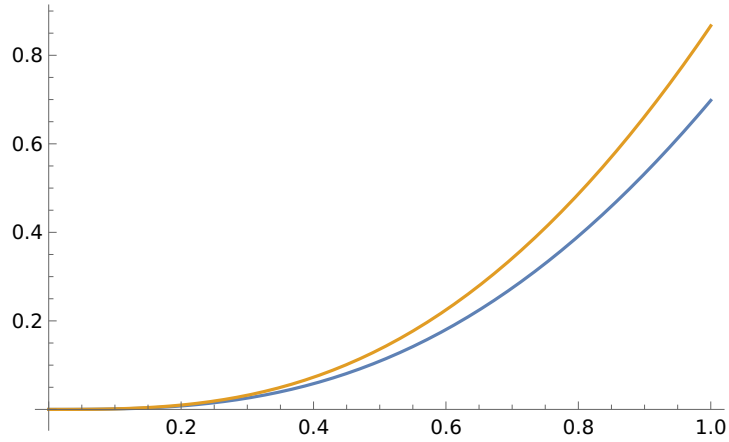

Figure 1 – The lower plot is the numerical solution of (14), multiplied by a large coefficient 4×10^3 for comparison purposes, while the upper plot is the estimate of the above, given by the Green's function. Observe how the two curves present the same behavior as functions of ε.

EXAMPLE 2. Extrapolate the following application of the BVP

$$\begin{cases} -\xi^{(6)} + \frac{1}{50}\left[\varepsilon + \sin\xi(\varepsilon) + \cos\left(\xi'(\varepsilon)\right)^4 + \xi^{(5)}(\varepsilon)\right] = 0, \quad 0 < \varepsilon < 1, \\ \xi(0) = \xi'(0) = \xi''(0) = 0, \\ \xi'''(1) = \xi^{(4)}(1) = \xi^{(5)}(0) = 0. \end{cases} \tag{15}$$

There is $\hbar(\varepsilon, \mu, \nu, \tau) = \frac{1}{50}[\varepsilon + \sin\mu + \cos(\nu)^4 + \tau]$. It is not difficult to verify that the values $\varpi = 25$, $\kappa = 0$ meet conditions (12) and (13), respectively; hence,

$$\zeta(\varepsilon) = 0, \qquad \eta(\varepsilon) = 25\int_0^1 \chi(\varepsilon, \varrho)\varrho\,\mathrm{d}\varrho,$$

are the lower and upper solutions of (15). According to Theorem 2, problem (15) admits a positive solution ξ^* such that

$$0 \le \xi^*(\varepsilon) \le 25\int_0^1 \chi(\varepsilon, \varrho)\varrho\,\mathrm{d}\varrho.$$

Figure (2) shows the desired result of the comparison of the numerical solution to (15) and its estimate given by the Green's function.

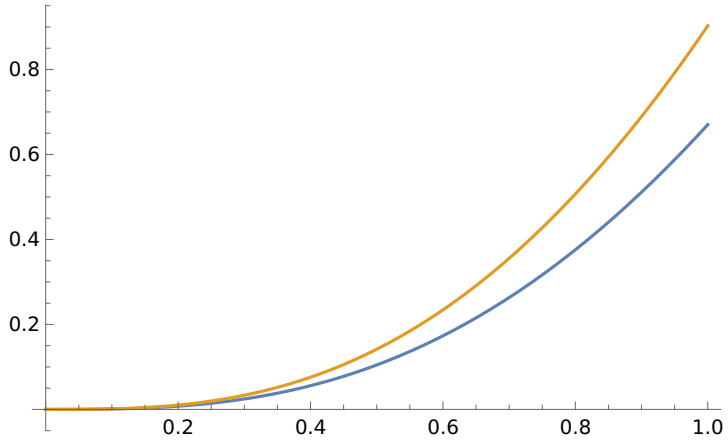

Figure 2 – The lower plot is the numerical solution of (15)*, multiplied by a large coefficient* 4×10^3 *for comparison purposes, while the upper plot is the estimate of the above, given by the Green's function. Observe how the two curves present the same behavior as functions of* ε.

References

Agarwal, R.P., Kovacs, B. & O'Regan, D. 2013. Positive solutions for a sixth-order boundary value problem with four parameters. *Boundary Value Problems*, 2013, art.number:184. Available at: https://doi.org/10.1186/1687-2770-2013-184.

Amiri, P. & Samei, M.E. 2022. Existence of Urysohn and Atangana-Baleanu fractional integral inclusion systems solutions via common fixed point of multi-valued operators. *Chaos, Solitons & Fractals*, 165(2, art.number:112822). Available at: https://doi.org/10.1016/j.chaos.2022.112822.

Bekri, Z. & Benaicha, S. 2018. Nontrivial Solution of a Nonlinear Sixth-Order Boundary Value Problem. *Waves, Wavelets and Fractals*, 4(1), pp. 10–18. Available at: https://doi.org/10.1515/wwfaa-2018-0002.

Bekri, Z. & Benaicha, S. 2020. Positive solutions for boundary value problem of sixth-order elastic beam equation. *Open Journal of Mathematical Sciences*, 4, pp. 9–17. Available at: https://doi.org/10.30538/oms2020.0088.

Boutiara, A., Benbachir, M., Alzabut, J. & Samei, M.E. 2021. Monotone iterative and upper-lower solutions techniques for solving nonlinear $\psi-$Caputo fractional boundary value problem. *Fractal and Fractional*, 5(9, art.number:194). Available at: https://doi.org/10.3390/fractalfract5040194.

Boutiara, A., Matar, M.M., Alzabut, J., Samei, M.E. & Khan, H. 2023. On $\mathcal{ABC}$ coupled Langevin fractional differential equations constrained by Perov's fixed point in generalized Banach spaces. *AIMS Mathematics*, 8(5), pp. 12109–12132. Available at: https://doi.org/10.3934/math.2023610.

Chabanea, F., Benbachir, M., Hachama, M. & Samei, M.E. 2022. Existence of positive solutions for p-Laplacian boundary value problems of fractional differential equationss. *Boundary Value Problems*, 2022, art.number:65. Available at: https://doi.org/10.1186/s13661-022-01645-7.

Deimling, K. 1985. *Nonlinear Functional Analysis*. Berlin: Springer. Available at: https://doi.org/10.1007/978-3-662-00547-7.

Fabiano, N., Nikolić, N., Shanmugam, T., Radenović, S. & Čitaković N. 2020. Tenth order boundary value problem solution existence by fixed point theorem. *Journal of Inequalities and Applications*, 2020, art.number:166. Available at: https://doi.org/10.1186/s13660-020-02429-2.

Fabiano, N. & Parvaneh, V. 2021. Existence of a solution for a general order boundary value problem using the Leray-Schauder fixed point theorem. *Vojnotehnički glasnik/Military Technical Courier*, 69(2), pp. 323–337. Available at: https://doi.org/10.5937/vojtehg69-29703.

Hammad, H.A., Rashwan, R.A., Nafea, A., Samei, M.E. & De la Sen, M. 2022. Stability and Existence of Solutions for a Tripled Problem of Fractional Hybrid Delay Differential Equations. *Symmetry*, 14(12, art.number:2579). Available at: https://doi.org/10.3390/sym14122579.

Houas, M. & Samei, M.E. 2023. Existence and Stability of Solutions for Linear and Nonlinear Damping of $q-$Fractional Duffing–Rayleigh Problem. *Mediterranean Journal of Mathematics*, 20, art.number:148. Available at: https://doi.org/10.1007/s00009-023-02355-9.

Ji, Y., Guo, Y., Yao, Y. & Feng, Y. 2012. Nodal solutions for sixth-order m-point boundary-value problems using bifurcation methods. *Electronic Journal of Differential Equations*, 2012(217), pp. 1–18 [online]. Available at: https://ejde.math.txstate.edu/ [Accessed: 7 February 2024].

Kovács, B. & Guedda, M. 2014. Positive solution for m-point sixth-order boundary value problem with variable parameter. *Scientific Bulletin of the "Petru Maior" University of Tîrgu Mureș (Acta Marisiensis. Seria Technologica)*, 11(2), pp. 50–61 [online]. Available at: https://amset.umfst.ro/papers/2014-2/09%20Positive%20solution%20Kovacs.pdf [Accessed: 7 February 2024].

Li, W. 2012. The existence and multiplicity of positive solutions of nonlinear sixth-order boundary value problem with three variable coefficients. *Boundary Value Problems*, 2012, art.number:22. Available at: https://doi.org/10.1186/1687-2770-2012-22.

Mirzaei, H. 2016. Existence and nonexistence of positive solution for sixth-order boundary value problems. *Bulletin of the Iranian Mathematical Society*, 42(6), pp. 1451–1458 [online]. Available at: http://bims.iranjournals.ir/article_902_2e9751112c0f6a8a0ad4c17431e11af8.pdf [Accessed: 7 February 2024] .

Möller, M. & Zinsou, B. 2013. Sixth order differential operators with eigenvalue dependent boundary conditions. *Applicable Analysis and Discrete Mathematics*, 7(2), pp. 378–389. Available at: https://doi.org/10.2298/AADM130608010M.

Samei, M.E., Ahmadi, A., Hajiseyedazizi, S.N., Mishra, S.K. & Ram, B. 2021a. The existence of non-negative solutions for a nonlinear fractional q-differential problem via a different numerical approach. *Journal of Inequalities and Applications*, 2021, art.number:75. Available at: https://doi.org/10.1186/s13660-021-02612-z.

Samei, M.E., Ahmadi, A., Maria Selvam, A.G., Alzabut, J. & Rezapour, S. 2021b. Well-posed conditions on a class of fractional q-differential equations by using the Schauder fixed point theorem. *Advances In Difference Equations*, 2021, art.number:482. Available at: https://doi.org/10.1186/s13662-021-03631-2.

Santra, S.S., Mondal, P., Samei, M.E., Alotaibi, H., Altanjii, M. & Botmart, T. 2023. Study on the oscillation of solution to second-order impulsive systems. *AIMS Mathematics*, 8(9), pp. 22237–22255. Available at: https://doi.org/10.3934/math.20231134.

Tersian, S. & Chaparova, J. 2002. Periodic and homoclinic solutions of some semilinear sixth-order differential equations. *Journal of Mathematical Analysis and Applications*, 272(1), pp. 223–239. Available at: https://doi.org/10.1016/S0022-247X(02)00153-1.

Yang, B. 2019. Positive solutions to a nonlinear sixth order boundary value problem. *Differential Equations & Applications*, 11(2), pp. 307–317. Available at: https://doi.org/10.7153/dea-2019-11-13.

Zhang, L. & An, Y. 2010. Existence and Multiplicity of Positive Solutions of a Boundary-Value Problem for Sixth-Order ODE with Three Parameters. *Boundary Value Problems*, 2010, art.number:878131. Available at: https://doi.org/10.1155/2010/878131.

Confinar una solución no negativa entre una solución superior e inferior para un problema de valor límite de sexto grado

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CAMPO: matemáticas
TIPO DE ARTÍCULO: artículo científico original

Resumen:

Introducción/objetivo: El objetivo del artículo es demostrar la existencia de soluciones para un caso especial del problema del valor límite de sexto orden.

Métodos: El teorema del punto fijo de Leray-Schauder se utiliza para determinar las soluciones de límite superior.

Resultados: Se han encontrado soluciones de límite inferior y superior.

Conclusión: El problema del valor límite de sexto orden admite soluciones.

Palabras claves: alternativa no lineal de Leray-Schauder, función de Green, teorema del punto fijo, soluciones inferior y superior, problema de valor límite.

Ограничение неотрицательного решения между нижним и верхним решениями в краевых задачах шестого порядка

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РУБРИКА ГРНТИ: 27.25.17 Метрическая теория функций,
27.29.15 Общая теория обыкновенных дифференциальных уравнений и систем уравнений,
27.39.15 Линейные пространства, снабженные топологией, порядком и другими структурами
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: Доказательство существования решения частного случая краевой задачи шестого порядка.

Методы: Теорема Лере-Шаудера о неподвижной точке используется в определении нижней и верхней границы решения задачи.

Результаты: В ходе исследования были найдены решения нижней и верхней границы.

Выводы: Краевая задача шестого порядка допускает решения.

Ключевые слова: нелинейная альтернатива Лере-Шаудера, функция Грина, теорема о неподвижной точке, нижние и верхние решения, краевая задача.

Ограничавање ненегативног решења између доњег и горњег решења за шести степен проблема граничних вредности

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ОБЛАСТ: математика
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: Доказивање постојања решења за посебан случај граничног проблема шестог реда.

Методе: Лерај-Шаудерова теорема о фиксној тачки користи се да би се одредиле ниже и горње границе решења.

Резултати: Пронађена су решења доње и горње границе.

Закључак: Гранични проблем шестог реда дозвољава решења.

Кључне речи: Лерај-Шаудерова нелинеарна алтернатива, Гринова функција, теорема фиксне тачке, доња и горња решења, проблем граничних вредности.

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Exploring multivalued probabilistic ψ-contractions with orbits in b-Menger spaces

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Abstract:

Introduction/purpose: The paper presents a novel approach to certain well-established fixed point theorems for multivalued probabilistic contractions in b-Menger spaces, leveraging the boundedness of the orbits. The aim was to generalize and enhance the results previously derived by Fang and Hadžić.

Methods: The boundedness of orbits in b-Menger spaces is used to establish their approach for multivalued probabilistic contractions.

Results: The findings of the study not only generalized the existing fixed point theorems but also enhanced them significantly. The effectiveness of the approach in extending the results originally proposed by Fang and Hadžić was showcased. Moreover, the applicability of the coincidence fixed point theorem in fuzzy b-metric spaces was demonstrated.

Conclusions: The study presented a novel perspective on fixed point theorems in multivalued probabilistic contractions within b-Menger spaces. By leveraging boundedness and introducing a coincidence fixed point

theorem for fuzzy b-metric spaces, the work contributed to the advancement in this field.

Key words: fixed point, b-Menger spaces, multivalued ψ-contraction, fuzzy b-metric space.

Introduction

In 1981, Vul'pe et al. (Berinde & Păcurar, 2022) introduced the concept of b-metric space as a generalization of metric spaces, a framework later utilized by Bakhtin and Czerwik (Bakhtin, 1989; Czerwik, 1993) to establish the well-known Banach fixed point theorem in these spaces (Banach, 1922). The significance of the fixed point theory resonates across various branches of pure and applied mathematics due to its broad range of applications.

The concept of probabilistic metric spaces, introduced by K. Menger in 1942 (Menger, 2003), constitutes a crucial extension of metric spaces. The exploration of the fixed point theory in Menger spaces, concerning both multivalued and single-valued contractions, has become an integral part of probabilistic analysis, attracting the attention of numerous mathematicians (Achtoun et al., 2023; Mbarki & Oubrahim, 2017; Huang et al., 2023; Mihet, 2005; Patle et al., 2019). Recently, Mbarki and Oubrahim (Mbarki & Oubrahim, 2017) introduced the b-metric version of probabilistic metric spaces, termed a b-Menger space, which stands as the most general concept among those mentioned earlier. Notably, numerous fixed point results have been derived within this type of space (Mbarki & Oubrahim, 2017; Mihet, 2005). A parallel idea emerged in the realm of fuzzy metric spaces, where Nădăban (Nădăban, 2016) introduced the concept of a fuzzy b-metric space, generalizing the notion put forth by Kramosil and Michálek (Kramosil & Michálek, 1975).

The concept of multivalued contractions in metric spaces was pioneered by Nadler (Nadler Jr, 1969), and Hadžić (Hadžic, 1989) later extended this notion to multivalued ψ-contractions in probabilistic metric spaces. She established a fixed point theorem employing the concept of probabilistic function of non-compactness. Building on this foundation, Fang (Fang, 1992) presented a generalization of Hadžić's results by substituting the condition of a continuous t-norm with a t-norm of H-type.

This paper contributes a new fixed point theorem for multivalued mappings satisfying ψ-contractive conditions in b-Menger spaces, leveraging

the concept of bounded orbits. As an application, these results are extended to establish a corresponding fixed point theorem in fuzzy b-metric spaces. These authors' findings not only improve upon the work of Hadžić (Hadžic, 1989) and Fang (Fang, 1992) but also generalize their results.

The structure of this article unfolds as follows: Section 2 provides essential concepts and lemmas in b-Menger spaces. Section 3 establishes the existence of fixed points for multivalued ψ-contractions in b-Menger spaces, employing two distinct approaches and offering illustrative examples. Finally, Section 4 identifies a coincidence fixed point for multivalued ψ-contraction mappings in fuzzy b-metric spaces.

Preliminaries

To start with, here are some basic definitions and facts from b-Menger spaces.

Definition 1. *Let Δ^+ be the class of all distance distribution mappings $\gamma : [0,+\infty] \to [0,1]$ such that:*

1. *γ is left continuous on $[0,+\infty]$,*
2. *γ is non-decreasing,*
3. *$\gamma(0) = 0$ and $\gamma(+\infty) = 1$.*

The subset $\mathcal{D}^+ \subset \Delta^+$ is the set $\mathcal{D}^+ = \left\{\gamma \in \Delta^+ : \lim_{\alpha\to+\infty} \gamma(\alpha) = 1\right\}$.

As a specific element of $\mathcal{D}^+$ is ϵ_a defined as:

$$\epsilon_a(\alpha) = \begin{cases} 0 & \text{if} \quad \alpha \in (-\infty, a]\,, \\ 1 & \text{if} \quad \alpha \in (a, +\infty). \end{cases}$$

Definition 2. *(Schweizer & Sklar, 1983) A triangular norm (briefly t-norm) is a binary operation $\urcorner$ on $[0,1]$ such that for all $u, v, w \in [0,1]$ the following conditions are verified:*

1. *$\urcorner(\alpha,\beta) = \urcorner(\beta,\alpha)$,*
2. *$\urcorner(\alpha,\urcorner(\beta,\gamma)) = \urcorner(\urcorner(\alpha,\beta),\gamma)$,*
3. *$\urcorner(\alpha,\beta) < \urcorner(\alpha,\gamma)$ for $\beta < \gamma$,*
4. *$\urcorner(\alpha,1) = \urcorner(1,\alpha) = \alpha$.*

Example 1. Here the most basic t-norms are cited:

1. The minimum t-norm $\top_M(\alpha,\beta) = min(\alpha,\beta)$.
2. The Lukasiewicz t-norm $\top_L(\alpha,\beta) = max(\alpha+\beta-1,0)$.
3. The product t-norm $\top_P(\alpha,\beta) = \alpha\cdot\beta$

Definition 3. *(Pap et al., 1996) A t-norm $\top$ is said of H-type if the family $(\top^n(\alpha))_{n\in\mathbb{N}}$ is equi-continuous at the point $\alpha = 1$, it means that :*

$$for\,all\,\epsilon\in(0,1),\,there\,exists\,\lambda\in(0,1):\;t>1-\lambda\;implies\;\top^n(t)>1-\epsilon\;\;for\,all\,n\geq 1,$$

where for all $\alpha\in[0,1]$ and $n\in\mathbb{N}$ there exists:

$$\top^n(\alpha) = \begin{cases} 1 & \text{if} \quad n=0, \\ \top(\top^{n-1}(\alpha),\alpha) & \text{otherwise}. \end{cases}$$

A simple example of H-type t-norm is $\top_M$, unlike $\top_L$ is not of H-type. The readers are referred to (Pap et al., 1996) for more details.

Definition 4. *(Mbarki & Oubrahim, 2017) A quadruple $(\Gamma, F, \top, s)$ where Γ is a nonempty set, F is a function from $\Gamma\times\Gamma$ into Δ^+, $\top$ is a t-norm and $s\geq 1$ is a real number, is called a b-Menger space if the following requirements are verified for all $\rho,\sigma,\vartheta\in\Gamma$ and $t,v>0$:*

1. $F_{\rho,\rho} = \epsilon_0$,
2. $F_{\rho,\sigma}\neq\epsilon_0 \;\; if \;\; \rho\neq\sigma$,
3. $F_{\rho,\sigma} = F_{\sigma,\rho}$,
4. $F_{\rho,\sigma}(s(t+v)) \geq \top(F_{\rho,\vartheta}(t), F_{\vartheta,\sigma}(v))$.

Note that a Menger space is a b-Menger space with $s=1$.
In the topology created by the family of (ϵ,λ)-neighborhoods:

$$\mathcal{N} = \{\mathcal{N}_p(\epsilon,\lambda):\; p\in\Gamma,\;\epsilon>0\;\;and\;\;\lambda>0\},$$

where:

$$\mathcal{N}_p(\epsilon,\lambda) = \{q\in\Gamma:\; F_{p,q}(\epsilon) > 1-\lambda\}.$$

The space $(\Gamma, F, \top, s)$ is a Hausdorff topological space if the t-norm $\top$ is continuous, as demonstrated by Mbarki and Oubrahim (Mbarki & Oubrahim, 2017)

Definition 5. *A sequence $\{\omega_n\}$ in a b-Menger space $(\Gamma, F, \top, s)$ is said to be:*

1. *Convergent to* $\omega \in \Gamma$ *if for any given* $\epsilon > 0$ *and* $\lambda > 0$ *there exist* $N \in \mathbb{N}$ *satisfying* $F_{\omega_n,\omega}(\lambda) > 1 - \epsilon$ *whenever* $n \geq N$.
2. *Strong Cauchy sequence if for any* $\epsilon > 0$ *and* $\lambda > 0$ *there exist* $N \in \mathbb{N}$ *satisfying* $F_{\omega_n,\omega_m}(\lambda) > 1 - \epsilon$ *whenever* $n, m \geq N$.

A b-Menger space $(\Gamma, F, \urcorner, s)$ *is complete if each Cauchy sequence in* Γ *is convergent to some point in* Γ.

In the following, it is assumed for the b-Menger space $(\Gamma, F, \urcorner, s)$ that $\urcorner$ is a continuous t-norm, and the class of all nonempty closed subsets of Γ is denoted by $C(\Gamma)$, where for all $U, V \in C(\Gamma)$ and $\omega \in \Gamma$ the functions $F_{\omega,U}(.)$ and $F_{U,V}(.)$ are defined as follows:

$$F_{\omega,U}(t) = \sup_{\upsilon \in U} F_{\omega,\upsilon}(t) \quad for\ all\ t \in \mathbb{R},$$

and

$$F_{U,V}(t) = \inf_{\omega \in U} \sup_{\upsilon \in V} F_{\omega,\upsilon}(t) \quad for\ all\ t \in \mathbb{R}.$$

The first result is the following:

Lemma 1. *Let* $(\Gamma, F, \urcorner, s)$ *be a b-Menger space, then for all* $U \in C(\Gamma)$ *and* $\omega, \upsilon \in \Gamma$ *there is*

$$F_{\omega,U}(t) = 1\ for\ all\ t > 0\ if\ and\ only\ if\ \omega \in U.$$

Proof. If $F_{\omega,U}(t) = 1$ for all $t > 0$, then for any $\epsilon > 0$ and $\lambda \in (0, 1)$ there exists $\omega_0 \in U$ such that $F_{\omega,\omega_0}(\epsilon) > 1 - \lambda$. As $U \in C(\Gamma)$ then $\omega \in U$.
On the other hand, if $\omega \in U$, then

$$\begin{aligned} F_{\omega,U}(t) &= \sup_{\upsilon \in U} F_{\omega,\upsilon}(t) \\ &\geq F_{\omega,\omega}(t) = 1 \quad for\ all\ t > 0. \end{aligned}$$

Hence $F_{\omega,U}(t) = 1 \quad for\ all\ t > 0.$ □

Definition 6. *Let* $(\Gamma, F, \urcorner, s)$ *be a b-Menger space and* U *a nonempty set of* Γ. *The function* $\mathcal{D}_U$ *defined on* $[0, +\infty]$ *by*

$$\mathcal{D}_U(\omega) = \begin{cases} \lim\limits_{t \to \omega^-} \theta_U(t) & \text{if} \quad 0 \leq \omega < +\infty, \\ 1 & \text{if} \quad \omega = +\infty, \end{cases}$$

where

$$\theta_U(t) = \inf \{F_{a,b}(t) \mid a, b \in U\},$$

is called the probabilistic diameter of U.

It is clear that $\mathcal{D}_U \in \Delta^+$ for any $U \subset \Gamma$, and for all $p, q \in U$. Also U is bounded if $\mathcal{D}_U$ is into $\mathcal{D}^+$.

Lemma 2. *Let* $(\Gamma, F, \urcorner, s)$ *be a b-Menger space and* U *a nonempty set of* Γ*, the probabilistic diameter has the following proprieties:*

1. *For all* $a, b \in U$*, there exists* $F_{a,b} \geq \mathcal{D}_U$.
2. $\mathcal{D}_U = \epsilon_0$ *if and only if* U *is a singleton.*
3. *If* $U \subset V$*, then* $\mathcal{D}_U \geq \mathcal{D}_V$.

Main result

Throughout this section, a point $z \in \Gamma$ is said to be a fixed point of $f : \Gamma \to C(\Gamma)$ if $z \in fz$. If for $\omega_0 \in \Gamma$, there exists a sequence $\{\omega_i\} \subset \Gamma$ such that $\omega_i \in f\omega_{i-1}$, then $\wp_f(\omega_0) = \{\omega_0, \omega_1, \omega_2, ...\}$ is called an orbit of f starting at ω_0.
Let χ denote the family of all function $\psi : [0, +\infty) \to [0, +\infty)$ satisyfing

$$0 < \psi(t) < t \quad and \quad \lim_{n \to +\infty} \psi^n(t) = 0 \quad for\ all\ t > 0.$$

The definition of multivalued probabilistic ψ-contraction is first introduced in a b-Menger space.

Definition 7. *Let* $(\Gamma, F, \urcorner, s)$ *be a b-Menger space and* $\psi : [0, +\infty) \to [0, +\infty)$.*A a mapping* $f : \Gamma \to C(\Gamma)$ *is called a multi-valued probabilistic* ψ*-contraction if for every* $\omega, \upsilon \in \Gamma$ *and every* $\rho \in f\omega$ *there exists* $\sigma \in f\upsilon$ *such that*

$$F_{\rho,\sigma}(\psi(t)) \geq F_{\omega,\upsilon}(st) \quad for\ all\ t > 0. \tag{1}$$

Remark 1. Note that if f is a multi-valued ψ-contraction, there exists

$$F_{f\omega,f\upsilon}(\psi(t)) \geq F_{\omega,\upsilon}(st) \quad for\ all\ \omega, \upsilon \in \Gamma,\ and\ t > 0. \tag{2}$$

Before stating the main result, one will use later the following lemma.

Lemma 3. *Let* $\{\omega_n\}$ *be a bounded sequence in a b-Menger space* $(\Gamma, F, \urcorner, s)$*where* $RanF \subset \mathcal{D}^+$*. If there exists a function* $\psi \in \chi$ *such that*

$$F_{\omega_n,\omega_m}(\psi(t)) \geq F_{\omega_{n-1},\omega_{m-1}}(st) \quad for\, all\, n, m > 0\, such\, that\, m > n\, and\, for\, all\, t > 0. \tag{3}$$

Then $\{\omega_n\}$ *is a Cauchy sequence.*

Proof. Let $\{\omega_n\}$ be a bounded sequence in Γ that satisfying the condition (3). Then one obtains

$$\begin{aligned} F_{\omega_n,\omega_m}(\psi^n(t)) &\geq F_{\omega_{n-1},\omega_{m-1}}(s\psi^{n-1}(t)) \\ &\geq F_{\omega_{n-1},\omega_{m-1}}(\psi^{n-1}(t)) \\ &\geq F_{\omega_{n-2},\omega_{m-2}}(s\psi^{n-2}(t)) \\ &\geq F_{\omega_{n-2},\omega_{m-2}}(\psi^{n-2}(t)) \\ &\vdots \\ &\geq F_{\omega_0,\omega_{m-n}}(st) \\ &\geq F_{\omega_0,\omega_{m-n}}(t) \\ &\geq \mathcal{D}_{\wp(\omega)}(t). \end{aligned}$$

On the other hand, let $\epsilon > 0$ and $\delta \in (0, 1)$ be given, since $\mathcal{D}_{\wp(\omega)}(t) \to 1$ as $t \to +\infty$, then there exist $t_0 > 0$ such that

$$\mathcal{D}_{\wp(\omega)}(t_0) > 1 - \delta.$$

From that $\psi^n(t_0) \to 0$ as $n \to +\infty$, then there exist $n_0 \in \mathbb{N}$ satisfying

$$\psi^n(t_0) < \epsilon \quad whenever \quad n \geq n_0.$$

By using the monotonicity of F, one obtains

$$\begin{aligned} F_{\omega_n,\omega_m}(\epsilon) &\geq F_{\omega_n,\omega_m}(\psi^n(t_0)) \\ &\geq \mathcal{D}_{\wp(\omega)}(t_0) \\ &\geq 1 - \delta. \end{aligned}$$

Therefore, $\{\omega_n\}$ is a Cauchy sequence. □

Theorem 1. *Let* $(\Gamma, F, \urcorner, s)$ *be a complete b-Menger space where* $RanF \subset \mathcal{D}^+$ *and* $f : \Gamma \to C(\Gamma)$ *is a multivalued probabilistic* ψ*-contraction mapping with* $\psi \in \chi$*. If all the orbits* $\wp_{f(\omega)}$ *for some* $\omega \in \Gamma$ *are bounded, then there exists* $z \in \Gamma$ *satisfying* $z \in fz$*.*

Proof. Let $\omega_0 \in \Gamma$ and $\omega_1 \in f\omega_0$ such that the orbit $\wp_{f(\omega)}$ starting at ω_0 is bounded. Then there exists $\omega_2 \in f\omega_1$ thus by (1) one obtains

$$F_{\omega_1,\omega_2}(\psi(t)) \geq F_{\omega_0,\omega_1}(st) \quad for\ all\ t > 0.$$

Inductively, one constructs a sequence $\{\omega_n\}$ satisfying the following conditions:

$$\omega_{n+1} \in f\omega_n \ \ and \ \ F_{\omega_n,\omega_{n+1}}(\psi(t)) \geq F_{\omega_{n-1},\omega_n}(st) \ \ for\ all\ n \in \mathbb{N},\ and\ t > 0.$$

It will shown first that for each $t > 0$,

$$F_{\omega_n,\omega_{n+m}}(\psi(t)) \geq F_{\omega_{n-1},\omega_{n+m-1}}(st) \quad for\ all\ m > 0. \tag{4}$$

It is obvious that (4) is true for $m = 1$.
It is claimed that (4) holds for $m > 0$.
Since $\omega_n \in f\omega_{n-1}$ and $\omega_{n+m+1} \in f\omega_{n+m}$, using Remark 1, one gets

$$\begin{aligned} F_{\omega_n,\omega_{n+m+1}}(\psi(t)) &\geq F_{f\omega_{n-1},\omega_{n+m+1}}(\psi(t)) \\ &\geq F_{f\omega_{n-1},f\omega_{n+m}}(\psi(t)) \\ &\geq F_{\omega_{n-1},\omega_{n+m}}(st). \end{aligned}$$

So, by induction, it is proved that (7) holds for all $m > 0$.
Therefore, from Lemma 3, it follows that $\{\omega_n\}$ is a Cauchy sequence.
As $(\Gamma, F, \urcorner, s)$ is complete, then $\{\omega_n\}$ converge to some $z \in \Gamma$.
It will be demonstrated that z is a fixed point within f. For that, let $t > 0$, then, from (1), one has

$$\begin{aligned} F_{\omega_n,fz}(\psi(t)) &\geq F_{\omega_{n-1},z}(st) \\ &\geq F_{\omega_{n-1},z}(t). \end{aligned}$$

Since that $\psi \in \chi$, it follows

$$F_{\omega_n,fz}(t) \geq F_{\omega_{n-1},z}(t),$$

by letting $n \to +\infty$ one gets

$$F_{z,fz}(t) \geq 1 \quad for\ each\ t > 0,$$

which implies by Lemma 1 that $z \in fz$. Hence, z is a fixed point of f.

□

Example 2. Let $\Gamma = [0, +\infty)$. Define $\digamma : \Gamma \times \Gamma \to \Delta^+$ by

$$\digamma_{\omega,\upsilon}(t) = \epsilon_0(t - |\omega - \upsilon|^2).$$

It is claimed that $(\Gamma, \digamma, \urcorner, 2)$ is a complete b-Menger space. Let us consider the mapping $f : \Gamma \to C(\Gamma)$ given by $f(\omega) = [0, \frac{\omega}{2}]$.
It will be proven that for all $\omega, \upsilon \in \Gamma$ and $\rho \in f\omega$ there exists $\sigma \in f\upsilon$ such that

$$\digamma_{p,q}(\psi(t)) \geq \digamma_{\omega,\upsilon}(2t).$$

With $\psi(t) = \frac{3}{4}t$. Let $\omega, \upsilon \in \Gamma$ and $\rho \in f\omega$ one has

Case 1 If $\rho < \frac{\upsilon}{2}$ then $\rho \in f\upsilon$. so there exists $\sigma \in [0, \frac{\upsilon}{2}]$ such that

$$|\rho - \sigma| \leq \left|\frac{\omega}{2} - \frac{\upsilon}{2}\right|.$$

Case 2 If $\rho \geq \frac{\upsilon}{2}$, since $0 \leq \rho \leq \frac{\omega}{2}$, one gets

$$0 \leq \rho - \frac{\upsilon}{2} \leq \frac{\omega}{2} - \frac{\upsilon}{2}$$

Then if one takse $\sigma = \frac{\upsilon}{2}$, one obtains

$$|\rho - \sigma| \leq \left|\frac{\omega}{2} - \frac{\upsilon}{2}\right|.$$

Therefore, from case 1 and case 2, one obtains that

$$\begin{aligned}
\digamma_{\rho,\sigma}(\psi(t)) &= \epsilon_0(\frac{3}{4}t - |\rho - \sigma|^2) \\
&\geq \epsilon_0(\frac{3}{4}t - \left|\frac{\omega}{2} - \frac{\upsilon}{2}\right|^2) \\
&= \epsilon_0(\frac{3}{4}t - \frac{1}{4}|\omega - \upsilon|^2) \\
&\geq \epsilon_0(3t - |\omega - \upsilon|^2) \\
&\geq \digamma_{\omega,\upsilon}(2t).
\end{aligned}$$

Since $\wp_f(0)$ is bounded, then all the conditions of this Theorem are satisfied. Hence f have a fixed point which is 0.

Remark 2. One should mark down that the condition propriety about the boundedness of the orbits $\wp_f(\omega)$ is an obligatory condition to prove the existence of a fixed point as the next example shows.

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Example 3. (Sherwood, 1971) Define the distribution function as:

$$\mathcal{K}(t) = \begin{cases} 0 & \text{if} \quad t \leq 4, \\ 1 - \frac{1}{a} & \text{Si} \quad 2^a < t < 2^{a+1}, \ \ a > 1. \end{cases}$$

Consider $\Gamma = \{1, 2, 3, ..., a, ...\}$. Define $F : \Gamma \times \Gamma \longrightarrow \mathcal{D}^+$ as follows :

$$F_{a,a+b}(t) = \begin{cases} 0 & \text{if} \quad t = 0, \\ \top_L^b \left(\mathcal{K}(2^a t), \mathcal{K}(2^{a+1} t), ..., \mathcal{K}(2^{a+b} t)\right) & \text{if} \quad t > 0. \end{cases}$$

Then, one obtains that $(\Gamma, F, \top_L, 1)$ is a complete b-Menger space, and since every single-valued mapping is a multi-valued mapping, one puts $f(a) = a + 1$, which is ψ-contractive with $\psi(t) = \frac{1}{2}t$. However, f have no fixed point, since there exists any $n \in \Gamma$ such that $\wp_f(\omega)$ is bounded.

Lemma 4. *Every Cauchy sequence in a b-Menger space* $(\Gamma, F, \top, s)$ *such that* $RanF \subset \mathcal{D}^+$ *is bounded.*

Proof. Let $\{\omega_n\}$ be a Cauchy sequence. Taking $\epsilon > 0$, then for $t > 0$ there exists a positive integer $N \in \mathbb{N}$ such that

$$F_{\omega_n,\omega_m}(t) > 1 - \epsilon \quad whenever \ n, m \geq N. \tag{5}$$

Since $RanF \subset \mathcal{D}^+$ there exists $t_0 > t$ such that

$$F_{\omega_n,\omega_m}(t_0) > 1 - \epsilon \quad whenever \ n, m < N. \tag{6}$$

Then, from (5) and (6), one obtains

$$F_{\omega_n,\omega_m}(t_0) > 1 - \epsilon \quad whenever \ n, m \in \mathbb{N}.$$

Hence,

$$\theta_{\wp(\omega)}(t_0) > 1 - \epsilon,$$

which implies also that for all $t_1 \geq t_0$ one gets

$$\theta_{\wp(\omega)}(t_1) \geq \theta_{\wp(\omega)}(t_1) > 1 - \epsilon.$$

Since that $\epsilon > 0$ is arbitrary, there is $t_1 > 0$ such that

$$\mathcal{D}_{\wp(\omega)}(t_1) > 1 - \epsilon.$$

Thus,

$$\mathcal{D}_{\wp(\omega)}(t_1) \to 1 \quad as \ t_1 \to +\infty.$$

The proof is completed. □

Lemma 5. *Let* $(\Gamma, F, \urcorner, s)$ *be a complete b-Menger space where* $RanF \subset \mathcal{D}^+$ *and* $f : \Gamma \to C(\Gamma)$ *is a multivalued* ψ*-probabilistic contraction mapping on* Γ *with* $\psi \in \chi$. *If the t-norm* $\urcorner$ *is of H-type, then for all* $\omega \in \Gamma$, *the orbit* $\wp_f(\omega)$ *is bounded.*

Proof. Let $\omega \in \Gamma$ and $\{\omega_n\}$ be a sequence of the orbit $\wp_f(\omega)$ starting at ω. From Lemma 4, it suffices to show that $\{\omega_n\}$ is a Cauchy sequence.
Since f is ψ-probabilistic, then there exists $\psi \in \chi$ such that

$$F_{\omega_n,\omega_{n+1}}(\psi(t)) \geq F_{\omega_{n-1},\omega_n}(st) \quad for\ all\ n \in \mathbb{N},\ and\ t > 0.$$

Then, by induction, it is shown, as in the proof of the Theorem, that

$$F_{\omega_n,\omega_{n+k}}(\psi(t)) \geq F_{\omega_{n-1},\omega_{n+k-1}}(st) \quad for\ all\ k > 0. \tag{7}$$

Next, for $k = 1$, one obtains that

$$\begin{aligned} F_{\omega_n,\omega_{n+1}}(\psi^n(t)) &\geq F_{\omega_0,\omega_1}(st) \\ &\geq F_{\omega_0,\omega_1}(t) \quad for\ all\ n \in \mathbb{N}\ and t > 0. \end{aligned}$$

Since $\lim_{t\to+\infty} F_{\omega_0,\omega_1}(t) = 1$.
Then, for any $\epsilon \in (0, 1]$, there exists $t_0 > 0$ such that

$$F_{\omega_0,\omega_1}(t_0) > 1 - \epsilon.$$

As $\psi \in \chi$, then there exists $t_1 \geq t_0$ such that

$$\lim_{n\to+\infty} \psi^n(t_1) = 0.$$

So for any $t > 0$, there exists $n_0 \in \mathbb{N}$ such that

$$\psi^n(t_1) < t \quad for\ all\ n \geq n_0.$$

By the monotonicity of F, one has for all $n \geq n_0$,

$$\begin{aligned} F_{\omega_n,\omega_{n+1}}(t) &\geq F_{\omega_n,\omega_{n+1}}(\psi^n(t_1)) \\ &\geq F_{\omega_0,\omega_1}(t_1) \\ &> F_{\omega_0,\omega_1}(t_0) \\ &> 1 - \epsilon. \end{aligned}$$

Hence

$$\lim_{n\to+\infty} F_{\omega_n,\omega_{n+1}}(t) = 1 \quad for\ all\ t > 0. \tag{8}$$

Now, one proves by induction that for any $k > 2$,

$$F_{\omega_n,\omega_{n+k}}(st) \geq \urcorner^{k-1}\left(F_{\omega_n,\omega_{n+1}}(t-\psi(t))\right). \tag{9}$$

Inequality (9) is satisfied for $k = 3$.
Now, suppose that (9) holds for $k > 2$.
Using (7), the monotonicity of $\urcorner$ and the induction hypothesis, one obtains

$$\begin{aligned} F_{\omega_n,\omega_{n+k+1}}(st) &= F_{\omega_n,\omega_{n+k+1}}\left(s(t-\psi(t)) + s\psi(t)\right) \\ &\geq \urcorner(F_{\omega_n,\omega_{n+1}}(t-\psi(t)), F_{\omega_{n+1},\omega_{n+1+k}}(\psi(t)) \\ &\geq \urcorner(F_{\omega_n,\omega_{n+1}}(t-\psi(t)), F_{\omega_n,\omega_{n+k}}(st)) \\ &\geq \urcorner(F_{\omega_n,\omega_{n+1}}(t-\psi(t)), \urcorner^{k-1}(F_{\omega_n,\omega_{n+1}}(t-\psi(t))) \\ &= \urcorner^{k}(F_{\omega_n,\omega_{n+1}}(t-\psi(t))). \end{aligned}$$

Hence, (9) is proved for all $k > 2$.
Now, let $\epsilon \in (0,1)$ be given. From that $\urcorner$ is of H-type, there exists $\delta > 0$ such that

$$\urcorner^{n}(t) > 1-\epsilon \quad for\ all\ t \in (1-\delta, 1]\ and\ n \in \mathbb{N}. \tag{10}$$

As $\frac{t-\psi(t)}{s} > 0$, then by (8), one has that

$$\lim_{n\to+\infty} F_{\omega_n,\omega_{n+1}}\left(\frac{t-\psi(t)}{s}\right) = 1.$$

So, there exists $N \in \mathbb{N}$ such that for all $n \geq N$ one obtains

$$F_{\omega_n,\omega_{n+1}}\left(\frac{t-\psi(t)}{s}\right) > 1-\delta.$$

Finally, from (9) and (10), one gets

$$F_{\omega_n,\omega_{n+k}}(t) \geq \urcorner^{k-1}\left(F_{\omega_n,\omega_{n+1}}\left(\frac{t-\psi(t)}{s}\right)\right) > 1-\epsilon \quad for\ all\ n \geq N,\ and\ k > 1.$$

Therefore, $\{\omega_n\}$ is a Cauchy sequence, which implies from Lemma 5 that $\wp_f(\omega)$ is bounded. □

As a direct consequence of Theorem 1, Lemma 4, and Lemma 5, one obtains the following result

Corollary 1. *Let* $(\Gamma, \digamma, \urcorner, s)$ *be a complete b-Menger space with* $\urcorner$ *is of H-type and* $f : \Gamma \to C(\Gamma)$ *is a probabilistic* ψ*-contraction mapping where* $\psi \in \chi$*. Then there exists* $z \in \Gamma$ *satisfying* $z \in fz$*.*

Next, here is an example to illustrate corollary 1.

Example 4. Let $\Gamma = [0, +\infty)$. Define $\digamma : \Gamma \times \Gamma \to \Delta^+$ as follows

$$\digamma_{\omega,\upsilon}(t) = \epsilon_0(t - |\omega - \upsilon|^2).$$

It is easy to check that $(\Gamma, \digamma, \urcorner_M, 2)$ is a complete b-Menger space with $\urcorner_M$ is of H-type. And one considers the function $f : \Gamma \to C(\Gamma)$ given by $f(\omega) = \{1, \frac{\omega}{2}, \frac{\omega}{3}\}$.
Then, for any $\omega, y \in \Gamma$ and $\rho \in f\omega$, there are the following cases:

Case 1 If $\rho = 1 \in f\omega$, then one chooses $\rho = \sigma$.

Case 2 If $\rho = \frac{\omega}{2} \in f\omega$, then one chooses $\sigma = \frac{\upsilon}{2}$.

Case 3 If $\rho = \frac{\omega}{3} \in f\omega$, then one chooses $\sigma = \frac{\upsilon}{3}$.

Now, it is necessary to show that the ψ-contraction is satisfied with $\varphi(t) = \frac{1}{2}t$.
For case 1, there is

$$\digamma_{\rho,\sigma}(\frac{1}{2}t) = \epsilon_0(\frac{1}{2}t) = \epsilon_0(2t),$$

hence

$$\begin{aligned}\digamma_{\rho,\sigma}(\frac{1}{2}t) &\geq \epsilon_0(2t - |\omega - \upsilon|^2) \\ &= \digamma_{\omega,\upsilon}(2t).\end{aligned}$$

Case 2 gives

$$\digamma_{\rho,\sigma}(\frac{1}{2}t) = \epsilon_0(\frac{1}{2}t - \left|\frac{\omega}{2} - \frac{\upsilon}{2}\right|^2) = \epsilon_0(2t - |\omega - \upsilon|^2) = \digamma_{\omega,\upsilon}(2t).$$

Finally, for case 3, one obtains

$$\digamma_{\rho,\sigma}(\frac{1}{2}t) = \epsilon_0(\frac{1}{2}t - \left|\frac{\omega}{3} - \frac{\upsilon}{3}\right|^2) = \epsilon_0(\frac{9}{2}t - |\omega - \upsilon|^2),$$

hence

$$\digamma_{\rho,\sigma}(\frac{1}{2}t) \geq \epsilon_0(2t - |\omega - \upsilon|^2)$$

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$$= F_{\omega,\upsilon}(2t).$$

Thus, all the conditions of the above Corollary are satisfied, which implies that f admits a fixed point.

Coincidence point theorems in a fuzzy b-metric space

Prior to announcing the coincidence, recall first the Definition of a fuzzy b-metric space.

Definition 8. *A quadruple $(\Gamma, \mathcal{Z}, \urcorner, s)$ where Γ is an arbitrary nonempty set, Γ is a continuous t-norm, $\mathcal{Z}$ is a fuzzy set on $\Gamma \times \Gamma \times (0, +\infty)$ and $s \geq 1$ is a real number, is called a fuzzy b-metric space if the following conditions are verified:*

1. $\mathcal{Z}(\alpha, \beta, 0) = 0$,
2. $\mathcal{Z}(\alpha, \beta, t) = 1$ *for all* $t > 0$ *if and only if* $\alpha = \beta$,
3. $\mathcal{Z}(\alpha, \beta, t) = \mathcal{Z}(\beta, \alpha, t)$,
4. $\mathcal{Z}(\alpha, \gamma, s(t + v)) \geq \urcorner(\mathcal{Z}(\alpha, \beta, t), \mathcal{Z}(\beta, \gamma, v))$,
5. $\mathcal{Z}(\alpha, \beta, .) : [0, +\infty) \longrightarrow [0, 1]$ *is left-continuous and nondecreasing for all* $\alpha, \beta, \gamma \in \Gamma$ *and* $t, v > 0$.

When $s = 1$ then $(\Gamma, \mathcal{Z}, \urcorner, s)$ is a fuzzy metric space in the form of Kramosil and Michalek (Kramosil & Michálek, 1975).

The definition of a multivalued ψ-contraction in a fuzzy b-metric version is given as the following.

Definition 9. *Let $(\Gamma, \mathcal{Z}, \urcorner, s)$ be a fuzzy b-metric space and $\psi : [0, +\infty) \to [0, +\infty)$. A mapping $f : \Gamma \to C(\Gamma)$ is called a multivalued fuzzy ψ-contraction if for every $\omega, \upsilon \in \Gamma$ and every $\rho \in f\omega$ there exists $\sigma \in f\upsilon$ such that*

$$\mathcal{Z}(\rho, \sigma, \psi(t)) \geq \mathcal{Z}(\omega, \upsilon, st) \quad for\ all\ t > 0.$$

Theorem 2. *Let $(\Gamma, \mathcal{Z}, \urcorner, s)$ be a complete fuzzy b-metric space where $\lim_{t \to +\infty} \mathcal{Z}(\omega, \upsilon, t) = 1$ for all $\omega, \upsilon \in \Gamma$ and $f : \Gamma \to C(\Gamma)$ is a multivalued fuzzy ψ-contraction mapping with $\psi \in \chi$. If all the orbits $\wp_{f(\omega)}$ for some $\omega \in \Gamma$ are bounded, then there exists $z \in \Gamma$ satisfying $z \in fz$.*

Proof. From that $\mathcal{Z}(\omega, \upsilon, .)$ is left-continuous and nondecreasing mapping for all $\omega, \upsilon \in \Gamma$, then by taking $\digamma_{\omega,\upsilon}(t) = \digamma(\omega, \upsilon, t)$ for all $t > 0$ and since the condition of $\digamma_{\rho,\sigma}(+\infty) = 1$ has not been used in the proof of theorem 1, it implies that this result holds. □

Similarly, from Corollary 1, one obtains

Corollary 2. *Let* $(\Gamma, \mathcal{Z}, \urcorner, s)$ *be a complete fuzzy b-metric space with* $\urcorner$ *is of H-type and* $f : \Gamma \to C(\Gamma)$ *is a fuzzy* ψ*-contraction mapping where* $\psi \in \chi$*. Then there exists* $z \in \Gamma$ *satisfying* $z \in fz$*.*

Conclusion

In summary, the novel approach applied in this study has led to significant advancements, generalizing and enhancing the results originally proposed by Fang (Fang, 1992) and Hadžić (Hadžic, 1989). These achievements mark a notable contribution to the fixed point theory literature, particularly in the context of multivalued maps within probabilistic metric spaces. Additionally, the authors introduced and defined the concept of multivalued ψ-contraction in a b-Menger space, extending it to encompass fuzzy b-metric spaces. Moreover, this exploration uncovered a meaningful connection between the boundedness of orbits and the H-type t-norms, providing valuable insights into the interplay between these concepts. As a consequential outcome, coincidence point theorems applicable to fuzzy b-metric spaces are derived, adding a new dimension to the understanding of these spaces and their applications in the context of multivalued mappings. This comprehensive study not only broadens the theoretical foundations but also opens avenues for further research and exploration in the rich and diverse field of the fixed point theory.

References

Achtoun, Y., Sefian, M.L. & Tahiri, I. 2023. (f, g)-φ-Contraction Mappings in Menger. *Results in Nonlinear Analysis*, 6(3), pp. 97–106 [online]. Available at: https://nonlinear-analysis.com/index.php/pub/article/view/201 [Accessed: 1 February 2024].

Bakhtin, I.A. 1989. The contraction mapping principle in almost metric spaces. *Func. An., Gos. Ped. Inst. Unianowsk*, 30, pp. 26–37.

Banach, S. 1922. Sur les opérations dans les ensembles abstraits et leur applications aux équations intégrales. *Fundamenta mathematicae*, 3, pp. 133–181. Available at: https://doi.org/10.4064/fm-3-1-133-181.

Berinde, V. & Păcurar, M. 2022. The early developments in fixed point theory on b-metric spaces: a brief survey and some important related aspects. *Carpathian Journal of Mathematics*, 38(3), pp. 523–538 [online]. Available at: https://www.carpathian.cunbm.utcluj.ro/wp-content/uploads/carpathian_2022_38_3_523_538.pdf [Accessed: 1 February 2024].

Czerwik, S. 1993. Contraction mappings in b-metric spaces. *Acta Mathematica et Informatica Universitatis Ostraviensis*, 1(1), pp. 5–11 [online]. Available at: https://dml.cz/handle/10338.dmlcz/120469 [Accessed: 1 February 2024].

Fang, J.X. 1992. A note on fixed point theorems of Hadžic. *Fuzzy Sets and Systems*, 48(3), pp. 391–395. Available at: https://doi.org/10.1016/0165-0114(92)90355-8.

Hadžic, O. 1989. Fixed point theorems for multivalued mappings in some classes of fuzzy metric spaces. *Fuzzy sets and Systems*, 29(1), pp. 115–125. Available at: https://doi.org/10.1016/0165-0114(89)90140-1.

Huang, H., Došenović, T., Rakić, D. & Radenović, S. 2023. Fixed Point Results in Generalized Menger Probabilistic Metric Spaces with Applications to Decomposable Measures. *Axioms*, 12(7), art.number:660. Available at: https://doi.org/10.3390/axioms12070660.

Kramosil, I. & Michálek, J. 1975. Fuzzy metrics and statistical metric spaces. *Kybernetika*, 11(5), pp. 336–344 [online]. Available at: https://dml.cz/handle/10338.dmlcz/125556 [Accessed: 1 February 2024].

Mbarki, A. & Oubrahim, R. 2017. Probabilistic b-metric spaces and nonlinear contractions. *Fixed Point Theory and Applications*, 2017, art.number:29. Available at: https://doi.org/10.1186/s13663-017-0624-x.

Menger, K. 2003. Statistical Metrics. In: *Schweizer, B. et al. (Eds.) Selecta Mathematica*. II, pp.433–435. Vienna: Springer. Available at: par https://doi.org/10.1007/978-3-7091-6045-9_35.

Mihet, D. 2005. Multivalued generalisations of probabilistic contractions. *Journal of Mathematical Analysis and Applications*, 304(2), pp. 464–472. Available at: https://doi.org/10.1016/j.jmaa.2004.09.034.

Nădăban, S. 2016. Fuzzy b-metric spaces. *International Journal of Computers Communications & Control*, 11(2), pp. 273–281 [online]. Available at: https://univagora.ro/jour/index.php/ijccc/article/view/2443 [Accessed: 1 February 2024].

Nadler Jr, S.B. 1969. Multi-valued contraction mappings. *Pacific Journal of Mathematics*, 30(2), pp. 475–488. Available at: https://doi.org/10.2140/pjm.1969.30.475.

Pap, E., Hadžić, O. & Mesiar, R. 1996. A Fixed Point Theorem in Probabilistic Metric Spaces and an Application. *Journal of Mathematical Analysis and Applications*, 202(2), pp. 433–449. Available at: https://doi.org/10.1006/jmaa.1996.0325.

Patle, P., Patel, D., Aydi, H. & Radenović, S. 2019. ON H+Type Multivalued Contractions and Applications in Symmetric and Probabilistic Spaces. *Mathematics*, 7(2), art.number:144. Available at: https://doi.org/10.3390/math7020144.

Schweizer, B. & Sklar, A. 1983. *Probabilistic Metric Spaces*. Mineola, New York: Dover Publications, Inc. ISBN: 0-486-44514-3.

Sherwood, H. 1971. Complete probabilistic metric spaces. *Zeitschrift für Wahrscheinlichkeitstheorie und Verwandte Gebiete*, 20, pp. 117–128. Available at: https://doi.org/10.1007/BF00536289.

Explorando la probabilidad multivaluada ψ-contracciones con órbitas en espacios b-Menger

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CAMPO: matemáticas

TIPO DE ARTÍCULO: artículo científico original

Resumen:

Introducción/objetivo: El artículo presenta un enfoque novedoso para ciertos teoremas bien establecidos de punto fijo para contracciones probabilísticas multivaluadas en espacios de b-Menger, aprovechando la acotación de las órbitas. El objetivo era generalizar y mejorar los resultados obtenidos anteriormente por Fang y Hadžić.

Métodos: La delimitación de las órbitas en los espacios b-Menger se utiliza para establecer su enfoque para contracciones probabilísticas multivaluadas.

Resultados: Los hallazgos del estudio no sólo generalizaron los teoremas del punto fijo existentes, sino que también los mejoraron significativamente. Se demostró la eficacia del enfoque para ampliar los resultados propuestos originalmente por Fang y Adžić. Además, se demostró la aplicabilidad del teorema del punto fijo de coincidencia en espacios b-métricos difusos.

Conclusión: El estudio presentó una perspectiva novedosa sobre los teoremas del punto fijo en contracciones probabilísticas multivaluadas dentro de espacios de b-Menger. Al aprovechar la acotación e introducir un teorema de punto fijo de coincidencia para espacios b-métricos difusos, el trabajo contribuyó al avance en este campo.

Palabras claves: punto fijo, espacios b-Menger, contracción ψ-multivaluada, espacio b-métrico difuso.

Исследование многозначной вероятности ψ-сжатия с орбитами в b-пространстве Менгера

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РУБРИКА ГРНТИ: 27.25.17 Метрическая теория функций,
27.39.15 Линейные пространства, снабженные топологией, порядком и другими структурами

ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: В данной статье представлен новый подход к некоторым общепризнанным теоремам о неподвижной точке для многозначных вероятностных сокращений в b-менгеровских пространствах с использованием ограниченности орбит. Целью данной статьи было обобщить и улучшить предыдущие результаты, полученные Фангом и Хаджичем.

Методы: Ограниченность орбит в b-пространствах Менгера используется для определения их подхода к многозначным вероятностным сжатиям.

Результаты: Результаты исследования не только обобщили существующие теоремы о неподвижной точке, но и существенно их усовершенствовали. Была продемонстрирована эффективность подхода в расширении результатов, первоначально предложенного Фангом и

Хаджичем. Кроме того, была продемонстрирована применимость теоремы о неподвижных точках и точках совпадения в нечетких b-метрических пространствах.

Выводы: В исследовании представлен новый взгляд на теоремы о неподвижных точках в многозначных вероятностных сжатиях в b-пространствах Менгера. Используя ограниченность и вводя теорему о совпадении неподвижных точек для нечетких b-метрических пространств, данная статья вносит большой вклад в изучение данной области.

Ключевые слова: неподвижная точка, b-пространства Менгера, многозначное ψ-сжатие, нечеткое b-метрическое пространство.

Истраживање вишевредносне вероватноће ψ-контракције са орбитама у b-Менгеровим просторима

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ОБЛАСТ: математика
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: Рад представља нови приступ одређеним добро утврђеним теоремама о фиксној тачки за вишезначне вероватносне контракције у b-Менгеровим просторима, користећи ограниченост орбите. Циљ је био да се генерализују и побољшају претходни резултати које су извели Фанг и Хаџић.

Методе: Коришћене су ограничености орбита у b-Менгеровим просторима које успостављају свој приступ за вишезначне вероватносне контракције.

Резултати: Налази студије нису само генерализовали постојеће теореме о фиксној тачки већ су их и значајно побољшали. Представљена је и ефективност приступа у проширењу резултата који су првобитно предложили Фанг

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и Хаџић. Такође, демонстрирана је применљивост теореме коинциденције о фиксној тачки у расплинутим b-метричким просторима.

Закључак: Студија је представила нову перспективу теореме фиксне тачке у вишезначним вероватносним контракцијама унутар b-Менгерових простора. Коришћење ограничености и увођење фиксне случајности теорема тачке за расплинуте b-метричке просторе представља допринос унапређењу ове области.

Кључне речи: фиксна тачка, b-Менгерови простори, вишезначно пресликавање ψ-контракција, расплинута b-метрика.

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Zamfirescu mappings under Pata-type condition: results and application to an integral equation

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Abstract:

Introduction/purpose: Pata-type and Zamfirescu mappings are extended beyond metric spaces.

Methods: The concept of Pata-type Zamfirescu mapping within the framework of S-metric spaces is employed.

Results: A series of corresponding outcomes has been established. Furthermore, the obtained results are employed to solve an integral equation.

Conclusions: S-Pata type and Zamfirescu mappings have unique fixed points.

Key words: Pata-type contraction, Zamfirescu mapping, S-Metric space, fixed point.

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Introduction

In 1922, Banach (Banach, 1922) established that every contraction mapping on a complete metric space possesses a unique fixed point. This theorem is commonly referred to as the Banach fixed point theorem.

Since Banach's theorem was proven, various other types of mappings have been demonstrated to possess the same fixed point property. Among these mappings are Kannan-type mappings and Chatterjea-type mappings, both of which were introduced in the 1960s. These mappings hold significance because they enable the existence of fixed points even for non-continuous mappings.

In 1972, Zamfirescu (Zamfirescu, 1972) introduced a generalized contraction mapping that further extended the class of mappings for which the fixed point property can be guaranteed. Zamfirescu's results generalized the work of several other mathematicians, including Kannan (Kannan, 1968) and Chatterjea (Chatterjea, 1972).

In the paper, Ψ represents the set of ascending functions $\psi : [0,1] \to [0,+\infty)$, where ψ exhibits continuity at 0 and starts at $\psi(0) = 0$.

Definition 1. (Zamfirescu, 1972) If (∇, d) is a metric space, a function $\Gamma : \nabla \to \nabla$ is referred to as a Zamfirescu mapping if it satisfies the following condition for any points ϑ and θ in ∇ and real numbers a, b, and c within the interval $[0,1)$:

$$d(\Gamma(\vartheta),\Gamma(\theta)) \leq$$
$$\max\left\{ad(\vartheta,\theta), \tfrac{b}{2}[d(\vartheta,\Gamma(\vartheta)) + d(\theta,\Gamma(\theta))], \tfrac{c}{2}[d(\vartheta,\Gamma(\theta)) + d(\theta,\Gamma(\vartheta))]\right\}$$

In 2011, Pata (Pata, 2011) introduced an improved version of the classical Banach Principle. This enhancement enables the identification of fixed points for mappings that lack strict contraction properties, instead relying on approximate contraction characteristics.

Theorem 1. *(Pata, 2011) If (X,d) is a metric space that is complete and fixed constants $\Lambda \geq 0$, $\alpha \geq 1$ and β which lies in the interval $[0,\alpha]$. If the mapping $\Gamma : X \to X$ fulfills the subsequent inequality for each $\varepsilon \in [0,1]$ and all $\vartheta, \theta \in X$,*

$$d(\Gamma\vartheta,\Gamma\theta) \leq (1-\varepsilon)d(\vartheta,\theta) + \Lambda\varepsilon^{\alpha}[1 + \|\vartheta\| + \|\theta\|]^{\beta}$$

then Γ *possesses a unique fixed point* $\vartheta^* \in X$*, and the sequence* $\{\Gamma^n \vartheta_0\}$ *exhibits convergence towards* ϑ^* *for any given initial element* $\vartheta_0 \in X$*.*

Many other authors have previously employed the Pata-type condition to derive novel fixed point outcomes (Kadelburg & Radenović, 2014; Özgür & Taş, 2021; Kadelburg & Radenović, 2016; Karapinar et al., 2020a; Saleem et al., 2020; Karapınar et al., 2020b; Aktay & Özdemir, 2022; Yahaya et al., 2023; Roy et al., 2024).

Further, in 2018 Jacob et al. (Jacob et al., 2018) defined Pata type Zamfirescu mapping and generalized the results of (Chatterjea, 1972; Pata, 2011).

Definition 2. (Jacob et al., 2018) If (∇, d) is a metric space, a mapping $\Gamma : \nabla \to \nabla$ is considered as a Pata-type Zamfirescu mapping if, for all ϑ and θ in ∇, and for every $\varepsilon \in [0, 1]$, it holds the following inequality with ψ in Ψ,:

$$d(\Gamma(\vartheta), \Gamma(\theta)) \leq (1 - \varepsilon) M(\vartheta, \theta) + \Lambda \varepsilon^{\alpha} \psi(\varepsilon)[1 + \|\vartheta\| + \|\theta\| + \|\Gamma\vartheta\| + \|\Gamma\theta\|]^{\beta}$$

where $M(\vartheta, \theta) = \max\left\{d(\vartheta, \theta), \frac{d(\vartheta, \Gamma(\vartheta)) + d(\theta, \Gamma(\theta))}{2}, \frac{d(\vartheta, \Gamma(\theta)) + d(\theta, \Gamma(\vartheta))}{2}\right\}$ and $\Lambda \geq 0$, $\alpha \geq 1$, $\beta \in [0, \alpha]$ are constants.

In 2012, Sedghi et al. (Sedghi et al., 2012) presented the notion of an S-metric space.

Definition 3. (Sedghi et al., 2012) If ∇ is a nonempty set, an S-metric is a function $S : \nabla \times \nabla \times \nabla \to [0, +\infty)$ on ∇ that meets the requirements for every $\vartheta, \theta, \delta, a \in \nabla$ as follows:

(i) $S(\vartheta, \theta, \delta) \geq 0$,

(ii) $S(\vartheta, \theta, \delta) = 0$ if and only if $\vartheta = \theta = \delta$,

(iii) $S(\vartheta, \theta, \delta) \leq S(\vartheta, \vartheta, a) + S(\theta, \theta, a) + S(\delta, \delta, a)$.

The term "S-metric space" refers to the pair (∇, S).

Example 1. (Sedghi et al., 2012) If ∇ is a nonempty set equipped with an ordinary metric d on ∇, then the following are S-metrics on ∇.

- $S(\vartheta, \theta, \delta) = d(\vartheta, \delta) + d(\theta, \delta)$
- $S(\vartheta, \theta, \delta) = d(\vartheta, \theta) + d(\theta, \delta) + d(\delta, \vartheta)$

Lemma 1. *(Sedghi et al., 2012) If the space* (∇, S) *is an* S*-metric space, then as a result, there is for all* $\vartheta, \theta \in \nabla$*,*

$$S(\vartheta, \vartheta, \theta) = S(\theta, \theta, \vartheta)$$

.

Lemma 2. *(Sedghi et al., 2012) In an* S*-metric space* (∇, S)*, for all* $\vartheta, \theta, \delta \in \nabla$*, there is*

$$S(\vartheta, \vartheta, \theta) \leq 2S(\vartheta, \vartheta, \delta) + S(\theta, \theta, \delta)$$

and

$$S(\vartheta, \vartheta, \theta) \leq 2S(\vartheta, \vartheta, \delta) + S(\delta, \delta, \theta)$$

Definition 4. (Sedghi et al., 2012) If (∇, S) is an S-metric space,

(i) a sequence $\{\vartheta_n\}$ in ∇ converges to ϑ if and only if $S(\vartheta_n, \vartheta_n, \vartheta) \to 0$ as $n \to +\infty$. This convergence is denoted as $\lim_{n\to+\infty} \vartheta_n = \vartheta$,

(ii) a sequence $\{\vartheta_n\}$ in ∇ is referred to as a Cauchy sequence if, for given $\varepsilon > 0$ there is a $n_0 \in \mathbb{N}$ such that $S(\vartheta_n, \vartheta_n, \vartheta_m) < \varepsilon$ for every $n, m \geq n_0$, and

(iii) the space (∇, S) is defined as complete when it satisfies the condition that every Cauchy sequence in ∇ converges.

Several other authors have contributed to the field of S-metric spaces, establishing numerous results within this framework as well as in various extended spaces related to S-metric spaces. Some of these pertinent works can be found in the references (Sedghi et al., 2012; Chand & Rohen, 2023; Özgür & Taş, 2023; Priyobarta et al., 2022).

Inspired by the findings outlined above, this paper introduces the concept of S-Pata type Zamfirescu mappings and demonstrates the existence of fixed point results within the framework of S-metric spaces. Notably, these results extend the findings from a previous study (Jacob et al., 2018). Furthermore, the best proximity point theorem has been established and findings applied to the context of integral equations.

Main results

In this section, the aim is to demonstrate the existence and uniqueness of fixed points for S-Pata type Zamfirescu mappings. Consider an S-metric

space denoted as (∇, S). Throughout this discussion, the norm of an element ϑ is represented as $\|\vartheta\| = S(\vartheta_0, \vartheta_0, \vartheta)$, where ϑ_0 is a chosen element in ∇.

Definition 5. In an S-metric space (∇, S), a mapping $\Gamma : \nabla \to \nabla$ is referred to as an S-Pata type Zamfirescu mapping if it satisfies the following inequality for all $\vartheta, \theta, \delta \in \nabla$, $\psi \in \Psi$, and every $\varepsilon \in [0, 1]$:

$$S(\Gamma\vartheta, \Gamma\theta, \Gamma\delta) \leqslant (1-\epsilon)M(\vartheta, \theta, \delta) + \Lambda\epsilon^{\alpha}\psi(\epsilon)[1+ \\ \| \vartheta \| + \| \theta \| + \| \delta \| + \| \Gamma\vartheta \| + \| \Gamma\theta \| + \| \Gamma\delta \|]^{\beta}$$

where

$$M(\vartheta, \theta, \delta) = \max\left\{S(\vartheta, \theta, \delta), \frac{S(\vartheta, \vartheta, \Gamma\vartheta) + S(\theta, \theta, \Gamma\theta) + S(\delta, \delta, \Gamma\delta)}{3}, \right. \\ \left. \frac{S(\vartheta, \vartheta, \Gamma\theta) + S(\theta, \theta, \Gamma\delta) + S(\delta, \delta, \Gamma\vartheta)}{4}\right\}$$

$\Lambda \geqslant 0, \alpha \geqslant 1, \beta \in [0, \alpha]$ are the constants.

Note: From the above definition, it can easily be deduced that

$$S(\Gamma\vartheta, \Gamma\vartheta, \Gamma\theta) \leqslant (1-\epsilon)M(\vartheta, \vartheta, \theta) + \Lambda\epsilon^{\alpha}\psi(\epsilon)[1+2\|\vartheta\| + \|\theta\| + 2\|\Gamma\vartheta\| + \|\Gamma\theta\|]^{\beta}$$

where

$$M(\vartheta, \vartheta, \theta) = \max\left\{S(\vartheta, \vartheta, \theta), \frac{2S(\vartheta, \vartheta, \Gamma\vartheta) + S(\theta, \theta, \Gamma\theta)}{3}, \right. \\ \left. \frac{S(\vartheta, \vartheta, \Gamma\vartheta) + S(\vartheta, \vartheta, \Gamma\theta) + S(\theta, \theta, \Gamma\vartheta)}{4}\right\}$$

$\Lambda \geqslant 0, \alpha \geqslant 1, \beta \in [0, \alpha]$ are the constants.

The following lemma is a key ingredient in the proof of this work. This lemma will be used to prove the main results. The proof of the lemma in a metric space can be found in (Alghamdi et al., 2021). Here, it is extended it to the framework of an S-metric space.

Lemma 3. *(Alghamdi et al., 2021) Consider an S-metric space (∇, S). If the sequence $\{\vartheta_n\}$ in ∇ which is not Cauchy with $\lim_{n\to+\infty} S(\vartheta_n, \vartheta_n, \vartheta_{n+1}) = 0$.*

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Then, two sub-sequences $\{\vartheta_{n_k}\}$ *and* $\{\vartheta_{m_k}\}$ *of* $\{\vartheta_n\}$ *exist for any* $\varepsilon > 0$ *such that*

$$\lim_{k\to+\infty} S(\vartheta_{n_k+1}, \vartheta_{n_k+1}, \vartheta_{m_k+1}) = \varepsilon^{+} \tag{1}$$

$$\lim_{k\to+\infty} S(\vartheta_{n_k}, \vartheta_{n_k}, \vartheta_{m_k}) = \lim_{k\to+\infty} S(\vartheta_{n_k+1}, \vartheta_{n_k+1}, \vartheta_{m_k}) = \lim_{k\to+\infty} S(\vartheta_{n_k}, \vartheta_{n_k}, \vartheta_{m_k+1}) = \varepsilon \tag{2}$$

Proof. Since, $\{\vartheta_n\}$ is not a Cauchy sequence and $\lim_{n\to+\infty} S(\vartheta_n, \vartheta_n, \vartheta_{n+1}) = 0$, one can get $\varepsilon > 0$ and $N_0 \geq 1$ such that for any $N > N_0$ there is $m, n > N$ with $m \geq n$ and

$$S(\vartheta_{n+1}, \vartheta_{n+1}, \vartheta_{m+1}) > \varepsilon \; and \; S(\vartheta_{n+1}, \vartheta_{n+1}, \vartheta_n) \leq \varepsilon.$$

By selecting the smallest $m \geq n$ so that $S(\vartheta_{n+1}, \vartheta_{n+1}, \vartheta_{m+1}) > \varepsilon$ holds, it is concluded that for each $N > N_0$ there exists $m, n > N$ such that

$$S(\vartheta_{n+1}, \vartheta_{n+1}, \vartheta_{m+1}) > \varepsilon \; and \; S(\vartheta_{n+1}, \vartheta_{n+1}, \vartheta_m) \leq \varepsilon.$$

Thus, one can construct two sub-sequences $\{\vartheta_{n_k}\}$ and $\{\vartheta_{m_k}\}$ of $\{\vartheta_n\}$ such that

$$S(\vartheta_{n_k+1}, \vartheta_{n_k+1}, \vartheta_{m_k+1}) > \varepsilon \; and \; S(\vartheta_{n_k+1}, \vartheta_{n_k+1}, \vartheta_{m_k}) \leq \varepsilon.$$

These inequalities, along with the triangular inequality, lead to

$$\begin{aligned} \varepsilon < S(\vartheta_{n_k+1}, \vartheta_{n_k+1}, \vartheta_{m_k+1}) &\leq S(\vartheta_{n_k+1}, \vartheta_{n_k+1}, \vartheta_{m_k}) + 2S(\vartheta_{m_k}, \vartheta_{m_k}, \vartheta_{m_k+1}) \\ &\leq \varepsilon + 2S(\vartheta_{m_k}, \vartheta_{m_k}, \vartheta_{m_k+1}). \end{aligned}$$

By means of the Sandwich Theorem, one arrives at (1). Furthermore, there exists

$$S(\vartheta_{n_k+1}, \vartheta_{n_k+1}, \vartheta_{m_k+1}) - 2S(\vartheta_{m_k+1}, \vartheta_{m_k+1}, \vartheta_{m_k}) \leq S(\vartheta_{n_k+1}, \vartheta_{n_k+1}, \vartheta_{m_k}) \leq \varepsilon$$

which implies the second limit of (2). From the subsequent two inequalities,

$$\begin{aligned} &S(\vartheta_{n_k+1}, \vartheta_{n_k+1}, \vartheta_{m_k}) - 2S(\vartheta_{n_k}, \vartheta_{n_k}, \vartheta_{n_k+1}) \leq S(\vartheta_{n_k}, \vartheta_{n_k}, \vartheta_{m_k}) \leq \\ &\varepsilon + 2S(\vartheta_{n_k}, \vartheta_{n_k}, \vartheta_{n_k+1}), \\ &\varepsilon - 2S(\vartheta_{n_k}, \vartheta_{n_k}, \vartheta_{n_k+1}) < S(\vartheta_{n_k}, \vartheta_{n_k}, \vartheta_{m_k+1}) \leq S(\vartheta_{n_k+1}, \vartheta_{n_k+1}, \vartheta_{m_k+1}) + \\ &2S(\vartheta_{n_k}, \vartheta_{n_k}, \vartheta_{n_k+1}) \end{aligned}$$

from these inequalities one will get the required limits. □

Theorem 2. *Let (∇, S) be a complete S-metric space. If $\Gamma : \nabla \to \nabla$ is an S-Pata type Zamfirescu mapping, then Γ possesses one and only one fixed point.*

Proof. Assume ϑ_0 is any element within the set ∇. Create a sequence with the definitions: $\vartheta_{n+1} = \Gamma(\vartheta_n)$ and $c_n = S(\vartheta_n, \vartheta_n, \vartheta_0)$. In order to demonstrate that the sequence $S(\vartheta_{n+1}, \vartheta_n, \vartheta_n)$ is non increasing, consider setting $\varepsilon = 0$, which leads to the following result

$$S(\vartheta_n, \vartheta_n, \vartheta_{n+1}) \leq$$
$$\max \left\{ S(\vartheta_{n-1}, \vartheta_{n-1}, \vartheta_n), \frac{S(\vartheta_{n-1},\vartheta_{n-1},\vartheta_n)+S(\vartheta_{n-1},\vartheta_{n-1},\vartheta_n)+S(\vartheta_n,\vartheta_n,\vartheta_{n+1})}{3}, \right.$$
$$\left. \frac{S(\vartheta_{n-1},\vartheta_{n-1},\vartheta_n)+S(\vartheta_{n-1},\vartheta_{n-1},\vartheta_{n+1})+S(\vartheta_n,\vartheta_n,\vartheta_n)}{4} \right\}$$
$$S(\vartheta_n, \vartheta_n, \vartheta_{n+1}) \leq \max \left\{ S(\vartheta_{n-1}, \vartheta_{n-1}, \vartheta_n), \frac{2S(\vartheta_{n-1},\vartheta_{n-1},\vartheta_n)+S(\vartheta_n,\vartheta_n,\vartheta_{n+1})}{3}, \right.$$
$$\left. \frac{S(\vartheta_{n-1},\vartheta_{n-1},\vartheta_n)+S(\vartheta_{n-1},\vartheta_{n-1},\vartheta_{n+1})}{4} \right\}$$
$$S(\vartheta_n, \vartheta_n, \vartheta_{n+1}) \leq \max \left\{ S(\vartheta_{n-1}, \vartheta_{n-1}, \vartheta_n), \frac{2S(\vartheta_{n-1},\vartheta_{n-1},\vartheta_n)+S(\vartheta_n,\vartheta_n,\vartheta_{n+1})}{3}, \right.$$
$$\left. \frac{3S(\vartheta_{n-1},\vartheta_{n-1},\vartheta_n)+S(\vartheta_n,\vartheta_n,\vartheta_{n+1})}{4} \right\}$$

Now, considering $S(\vartheta_{n-1}, \vartheta_{n-1}, \vartheta_n) \leq S(\vartheta_n, \vartheta_n, \vartheta_{n+1})$, one gets

$$S(\vartheta_n, \vartheta_n, \vartheta_{n+1}) \leq \frac{2S(\vartheta_{n-1}, \vartheta_{n-1}, \vartheta_n) + S(\vartheta_n, \vartheta_n, \vartheta_{n+1})}{3}$$
$$2S(\vartheta_n, \vartheta_n, \vartheta_{n+1}) \leq 2S(\vartheta_{n-1}, \vartheta_{n-1}, \vartheta_n) + S(\vartheta_n, \vartheta_n, \vartheta_{n+1})$$
$$S(\vartheta_n, \vartheta_n, \vartheta_{n+1}) \leq S(\vartheta_{n-1}, \vartheta_{n-1}, \vartheta_n)$$

This results in a contradiction. Therefore, it can be deduced that

$$S(\vartheta_n, \vartheta_n, \vartheta_{n+1}) \leq S(\vartheta_{n-1}, \vartheta_{n-1}, \vartheta_n) \leq \cdots \leq S(\vartheta_0, \vartheta_0, \vartheta_1) = c_1.$$

Claim1: c_n is bounded.
Define

$$\begin{aligned} c_n = S(\vartheta_0, \vartheta_0, \vartheta_n) &\leq 2S(\vartheta_0, \vartheta_0, \vartheta_1) + S(\vartheta_n, \vartheta_n, \vartheta_1) \\ &\leq 2S(\vartheta_0, \vartheta_0, \vartheta_1) + 2S(\vartheta_n, \vartheta_n, \vartheta_{n+1}) + S(\vartheta_{n+1}, \vartheta_{n+1}, \vartheta_1) \\ &\leq 2c_1 + 2c_1 + S(\vartheta_{n+1}, \vartheta_{n+1}, \vartheta_1) \\ &\leq 2c_1 + 2c_1 + S(\vartheta_1, \vartheta_1, \vartheta_{n+1}) \\ &\leq 4c_1 + S(T\vartheta_0, T\vartheta_0, T\vartheta_n) \end{aligned}$$

$$\leq 4c_1 + (1-\varepsilon)\max\left\{\begin{matrix} S(\vartheta_0,\vartheta_0,\vartheta_n), \frac{S(\vartheta_0,\vartheta_0,\vartheta_1)+S(\vartheta_0,\vartheta_0,\vartheta_1)+S(\vartheta_n,\vartheta_n,\vartheta_{n+1})}{3}, \\ \frac{S(\vartheta_0,\vartheta_0,\vartheta_1)+S(\vartheta_0,\vartheta_0,\vartheta_{n+1})+S(\vartheta_n,\vartheta_n,\vartheta_1)}{4} \end{matrix}\right\}$$
$$+ \Lambda\varepsilon^{\alpha}\psi(\varepsilon)[1+\|\vartheta_0\|+\|\vartheta_0\|+\|\vartheta_n\|+\|\vartheta_1\|+\|\vartheta_1\|+\|\vartheta_{n+1}\|]^{\beta}$$
$$\leq 4c_1 + (1-\varepsilon)\cdot$$
$$\max\left\{\begin{matrix} S(\vartheta_0,\vartheta_0,\vartheta_n), \frac{2S(\vartheta_0,\vartheta_0,\vartheta_1)+S(\vartheta_n,\vartheta_n,\vartheta_{n+1})}{3}, \\ \frac{S(\vartheta_0,\vartheta_0,\vartheta_1)+2S(\vartheta_0,\vartheta_0,\vartheta_n)+S(\vartheta_n,\vartheta_n,\vartheta_{n+1})+2S(\vartheta_0,\vartheta_0,\vartheta_n)+S(\vartheta_0,\vartheta_0,\vartheta_1)}{4} \end{matrix}\right\}$$
$$+ \Lambda\varepsilon^{\alpha}\psi(\varepsilon)[1+2\|\vartheta_1\|+\|\vartheta_n\|+(\|\vartheta_1\|+\|\vartheta_n\|)]^{\beta}$$
$$\leq 4c_1 + (1-\varepsilon)\max\{c_n, c_1, \frac{3c_1+4c_n}{4}\} + \Lambda\varepsilon^{\alpha}\psi(\varepsilon)[1+3\|\vartheta_1\|+2\|\vartheta_n\|]^{\beta}$$
$$\leq 4c_1 + (1-\varepsilon)\max\{c_n, c_1, \frac{3c_1}{4}+c_n\} + \Lambda\varepsilon^{\alpha}\psi(\varepsilon)[1+3c_1+2c_n]^{\beta}$$
$$\leq 4c_1 + (1-\varepsilon)\max\{c_n, c_1, \frac{3c_1}{4}+c_n\} + \Lambda\varepsilon^{\alpha}\psi(\varepsilon)[1+3c_1+2c_n]^{\alpha}$$

If there is a subsequence $c_{n_i} \to +\infty$,

$$c_{n_i} \leq 4c_1 + (1-\varepsilon_i)(\frac{3c_1}{4}+c_{n_i}) + \Lambda\varepsilon_i^{\alpha}\psi(\varepsilon_i)[1+3c_1+2c_{n_i}]^{\alpha}$$
$$c_{n_i} - (1-\varepsilon_i)c_{n_i} \leq 4c_1 + \frac{3c_1}{4}(1-\varepsilon_i) + \Lambda\varepsilon_i^{\alpha}\psi(\varepsilon_i)[1+3c_1+2c_{n_i}]^{\alpha}$$
$$\varepsilon_i c_{n_i} \leq A + B\varepsilon_i^{\alpha}\psi(\varepsilon_i)c_{n_i}^{\alpha}$$

for some $A, B > 0$. The choice $\varepsilon_i = \frac{1+A}{c_{n_i}}$ leads to the inequality,

$$1 \leq B(1+A)^{\alpha}\psi(\varepsilon_i) \to 0,$$

which is a contradiction. Hence, $\{c_n\}$ is a bounded sequence.

As $S(\vartheta_{n-1},\vartheta_{n-1},\vartheta_n)$ is a non-increasing sequence and it has a lower bound of 0, it follows that

$$\lim_{n\to+\infty} S(\vartheta_n,\vartheta_n,\vartheta_{n-1}) = d \geq 0$$

$$S(\vartheta_n,\vartheta_n,\vartheta_{n+1}) = S(\Gamma\vartheta_{n-1},\Gamma\vartheta_{n-1},\Gamma\vartheta_n)$$
$$\leq (1-\varepsilon)\cdot$$

$$\max\left\{\begin{array}{c} S(\vartheta_{n-1},\vartheta_{n-1},\vartheta_n),\ \frac{S(\vartheta_{n-1},\vartheta_{n-1},\vartheta_n)+S(\vartheta_{n-1},\vartheta_{n-1},\vartheta_n)+S(\vartheta_n,\vartheta_n,\vartheta_{n+1})}{3},\\ \frac{S(\vartheta_{n-1},\vartheta_{n-1},\vartheta_n)+S(\vartheta_{n-1},\vartheta_{n-1},\vartheta_{n+1})+S(\vartheta_n,\vartheta_n,\vartheta_n)}{4}\end{array}\right\}$$
$$+\Lambda\varepsilon^{\alpha}\psi(\varepsilon)[1+\|\vartheta_{n-1}\|+\|\vartheta_{n-1}\|+\|\vartheta_n\|+\|\vartheta_n\|+\|\vartheta_n\|+\|\vartheta_{n+1}\|]^{\beta}$$
$$\leq(1-\varepsilon)\max\left\{\begin{array}{c} S(\vartheta_{n-1},\vartheta_{n-1},\vartheta_n),\ \frac{2S(\vartheta_{n-1},\vartheta_{n-1},\vartheta_n)+S(\vartheta_n,\vartheta_n,\vartheta_{n+1})}{3},\\ \frac{S(\vartheta_{n-1},\vartheta_{n-1},\vartheta_n)+2S(\vartheta_{n-1},\vartheta_{n-1},\vartheta_n)+S(\vartheta_n,\vartheta_n,\vartheta_{n+1})}{4}\end{array}\right\}$$
$$+\Lambda\varepsilon^{\alpha}\psi(\varepsilon)[1+2\|\vartheta_{n-1}\|+3\|\vartheta_n\|+\|\vartheta_{n+1}\|]^{\beta}$$
$$\leq(1-\varepsilon)\max\left\{\begin{array}{c} S(\vartheta_{n-1},\vartheta_{n-1},\vartheta_n),\ \frac{2S(\vartheta_{n-1},\vartheta_{n-1},\vartheta_n)+S(\vartheta_n,\vartheta_n,\vartheta_{n+1})}{3},\\ \frac{3S(\vartheta_{n-1},\vartheta_{n-1},\vartheta_n)+S(\vartheta_n,\vartheta_n,\vartheta_{n+1})}{4}\end{array}\right\}+K\varepsilon\psi(\varepsilon)$$

Now, the limit as n approaches infinity is considered, one obtains $d\leq K\Psi(\varepsilon)$, and consequently, one gets $d=0$.

Claim2: The sequence $\{\vartheta_n\}$ is a type of Cauchy sequence.
Assuming that $\{\vartheta_n\}$ is not Cauchy, one can apply Lemma 3 to conclude that there exists a subsequence $\{\vartheta_{n_k}\}$ and another subsequence $\{\vartheta_{m_k}\}$ of $\{\vartheta_n\}$ where $n_k>m_k>k$, such that

$$\delta\leq S(\vartheta_{m_k},\vartheta_{m_k},\vartheta_{n_k})=S(\Gamma\vartheta_{m_k-1},\Gamma\vartheta_{m_k-1},\Gamma\vartheta_{n_k-1})$$
$$\leq(1-\varepsilon)\max\left\{\begin{array}{c} S(\vartheta_{m_k-1},\vartheta_{m_k-1},\vartheta_{n_k-1}),\\ \frac{S(\vartheta_{m_k-1},\vartheta_{m_k-1},\vartheta_{m_k})+S(\vartheta_{m_k-1},\vartheta_{m_k-1},\vartheta_{m_k})+S(\vartheta_{n_k-1},\vartheta_{n_k-1},\vartheta_{n_k})}{3},\\ \frac{S(\vartheta_{m_k-1},\vartheta_{m_k-1},\vartheta_{m_k})+S(\vartheta_{m_k-1},\vartheta_{m_k-1},\vartheta_{n_k})+S(\vartheta_{n_k-1},\vartheta_{n_k-1},\vartheta_{m_k})}{4}\end{array}\right\}$$
$$+K\varepsilon\psi(\varepsilon)$$
$$\leq(1-\varepsilon)\max\left\{\begin{array}{c} (\vartheta_{m_k-1},\vartheta_{m_k-1},\vartheta_{n_k})+S(\vartheta_{n_k-1},\vartheta_{n_k-1},\vartheta_{n_k}),\\ \frac{2S(\vartheta_{m_k-1},\vartheta_{m_k-1},\vartheta_{m_k})+S(\vartheta_{n_k-1},\vartheta_{n_k-1},\vartheta_{n_k})}{3},\\ \frac{S(\vartheta_{m_k-1},\vartheta_{m_k-1},\vartheta_{m_k})+S(\vartheta_{m_k-1},\vartheta_{m_k-1},\vartheta_{n_k})+S(\vartheta_{n_k-1},\vartheta_{n_k-1},\vartheta_{m_k})}{4}\end{array}\right\}$$
$$+K\varepsilon\psi(\varepsilon)\ .$$

As k approaches infinity, one obtains $\delta\leq K\psi(\varepsilon)$. Consequently, it follows that $\delta=0$, which presents a contradiction. Therefore, it can be asserted that $\{\vartheta_n\}$ is indeed a Cauchy sequence. Considering that ∇ is a complete S-metric space, it can be concluded that there exists an element ϑ within ∇ such that the sequence ϑ_n converges to ϑ. Now, for all n in the natural numbers, and when ε is set to zero, one obtains

$$S(\vartheta,\vartheta,\Gamma\vartheta) \leq 2S(\vartheta,\vartheta,\vartheta_{n+1}) + S(\Gamma\vartheta,\Gamma\vartheta,\vartheta_{n+1})$$
$$\leq 2S(\vartheta,\vartheta,\vartheta_{n+1}) + \max\left\{\begin{array}{c} S(\vartheta,\vartheta,\vartheta_n), \\ \frac{S(\vartheta,\vartheta,\Gamma\vartheta)+S(\vartheta,\vartheta,\Gamma\vartheta)+S(\vartheta_n,\vartheta_n,\Gamma\vartheta_n)}{3}, \\ \frac{S(\vartheta,\vartheta,\Gamma\vartheta)+S(\vartheta,\vartheta,\Gamma\vartheta_n)+S(\vartheta_n,\vartheta_n,\Gamma\vartheta)}{4} \end{array}\right\}$$
$$\leq 2S(\vartheta,\vartheta,\vartheta_{n+1}) + \max\left\{\begin{array}{c} S(\vartheta,\vartheta,\vartheta_n), \\ \frac{2S(\vartheta,\vartheta,\Gamma\vartheta)+S(\vartheta_n,\vartheta_n,\vartheta_{n+1})}{3}, \\ \frac{S(\vartheta,\vartheta,\Gamma\vartheta)+S(\vartheta,\vartheta,\vartheta_{n+1})+S(\vartheta_n,\vartheta_n,\Gamma\vartheta)}{4} \end{array}\right\}$$

Allowing n to approach infinity, the aforementioned inequality follows as:

$$S(\vartheta,\vartheta,\Gamma\vartheta) \leq \frac{2}{3}S(\vartheta,\vartheta,\Gamma\vartheta)$$
$$\Rightarrow S(\vartheta,\vartheta,\Gamma\vartheta) = 0$$

Hence, ϑ is a fixed point of Γ as $S(\Gamma\vartheta,\Gamma\vartheta,\vartheta) = 0$, one obtains $\Gamma\vartheta = \vartheta$.

To establish the uniqueness of the fixed point, assume that both $\vartheta, \theta \in \nabla$, are the fixed points of Γ. One obtains

$$S(\Gamma\vartheta,\Gamma\vartheta,\Gamma\theta) \leq (1-\varepsilon)\max\left\{\begin{array}{c} S(\vartheta,\vartheta,\theta), \frac{S(\vartheta,\vartheta,\Gamma\vartheta)+S(\vartheta,\vartheta,\Gamma\vartheta)+S(\theta,\theta,\Gamma\theta)}{3}, \\ \frac{S(\vartheta,\vartheta,\Gamma\vartheta)+S(\vartheta,\vartheta,\Gamma\theta)+S(\theta,\theta,\Gamma\vartheta)}{4} \end{array}\right\} + K\varepsilon\psi(\varepsilon)$$

Consequently, one obtains $S(\vartheta,\vartheta,\theta) \leq K\psi(\varepsilon)$, which leads to the conclusion that $\vartheta = \theta$. Hence, it can be asserted that Γ possesses a unique fixed point in ∇. □

Example 2. Let $\nabla = \mathbb{R}$. Define a function $S : \nabla \times \nabla \times \nabla$ equipped by $S(\vartheta,\theta,\delta) = \{|\vartheta-\theta| + |\theta-\delta| + |\delta-\vartheta|\}$ for all $\vartheta,\theta,\delta \in \nabla$. Then (∇, S) is a complete metric space.

If one defines a self mapping Γ on ∇ by $\Gamma\vartheta = \frac{3}{8}\vartheta$, then Γ satisfies the conditions of **Theorem 2**. For all $\vartheta,\theta,\delta \in \nabla$ one obtains

$$S(\Gamma\vartheta,\Gamma\theta,\Gamma\delta) = S(\frac{3}{8}\vartheta,\frac{3}{8}\theta,\frac{3}{8}\delta) = \{|\frac{3}{8}\vartheta - \frac{3}{8}\theta| + |\frac{3}{8}\theta - \frac{3}{8}\delta| + |\frac{3}{8}\delta - \frac{3}{8}\vartheta|\}$$
$$= \frac{3}{8}\sup\{|\vartheta-\theta| + |\theta-\delta| + |\delta-\vartheta|\} = \frac{3}{8}S(\vartheta,\theta,\delta)$$

$$\leq (1-\varepsilon)S(\vartheta,\theta,\delta)+(\frac{3}{8}-(1-\varepsilon))S(\vartheta,\theta,\delta)$$
$$\leq (1-\varepsilon)M(\vartheta,\theta,\delta)+\frac{3}{8}(1-\frac{8}{3}(1-\varepsilon))[S(\vartheta,\vartheta,\vartheta_0)+S(\theta,\theta,\vartheta_0)+S(\delta,\delta,\vartheta_0)]$$
$$\leq (1-\varepsilon)M(\vartheta,\theta,\delta)+\frac{3}{8}\varepsilon^{\frac{8}{3}}[\|\vartheta\|+\|\theta\|+\|\delta\|]$$
$$\leq (1-\varepsilon)M(\vartheta,\theta,\delta)+\frac{3}{8}\varepsilon^{2}\varepsilon^{\frac{2}{3}}[1+\|\vartheta\|+\|\theta\|+\|\delta\|+\|\Gamma\vartheta\|+\|\Gamma\theta\|+\|\Gamma\delta\|]$$

for all $\varepsilon\in[0,1]$. This implies that Γ is an S-Pata type Zamfirescu mapping for $\alpha=2$, $\beta=1$, $\Lambda=\frac{3}{8}$ and $\psi(\varepsilon)=\varepsilon^{\frac{2}{3}}$. Furthermore, it can be affirmed that $\vartheta=0$ is indeed the unique fixed point of Γ in ∇, as asserted by Theorem 2.

Corollary 1. *In a complete S-metric space (∇,S), if the mapping $\Gamma:\nabla\to\nabla$ is a Zamfirescu mapping that meets the following inequality criteria for all $\vartheta,\theta,\delta\in\nabla$ and $a,b,c\in[0,1)$,*

$$S(\Gamma\vartheta,\Gamma\theta,\Gamma\delta)\leq \max\left\{\begin{matrix} aS(\vartheta,\theta,\delta), b[\frac{S(\vartheta,\vartheta,\Gamma\vartheta)+S(\theta,\theta,\Gamma\theta)+S(\delta,\delta,\Gamma\delta)}{3}], \\ c[\frac{S(\vartheta,\vartheta,\Gamma\theta)+S(\theta,\theta,\Gamma\delta)+S(\delta,\delta,\Gamma\vartheta)}{4}]\end{matrix}\right\}$$

In that case, Γ possesses a unique fixed point within the space ∇.

Proof. Considering $d=\max\{a,b,c\}$, one obtains that

$$S(\Gamma\vartheta,\Gamma\theta,\Gamma\delta)\leq d\max\left\{\begin{matrix} S(\vartheta,\theta,\delta), \frac{S(\vartheta,\vartheta,\Gamma\vartheta)+S(\theta,\theta,\Gamma\theta)+S(\delta,\delta,\Gamma\delta)}{3}, \\ \frac{S(\vartheta,\vartheta,\Gamma\theta)+S(\theta,\theta,\Gamma\delta)+S(\delta,\delta,\Gamma\vartheta)}{4}\end{matrix}\right\}$$
$$\leq (1-\varepsilon)\max\left\{\begin{matrix} S(\vartheta,\theta,\delta), \frac{S(\vartheta,\vartheta,\Gamma\vartheta)+S(\theta,\theta,\Gamma\theta)+S(\delta,\delta,\Gamma\delta)}{3}, \\ \frac{S(\vartheta,\vartheta,\Gamma\theta)+S(\theta,\theta,\Gamma\delta)+S(\delta,\delta,\Gamma\vartheta)}{4}\end{matrix}\right\}$$
$$+(d+\varepsilon-1)\max\left\{\begin{matrix} S(\vartheta,\theta,\delta), \frac{S(\vartheta,\vartheta,\Gamma\vartheta)+S(\theta,\theta,\Gamma\theta)+S(\delta,\delta,\Gamma\delta)}{3}, \\ \frac{S(\vartheta,\vartheta,\Gamma\theta)+S(\theta,\theta,\Gamma\delta)+S(\delta,\delta,\Gamma\vartheta)}{4}\end{matrix}\right\}$$
$$\leq (1-\varepsilon)M(\vartheta,\theta)+d\left(1+\frac{\varepsilon-1}{d}\right)\cdot$$
$$\max\left\{\|\vartheta\|+\|\theta\|+\|\delta\|, \frac{2(\|\vartheta\|+\|\theta\|+\|\delta\|)+\|\Gamma\vartheta\|+\|\Gamma\theta\|+\|\Gamma\delta\|}{3}\right\}$$
$$\leq (1-\varepsilon)M(\vartheta,\theta)+d\varepsilon^{\frac{1}{d}}[1+\|\vartheta\|+\|\theta\|+\|\delta\|+\|\Gamma\vartheta\|+\|\Gamma\theta\|+\|\Gamma\delta\|]$$
$$\leq (1-\varepsilon)M(\vartheta,\theta)+d\varepsilon\varepsilon^{\frac{1-d}{d}}[1+\|\vartheta\|+\|\theta\|+\|\delta\|+\|\Gamma\vartheta\|+\|\Gamma\theta\|+\|\Gamma\delta\|]$$

Therefore, by Theorem 2 with $\Lambda = d$, $\psi(\varepsilon) = \varepsilon^{\frac{1-d}{d}}$ and $\alpha = \beta = 1$, it follows that Γ has a unique fixed point. □

Corollary 2. *Consider a complete S-metric space (∇, S), and let $\Gamma : \nabla \to \nabla$ be a mapping. If for all $\lambda \in [0, 1)$, Γ satisfies the following inequalities*

$$S(\Gamma\vartheta, \Gamma\theta, \Gamma\delta) \leq \lambda S(\vartheta, \theta, \delta) \tag{3}$$

OR

$$S(\Gamma\vartheta, \Gamma\theta, \Gamma\delta) \leq \frac{\lambda}{3}[S(\vartheta, \vartheta, \Gamma\vartheta) + S(\theta, \theta, \Gamma\theta) + S(\delta, \delta, \Gamma\delta)] \tag{4}$$

OR

$$S(\Gamma\vartheta, \Gamma\theta, \Gamma\delta) \leq \frac{\lambda}{4}[S(\vartheta, \vartheta, \Gamma\theta) + S(\theta, \theta, \Gamma\delta) + S(\delta, \delta, \Gamma\vartheta)] \tag{5}$$

Then, Γ has a unique fixed point in ∇.

Proof. In Corollary 1, if one takes
(1). $a = \lambda$, $b = c = 0$, inequality (3) is obtained
(2). $b = \lambda$, $a = c = 0$, inequality (4) is obtained
(3). $c = \lambda$, $a = b = 0$, inequality (5) is obtained
further steps followed from Corollary 1. □

Existence of the best proximity point for S-Pata type proximal contraction

This section introduces a new type of proximal mappings called S-Pata type proximal mappings. It is then proved that these mappings have the property of having the best proximity points. Let A and B be subsets of a complete S-metric space (∇, S). The distance between two sets is denoted by $D(A, B)$ and defined by

$$D(A, B) = \inf\{S(\vartheta, \vartheta, \theta) : \vartheta \in A \text{ and } \theta \in B\}.$$

The notation A_0 is used to represent the subset of A defined as follows:

$$A_0 = \{\vartheta \in A : S(\vartheta, \vartheta, \theta) = D(A, B), \text{ for some } \theta \in B\}$$

Likewise, B_0 is the subset of B defined as follows:

$$B_0 = \{\theta \in B : S(\vartheta, \vartheta, \theta) = D(A, B), \text{ for some } \vartheta \in A\}$$

Throughout the section, the assumption that both A_0 and B_0 are closed sets is maintained.

Definition 6. A mapping $\Gamma : A \to B$ is said to be an S-Pata type proximal contraction of type-I if, for all $\vartheta, \theta, \delta \in A$, $\psi \in \Psi$, and for any $\varepsilon \in [0,1]$, it satisfies the following inequality:

$$S(u,v,w) \leq (1-\varepsilon)S(\vartheta,\theta,\delta) + \Lambda\varepsilon^{\alpha}\psi(\varepsilon)[1 + \|\vartheta\| + \|\theta\| + \|\delta\|]^{\beta}$$

where $S(u,u,\Gamma(\vartheta)) = S(v,v,\Gamma(\theta)) = S(w,w,\Gamma(\delta)) = D(A,B)$ and $\Lambda \geq 0$, $\alpha \geq 1$, $\beta \in [0,\alpha]$ are arbitrary constants.

Definition 7. A mapping $\Gamma : A \to B$ is said to be an S-Pata type proximal contraction of type-II if, for all $\vartheta, \theta, \delta \in A$, $\psi \in \Psi$, and for any $\varepsilon \in [0,1]$, it satisfies the following inequality:

$$S(u,u,v) \leq (1-\varepsilon)S(\vartheta,\vartheta,\theta) + \Lambda\varepsilon^{\alpha}\psi(\varepsilon)[1 + 2\|\vartheta\| + \|\theta\|]^{\beta}$$

where $S(u,u,\Gamma(\vartheta)) = S(v,v,\Gamma(\theta)) = D(A,B)$ and $\Lambda \geq 0$, $\alpha \geq 1$, $\beta \in [0,\alpha]$ are arbitrary constants.

Theorem 3. *In a complete S-metric space (∇, S), consider non-empty closed subsets A and B. Suppose that there exists a mapping $\Gamma : A \to B$ that is an S-Pata type proximal contraction, and additionally, it holds that $\Gamma(A_0) \subset B_0$. Then Γ possesses one and only one best proximity point within the set A.*

Proof. Let ϑ_0 be an arbitrary element in A_0. Then $\Gamma(\vartheta_0) \in B_0$ and so there exists an element $\vartheta_1 \in A_0$ such that $S(\vartheta_1,\vartheta_1,\Gamma(\vartheta_0)) = S(A,A,B)$. Similarly, define $\vartheta_{n+1} \in A_0$ such that $S(\vartheta_{n+1},\vartheta_{n+1},\Gamma(\vartheta_n)) = S(A,A,B)$ and $c_n = S(\vartheta_n,\vartheta_n,\vartheta_0)$. Then, one gets

$$S(\vartheta_n,\vartheta_n,\vartheta_{n+1}) \leq (1-\varepsilon)S(\vartheta_{n-1},\vartheta_{n-1},\vartheta_n) + \Lambda\varepsilon^{\alpha}\psi(\varepsilon)[1 + 2\|\vartheta_n\| + \|\vartheta_{n-1}\|]^{\beta}$$

where $\varepsilon \in [0,1]$.

Taking $\varepsilon = 0$ in the above inequality, it follows that $\{S(\vartheta_n,\vartheta_n,\vartheta_{n+1})\}$ is a nonincraesing sequence. Therefore,

$$S(\vartheta_n,\vartheta_n,\vartheta_{n+1}) \leq S(\vartheta_{n-1},\vartheta_{n-1},\vartheta_n) \leq \ldots S(\vartheta_0,\vartheta_0,\vartheta_1) = c_1$$

Now, one shows that $\{c_n\}$ is bounded:

$$\begin{aligned} c_n &= S(\vartheta_0, \vartheta_0, \vartheta_n) \\ &\leq 2S(\vartheta_0, \vartheta_0, \vartheta_1) + 2S(\vartheta_n, \vartheta_n, \vartheta_{n+1}) + S(\vartheta_1, \vartheta_1, \vartheta_{n+1}) \\ &\leq 4c_1 + (1-\varepsilon)S(\vartheta_0, \vartheta_0, \vartheta_n) + \Lambda\varepsilon^\alpha\psi(\varepsilon)[1 + 2\|\vartheta_0\| + \|\vartheta_n\|]^\beta \\ &\leq 4c_1 + (1-\varepsilon)c_n + \Lambda\varepsilon^\alpha\psi(\varepsilon)[1 + c_n]^\beta \\ &\leq a + (1-\varepsilon)c_n + b\varepsilon^\alpha\psi(\varepsilon)c_n^\alpha \end{aligned} \tag{6}$$

where $a, b > 0$ are constants. Accordingly,

$$\varepsilon c_n \leq a + b\varepsilon^\alpha\psi(\varepsilon)c_n^\alpha$$

If there is a subsequence $c_{n_i} \to +\infty$, the choice $\varepsilon = \varepsilon_i = (1+a)/c_n$, leads to the contradiction

$$1 \leq b(1+a)^\alpha\psi(\varepsilon_i) \to 0$$

Hence, $\{c_n\}$ is a bounded sequence.

Let $\lim_{n\to+\infty} S(\vartheta_{n-1}, \vartheta_{n-1}, \vartheta_n) = d$. Since $S(\vartheta_{n-1}, \vartheta_{n-1}, \vartheta_n)$ is non increasing,

$$\begin{aligned} S(\vartheta_n, \vartheta_n, \vartheta_{n+1}) &\leq (1-\varepsilon)S(\vartheta_{n-1}, \vartheta_{n-1}, \vartheta_n) + \Lambda\varepsilon^\alpha\psi(\varepsilon)[1 + 2\|\vartheta_{n-1}\| + \|\vartheta_n\|]^\beta \\ &\leq (1-\varepsilon)S(\vartheta_{n-1}, \vartheta_{n-1}, \vartheta_n) + K\varepsilon\psi(\varepsilon) \end{aligned}$$

As the limit as n approaches infinity is considered, it is deduced that $d \leq K\psi(\varepsilon)$ implies $d = 0$. One now makes the assertion that $\{\vartheta_n\}$ is a Cauchy sequence.

In order to avoid contradiction, assume that $\{\vartheta_n\}$ is not a Cauchy sequence. In such a case, according to Lemma 3, there must exist subsequences $\{\vartheta_{n_k}\}$ and $\{\vartheta_{m_k}\}$ of $\{\vartheta_n\}$ with $n_k > m_k > k$ such that

$$\begin{aligned} d &\leq S(\vartheta_{n_k}, \vartheta_{n_k}, \vartheta_{m_k}) \\ &\leq (1-\varepsilon)S(\vartheta_{n_k-1}, \vartheta_{n_k-1}, \vartheta_{m_k-1}) + K\varepsilon\psi(\varepsilon) \\ &\leq (1-\varepsilon)[2S(\vartheta_{n_k-1}, \vartheta_{n_k-1}, \vartheta_{m_k}) + S(\vartheta_{m_k-1}, \vartheta_{m_k-1}, \vartheta_{n_k})] + K\varepsilon\psi(\varepsilon). \end{aligned}$$

As k tends towards infinity, one reaches the conclusion that $d \leq K\psi(\varepsilon)$, which leads to a contradiction. Therefore, it can be affirmed that $\{\vartheta_n\}$ is indeed a Cauchy sequence. Given that ∇ is a complete space, there

exists an element ϑ in ∇ such that $\{\vartheta_n\}$ converges to ϑ.

Now, consider $S(u,u,\Gamma(\vartheta)) = D(A,B)$ and set ε to zero. Then, for all $n \in N$, one obtains

$$\begin{aligned} S(u,u,\vartheta) &\leq 2S(u,u,\vartheta_{n+1}) + S(\vartheta,\vartheta,\vartheta_{n+1}) \\ &\leq 2S(\vartheta,\vartheta,\vartheta_n) + S(\vartheta,\vartheta,\vartheta_{n+1}) \end{aligned}$$

This leads to the conclusion that $S(u,u,\vartheta) = 0$. Consequently, it can be established that ϑ serves as a proximity point of Γ.

In order to demonstrate the uniqueness of the proximity point, suppose, for the sake of contradiction, that Γ has two distinct proximity points ϑ and θ in ∇. One obtains

$$S(\vartheta,\vartheta,\theta) \leq (1-\varepsilon)S(\vartheta,\vartheta,\theta) + K\varepsilon\psi(\varepsilon)$$

Hence, one obtains $S(\vartheta,\vartheta,\theta) \leq K\psi(\varepsilon)$, which implies $\vartheta = \theta$. Thus, Γ has unique proximity point ϑ in A. □

Corollary 3. *Consider a complete metric space* (∇, S)*, and let* $\Gamma : \nabla \to \nabla$ *be a mapping that adheres to the following inequality:*

$$S(\Gamma\vartheta,\Gamma\theta,\Gamma\delta) \leq (1-\varepsilon)S(\vartheta,\theta,\delta) + \Lambda\varepsilon^{\alpha}\psi(\varepsilon)[1 + \|\vartheta\| + \|\theta\| + \|\delta\|]^{\beta}$$

Then, there exists a unique fixed point for Γ*.*

Proof. The proof can be derived directly from the previous theorem when $A = B$. □

Example 3. Let $\nabla = R^2$ under 1-norm and (∇, S) be an S-metric space with a metric defined by $S(\vartheta,\theta,\delta) = \frac{1}{2}\{|\vartheta-\delta|+|\theta-\delta|\}$. Consider $A = \{(0,a)|a \in [0,1]\}$ and $B = \{(1,b)|b \in [0,1]\}$ then $D(A,B) = 1$. Define $f : A \to B$ as $f(0,\vartheta) = (1, \frac{\vartheta^2}{4})$, $\Lambda = \alpha = \beta = 1$, and for $\delta \in (0, \frac{1}{2})$

$$\psi(s) = \begin{cases} \frac{s}{2} & if\ s \in [0,\delta), \\ 1 & if\ s \in [\delta,1], \end{cases}$$

One needs to demonstrate that, for all $\varepsilon \in [0,1]$, f satisfies the inequality of S-Pata type proximal contraction,

$$\begin{cases} for\ \varepsilon = 0 & \Longrightarrow\ S(u,u,v) \leq S(\vartheta',\vartheta',\theta'), \\ for\ \varepsilon \in (0,1] & \Longrightarrow\ S(u,u,v) \leq (1-\varepsilon)S(\vartheta',\vartheta',\theta') + \\ & \varepsilon\psi(\varepsilon)[1 + 2\|\vartheta'\| + \|\theta'\|], \end{cases}$$

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where $S(u,u,f(\vartheta'))=S(v,v,f(\theta))=D(A,B)=1$.
The following inequality shows that f satisfies the first case when $\varepsilon=0$.
For all $\vartheta'=(0,\vartheta)$, $\theta'=(0,\theta)\in A$.

$$\begin{aligned}S(u,u,v)&=S((0,\frac{\vartheta^2}{4}),(0,\frac{\vartheta^2}{4}),(0,\frac{\theta^2}{4}))\\&=|(0,\frac{\vartheta^2}{4})+(0,\frac{\theta^2}{4})|\\&=|\frac{\vartheta^2}{4}-\frac{\theta^2}{4}|=|(\frac{\vartheta}{2}+\frac{\theta}{2})(\frac{\vartheta}{2}-\frac{\theta}{2})|\\&\leq|\frac{\vartheta}{2}-\frac{\theta}{2}|\\&\leq S(\vartheta',\vartheta',\theta')\end{aligned}$$

The following inequalities demonstrate that f satisfies the second case when $\varepsilon\in(0,1]$:
For $\varepsilon\in(0,\delta)$ and for all $\vartheta',\theta'\in A$

$$\begin{aligned}S(u,u,v)=S((0,\frac{\vartheta^2}{4}),(0,\frac{\vartheta^2}{4}),(0,\frac{\theta^2}{4}))&=|\frac{\vartheta^2}{4}-\frac{\theta^2}{4}|\\&\leq\frac{1}{2}S(\vartheta',\vartheta',\theta')\\&=(1-\varepsilon)S(\vartheta',\vartheta',\theta')+(\frac{1}{2}+(\varepsilon-1))S(\vartheta',\vartheta',\theta')\\&\leq(1-\varepsilon)S(\vartheta',\vartheta',\theta')+\frac{1}{2}(1+\frac{\varepsilon-1}{\frac{1}{2}})[2S(\vartheta'_0,\vartheta',\vartheta')+S(\vartheta'_0,\theta',\theta')]\\&\leq(1-\varepsilon)S(\vartheta',\vartheta',\theta')+\frac{1}{2}\varepsilon^2[2\|\vartheta'\|+\|\theta\|]\\&\leq(1-\varepsilon)S(\vartheta',\vartheta',\theta')+\varepsilon\psi(\varepsilon)[1+2\|\vartheta'\|+\|\theta'\|].\end{aligned}$$

For $\varepsilon\in[\delta,1]$ and for all $\vartheta',\theta'\in A$,

$$\begin{aligned}S(u,u,v)=S((0,\frac{\vartheta^2}{4}),(0,\frac{\vartheta^2}{4}),(0,\frac{\theta^2}{4}))&=|\frac{\vartheta^2}{4}-\frac{\theta^2}{4}|\\&\leq S(\vartheta',\vartheta',\theta')\\&=(1-\varepsilon)S(\vartheta',\vartheta',\theta')+\varepsilon S(\vartheta',\vartheta',\theta')\\&=(1-\varepsilon)S(\vartheta',\vartheta',\theta')+\varepsilon[2S(\vartheta'_0,\vartheta',\vartheta')+S(\vartheta'_0,\theta',\theta')]\\&=(1-\varepsilon)S(\vartheta',\vartheta',\theta')+\varepsilon\psi(\varepsilon)[1+2\|\vartheta'\|+\|\theta'\|].\end{aligned}$$

Hence, f fits the criteria of being an S-Pata type proximal contraction, and as a result, there exists a best proximity point $(0,0)$ within the set A.

Application to the integral equation

In this section, an application of the main result is explored by describing a solution of the integral equation.

Consider $\mathcal{M} = C(I, \mathbb{R})$, which represents the set of all continuous functions on $I = [0, 1]$, equipped with the metric $S(\vartheta, \theta, \delta) = \sup\{|\vartheta(s) - \theta(s)| + |\theta(s) - \delta(s)| + |\delta(s) - \vartheta(s)|,\ s \in I\}$ for all $\vartheta, \theta, \delta \in \mathcal{M}$. It is worth noting that $(\mathcal{M}, S)$ forms a complete S-metric space. In this context, one delves into the investigation of the integral equation

$$\vartheta(s) = \chi(s) + \int_0^1 \mathcal{K}(s, u)\eta(u, \vartheta(u))du,\ s \in I, \tag{7}$$

where, the functions $\eta : I \times \mathbb{R} \to \mathbb{R}$ and $\chi : I \to \mathbb{R}$ are continuous, and $\mathcal{K} : I \times I \to \mathbb{R}_0^+$ is a function satisfying $\mathcal{K}(s, \cdot) \in L^1(I)$ for all $s \in I$. One examines the mapping $\Gamma : \mathcal{M} \to \mathcal{M}$, which is defined as follows:

$$\Gamma(\vartheta)(s) = \chi(s) + \int_0^1 \mathcal{K}(s, u)\eta(u, \vartheta(u))du,\ s \in I. \tag{8}$$

Theorem 4. *Equation (8) has at least one solution in $\mathcal{M}$, if for all $u \in I$ and $a, b \in \mathbb{R}$, there is*

$$|\eta(u, a) - \eta(u, b)| \leq \frac{1}{4}(|a - \Gamma a| + |a - \Gamma b| + |b - \Gamma a|),\ for\ all\ u \in I,$$

followed by the assumed inequality

$$\sup_{s \in I} \int_0^1 \mathcal{K}(s, u)du = \delta \leq 1.$$

where δ is a fixed constant.

Proof. Note that finding a solution of (7) is equivalent to finding $\vartheta^* \in \mathcal{M}$ that is a fixed point of Γ. Now let $\vartheta, \theta \in \mathcal{M}$, on account of the above inequalities, one finds that

$$|\Gamma(\vartheta)(s) - \Gamma(\theta)(s)| = \left| \int_0^1 \mathcal{K}(s, u)[\eta(u, \vartheta(u)) - \eta(u, \theta(u))]du \right|$$
$$\leq \int_0^1 \mathcal{K}(s, u)du \cdot |\eta(u, \vartheta(u)) - \eta(u, \theta(u))|$$

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$$\leq \int_0^1 \mathcal{K}(s,u)du \cdot \frac{1}{4}(|\vartheta(s) - \Gamma\vartheta(s)| + |\vartheta(u) - \Gamma(\theta)(u)| + |\theta(u) - \Gamma(\vartheta)(u)|)$$

$$\implies S(\Gamma\vartheta, \Gamma\vartheta, \Gamma\theta) = \delta \cdot \left(\frac{S(\vartheta,\vartheta,\Gamma\vartheta) + S(\vartheta,\vartheta,\Gamma\theta) + S(\theta,\theta,\Gamma\vartheta)}{4}\right)$$

$$\leq \delta \cdot M(\vartheta,\vartheta,\theta)\ ,$$

where $M(\vartheta,\theta,\delta) = \max\left\{S(\vartheta,\theta,\delta), \frac{S(\vartheta,\vartheta,\Gamma(\vartheta))+S(\theta,\theta,\Gamma(\theta))+S(\delta,\delta,\Gamma(\delta))}{3}, \frac{S(\vartheta,\vartheta,\Gamma(\theta))+S(\theta,\theta,\Gamma\delta)+S(\delta,\delta,\Gamma\vartheta)}{4}\right\}$.

Hence, it is derived that

$$S(\Gamma\vartheta,\Gamma\vartheta,\Gamma\theta) \leq (1-\varepsilon)M(\vartheta,\vartheta,\theta) + (\delta + (\varepsilon - 1))M(\vartheta,\vartheta,\theta)$$

$$\leq (1-\varepsilon)M(\vartheta,\vartheta,\theta) + \delta\left(1 + \frac{\varepsilon-1}{\delta}\right) \cdot$$

$$\max\left\{S(\vartheta,\vartheta,\theta), \frac{S(\vartheta,\vartheta,\Gamma(\vartheta))+S(\vartheta,\vartheta,\Gamma(\vartheta))+S(\theta,\theta,\Gamma(\theta))}{3}, \frac{S(\vartheta,\vartheta,\Gamma(\vartheta))+S(\vartheta,\vartheta,\Gamma\theta)+S(\theta,\theta,\Gamma\vartheta)}{4}\right\}$$

$$\leq (1-\varepsilon)M(\vartheta,\vartheta,\theta) + \delta\varepsilon^{\frac{1}{\delta}} \max\left\{\|\vartheta\| + \|\vartheta\| + \|\theta\|, \frac{4\|\vartheta\|+2\|\theta\|+2\|\Gamma\vartheta\|+\|\Gamma\theta\|}{3}\right\}$$

$$\leq (1-\varepsilon)M(\vartheta,\vartheta,\theta) + \delta\varepsilon\varepsilon^{\frac{1}{\delta}-1}[1 + 2\|\vartheta\| + \|\theta\| + 2\|\Gamma\vartheta\| + \|\Gamma\theta\|]$$

for all $u \in I$ and $\vartheta, \theta \in \mathcal{M}$. Hence, Γ is an S-Pata type Zamfirescu mapping with $\Lambda = \delta, \alpha = 1, \beta = 1$ and $\psi(\varepsilon) = \varepsilon^{\frac{1-\delta}{\delta}}$. Therefore, one deduces the existence of $\vartheta^* \in \mathcal{M}$ such that $\vartheta^* = \Gamma\vartheta^*$ that is ϑ^* is a solution of integral equation (7). □

References

Aktay, M. & Özdemir, M. 2022. On (α, φ)-weak Pata contractions. *MANAS Journal of Engineering*, 10(2), pp. 228–240. Available at: https://doi.org/10.51354/mjen.1085695.

Alghamdi, M.A., Gulyaz-Ozyurt, S. & Fulga, A. 2021. Fixed points of Proinov $E-$contractions. *Symmetry*, 13(6), art.number:962. Available at: https://doi.org/10.3390/sym13060962.

Banach, S. 1922. Sur les opérations dans les ensembles abstraits et leur application aux équations intégrales. *Fundamenta mathematicae*, 3, pp. 133–181. Available at: https://doi.org/10.4064/fm-3-1-133-181.

Chand, D. & Rohen, Y. 2023. Fixed Points of $(\alpha_s - \beta_s - \psi)$-Contractive Mappings in S-Metric Spaces. *Nonlinear Functional Analysis and Applications*, 28(2), pp. 571–587. Available at: https://doi.org/10.22771/nfaa.2023.28.02.15.

Chatterjea, S. 1972. Fixed-point theorems. *Dokladi na Bolgarskata Akademiya na Naukite*, 25(6), p. 727.

Jacob, G.K., Khan, M.S., Park, C. & Yun, S. 2018. On Generalized Pata Type Contractions. *Mathematics*, 6(2), art.number:25. Available at: https://doi.org/10.3390/math6020025.

Kadelburg, Z. & Radenović, S. 2014. Fixed Point and Tripled Fixed Point Theorems under Pata-Type Conditions in Ordered Metric Spaces. *International Journal of Analysis and Applications*, 6(1), pp. 113–122 [online]. Available at: https://www.etamaths.com/index.php/ijaa/article/view/392 [Accessed: 7 February 2024].

Kadelburg, Z. & Radenović, S. 2016. Fixed point theorems under Pata-type conditions in metric spaces. *Journal of the Egyptian Mathematical Society*, 24(1), pp. 77–82. Available at: https://doi.org/10.1016/j.joems.2014.09.001.

Kannan, R. 1968. Some results on fixed points. *Bulletin of the Calcutta Mathematical Society*, 60, pp. 71–76.

Karapinar, E., Fulga, A. & Aydi, H. 2020a. Study on Pata $E-$contractions. *Advances in Difference Equations*, 2020, art.number:539. Available at: https://doi.org/10.1186/s13662-020-02992-4.

Karapınar, E., Fulga, A. & Rakočević, V. 2020b. A discussion on a Pata type contraction via iterate at a point. *Filomat*, 34(4), pp. 1061–1066. Available at: https://doi.org/10.2298/FIL2004061K.

Özgür, N. & Taş, N. 2021. Pata Zamfirescu Type Fixed-Disc Results with a Proximal Application. *Bulletin of the Malaysian Mathematical Sciences Society*, 44, pp. 2049–2061. Available at: https://doi.org/10.1007/s40840-020-01048-w.

Özgür, N. & Taş, N. 2023. On S-metric spaces with some topological aspects. *Electronic Journal of Mathematical Analysis and Applications*, 11(2), pp. 1–8. Available at: https://doi.org/10.21608/ejmaa.2023.206319.1029.

Pata, V. 2011. A fixed point theorem in metric spaces. *Journal of Fixed Point Theory and Applications*, 10(2), pp. 299–305. Available at: https://doi.org/10.1007/s11784-011-0060-1.

Priyobarta, N., Rohen, Y., Thounaojam, S. & Radenović, S. 2022. Some remarks on α-admissibility in $S-$metric spaces. *Journal of Inequalities and Applications*, 2022, art.number:34. Available at: https://doi.org/10.1186/s13660-022-02767-3.

Roy, S., Chakraborty, P., Ghosh, S., Saha, P. & Choudhury, B.S. 2024. Investigation of a fixed point problem for Pata-type contractions with respect to w-distance. *The Journal of Analysis*, 32, pp. 125–136. Available at: https://doi.org/10.1007/s41478-023-00612-4.

Saleem, N., Abbas, M., Bin-Mohsin, B. & Radenovic, S. 2020. Pata type best proximity point results in metric spaces. *Miskolc Mathematical Notes*, 21(1), pp. 367–386. Available at: https://doi.org/10.18514/MMN.2020.2764.

Sedghi, S., Shobe, N. & Aliouche, A. 2012. A generalization of fixed point theorems in S-metric spaces. *Matematički vesnik*, 64(3), pp. 258–266 [online]. Available at: http://www.vesnik.math.rs/landing.php?p=mv123.cap&name=mv12309 [Accessed: 7 February 2024].

Yahaya, S., Shagari, M.S. & Ali, T.A. 2023. Multivalued hybrid contraction that involves Jaggi and Pata-type inequalities. *Mathematical Foundations of Computing*. Available at: https://doi.org/10.3934/mfc.2023045.

Zamfirescu, T. 1972. Fix point theorems in metric spaces. *Archiv der Mathematik*, 23. Available at: https://doi.org/10.1007/BF01304884.

Mapeos de Zamfirescu bajo condición tipo Pata: resultados y aplicación a Ecuación integral

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CAMPO: matemáticas

TIPO DE ARTÍCULO: artículo científico original

Resumen:

Introducción/objetivo: Las asignaciones tipo Pata y Zamfirescu se extienden más allá de los espacios métricos.

Métodos: Se emplea el concepto de mapeo de Zamfirescu tipo Pata en el marco de espacios S-métricos.

Resultados: Se han establecido una serie de resultados correspondientes. Además, los resultados obtenidos se emplean para resolver una ecuación integral.

Conclusión: Los mapeos de tipo S-Pata y Zamfirescu tienen puntos fijos únicos.

Palabras claves: contracción tipo Pata, mapeo de Zamfirescu, espacio S-métrico, punto fijo.

Отображения Замфиреску в условиях типа Пата: результаты и применение в итегральных уравнениях

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РУБРИКА ГРНТИ: 27.25.17 Метрическая теория функций,
27.39.15 Линейные пространства, снабженные топологией, порядком и другими структурами

ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: Отображения типа Паты и Замфиреску выходят за пределы метрических пространств.

Методы: В статье применяется концепция отображения Замфиреску типа Паты в рамках S-метрических пространств.

Результаты: Был подтвержден ряд соответствующих результатов. Полученные результаты были использованы в решении интегральных уравнений.

Выводы: Отображения типа S-Pata и Замфиреску имеют уникальные неподвижные точки.

Ключевые слова: сжатие типа Паты, отображение типа Замфиреску, S-метрическое пространство, неподвижная точка.

Замфиреску пресликавања под условима типа Пата: резултати и примена на интегралну једначину

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Chand, D. et al, Zamfirescu mappings under Pata-type condition: results and application to an integral equation, pp.583–604

Сажетак:

Увод/циљ: Пресликавања типа Пата и Замфиреску су проширена изван метричких простора.

Методе: Примењен је концепт Замфиреску пресликавања типа Пата у оквиру S-метричких простора.

Резултати: Утврђен је низ одговарајућих исхода. Затим су се добијени резултати користили за решавање интегралне једначине.

Закључак: Пресликавања типа S-Пата и Замфиреску имају јединствене непокретне тачке.

Кључне речи: контракција типа Пата, пресликавање типа Замфиреску, S-метрички простор, непокретна тачка.

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Utilizing a hybrid decision-making approach with fuzzy and rough sets on linguistic data for analyzing voting patterns

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FIELD: mathematics, computer sciences
ARTICLE TYPE: original scientific paper

Abstract:

Introduction/purpose: The significance of studying voting behaviour is underscored by its ability to gauge the continuity or divergence of electoral politics from historical trends, elucidating the real impact of the transformative ballot box, and contributing to the examination of democracy as a value among both masses and elites. Additionally, it aids in comprehending the intricate process of political socialization.

Methods: An inherent strength of the rough set lies in its reliance solely on raw data, devoid of external inputs. The decision-theoretic rough set framework, an evolution of the rough set, has garnered widespread application across diverse domains, serving as a proficient tool for acquiring knowledge, particularly in navigating situations marked by vagueness and uncertainty. Despite the proliferation of mathematical models designed to discern people's voting behavior, a decision-based rough set recommendation remains noticeably absent in existing literature. This paper introduces an innovative three-way decision approach grounded in linguistic information for identifying voting behavior. The proposed approach is based on a hybrid probabilistic rough fuzzy model incorporating linguistic information and providing insights into voting patterns.

Results: The three-way decision hybrid models are tested on people and a highly satisfactory result was achieved for identifying their voting behaviours. The justification of results was validated through the mathematical process.

Conclusion: A practical illustration is provided to highlight the importance of this hybrid model and to confirm its usefulness in identifying and forecasting voting behaviour.

Keywords: linguistic term, rough set, fuzzy set, three-way decision, voting behaviour.

Introduction

The fuzzy set and the rough set are two different but complementary approaches for modelling uncertainty and vagueness in knowledge (Dubois & Prade, 1990; Wong & Ziarko, 1987). Zadeh (1965) introduced fuzzy sets to handle uncertainties in datasets. Pawlak (1982) proposed the concept of a rough set. The main advantage is that each one is potentially able to deal with two different types of uncertainty, vagueness for fuzzy sets and indiscernibility for rough sets. Equivalence relation generates the indiscernibility between objects. In rough sets, crisp sets are approximated using equivalence classes which also allow us to eliminate irrelevant attributes. In the fuzzy set theory, indiscernibility between objects is not used, which may be considered as a class with unsharp boundaries. Each of these concepts appears to have its own set of constraints and limitations.

Deviation and extension are two views that provide distinct generalizations of rough sets from the classical set theory. For interpreting rough sets and fuzzy sets, Klir (1994) compared the roles played by non-classical logic which are both extension and deviation of classical logic. In the framework of the set theory, it can be achieved with the combination of a rough set and a fuzzy set. An extended notation of a rough set, namely a rough fuzzy set can be obtained by introducing upper and lower approximations in fuzzy sets (Yao, 1997). Alternatively, by replacing an equivalence relation with a fuzzy similarity relation, one can get a fuzzy rough set. By interpreting the membership function in terms of conditional probability, one can treat a rough set as a special class of fuzzy sets (Wong & Ziarko, 1987). A salient feature of both models is that the theoretic operators, interpretation, and formulation of the membership function are embodied in the theory. Moreover, rough set operators are not truth-functional.

When a rough set and a fuzzy set are put together in a hybrid model, these offer a robust framework to deal with any kind of uncertain, incomplete and complex information. In many contexts, it enhances the quality of the decision-making process. The combination of the rough set and fuzzy set theories has been successfully applied in expert systems, data mining, knowledge acquisition, process control, etc. Using the rough set theory, Sharma et al (2018, 2022) developed various hybrid methods to create decision rules useful for real-world problems. Pal & Kar (2019) represent time series forecasting for stock market prediction through data discretization by fuzzistics and rule generation by the rough set theory. Tufail et al (2022) proposed a novel multiple attributes group decision-

making algorithm with the combination of a rough set and a bipolar soft set. Saqlain & Saeed (2024) unravelled the power of similarity measures in multi-polar interval-valued intuitionistic fuzzy soft sets.

Research in multiple attribute group decision-making problems using fuzzy sets, rough sets, and soft sets has increased in recent years (Gurmani et al, 2023). Donbosco & Ganesan (2022) proposed a rough neutrosophic matrix and its application to the MCDM problem for selecting the best building construction site. Narang et al (2023) introduced a fuzzy extension of the MEREC method using a parabolic measure and its applications. Zhan & Wang (2019) defined five forms of the soft covering based rough set and described the relationship between soft rough sets and soft covering based rough sets. Zhan & Wang (2019), Zhan & Sun (2019) and Zhang & Zhan (2019) defined four different fuzzy soft β covering based fuzzy rough sets and contributed fuzzy soft β-coverings. Yang (2022) proposed a fuzzy covering based rough set over a dual universe as an extension of the single universe concept.

Motivation

The examination of voting behaviour typically relies on insights derived from sample surveys, particularly when analysing patterns of election results at the state or country level. However, such aggregated data proves inadequate for scrutinizing individual voter dynamics. A comprehensive understanding of the factors influencing voting necessitates information on individuals, encompassing voting behaviour, attitudes, beliefs, and personal characteristics. Recognizing the impracticality of acquiring such data for every electorate member, conventional practice involves sampling individuals from the population for interviews. Subsequently, survey data undergoes processing and storage conducive to computer-assisted analysis, focusing on elucidating and providing insights into political opinions and patterns of electoral behaviour.

Konlan (2017) introduced a case study in the volta region of Ghana which provides some prediction for identifying voting behaviour. After reviewing the related literature, it revels that some key attention is required. Several scholars have made several approaches to improve the identification of voting behaviour. But their response and effort did not give convincing results. Lees-Marshment (2019) argued that the growing mixed findings are worth scholarly attention as they may lead to poor policy implementation and missed guidance. Bukari et al (2022) introduced the role of social media in the determination of voting behaviour.

The literature review shows that identifying voting behavior is not adequately represented by any existing mathematical framework. This paper delves into the realm of voting behaviour identification, utilizing fuzzy logic, the rough set theory and its expanded applications, including probabilistic rough sets and decision-theoretic rough sets. The objective is to develop a three-way decision model for distinguishing voting behaviour, informed by linguistic data, concerning attribute values. In instances where individuals may not provide precise quantitative descriptions, opinions are expressed using linguistic terms such as "not so good," "good," or "very good."

Neutrosophic logic is also used to deal with incomplete and indeterminate data. The neutrosophic determinacy component (truth, falsehood) and the indeterminacy component exhibit symmetry as the falsehood and the truth look the same and they behave in a symmetrical way with respect to the indeterminacy element which provides a line of symmetry. Sometimes it seems that neutrosophic logic is more generic than fuzzy intuitionistic logic. When it comes to real life scenarios, there are so many cases where intuitionistic fuzzy logic seems more logical than neutrosophic logic. Consider a following situation in neutrosophic logic.

(T,I,F) : (1,1,0) , (1,0,1) , (1,1,1) , (0,0,0) , (0,1,1)

Such a situation is not possible in a real life scenario. But such a scenario will not appear in intuitionistic fuzzy logic.

The main aim of this paper is to contribute some knowledge by proposing a hybrid fuzzy rough empirically testing model which deals with the voting behavior of people in political marketing in India. As a way forward measure, we have introduced a fuzzy logic operator in the model to examine the intention of the voting behaviour of people based on their linguistic information. With the right kind of implementation of our model, political parties can improve their electoral outcome.

Background and research issues

This section provides a succinct overview of the key concepts in the rough set theory, specifically the classical rough set proposed by Pawlak (1982), the probabilistic rough set, the three-way decision based on the probabilistic rough set, and the decision-theoretic rough set model grounded in the Bayesian decision-making process (Hu, 2014; Ziarko, 1993; Yang & Yao, 2012; Yao & Wong, 1992; Yao & Deng, 2014).

Classical rough set

For an information system $\pi = (\tau, B, V, \varphi)$. τ is a finite and non-empty set of objects called the universe. B is a finite set of attributes. V is a set of the values with φ: $\tau \times B \rightarrow V$ as an information function.

Subsequently, for any $F \subseteq B$, the indiscernible relation IND (F) on τ is denoted as

$$IND(F) = \{(x, y) \in \tau \times \tau | f(x) = f(y), \forall f \in F\}$$

Clearly, IND (F) is the equivalence relation on τ. Hence, it leads to a partition of τ.

For any $Y \subseteq \tau$, the lower and upper approximations of Y are shown below.

$$\underline{Apr}(Y) = \{x \in \tau | [y] \subseteq Y\}$$

$$\overline{Apr}\,(Y) = \{x \in \tau | [y] \cap Y \neq \emptyset\}$$

It can further be partitioned into three disjoint regions such as:

POSITIVE (Y) = $\underline{Apr}\,(Y)$

BOUNARY (Y) = $\overline{Apr}\,(Y) - \underline{Apr}\,(Y)$

NEGATIVE (Y) = $\tau - \overline{Apr}$ (Y).

Hence, if $y \in \text{POSITIVE}\,(Y)$, then y belongs to the concept Y for sure. If $y \in$ NEGATIVE (Y), then y certainly does not belong to Y. If $y \in \text{BOUNARY}(Y)$, then y may or may not belong to Y.

Probabilistic rough set theory with a three-way decision framework

While classical rough sets offer distinct decision regions, they struggle with making decisions for the majority of objects. Addressing this limitation, Wong & Ziarko (1987) introduced the probabilistic rough set model, aiming to reduce the boundary region and expand the positive and negative regions. This adjustment relies on the threshold values.

Let $\lessdot \tau, E, P \gtrdot$ be a probabilistic approximation space, where P is the probabilistic measure defined on any subset of the universal set τ. Then for any $y \in Y$, an overlap between the equivalence class $[y]$ and the set Y is defined in the form of conditional probability as

$$Pr(Y|[y]) = \frac{|Y \cap [y]|}{|[y]|},$$

where |. |denotes the cardinality. (1)

Using the threshold pair (α, β) with $0 \leq \delta < \gamma \leq 1$, the lower and upper approximations of the concept Y are defined as follows:

$$\underline{Apr}_{(\gamma,\delta)}(Y) = \{y \in \tau: Pr(Y|[y]) \geq \gamma\}$$
$$= \cup \{[y] \in Y/E: Pr(Y|[y]) \geq \gamma\}$$
$$\overline{Apr}_{(\gamma,\delta)}(Y) = \{y \in \tau: Pr(Y|[y]) > \delta\}$$
$$= \cup \{[y] \in Y/E: Pr(Y|[y]) > \delta\}$$

Based on (γ, δ) - the lower and upper approximation, the probabilistic three-way decision regions are given by

$$POS_{(\gamma,\delta)}(Y) = \underline{Apr}_{(\gamma,\delta)}(Y)$$
$$= \{y \in \tau: Pr(Y|[y]) \geq \gamma\} \quad (2)$$
$$NEG_{(\gamma,\delta)}(Y) = \tau \setminus \overline{Apr}_{(\gamma,\delta)}(Y)$$
$$= \{y \in \tau: Pr(Y|[y]) \leq \delta\} \quad (3)$$
$$BND_{(\gamma,\delta)}(Y) = \overline{Apr}_{(\gamma,\delta)}(Y) \setminus \underline{Apr}_{(\gamma,\delta)}(Y)$$
$$= \{y \in \tau: \delta < Pr(Y|[y]) < \gamma\} \quad (4)$$

The conditional probability of any object may be considered as a confidence level which an object is having the similar description as y belongs to Y. If $\Pr(Y|[y]) \geq \gamma$, i.e, the confidence level is greater than or equal to γ, then we accept y to be in Y, the same is rejected to be in Y if the confidence level is lesser than or equal to δ, i.e., $Pr(Y|[y]) \leq \delta$. If $\delta < Pr(Y|[y]) < \gamma$, then the decision about y to be in Y may be deferred. For $\gamma = 1$ and $\delta = 0$, the probabilistic rough set model coincides with the classical rough set model. For $\gamma = \delta$, one can get the probabilistic two-way decision model.

Decision-theoretic rough set

The probabilistic rough set model faces challenges in determining the threshold pair (γ, δ). To overcome this, the decision-theoretic rough set model emerges as a straightforward application of the Bayesian decision theory. This model provides a systematic procedure for threshold parameter determination, offering a practical and theoretical foundation for probabilistic rough set applications for a given object $y \in$Y.

Let $\pi = \{e_1, e_2, e_3, \ldots\ldots\ldots, e_m\}$ be a finite set of m possible states and $\Sigma = \{b_1, b_2, b_3, \ldots\ldots\ldots, b_n\}$ be a set of possible actions. Hence, an $m \times n$, matrix of the loss function can be constructed. If the object is in the state e_r, then $\mu(b_k|\, e_r)$ represents the loss for selecting the action b_k and $\mathrm{P}(e_r|y)$ represents the conditional probability of y belongs to the state

e_r.When the action $b_k$is taken for the object y, the expected risk involved with the action b_k is shown next.

G($b_k|y$) = $\sum_{r=1}^{m} \mu(b_k|\, e_r)$ Pr($e_r|y$).

Let $Y \subseteq \tau$, then with respect to Y, a set of two states, $\pi = \{Y, Y^c\}$ can be constructed and the set of actions is given by $A = \{ b_P, b_N, b_B\}$ where b_P represent the action for classifying an object $y \in$ POSITIVE (Y), b_N represent the action for classifying an object $y \in$ NEGATIVE (Y) and b_B indicate the action for classifying an object $y \in$ BOUNDARY (Y).Thus, a 3×2 matrix of loss function can be constructed as shown in Table 1 where $\mu(b_P/Y) = \mu_{PP}$, $\mu(b_N/Y) = \mu_{NP}$ and $\mu\ (b_B/Y) = \mu_{BP}$ represent the loss incurred for taking the action b_P, b_N, b_B, respectively, when an object belongs to Y. Similarly, $\mu\ (b_P/Y^c) = \mu_{PN}$, $\mu\ (b_N/Y^c) = \mu_{NN}$, $\mu\ (b_B/Y^c) = \mu_{BN}$ represent the loss incurred for taking the action b_P, b_N, b_B, respectively, when an object belongs to Y^c.

Now, the expected losses for taking different actions when the objects are in $[y]$ can be written as

G $(b_P/[y]) = \mu_{PP}$ Pr $(Y/[y]) + \mu_{PN}$Pr $(Y^c/[y])$

G $(b_B/[y]) = \mu_{BP}$ Pr $(Y/[y]) + \mu_{BN}$ Pr $(Y^c/[y])$

G $(b_N/[y]) = \mu_{NP}$ Pr $(Y/[y]) + \mu_{NN}$ Pr $(Y^c/[y])$

Now, applying the Bayesian decision procedure, the following rules associated with minimum risk are obtained:

(P): If G $(b_P/[y]) \leq$G $(b_B/[y])$ and G $(b_P/[y]) \leq$G $(b_N/[y])$, then decide $y \in$ POSITIVE(Y).

(N): If G $(b_N/[y]) \leq$G $(b_B/[y])$ and G $(b_N/[y]) \leq$G $(b_P/[y])$, then decide $y \in$ NEGATIVE (Y).

(B): If G $(b_B/[y]) \leq$G $(b_N/[y])$ and G $(b_B/[y]) \leq$G $(b_P/[y])$, then decide $y \in$ BOUNDARY (Y).

In order for each object to be classified into only one region, the tribreaker rule should be considered. The loss function inequality is considered as

$\mu_{PP} \leq \mu_{BP} < \mu_{NP}$ and $\mu_{NN} \leq \mu_{BN} < \mu_{PN}$, with

$(\mu_{NP} - \mu_{BP})\ (\mu_{PN} - \mu_{BN}) > (\mu_{BP} - \mu_{PP})\ (\mu_{BN} - \mu_{NN})$

Under the special condition of the loss function, the decision rules (P-R), (N-R) and (B-R) can be formulated as follows:

(P-R): If Pr $(Y/[y]) \geq \gamma$, then y belongs to POSITIVE(Y). (5)

(N-R): If Pr $(Y/[y]) \leq \delta$, then y belongs to NEGATIVE (Y). (6)

(B-R): If $\delta <$ Pr $(Y/[y]) < \gamma$, then y belongs to BOUNDARY(Y), (7)

where the threshold α and β are given by

$$\gamma = \frac{(\mu_{PN} - \mu_{BN})}{(\mu_{PN} - \mu_{BN}) + (\mu_{BP} - \mu_{PP})} \quad (8)$$

$$\delta = \frac{(\mu_{BN} - \mu_{NN})}{(\mu_{BN} - \mu_{NN}) + (\mu_{NP} - \mu_{BP})} \quad (9)$$

The parameters γ and δ denote the regions and show the associated risk in classification. The parameter γ makes a division between the positive region and the boundary region. The parameter δ similarly creates a division between the boundary region and the negative region.

The parameters of the decision-theoretic rough set model are derived methodically from loss functions, providing a theoretical foundation and practical interpretation for the probabilistic rough set. This approach is also readily applicable to real-world problems involving profit, loss, cost, risk, and other variables.

Fundamentals of the fuzzy set theory

The fuzzy set theory was first presented in 1965 by Professor L.A. Zadeh (1965) as an expansion of the classical set theory. Uncertain boundaries are accommodated by fuzzy sets which use linguistic variables to describe imprecise concepts. Fuzzy sets have thus evolved as a substitute approach to handling uncertainty (Klement & Schwyhla, 1982; Mazandarani et al, 2018; Sugeno, 1985; Wu & Xu, 2016; Pawlak, 1985).

The theory introduces the notion of a membership function, assigning elements a degree of membership within the interval [0, 1]. Let 'Y' denotes the universe of discourse and $m_{\tilde{Q}}(y)$ is the membership function for fuzzy sets $\tilde{Q}$; then, $m_{\tilde{Q}}(y)$ maps each element of Y to the interval [0, 1], i.e.

$m_{\tilde{Q}}(y)$: Y → [0, 1].

Henceforth, the set $\tilde{Q}$ defined on Y is further obtained as $\tilde{Q}$= {(y,$m_{\tilde{Q}}(y)$) | y∈Y}. In case of an example, let Y = {y_1,y_2,y_3, y_4, y_5 } be the reference set of students and $\tilde{Q}$ be the reference set of "smart" students, where "smart" is fuzzy term and represented by

$\tilde{Q}$ = {(y_1, 0.6), (y_2, 0.7), (y_3, 1), (y_4, 0.5), (y_5, 0.3)}.

Here, $\tilde{Q}$ indicates that the smartness of $y_1$is 0.6, y_2 is 0.7, etc. As a result, the membership function gives an indication of how similar an element is to a fuzzy set. Since the membership function is unique to each assessor or group of assessors, it is evidently subjective. In such case, for each y ∈Y, the assessor is able to find an $m_{\tilde{Q}}(y)$.

For a crisp set, the membership function can be obtained as follows:

$m_{\tilde{Q}}(y) = \begin{cases} 1, & \text{if } y \in Q \\ 0, & \text{if } y \notin Q \end{cases}$

It shows that the crisp set has sharp boundaries, but the fuzzy set contains vague boundaries.

Basic terminology in the fuzzy set

1.μ-cut: A fuzzy set defined on Y and any number $\mu \in [0, 1]$, the μ-cut is the crisp set $\tilde{Q}_{\mu} = \{y | m_{\tilde{Q}}(y) \geq \mu\}$ and a strong μ-cut is the set $\tilde{Q}_{\mu*} = \{y | m_{\tilde{Q}}(y) > \mu\}$

2. Level set of $\tilde{Q}$: All possible levels $\mu \in [0, 1]$ that represent distinct μ-cuts of the associated fuzzy set $\tilde{Q}$is denoted as a level set of Q.

$L(\tilde{Q}_{\mu}) = \{|m_{\tilde{Q}}(y) = \mu\}$, for some $y \in Y$.

3. Support: For the fuzzy set $\tilde{Q}$, its support is a crisp set defined as s $(\tilde{Q}) = \{y | m_{\tilde{Q}}(y) \geq 0\}$.

4. Normal and subnormal fuzzy sets: The height of the fuzzy set is the maximum value of the membership degree of any fuzzy set. When the height is 1, the fuzzy set $\tilde{Q}$ is normal and subnormal in the case of its height being below 1. The core of a fuzzy set are those y for which $m_{\tilde{Q}}(y) = 1$.

5. Convex fuzzy set: In the case of the fuzzy set, $\tilde{A}$ is convex if $m_{\tilde{A}}$ (r (y_1) + (1 − r) $(y_2)) \geq$ min $\{m_{\tilde{Q}}(y_1), m_{\tilde{Q}}(y_2)\}$, $y_1, y_2 \in Y$, r ∈ [0, 1].

6. Cardinality: In the case of a finite fuzzy set $\tilde{Q}$, the cardinality $|\tilde{Q}|$ is defined as $|\tilde{Q}| = \sum_{y \in Y} m_{\tilde{Q}}(y)$and $||\tilde{Q}|| = \frac{|\tilde{Q}|}{|Y|}$ is called relative cardinality of $\tilde{Q}$.

There are numerous definitions available for fuzziness measurement. These facts are discussed in Dubois & Prade (1982), Klement & Schwyhla (1982) and Sugeno (1985).

Elementary operations with the fuzzy set

Let $\tilde{Q}$,$\widetilde{W}$denote distinct fuzzy sets, then they are equivalent if $m_{\tilde{Q}}(y) = m_{\widetilde{W}}(y)$ $\forall\, y \in Y$ and $\tilde{Q} \subseteq \widetilde{W}$ if $m_{\tilde{Q}}(y) \leq m_{\widetilde{W}}(y)$,$\forall\, y \in Y$

1. Union:$\tilde{T} = \tilde{Q} \cup \widetilde{W}$ where, $\tilde{T} = \{(y, m_{\tilde{T}}(y))\}$ and, $m_{\tilde{T}}(y) = \max\{m_{\tilde{Q}}(y), m_{\widetilde{W}}(y))\}$.

2. Intersection: $\tilde{H} = \tilde{Q} \cap \widetilde{W}$where, $\tilde{H} = \{(y, m_{\tilde{H}}(y))\}$ and $m_{\tilde{H}}(y) = \min\{m_{\tilde{Q}}(y), m_{\widetilde{W}}(y))\}$.

3. Complement: $\tilde{Q}^c = \{(y, m_{\tilde{Q}^c}(y)\}$ where, $m_{\tilde{Q}^c}(y) = 1 - m_{\tilde{Q}}(y)$.

Significance of the fuzzy set

By measuring fuzziness, fuzzy sets provide a useful framework for expressing ambiguous ideas in plain language and addressing uncertainties. Fuzzy variables enable gradual transitions between states, providing a means to express and manage observation and measurement of uncertainties. The Bayesian decision framework may include fuzzy choice objects in the set of states of reality, enabling the creation of decision rules based on a 3×4 matrix of loss functions.

Remark 1: If there are fuzzy decision objects in the set of states of reality, suppose ∇ = {G, H, I, J} where G, H, I, J∈ F(τ) and satisfy G(y) + H(y) + I(y) + J(y) = 1 for any y∈τ . Here, F (τ) is a set of all fuzzy subsets of τ and a set of actions A = {b_P,b_N,b_B}, then we can formulate a 3×4 matrix for all the values of the loss function. Based on the loss function inequality, one can formulate Bayesian decision rules.

Operation on a linguistic variable

A variable whose values appear as words or phrases in a natural or artificial language is called a linguistic variable. Words and phrases that are obtained through qualitative or quantitative reasoning are included in these values; they are frequently linked to fuzzy or probabilistic systems, see Deng & Yao (2014), Xu (2005), Pawlak (1985), Zadeh (1965), Klir & Yuan (1995) and Chakraborty (2011).

Let M = {k_α| α = 0, 1, ...,r} be a totally ordered discrete term set. In this case, r+1 is the granularity of the set M. As the M is totally ordered, the law of tracheotomy is operated on it, i.e.,$k_\alpha \geq k_\beta$, $k_\alpha \leq k_\beta$, $k_\alpha = k_\beta$iff α ≥ β, α ≤ β, α = β, respectively.

The linguistic term set with the symmetric subscript M = {k | α = −r, ..., −1, 0, 1, ...,r} is also present. Here, 2r + 1 denotes the granularity of M and k_0 represents an assessment of fairness. $k_{-\mathrm{r}}$ and k_r are the lower and upper limits. In the case of the example below:

M = {k_{-3} = very bad, k_{-2}= bad, k_{-1}= slightly bad, k_0= fair, k_1= slightly good k_2= good, k_3= very good}.

The discrete term set M can further be extended to the continuous term set M^* = { k_λ| $k_{-\mathrm{r}} \leq k_{-\lambda} \leq k_\mathrm{r}$, λ ∈ [−r, r]} where k_λ of $M^*$are the same as $k_\alpha$of M for λ = α.

In M^*, index of any term denotes the degree of the term. So, we define a real-valued function from M^*as follows:

M^*= {k_λ | $k_{-\mathrm{r}} \leq k_{-\lambda} \leq k_\mathrm{r}$, λ ∈ [−r, r]} be a continuous linguistic term set

J : $M^* \rightarrow$ [−r,r] be a real-valued function where J(k_λ) = λ for any $k_\lambda \in M^*$.

It deals with decision-making problems under uncertainty. When $k_\lambda \in$ M, then k_λ is the original term, while λ is the original index. In other words, k_λ is the virtual term and λ is the virtual term index. The decision maker consistently employs the initial linguistic terms for assessing alternatives, while the virtual linguistic term is solely applicable during operations.

In case of a continuous term set M^*, for any $k_\lambda, k_\mu \in M^*$ and α, α_1, $\alpha_2 \in$ [0, 1], the following operational laws hold:

(1) $k_\lambda \pm k_\mu = k_{\lambda \pm \mu}$

(2) $\alpha\, k_\lambda = k_{\alpha\lambda}$

(3) $(\alpha_1+\alpha_2)k_\lambda = \alpha_1 k_\lambda + \alpha_2 k_\lambda$

(4) $\alpha\,(k_\lambda \pm k_\mu) = \alpha k_\lambda \pm \alpha k_\mu$.

Three-way decision utilizing linguistic information

In this chapter, our main goal is to identify voting patterns using linguistic term-based information pertaining to all attributes. This involves addressing two key challenges:

(i) Computing the conditional probability for each individual concerning the decision object, where the decision object encompasses all individuals within the sample space.

(ii) Determining the threshold values, denoted as γ and δ, is crucial for the lower and upper approximation, respectively, see Greco et al (2008) and Pauker & Kassirer (1980).

In order to address the first challenge, a conceptual framework for probability within a fuzzy event is introduced, specifically tailored to a linguistic-valued attribute set. This framework enables a nuanced analysis of voting behavior, considering the inherent linguistic expressions associated with each attribute.

Definition Let Q = $\{(y, m_Q(y)) \mid y \in R^n\}$ is a real-valued fuzzy set. The associated crisp probability of a fuzzy event is denoted as P (Q) $= \sum_y m_Q(y)\mathrm{P}(y)$.

Let $Q_\gamma = \{y \mid m_Q(y) \geq \gamma\}$, then the fuzzy probability of the fuzzy event is P (Q) = $\{(\mathrm{P}(Q_\gamma, \gamma)) \mid \gamma \in [0, 1]\}$.

Linguistic-valued framework for the information system

Linguistic variables provide the attribute values in an information system. Consider a linguistic-valued information system as follows:

$\varphi_1(y_1,a_1) = k_{-3}$, $\varphi_1(y_2,a_1) = k_1$, $\varphi_1(y_3,a_1) = k_0$,
$\varphi_2(y_1, a_2) = k_1$,$\varphi_2(y_2, a_2) = k_{-2}$, $\varphi_2(y_3,a_2) = k_4$,
$\varphi_3(y_1,a_3)= k_0$, $\varphi_3(y_2,a_3) = k_2$, $\varphi_3(y_3,a_3) = k_{-1}$,
$\varphi_4(y_1,a_4) = k_2$, $\varphi_4(y_2,a_4) = k_0$, $\varphi_4(y_3,a_4) = k_{-2}$

In a table, the information system can be represented as follows:

Table 1 – Linguistic valued information system

U/A	a_1	a_2	a_3	a_4
y_1	k_{-3}	k_1	k_0	k_2
y_2	k_1	k_{-2}	k_2	k_0
y_3	k_0	k_4	k_{-1}	k_{-2}

In case of a fuzzy set B having membership valuem_B (y_1) = 0.5, m_B (y_2) = 0.7 and m_B (y_3) = 0.8 and the probabilistic measure P denotes as P(y_1) = 0.2, P(y_2) = 0.3 and P(y_3) = 0.5 Then, $P(B) = \sum_{i=1}^{3} m(y_i)\, P(y_i) = 0.5 \times 0.2 + 0.7 \times 0.3 + 0.8 \times 0.5 = 0.71$.

Next, the associated real-valued function can be defined as below.

Z: M→ [0, 1]

Z (k_λ) = $\frac{J\,(k_\lambda)}{r-1}$ (10)

where r is the total number of terms in M.

For the symmetric subscript linguistic set Z: M^*= → [0, 1] by

Z (k_λ) = $\frac{|\mathrm{J}(k_\lambda) - \mathrm{J}(k_{-\mathrm{r}})|}{2\mathrm{r}}$ (11)

Here, Z (k_λ) is a continuous mapping having transformation between M^*= and [0, 1].

Proposition

Let M^*= $\{k_\lambda | k_{-\mathrm{r}} \leq k_\lambda \leq k_{\mathrm{r}}, \lambda \in [-\mathrm{r}, \mathrm{r}]\}$ be a set of continuous linguistic terms 'Z' is the transformation between $M^*$and real-valued over [0, 1]; then

1. Z $(k_{-\mathrm{r}})$ = 0, Z (k_0) = 0.5, Z (k_{r}) = 1
2. Z is an increasing function over M^*

Proof (1): By definition Z (k_λ) = $\frac{|\mathrm{J}(k_\lambda) - \mathrm{J}(k_{-\mathrm{r}})|}{2\mathrm{r}}$

So, Z $(k_{-\mathrm{r}})$ = $\frac{|\mathrm{J}(k_{-\mathrm{r}}) - \mathrm{J}(k_{-\mathrm{r}})|}{2\mathrm{r}}$ = 0

Z (k_0) = $\frac{|\mathrm{J}(k_0) - \mathrm{J}(k_{-\mathrm{r}})|}{2\mathrm{r}}$ = $\frac{|\,0-(-r)|}{2r}$ = 0.5

Z (k_{r}) = $\frac{|\mathrm{J}(k_{\mathrm{r}}) - \mathrm{J}(k_{-\mathrm{r}})|}{2\mathrm{r}}$ = $\frac{|\,r-(-r)|}{2r}$ = 1

(2): Let −r ≤ λ_1 ≤ λ_2≤ r, then, $k_{\lambda_2} \geq k_{\lambda_1}$

Z (k_{λ_2}) = $\frac{|\mathrm{J}(k_{\lambda_2}) - \mathrm{J}(k_{-\mathrm{r}})|}{2\mathrm{r}}$ = $\frac{\lambda_2+r}{2r}$

Z (k_{λ_1}) = $\frac{|\mathrm{J}(k_{\lambda_1}) - \mathrm{J}(k_{-\mathrm{r}})|}{2\mathrm{r}}$ = $\frac{\lambda_1+r}{2r}$, as $\lambda_2 \geq \lambda_1$ so $\frac{\lambda_2+r}{2r} \geq \frac{\lambda_1+r}{2r}$

Hence, Z (k_{λ_2}) ≥ Z (k_{λ_1}), so, 'Z' can be considered as an increasing function over M^* . The middle linguistic label denotes an assessment of 'in

difference' and the transformation function Z (k_λ) can further be denoted using Z (k_0) as next.

Proposition

Z (k_λ) = $\frac{J(k_\lambda)}{2r}$+ Z (k_0) = 0.5 + $\frac{J(k_\lambda)}{2r}$

Proof:

Z (k_λ) = $\frac{|\mathrm{J}(k_\lambda) - \mathrm{J}(k_{-\mathrm{r}})|}{2\mathrm{r}}$

= $\frac{\mathrm{J}(k_\lambda) - \mathrm{J}(k_{-\mathrm{r}})}{2\mathrm{r}}$ as λ ∈ [−r, r]

= $\frac{J(k_\lambda)+r}{2r}$ = 0.5 + $\frac{J(k_\lambda)}{2r}$ = Z (k_0) + $\frac{J(k_\lambda)}{2r}$ [as Z (k_0) = 0.5].

Conditional probability in the linguistic valued information system

Let $D \in F(\tau)$ and $y \in \tau$, then the conditional probability of D with respect to y denoted by

P (D|y) = $\frac{\sum_{a_j \in A} \Delta(\mathrm{D}(y), \mathrm{Z}(\varphi_j(y,a_j)))}{\sum_{a_j} \mathrm{Z}(\varphi_j(y,a_j))}$, $y \in \tau$, for all attribute j (12)

where Δ: [0, 1] × [0, 1] →[0, 1] is a fuzzy logic operator (Klir & Yaun, 1995; Zadeh, 1965; Wong & Ziarko, 1987).

We define the fuzzy logic operator as Δ (x, y) = min (x, y).

Thus, P (D|y) = $\frac{\sum_{a_j \in A} \mathrm{D}(y) \wedge \mathrm{Z}(\varphi_j(y,a_j))}{\sum_{a_j} \mathrm{Z}(\varphi_j(y,a_j))}$, $y \in \tau$, for all attribute j (13)

We demonstrate this with an example from Table 1.

Let M = = {k_λ| $k_{-\mathrm{r}} \le k_\lambda \le k_\mathrm{r}$, λ ∈ [−4, 4]}

z_{a_1}= Z (φ_1, (y_2,a_1)); z_{a_1}= Z (φ_2, (y_2,a_2)); z_{a_3}= Z (φ_3, (y_2,a_3)); z_{a_4}= Z (φ_4, (y_2,a_4))

P (D|y_2) = $\frac{\sum_{a_j \in A} \Delta(\mathrm{D}(y_2), \mathrm{Z}(\varphi_j(y_2,a_j)))}{\sum_{a_j} \mathrm{Z}(\varphi_j(y_2,a_j))}$ = $\frac{\sum_{a_j \in A} \mathrm{D}(y_2) \wedge \mathrm{Z}(\varphi_j(y_2,a_j))}{\sum_{a_j} \mathrm{Z}(\varphi_j(y_2,a_j))}$

= $\frac{\mathrm{D}(y_2) \wedge z_{a_1} + \mathrm{D}(y_2) \wedge z_{a_2} + \mathrm{D}(y_2) \wedge z_{a_3} + \mathrm{D}(y_2) \wedge z_{a_4}}{v_{a_1} + v_{a_2} + v_{a_3} + v_{a_{14}}}$

= $\frac{0.7 \wedge z(k_1) + 0.7 \wedge z(k_{-2}) + 0.7 \wedge z(k_2) + 0.7 \wedge z(k_0)}{z(k_1) + z(k_{-2}) + z(k_2) + z(k_0)}$

= $\frac{0.7 \wedge 0.625 + 0.7 \wedge 0.25 + 0.7 \wedge 0.75 + 0.7 \wedge 0.5}{0.625 + 0.25 + 0.75 + 0.5}$ = $\frac{2.075}{2.125}$ = 0.976

Clearly, P(D| y) satisfies the axioms of probability. We can now define the lower and higher approximations with the aid of the conditional probability of a fuzzy event with a linguistic description of the attribute.

Let D∈ F (τ) and 0 ≤ δ < γ ≤ 1 and $y \in \tau$, then
$\underline{Apr_\gamma}$ (D) = { $y \in \tau$ | P (D| y) ≥ γ}
$\overline{Apr_\delta}$ (D) = { $y \in \tau$ | P (D| y)> δ}.

Next, the three-way decision regions are as shown next (Hu, 2014):

$$POS_{(\gamma,\delta)}(D) = \{y \in \tau | \frac{\sum_{a_j \in A} D(y) \wedge Z(\varphi_j(y,a_j))}{\sum_{a_j \in A} Z(\varphi_j(y,a_j))} \geq \gamma\} \quad (14)$$

$$NEG_{(\gamma,\delta)}(D) = \{y \in \tau | \frac{\sum_{a_j \in A} D(y) \wedge Z(\varphi_j(y,a_j))}{\sum_{a_j \in A} Z(\varphi_j(y,a_j))} \leq \delta\} \quad (15)$$

$$BND_{(\gamma,\delta)}(D) = \{y \in \tau | \delta < \frac{\sum_{a_j \in A} D(y) \wedge Z(\varphi_j(y,a_j))}{\sum_{a_j \in A} Z(\varphi_j(y,a_j))} < \gamma\} \quad (16)$$

When the loss function is represented in terms of a linguistic form, the function J is used to determine the threshold values γ and δ, thus resolving the second difficulty. So, inequality in the loss function is:

J (μ_{PP}) ≤ J (μ_{BP}) < J (μ_{NP}) and J (μ_{NN}) ≤ J (μ_{BN}) < J (μ_{PN}) with the condition

{J (μ_{NP}) – J (μ_{BP})} × {J (μ_{PN}) –J (μ_{BN})} > {J (μ_{BP}) – J (μ_{PP})} × {J (μ_{BN}) – J (μ_{NN})},

Then, $\gamma = \frac{J(\mu_{PN}) - J(\mu_{BN})}{\{J(\mu_{PN}) - J(\mu_{BN})\} + \{J(\mu_{BP}) - J(\mu_{PP})\}} = \{1 + \frac{J(\mu_{BP}) - J(\mu_{PP})}{J(\mu_{PN}) - J(\mu_{BN})}\}^{-1}$ (17)

$\delta = \frac{J(\mu_{BN}) - J(\mu_{NN})}{\{J(\mu_{BN}) - J(\mu_{NN})\} + \{J(\mu_{NP}) - J(\mu_{BP})\}} = \{1 + \frac{J(\mu_{NP}) - J(\mu_{BP})}{J(\mu_{BN}) - J(\mu_{NN})}\}^{-1}$

The parameters γ and δ define the regions and provide associated risk for classifying an object.

Remark: The main focus is to identify the voting behaviour so that political experts can choose the parameter values γ and δ on the basis of their experience (Karni, 2009; Pauker & Kassirer, 1980).

Real life example

This section gives an example which illustrates the main idea of the paper. Here, 26 people from four different age groups are considered and their linguistic information about different attributes related to their voting behaviour is collected. Using this linguistic information, a political party can get a clear idea regarding the share of the vote.

The voting behaviour in the Indian society is highly diversified in nature and composition, influenced by multiple factors. These factors can be classified into three categories: social, economic, and political. There are also some other factors that make an impact on the electoral behaviour in our society: (i) election campaign, (ii) candidate orientation, (iii) habitation (urban or rural), (iv) factionalism (one of the main features in politics from top to bottom levels), (vi) conditions of the economy at the time of elections, such as inflation, food, unemployment etc, and (vii) political events preceding an election like corruption, war, scandals, etc.

Considering all the above factors, here we select seven factors as conditional attributes, namely A_1, A_2,……, A_7, taking into account the past history of a few elections as well as some burning issues related with the coming election. In this example, we divide voters into four groups: Group-I (age from 18 to under 30), Group – II (age from 30 to under 45), Group – III (age from 45 to under 60), and Group – IV (age over 60). The decisional attribute which we denoted by "C" indicates the vote share in favour of the party. We consider different membership values for different groups, which reflects that the electoral behaviour of different age groups is different. For Group-I, the threshold is taken as $\gamma = 0.8$, $\delta = 0.7$, for Group-II, the threshold is taken as $\gamma = 0.7$, $\delta = 0.55$, for Group-III, the threshold is taken as $\gamma = 0.4$, $\delta = 0.25$, and for Group-IV, the threshold is taken as $\gamma = 0.3$, $\delta = 0.2$.

Due to the non-negative and discrete nature of the linguistic term index in this case, we compute the values using equations (10), (11) and (13) and make decisions by using values of$1 - P(\frac{c}{y_i})$rather than P$(\frac{c}{y_i})$. Let $P^*(\frac{c}{y_i}) = 1 - P(\frac{c}{y_i})$. Therefore, the region of acceptance (positive region) of a three-way choice can be described as follows:

1. Region of acceptance (Positive region) = $\{y_i \mid P^*(\frac{c}{y_i}) \geq \gamma\}$.
2. Region of rejection (Negative region) = $\{y_i | P^*(\frac{c}{y_i}) \leq \delta\}$.
3. Region of non-commitment (Boundary region) = $\{y_i | \ \delta < P^*(\frac{c}{y_i}) < \gamma\}$.

Here, the positive region indicates a confirmed vote share in favour of the party, the negative region reflects a confirmed vote share against the party, and the non-commitment region indicates that the vote share may or may not be in favour of the party.

Table 2 – Linguistic valued information related to the voting behaviour

Group	People	A_1	A_2	A_3	A_4	A_5	A_6	A_7	C	P $(\frac{c}{y_i})$	1- P $(\frac{c}{y_i})$
(i) (age from 18 to under 30)	y_1	k_0	k_2	k_2	k_1	k_0	k_1	k_2	0.1	0.25	0.75
	y_2	k_1	k_2	k_3	k_2	k_0	k_1	k_3	0.1	0.20	0.80
	y_3	k_2	k_3	k_2	k_3	k_2	k_1	k_3	0.1	0.17	0.82
	y_4	k_4	k_0	k_1	k_0	k_1	k_0	k_1	0.1	0.22	0.77
	y_5	k_3	k_4	k_1	k_3	k_2	k_1	k_3	0.1	0.16	0.83
	y_6	k_1	k_0	k_1	k_0	k_1	k_0	k_1	0.1	0.40	0.60
(ii) (age from 30 to under 45)	y_7	k_0	k_2	k_2	k_1	k_0	k_1	k_2	0.15	0.37	0.62
	y_8	k_1	k_2	k_3	k_2	k_0	k_1	k_3	0.15	0.30	0.70
	y_9	k_3	k_4	k_1	k_3	k_2	k_1	k_3	0.15	0.24	0.75
	y_{10}	k_2	k_3	k_2	k_3	k_2	k_1	k_3	0.15	0.26	0.73
	y_{11}	k_1	k_0	k_1	k_1	k_2	k_0	k_0	0.15	0.48	0.52
	y_{12}	k_4	k_1	k_1	k_2	k_1	k_1	k_3	0.15	0.32	0.67
(iii) (age from 45 to under 60)	y_{13}	k_2	k_0	k_1	k_0	k_1	k_0	k_0	0.35	0.85	0.15
	y_{14}	k_1	k_0	k_2	k_1	k_0	k_1	k_2	0.35	0.82	0.18
	y_{15}	k_3	k_1	k_2	k_3	k_1	k_0	k_3	0.35	0.58	0.41
	y_{16}	k_4	k_0	k_1	k_0	k_1	k_0	k_1	0.35	0.80	0.20
	y_{17}	k_4	k_2	k_1	k_2	k_2	k_1	k_2	0.35	0.64	0.35
	y_{18}	k_3	k_1	k_1	k_3	k_2	k_0	k_3	0.35	0.58	0.41
	y_{19}	k_2	k_0	k_2	k_2	k_1	k_1	k_2	0.35	0.62	0.38
(iv) Age over 60	y_{20}	k_0	k_2	k_2	k_1	k_1	k_0	k_2	0.4	0.85	0.15
	y_{21}	k_1	k_1	k_0	k_2	k_1	k_0	k_0	0.4	0.92	0.08
	y_{22}	k_4	k_0	k_2	k_2	k_1	k_2	k_3	0.4	0.64	0.35
	y_{23}	k_3	k_1	k_1	k_0	k_0	k_0	k_1	0.4	0.76	0.24
	y_{24}	k_3	k_1	k_2	k_3	k_1	k_0	k_2	0.4	0.70	0.30
	y_{25}	k_4	k_0	k_3	k_2	k_1	k_1	k_3	0.4	0.60	0.40
	y_{26}	k_2	k_0	k_1	k_0	k_1	k_1	k_2	0.4	0.88	0.12

For Group G_1: POSITIVE $(G_1) = \{y_2, y_3, y_5\}$, BOUNDARY $(G_1) = \{y_1, y_4\}$ and NEGATIVE $(G_1) = \{y_6\}$.

For Group G_2: POSITIVE $(G_2) = \{y_8, y_9, y_{10}\}$, BOUNDARY $(G_2) = \{y_7, y_{12}\}$ and NEGATIVE $(G_2) = \{y_{11}\}$.

For Group G_3: POSITIVE $(G_3) = \{y_{15}, y_{18}\}$, BOUNDARY $(G_3) = \{y_{17}, y_{19}\}$ and NEGATIVE $(G_3) = \{y_{13}, y_{14}, y_{16}\}$.

For Group G_4: POSITIVE $(G_4) = \{y_{22}, y_{24}, y_{25}\}$, BOUNDARY $(G_4) = \{y_{23}\}$ and NEGATIVE $(G_4) = \{y_{20}, y_{21}, y_{26}\}$.

Remark 1: The selection of a threshold is an important issue in a three-way decision-making problem. There are a few methods to calculate the threshold values. One of them is the Bayesian decision process which we discussed briefly in this paper. Most of the time, field experts also select the threshold values using their experience.

Remark 2: Here, we describe the calculation P ($\frac{c}{y_i}$) for the people y_2 as in Table 2**.**

Here, the granularity r = 5, using (13), we get

P (c|y_2) = $\frac{\sum_{a_j \in A} \mathrm{D}(y_2) \wedge \mathrm{Z}(\varphi_j(y_2,a_j))}{\sum_{a_j} \mathrm{Z}(\varphi_j(y_2,a_j))}$, $y \in \tau$, for all attribute j

=

$$\frac{\mathrm{D}(y_2) \wedge z_{a_1} + \mathrm{D}(y_2) \wedge z_{a_2} + \mathrm{D}(y_2) \wedge z_{a_3} + \mathrm{D}(y_2) \wedge z_{a_4} + \mathrm{D}(y_2) \wedge z_{a_5} + \mathrm{D}(y_2) \wedge z_{a_6} + \mathrm{D}(y_2) \wedge z_{a_7}}{z_{a_1} + z_{a_2} + z_{a_3} + z_{a_4} + z_{a_5} + z_{a_6} + z_{a_7}}$$

=

$$\frac{0.1 \wedge z(k_1) + 0.1 \wedge z(k_2) + 0.1 \wedge z(k_3) + 0.1 \wedge z(k_2) + 0.1 \wedge z(k_0) + 0.1 \wedge z(k_1) + 0.1 \wedge z(k_3)}{z(k_1) + z(k_2) + z(k_3) + z(k_2) + z(k_0) + z(k_1) + z(k_3)}$$

$$= \frac{0.1 \wedge 0.25 + 0.1 \wedge 0.5 + 0.1 \wedge 0.75 + 0.1 \wedge 0.5 + 0.1 \wedge 0 + 0.1 \wedge 0.25 + 0.1 \wedge 0.75}{0.25 + 0.5 + 0.75 + 0.5 + 0 + 0.25 + 0.75}$$

= $\frac{0.6}{3}$ = 0.20

Here, equation (10), Z (k_λ) = $\frac{J(k_\lambda)}{r-1}$ is used for calculating $z(k_\mathrm{i})$.

Conclusion

In this paper, a three-way decision model based on linguistic information of people is introduced to identify their voting behaviour. Electoral behavior entails an understanding of the factors and reasons that influence voting patterns. The proposed model addresses the research task by seamlessly integrating the rough set theory and the fuzzy set theory into linguistic information, offering a comprehensive approach. It excels in handling complex datasets, providing valuable insights through a computationally intensive yet effective methodology. A comparative analysis based on age groups indicates that this method is more feasible and effective compared to other approaches. When faced with numerous predetermined cases and a large number of boundary regions, the hybrid model proves advantageous by allowing the adjustment of the threshold parameter, reducing the complexity associated with decision making and facilitating a more efficient classification of cases into the specified regions. The significance of the proposed hybrid model has been justified through its application in a real-life scenario.

If political parties are faced with numerous predetermined cases and a large number of boundary regions, the hybrid model provides a chance

to get a favourable result in favour of political parties by allowing the adjustment of the threshold parameters γ and δ. It shows that the determination of voting behaviour allows political parties to create an environment for the voters to perform two distinct roles, evaluation of performance and promote the development. It also provides a nice relationship between the determination of voters' behaviour variables like the personality of a political leader, contingent situation, epistemic value, etc., with the voting intention of people.

The adjustment of the threshold values for preferable results indicates that the determination of the voting behaviour model may be considered an important political party resource that can influence the intention of voting behaviour by allowing the political parties to implement programs and policies to meet the requirements and expectations of voters. Current studies show that the effect of a linguistic valued information system hybrid fuzzy rough model has individual preferences with variable specific values. Hence, our model can be considered as an antecedent to voting intention.

Limitation

Like other research, this model is not without its limitations. The limitation of the proposed model is that the integration of the rough set theory and the fuzzy set theory may result in a computationally intensive model, particularly when dealing with large datasets. Analysis methods and alternative data collection such as longitudinal panel data, structural equation modelling, objective performance, and importance-performance matrix are for future studies to test this study's model. For example, the use of longitudinal data did not allow for examining the determination of voting patterns over time. Future researchers should explore cross sectional data to see the pattern of change in voting intentions over time in different political environments. Furthermore, even though this study does not segment the voter market and examine the effect of a specific segment on the model, it would be interesting for future studies to look at the nuances in specific segments and the effects in different contexts. If the data is collected from first-time voters, it may not give proper results. This study focuses only on Indian individuals. Although within a similar context, when India shares some similar characteristics, a few notable differences may appear in applying the hybrid model. Besides this limitation, this hybrid model provides insightful theoretical and practical implications in determining voting patterns.

Further, we may extend our studies beyond Indian politics, which may consider how voters react in the determination of their voting intentions.

For further studies, it would be more interesting to examine the effect of the proposed model on a specific segment of the voter market. Future work should refine the model, considering additional linguistic variables and exploring its application in diverse domains beyond voting behavior analysis. Future research could further focus on refining the hybrid model by exploring advanced machine learning algorithms, enhancing rule-based system interpretability, and developing mechanisms for dynamic rule adaptation.

References

Bukari, Z., Abdul Hamid, A.B., Md. Som, H., Agbemabiese, G.C. & Quansah, F. 2022. Does political issue matter in voting intention in Ghana? A political marketing perspective. *Cogent Business & Management*, 9(1), art.number: 2034227. Available at: https://doi.org/10.1080/23311975.2022.2034227.

Chakraborty, M.K. 2011. On Fuzzy Sets and Rough Sets from the Perspective of Indiscernibility. In: Banerjee, M. & Seth, A. (Eds.) *Logic and Its Applications. ICLA 2011. Lecture Notes in Computer Science*, 6521. Heidelberg: Springer, Berlin. Available at: https://doi.org/10.1007/978-3-642-18026-2_4.

Deng, X. & Yao, Y. 2014. Decision-theoretic three-way approximations of fuzzy sets. *Information Sciences*, 279, pp.702-715. Available at: https://doi.org/10.1016/j.ins.2014.04.022.

Donbosco, J.S.M & Ganesan, D. 2022. The Energy of rough neutrosophic matrix and its application to MCDM problem for selecting the best building construction site. *Decision Making: Applications in Management and Engineering*, 5(2), pp.30-45. Available at: https://doi.org/10.31181/dmame0305102022d.

Dubois, D. & Prade, H. 1982. A CLASS OF FUZZY MEASURES BASED ON TRIANGULAR NORMS A general framework for the combination of uncertain information. *International Journal of General System*, 8(1), pp.43-61. Available at: https://doi.org/10.1080/03081078208934833.

Dubois, D. & Prade, H. 1990. Rough fuzzy sets and fuzzy rough sets. *International Journal of General Systems*, 17(2-3), pp.191-209. Available at: https://doi.org/10.1080/03081079008935107.

Greco, S., Matarazzo, B. & Słowiński, R. 2008. Parameterized rough set model using rough membership and Bayesian confirmation measures. *International Journal of Approximate Reasoning*, 49(2), pp.285-300. Available at: https://doi.org/10.1016/j.ijar.2007.05.018.

Gurmani, S.H., Chen, H. & Bai, Y. 2023. Multi-attribute group decision-making model for selecting the most suitable construction company using the linguistic interval valued T-spherical 150 fuzzy TOPSIS method. *Applied Intelligence*, 53, pp.11768-11785. Available at: https://doi.org/10.1007/s10489-022-04103-0.

Hu, B.Q. 2014. Three-way decisions space and three way decisions. *Information Sciences*, 281, pp.21-52. Available at: https://doi.org/10.1016/j.ins.2014.05.015.

Karni, E. 2009. A theory of medical decision making under uncertainty. *Journal of Risk and Uncertainty*, 39, pp.1-16. Available at: https://doi.org/10.1007/s11166-009-9071-3.

Klement, E.P. & Schwyhla, W. 1982. Correspondence between fuzzy measures and classical measures. *Fuzzy Sets and Systems,* 7(1), pp.57-70. Available at: https://doi.org/10.1016/0165-0114(82)90040-9.

Klir, G.J. 1994. Multivalued logics versus modal logics: alternative frameworks for uncertainty modelling. In: Wang, P.P. (Ed.) *Advances in Fuzzy Theory and Technology*. Durham, North Carolina, USA: Duke University, Department of Electrical Engineering. ISBN: 978-0964345614.

Klir, G.J. & Yaun, B. 1995. FUZZY SETS AND FUZZY LOGIC: Theory and application. Upper Saddle River, NJ, USA: Prentice Hall PTR. ISBN: 0-13-101171-5.

Konlan, B. 2017. *Predictability of Identity Voting Behaviour, Perceived Exclusion and Neglect and the Paradox of Loyalty: A Case Study of a Conflict Involving the Ewe Group in the Volta Region of Ghana and the NDC-led Administrations*. PhD thesis. Ann Arbor, MI, USA: ProQuest LLC & Nova Southeastern University, College of Arts, Humanities, and Social Sciences [online]. Available at: https://www.proquest.com/openview/060098f4656dfc5bc2e04c1edf71d5a3/1?pq-origsite=gscholar&cbl=18750 [Accessed: 10 January 2024].

Lees-Marshment, J. 2019. Marketing Scholars and Political Marketing: the Pragmatic and Principled Reasons for Why Marketing Academics Should Research the Use of Marketing in the Political Arena. *Customer Needs and Solutions*, 6, pp.41-48. Available at: https://doi.org/10.1007/s40547-019-0091-0.

Mazandarani, M., Pariz, N. & Kamyad, A.V. 2018. Granular Differentiability of Fuzzy-Number-Valued Functions. *IEEE Transactions on Fuzzy Systems*, 26(1), pp.310-323. Available at: https://doi.org/10.1109/TFUZZ.2017.2659731.

Narang, M., Kumar, A. & Dhawan, R. 2023. A fuzzy extension of MEREC method using parabolic measure and its applications. *Journal of Decision Analytics and Intelligent Computing*, 3(1), pp.33-46. Available at: https://doi.org/10.31181/jdaic10020042023n.

Pal, S.S. & Kar, S. 2019. Time series forecasting for stock market prediction through data discretization by fuzzistics and rule generation by rough set theory. *Mathematics and Computers in Simulation*, 162, pp.18-30. Available at: https://doi.org/10.1016/j.matcom.2019.01.001.

Pauker, S.G. & Kassirer, J.P. 1980. The Threshold Approach to Clinical Decision Making. *New England Journal of Medicine*, 302(20), pp.1109-1117. Available at: https://doi.org/10.1056/NEJM198005153022003.

Pawlak, Z. 1982. Rough Sets. *International Journal of Computer & Information Sciences*, 11, pp.341-356. Available at: https://doi.org/10.1007/BF01001956.

Pawlak, Z. 1985. Rough sets and fuzzy sets. *Fuzzy Sets and Systems*, 17(1), pp.99-102. Available at: https://doi.org/10.1016/S0165-0114(85)80029-4.

Saqlain, M. & Saeed, M. 2024. From Ambiguity to Clarity: Unraveling the Power of Similarity Measures in Multi-Polar Interval-Valued Intuitionistic Fuzzy Soft Sets. *Decision Making Advances*, 2(1), pp.48-59. Available at: https://doi.org/10.31181/dma21202421.

Sharma, H.K., Kumari, K. & Kar, S. 2018. Air passengers forecasting for Australian airline based on hybrid rough set approach. *Journal of Applied Mathematics, Statistics and Informatics*, 14(1), pp.5-18. Available at: https://doi.org/10.2478/jamsi-2018-0001.

Sharma, H.K., Singh, A., Yadav, D. & Kar, S. 2022. Criteria selection and decision making of hotels using Dominance Based Rough Set Theory. *Operational Research in Engineering Sciences: Theory and Applications*, 5(1), pp.41-55 [online]. Available at: https://oresta.org/menu-script/index.php/oresta/article/view/151 [Accessed: 10 January 2024].

Sugeno, M. 1985. An introductory survey of fuzzy control. *Information Science*, 36(1-2), pp.59-83. Available at: https://doi.org/10.1016/0020-0255(85)90026-X.

Tufail, F., Shabir, M. & Abo-Tabl, E.-S.A. 2022. A Comparison of Promethee and TOPSIS Techniques Based on Bipolar Soft Covering-Based Rough Sets. *IEEE Access*, 10, pp.37586-37602. Available at: https://doi.org/10.1109/ACCESS.2022.3161470.

Wong, S.K.M & Ziarko, W. 1987. Comparison of the probabilistic approximate classification and the fuzzy set model. *Fuzzy Sets and Systems*, 21(3), pp.357-362. Available at: https://doi.org/10.1016/0165-0114(87)90135-7.

Wu, Z. & Xu, J. 2016. Managing consistency and consensus in group decision making with hesitant fuzzy linguistic preference relations. *Omega*, 65, pp.28-40. Available at: https://doi.org/10.1016/j.omega.2015.12.005.

Xu, Z. 2005. Deviation measures of linguistic preference relations in group decision making. *Omega*, 33(3), pp.249-254. Available at: https://doi.org/10.1016/j.omega.2004.04.008.

Yang, B. 2022. Fuzzy covering-based rough set on two different universes and its application. *Artificial Intelligence Review*, 55, pp.4717-4753. Available at: https://doi.org/10.1007/s10462-021-10115-y.

Yang, X. & Yao, J.T. 2012. Modelling Multi-agent Three-way Decisions with Decision-theoretic Rough Sets. *Fundamenta Informaticae*, 115(2-3), pp.157-171. Available at: https://doi.org/10.3233/FI-2012-647.

Yao, Y.Y. 1997. Combination of rough and fuzzy sets based on α-level sets. In: Lin, T.Y. & Cercone, N. (Eds.) *Rough Sets and Data Mining: Analysis for Imprecise Data*. Boston, MA, USA: Springer, pp.301-321. Available at: https://doi.org/10.1007/978-1-4613-1461-5_15.

Yao, Y. & Deng, X. 2014. Quantitative rough sets based on subsethood measures. *Information Sciences*, 267, pp.306-322. Available at: https://doi.org/10.1016/j.ins.2014.01.039.

Yao, Y.Y. & Wong, S.K.M. 1992. A decision-theoretic framework for approximating concepts. *International Journal of Man-Machine Studies*, 37(6), pp.793-809. Available at: https://doi.org/10.1016/0020-7373(92)90069-W.

Zadeh, L.A. 1965. Fuzzy sets. *Information and Control*, 8(3), pp.338-353. Available at: https://doi.org/10.1016/S0019-9958(65)90241-X.

Zhan, J. & Sun, B. 2019. Covering-based soft fuzzy rough theory and its application to multiple criteria decision making. *Computational and Applied Mathematics*, 38, art.number:149. Available at: https://doi.org/10.1007/s40314-019-0931-4.

Zhan, J. & Wang, Q. 2019. Certain types of soft coverings based rough sets with applications. *International Journal of Machine Learning and Cybernetics*, 10(5), pp.1065-1076. Available at: https://doi.org/10.1007/s13042-018-0785-x.

Zhang, L. & Zhan, J. 2019. Fuzzy soft β-covering based fuzzy rough sets and corresponding decision-making applications. *International Journal of Machine Learning and Cybernetics*, 10(6), pp.1487-1502. Available at: https://doi.org/10.1007/s13042-018-0828-3.

Ziarko, W. 1993. Variable precision rough set model. *Journal of Computer and System Sciences*, 46(1), pp.39-59. Available at: https://doi.org/10.1016/0022-0000(93)90048-2.

Utilizar un enfoque híbrido de toma de decisiones con conjuntos difusos y aproximados de datos lingüísticos para analizar patrones de votación

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CAMPO: matemáticas, ciencias de computación
TIPO DE ARTÍCULO: artículo científico original

Resumen:

Introducción/objetivo: La importancia de estudiar el comportamiento electoral se ve subrayada por su capacidad para medir la continuidad o divergencia de la política electoral con respecto a las tendencias históricas, dilucidando el impacto real de las urnas transformadoras y contribuyendo al examen de la democracia como un valor entre masas y élites. Además, ayuda a comprender el intrincado proceso de socialización política.

Métodos: Una fortaleza inherente del conjunto aproximado radica en su dependencia únicamente de datos sin procesar, desprovistos de insumos externos. El marco de conjunto aproximado de teoría de decisiones, una evolución del conjunto aproximado, ha obtenido una aplicación generalizada en diversos dominios, sirviendo como una herramienta competente para adquirir conocimientos, particularmente en situaciones marcadas por la vaguedad y la incertidumbre. A pesar de la proliferación de modelos matemáticos diseñados para discernir el comportamiento

electoral de las personas, una recomendación aproximada basada en decisiones sigue notablemente ausente en la bibliografía existente. Este artículo presenta un innovador enfoque de decisión de tres vías basado en información lingüística para identificar el comportamiento electoral. El enfoque propuesto se basa en un modelo probabilístico híbrido aproximado y difuso que incorpora información lingüística y proporciona información sobre los patrones de votación.

Resultados: Los modelos híbridos de decisión de tres vías se prueban en personas y se obtuvo un resultado altamente satisfactorio para identificar sus comportamientos electorales. La justificación de resultados fue validada mediante el proceso matemático.

Conclusión: Se proporciona una ilustración práctica para resaltar la importancia de este modelo híbrido y confirmar su utilidad para identificar y pronosticar el comportamiento electoral.

Palabras claves: término lingüístico, conjunto aproximado, conjunto difuso, decisión triple, comportamiento electoral.

Гибридный подход принятия решений с нечетким и грубым множествами, примененный к лингвистическим данным для анализа модели голосования

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РУБРИКА ГРНТИ: 27.47.19 Исследование операций,
28.17.31 Моделирование процессов управления
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: Исследование поведения избирателей имеет важное значение, поскольку оно позволяет измерить постоянность избирательной политики, а также отклонение данной политики от исторических тенденций, объясняя реальное влияние преобразующегося избирательного ящика, и вносит вклад в изучение демократической ценности как среди масс, так и среди элит. Кроме того, это способствует пониманию сложного процесса политической социализации.

Методы: Преимущество грубых множеств заключается в том, что они полагаются исключительно на необработанные данные без каких-либо внешних влияний. Структура грубых множеств для теоретического принятия решений как эволюция грубого множества обеспечила широкое применение в различных областях в качестве успешного инструмента приобретения знаний, особенно в ситуациях, когда присутствуют

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неуверенность и неопределенность. Несмотря на большое количество математических моделей, разработанных для объяснения поведения избирателей, в существующей литературе явно отсутствует рекомендация об использовании грубых множеств, основанных на принятии решений. В этой статье представлен инновационный трехфакторный подход к принятию решений, основанный на лингвистических данных, с целью выявления поведения избирателей. Предлагаемый подход основан на гибридной вероятностной грубой модели и модели нечеткого множества, которые включают лингвистические данные и дают представление о моделях голосования.

Результаты: Трехфакторные гибридные модели принятия решений были протестированы на людях и дали весьма удовлетворительные результаты при определении их избирательного поведения. Полученные результаты были подтверждены математическим методом.

Выводы: Пример из практики подчеркивает важность этой гибридной модели и подтверждает ее полезность в выявлении и прогнозировании поведения избирателей.

Ключевые слова: лингвистический термин, грубое множество, нечеткое множество, трехфакторное решение, поведение избирателя.

Хибридни приступ одлучивању са фази и грубим скуповима заснован на лингвистичким подацима ради анализирања образаца гласања

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Сажетак:

Увод/циљ: Проучавање понашања гласача је значајно јер омогућава мерење континуитета изборне политике као и одступања одређене политике од историјских трендова. Оно објашњава стварни утицај трансформативне бирачке кутије и доприноси испитивању демократије као вредности и међу масама и међу елитама. Поред тога, доприноси разумевању сложеног процеса политичке социјализације.

Методе: Снага грубих скупова лежи у њиховом ослањању искључиво на сирове податке, без икаквих спољашњих утицаја. Оквир грубих скупова за теоријско одлучивање, као еволуција грубог скупа,

обезбедио је широку примену у различитим областима као успешна алатка за стицање знања, нарочито у ситуацијама у којима је присутна неодређеност и несигурност. Упркос великом броју математичких модела пројектованих да утврђују понашање гласача, у литератури нема препоруке да се користе груби скупови засновани на одлучивању. Овај рад уводи иновативни трофакторски приступ одлучивању заснован на лингвистичким подацима ради идентификовања понашања гласача. Предложени приступ заснива се на хибридном пробабилистичком моделу грубих и фазних скупова који укључује лингвистичке податке и обезбеђује увид у обрасце гласања.

Резултати: Трофакторски хибридни модели одлучивања тестирани су на гласачима. У идентификацији њиховог понашања при гласању добијени су веома задовољавајући резултати. који су валидирани путем математичког процеса.

Закључак: Пример из праксе истиче значај овог хибридног модела и потврђује његову корисност за идентификацију и предвиђање понашања гласача.

Кључне речи: лингвистички термин, груби скуп, фази скуп, трофакторска одлука, понашање гласача.

EDITORIAL NOTE: The second author of this article, Samarjit Kar, is a current member of the Editorial Board of the *Military Technical Courier*. Therefore, the Editorial Team has ensured that the double blind reviewing process was even more transparent and more rigorous. The Team made additional effort to maintain the integrity of the review and to minimize any bias by having another associate editor handle the review procedure independently of the editor – author in a completely transparent process. The Editorial Team has taken special care that the referee did not recognize the author's identity, thus avoiding the conflict of interest.

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Leveraging Blockchain technology to accelerate financial and nonfinancial inclusion and empowerment in developing countries

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FIELD: mathematics, computer sciences
ARTICLE TYPE: original scientific paper

Abstract:

Introduction/purpose: Blockchain is a technology that first came into existence to optimize the cryptocurrency area by forming a decentralized network for online transactions and managing investors' data. With the advent of technology, new ideas have started taking shape in experts' minds regarding the potential of this technology if it were to be used in areas other than just cryptocurrency – mainly Bitcoin. Some of its potential features include security, distributed data, maintaining data integrity, anonymity, and the lack of need for third-party involvement. This research has analyzed the use of Blockchain technology in Pakistan, including its awareness amongst technical experts and the public. The focus areas are using Blockchain technology in hospitals as well as for voting, political documents, financial ledgers, and contracts. The research aimed to investigate which field is most appropriate to use Blockchain technology according to the general public belief.

Methods: A detailed survey has been carried out collecting answers from the public, and gathering expert opinions on the topic. The TOPSIS approach was then applied to determine which fields are the most favored.

Results: The results favored the use of Blockchain technology in the areas of political documentation. Based on the conducted study, there are recommendations and important insights provided from experts to facilitate the improvement of the system in Pakistan.

Conclusion: In conclusion, this study sets out to understand public and expert perspectives on using Blockchain technology in other sectors of the country. As a result of this research work, it is concluded that government/political documentation presents an exciting market for implementing this technology.

Keywords: cryptocurrency, bitcoin, blockchain, business innovation, computational trust, MCDM.

Introduction

Blockchain technology is at its infant stage and focuses on building a decentralized database connected in a string of scattered blocks, each connected to its consecutive block by a hash number and carrying information in bits and pieces. These blocks are scattered all over the Internet. The winning quality of blockchain technology is that, in order to alter information in one block, every consecutive block will have to be altered, which means umpteen blocks getting changed, which is virtually impossible for anyone to do so. This makes the information stored in blockchains unalterable and impossible to tamper with.

Blockchain technology was mainly used in cryptocurrency where this innovative technology handled cyber-currency like Bitcoin. As more and more people started focusing on working on blockchain technology, it became apparent that Blockchain is a revolution waiting to happen. With its unparalleled features, blockchain technology can expand out of the cryptocurrency area and improve other sectors of the cyber world, such as contracts, online voting, digital healthcare systems, etc.

This kind of change needs to be brought about in every sector of the world, and organizations smart enough to recognize this gem for what it is rapidly started working on taking on this new technology to help improve their systems. Blockchain technology aims to eliminate all third-party control from data by creating a decentralized environment that handles and holds all the transaction information and other data.

Work has been done on blockchain technology outside Pakistan on a large scale. Blockchain has been studied, and its uses have been analyzed for the healthcare center as well as for digital voting and contractual deals in the case of smart contracts. The work is still mostly in its theoretical phase and is far from becoming a norm, but it has started. Many different businesses and companies are looking at it as a means to innovate and modernize their business practices in whatever field they are. The benefit of this technology dramatically outweighs the difficulties in perfecting it and integrating it into everyday life. In the long run, everyone perceives only its help, which is why it catches this much attention.

In Pakistan, there is a lack of general awareness about blockchain technology, however. The only area looking at using this technology in Pakistan seems to be the financial sector, and even there it is in its infancy. Blockchain technology with its numerous applications needs to be recognized and appreciated by different sectors and organizations of the country as they will become imperative in improving many services and systems that right now are not handled as appropriately as they could be

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by the introduction of blockchain technology. Technical research and advent are not the only practices essential to practically implementing blockchain technology. The technology's current real-life implications and feasibility are also required to be studied. A couple of techniques have been used worldwide to conduct a feasibility study, recognize blockchain technology's impact factors, etc. A lot of different angles have been applied to look at it. TOPSIS is one of the first and foremost techniques experts used to assess the pros of blockchain technology over the other more conventional methods. Such MCDM approaches started eliminating other measures and techniques in favor of blockchain technology as research progressed on the topic. Considering numerous highlighted factors, they proved beneficial in most areas under discussion.

This sort of research added to the importance of blockchain technology and emphasized its importance worldwide. It gave the world confidence to work further on the technology by proving that it is the right direction to move in and needs to be built on more. Had it been the other way around, and Blockchain was proved useless and costly instead of beneficial, the research would have stopped as it would have been considered redundant and in vain to go with the technology if there was no feasible use in the real world.

Looking at the direction the world is taking on blockchain technology, there is a need to work on it in Pakistan and provide practical motivation that the technology needs for its implementation in Pakistan. In addition, the more valuable it proves to be, the more motivated experts will be to use it in multiple sectors and departments. There are challenges that need to be addressed at the national level related to blockchain technology. The first and foremost of these challenges is the lack of awareness among the general public about this technology. Blockchain technology, however, has features that can change how different sectors of the country work.

This research has studied some of these sectors – other than the financial sector – wherein data and information have been collected to understand the feasibility and demand of the public as to which sector they think needs blockchain technology the most at this point. Furthermore, the paper discusses the importance of introducing blockchain technology in this sector and recommends how to start implementing blockchain technology in different sectors in Pakistan. The rest of the article is organized as follows. Section 2 introduces the background of Blockchain and Bitcoin. Moreover, this study also examines the challenges and technical limitations of Blockchain technology, previous literature on TOPSIS and its applications, and the unique ways it identifies its application in this work. Section 3 describes the applied research

methodology and collects relevant research papers. Section 4 presents the results of the gathered articles and extracted data. Moreover, it also presents the analysis derived from the previously obtained results. Section 5 concludes the paper, followed by references.

Literature review

There has been research conducted on the usage of Blockchain technology. Still, as this technology is in its infancy, research is very scarce and only focuses on a few topics to give a bigger picture of what is happening with the technology. Speaking of Pakistan in particular, there is virtually no research on the importance, usage, and potential of Blockchain technology, which needs to be remedied immediately. There are a lot of questions that need to be answered about Blockchain technology. As yet, the primary use of Blockchain technology in Pakistan is in the financial sector which is introducing Blockchain technology to improve organizational methods, as it will be discussed further on.

Blockchain technology can also help improve many other nonfinancial systems in Pakistan. This research has studied some systems, such as hospitals (health care), voting, political documents, financial ledgers, and smart contracts. A few of these areas have been studied under the lens of Blockchain technology in some areas of the world, but seldom in Pakistan. The paper intends to assess what the people of Pakistan feel is the most feasible area to apply Blockchain technology in and which can benefit the most from its characteristic features.

In Pakistan, as mentioned above, Blockchain is only applied in the financial sector, and that started only very recently. According to a DAWN News article (DAWN, 2017), The State Bank of Pakistan (SBP) was talking about adopting Blockchain technology in all their transactions as that is what the world is moving towards. This article talks about moving to match the advent of technology in the world. SBP's Executive Director-Banking Supervision Group says that the world is moving towards adopting new technologies and that the country should also use this technology as its trades can significantly benefit from them and that they are open to other banks joining them in the interest of using new technology. It also talked about cybercrimes and mobile banking explaining how advanced technology and new techniques are essential to combat these issues and run things more smoothly.

Other than that, in Pakistan, Blockchain has been used in nonfinancial sectors in several places. It is a start, but at the very least, it has started. A paper written by Linn and Koo discusses how healthcare and information

technology are moving towards each other to increase productivity and convenience for patients, their next of kin, and healthcare staff. This paper discusses "a Blockchain-based access-control manager to health records" (Kuo et al, 2017), which has the potential to deal with "interoperability challenges" present in the healthcare system which will allow all stakeholders to access medical records and manage them securely and incorruptibly. Another study focused on Comparing Market Performance of Metaverse Crypto Assets. This sort of use of Blockchain technology is highly beneficial. It could also bring about a positive change in Pakistan's healthcare system if Pakistani hospitals started using it regularly.

Digital Voting with the Use of Blockchain Technology by Barnes, Brake, and Perry is a report written to analyze the problems with the current voting system and to propose a solution to that problem in the form of a digital voting system using Blockchain technology. Hsiao et al (2017) stated that, with the advent of technology, there must be an online voting system free of corruption, like the rigging of the results. Security of these online votes was the biggest concern and one of the unsolvable problems, but not anymore. According to this paper, the one foolproof way of minimizing security risks and issues is by using Blockchain technology in the online voting system. Another study mentioned that sustainable digitalization is a growing trend in which digital technology is used to promote environmental, social, and economic sustainability.

Blockchain has also been studied as a potential technology for smart contracts, which will eliminate third-party interference in contracts and make contracts more secure. Smart contracts are said to be computer agents as they form contracts based on the time of user's actions and Blockchain technology has emerged to be one of the best ways to keep track of these contracts as discussed in a paper "Blockchain and smart contracts" (Panisi, 2017). It is a difficult concept to brag – the integration of Blockchain in the world of contracts – but change is always the hardest to grasp and is always needed to be discussed, to adapt and improve for the sake of progress. According to this paper, the jury is still out on how much Blockchain can be trusted as it is a theoretical concept but there is no experience to ensure complete trust in the technology by using it as a basis for smart contracts. There is still a great debate going on about the usage of Blockchain technology as the right medium for smart contracts or not. Ledgers are directly connected to accounting and this is another area where Blockchain has the most chance of being used and will be greatly advantageous if done so. As discussed in the paper of Wang & Kogan (2018), modern-day accounts are based on a double-entry system which was introduced in the Renaissance period. It is, however, very difficult to

manually do this as it requires a lot of labor. By using Blockchain, it is easier to prove the integrity of electronic files. The hash string attached to each block is the fingerprint that needs to be presented and matched in case of any need of proof against the file. Blockchain technology can provide different ways to document the data otherwise being managed manually and leads to a more secure way of keeping the integrity of these ledgers intact.

"Computing Ledgers and the Political Ontology of the Blockchain" is a paper by Velasco (2017) which discusses the political forms that Blockchain technology can switch on and how it will benefit the integrity of political documents. This paper discusses the ontology of Blockchain in favor of political documents and the importance of keeping them secure and incorruptible. The paper recognizes that there will be an absence of necessary authority figures in the digitalization of ledgers and political documents, but that is what Blockchain is all about, removing authority from a central point and distributing responsibility over the whole network in a dynamic form of environment. Another study conducted by Ul Haq et al (2023) discussed the concept of Blockchain and its application. A lot needs to be considered when discussing Blockchain technology and its usage in different sectors. A study conducted by Arsyad et al (2022) proposed a farm transaction model by demonstrating a flow of farm transaction simulation implicated by Modular Block Chain. These precious few pieces of research are just the start of what would later become an essential and integral part of the technical world. Taking this research and all this material into account, a survey was conducted keeping the Pakistani populace in mind and collecting data from them to analyze how well they will be able to adjust to this very new technology and where they feel like it is needed the most, given its many advantageous features. In this article, a solid foundation has been built to analyze the significance of introducing Blockchain technology in Pakistan.

The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), developed by Hwang et al (1993), is a method to assess the capabilities of alternatives through the similitude with the ideal solution. As indicated by this procedure, the best option would be one nearest to the positive-ideal solution and most distant from the negative-ideal solution. The positive-ideal solution amplifies the advantage criteria and limits the cost criteria. The negative perfect arrangement augments the cost criteria and specifies the advantage criteria. In outline, the positive-ideal solution is made out of every single best value achievable of the criteria, and the negative-ideal solution comprises all the most exceedingly bad values attainable of the criteria.

The MCDM strategies manage the way toward settling on a choice within the sight of numerous criteria or objectives (Sahoo & Goswami, 2023). Puška et al. (2023) carried out a study based on the MCDM approach to find the index of economic freedom in Balkans countries. A study carried out th Fuzzy Analytic Hierarchal Process for a sustainable public transport system. Another study used the m-polar fuzzy set theory for the selection of non-traditional machining processes. TOPSIS is generally utilized to take care of issues having various criteria. Multi-criteria decision-making strategies have been widely used in multiple application zones. Liu et al (2010) connected AHP and TOPSIS MCDM strategies for security appraisal communication networks of power control systems. C. T. Chen (2002) connected the MCDM method to deal with issues of project selection. Angelou & Economides (2008) additionally connected MCDM strategies to allot ranks to a portfolio of ICT foundation ventures. F. Trojan & D. C. Morais (Trojan & Morais, 2012) presented the idea of cooperative choice to organize options for the upkeep of water appropriation systems.

Similarly, recent research implemented the use of the novel fuzzy decision making model to identify right policies for renewable energy transition. Another study was carried out by Dagistanli on the financial performance evaluation of energy companies. A similar application of MCDM can also be found in the “Examining the Impact of Product Innovation and Pricing Capability on the International Performance of Exporting Companies“ (Rezazadeh et al, 2023). Tešić & Marinković (2023) applied an aplication of fermatean fuzzy weight operators and the MCDM model DIBR-DIBR II-NWBM-BM for the efficiency-based selection of a complex combat system. The multiple options above showcase the use of TOPSIS in multi-criteria decision making as a very accurate and precise way of prioritizing and ranking numerous alternatives given specific criteria for each alternative. TOPSIS uniquely suits this research into the use of Blockchain technology in sectors, other than financial, of Pakistan's economy.

Methodology

The problem at hand was tackled using the Multi-Criteria Decision-Making technique called TOPSIS. This method revolves around using multiple criteria to rate and analyze the data using weights assigned to those criteria to evaluate the solution, which would be the best alternative for implementing Block Chain Technology in Pakistan in this case. TOPSIS was chosen among various alternative methods mainly because TOPSIS

makes a focused analysis on the criteria allotted, which is necessary while assigning weights to the criteria upon which eventually is concluded to a final solution. TOPSIS has been a prevalent method used to solve similar problems and has been around since 1981. Some researchers have combined AHP and TOPSIS for their methodology and used the combination to study power control systems. In contrast, others have used it alone to find the best alternatives for project implementation solutions, as discussed in more detail in the literature review above. This research paper uses the TOPSIS technique independently to best correspond to the public view with strict criteria and dimensions, making it the most suitable to be applied. The methodology has been divided into four main sectors: Survey Development and Analysis, Weight Calculation and Assignment, TOPSIS Implementation, and finally, Analysis and Conclusion. The process started with a thorough insight into the literature review of the technology that is under study, and five alternatives for the implementation of the technology were discovered, namely:

1. Hospitals,
2. Voting,
3. Political Documents,
4. Financial Ledgers, and
5. Contracts.

After discovering these options, experts in computer science and big data were contacted and asked to provide insight into what they thought were the criteria to be allotted to rank the data to be collected. The results from these experts classified the criteria into four main categories and were assigned weights according to the importance each expert assigned. They were:

1. Security,
2. Distributed,
3. Open Source, and
4. Implementation Cost.

After the methodology parameters were calculated, a survey was created for the general audience of Pakistan. It asked them to rank the importance of each criterion set as to which they thought would be most feasible and necessary to be implemented in Pakistan. The survey output data collected would qualify as the data required to evaluate the most viable solution through the TOPSIS method. After the collection of data, TOPSIS is applied in the manner of the following steps:

Step 1

The first step is to standardize the Decision Matrix. It is done by taking the square root of the sum of the elements of each row and dividing each element of the row with it. The formula

$$y_{ij} = \frac{x_{ij}}{\sum x_{ij}^2}$$

helps to attain the values where y is the output element, and x is the original element. The data is then normalized by dividing each matrix element by its consequent standardized value.

Step 2

After the Standardized Decision Matrix, the normalized decision matrix needs to be constructed. This is done by multiplying the assigned weights with each element in the row of the subsequent criteria. The following formula

$$y_{ij} = x_{ij} \times w_j$$

helps to attain these values where y represents the output element, x is the original element, and w is the weight. The weighted standardized decision matrix is thus created.

Step 3

This step works towards finding the Ideal and the Negative Ideal solutions for the data. The Ideal solution is given by

$$A^* = \{y_1^*, \dots, y_n^*\} \; where$$

$$y_{j^*} = \{\max(y_{ij}) \; if \; j \in J\} \; ; \{\min(y_{ij}) \; if \; j \in J'$$

The Negative Ideal solution is given by

$$A' = \{y_1', \dots, y_n'\} \quad where \; y_j' = \{\max(y_{ij}) \; if \; j \in J\} \; ; \{\min(y_{ij}) \; if \; j \in J'$$

Step 4

Now that the Ideal and Negative Ideal solutions have been calculated, the next step involves calculating the separation measures for each option in this problem. Essentially, the separation from the ideal alternative is given by

$$S_{i*} = \left[\sum (y_j^* - y_{ij})^2\right]^{1/2}$$

and consequently, the negative ideal alternative is given by

$$S_i' = \left[\sum (y_j' - y_{ij})^2\right]^{1/2}$$ where i goes from zero to m.

Step 5

The last step is to find the relative closeness of all the options to the Ideal Solution. This is done by using the formula

$$C_i^* = \frac{s_i'}{(s_i^* + s_i')}.$$

The resultant value that is closest to 1 is the option that is selected. Consequently, the desired results are generated by the application of TOPSIS. After this, the data analysis is done, and the reasons for the results attained are considered. From the said analysis, a conclusion is drawn, and a suggestion regarding the output of the analysis is illustrated. The structure of the methodology is summarized in Figure 1.

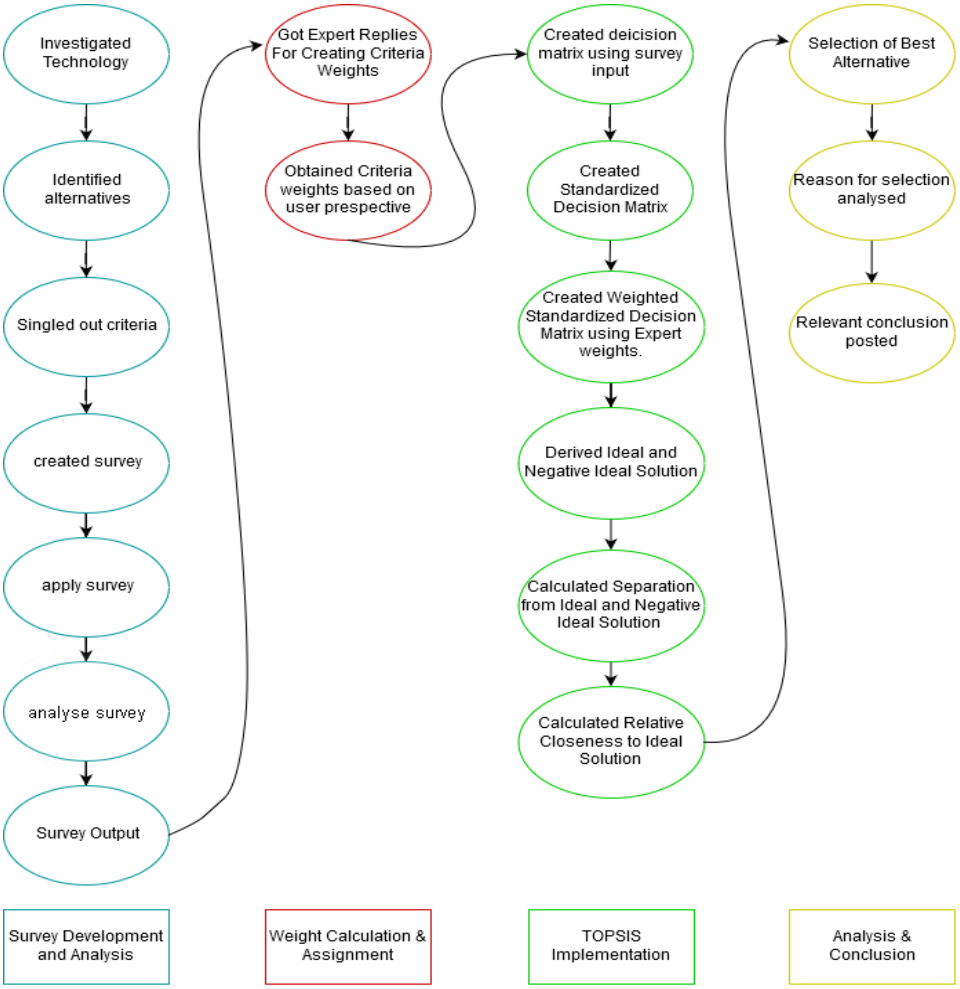

Figure 1 – Flow chart for the methodology

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Discussion and results

The foremost output received in the methodology was the experts' opinions. They were asked to draw up five criteria, which would then be assigned weights by taking the average rating they would assign each criterion. The result would give the desired weight assignment and the criteria to take forward into the research. The criteria and weights from the experts are summarized in Table 1.

Table 1 – The results from the experts & averaged weights

Name	Security	Distributed	Open Source	Implementation Cost
Ghulam Abbas	6	7.4	5	3.4
Hussain Ali	7.8	9.2	7.4	8
Daniyal Ahmed	8.6	8	6.4	5.8
Saif Bilal	8.6	8	5.8	4.8
Laila Khalid	8.8	8.2	6.4	7.2
Weights	7.96	8.16	6.2	5.84

It can be seen from the data collected from the experts that the highest weightage has been assigned to the Distributed category, which shows that the experts feel that the distribution of data in the implementation of Blockchain technology is of paramount importance. It is further seen that with a weight of 8.16, the experts believe that overall data should be distributed among the masses rather than being centrally controlled, hinting at the urge for transparency in the system that Blockchain technology would provide. Security got the second rank out of the four with a weight of 7.96, showing that while considering the implementation of the said technology, security is a very, if not the most, important while considering the option. Being Open Source got the third nod from the experts with a weight of 6.2, showcasing that the system's availability carries meaning and should be available as open source if implemented. The implementation cost of the system came in last with a weight of 5.84, signifying that the cost of the system is the least of the worries where its implementation is concerned. As mentioned earlier, a more detailed view of the expert can be seen in Figure 2.

Since the criteria have been defined and the weights assigned, the data from the general public was gathered through a survey, and a total of 150 responses were collected. Considering the public opinion as a deciding factor to determine which sector should have Blockchain technology implemented, these responses were the decision makers in this study. The data was then used for analysis, and TOPSIS was applied to it, thus achieving the results in Table 2 below.

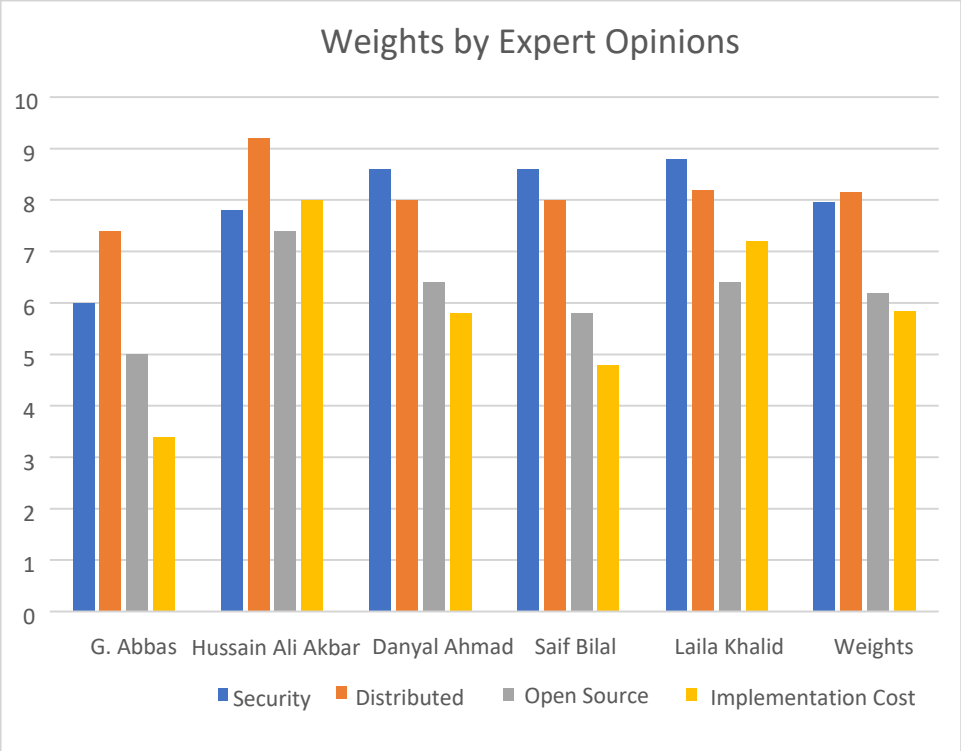

Figure 2 – Graphical representation of experts' weights

Table 2 – Relative Closeness to the Ideal Solution

	Hospital	Voting	Political Docs	Financial Ledgers	Contracts
Si*	0.651	0.803	0.365	0.588	0.504
Si'	0.630	0.279	0.759	0.561	0.568
Si*+Si'	1.281	1.082	1.124	1.149	1.072
Si'/(Si*+Si')	0.492	0.258	0.675	0.488	0.530

The resultant data in Table 2 shows that the highest relative closeness to the ideal solution is taken by Political Documents, with 0.68, which is the best option according to this method. The second-best alternative is Contracts with a mild closeness of 0.53. This shows that Political Documents is the best option by a considerate amount. The results in the chronological order are:

1. Political Documents,
2. Contracts,
3. Hospitals,
4. Financial Ledgers, and
5. Voting.

The results can further be summed up in Figure 3.

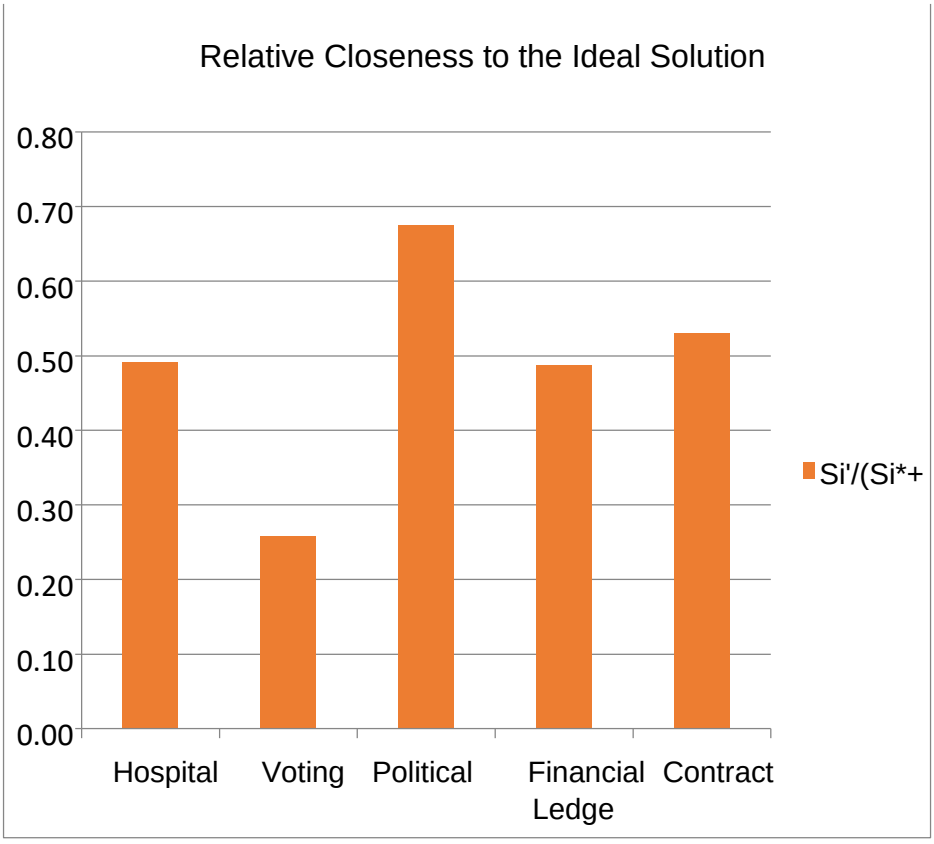

Figure 3 – Graphical representation of relative closeness to the ideal solution

The study's significant findings, as it can be seen in Figure 4, state that the public perspective, weighed by experts' opinions, dictates that one of the most favorable areas for the expansion of Blockchain technology is political documentation held by the government political parties. These documents include but are not limited to laws, codes, rules and regulations, census publications, etc., which are only a small portion of the government's collection. The findings suggest that the integral features of Blockchain technology apply the most to the implementation of a database containing these documents. The reason for the results, as mentioned earlier, is apparent. As it can be seen in the results, the features such as being 'open-source' and 'distributed' were the highest in the Political Documentation group. This shows that experts and the general populace agree that these documents should be available to everyone and be completely transparent, as well as be hosted within a distributed network, which would make it near impossible for these documents to be tampered with or modified for the needs or benefit of a particular group.

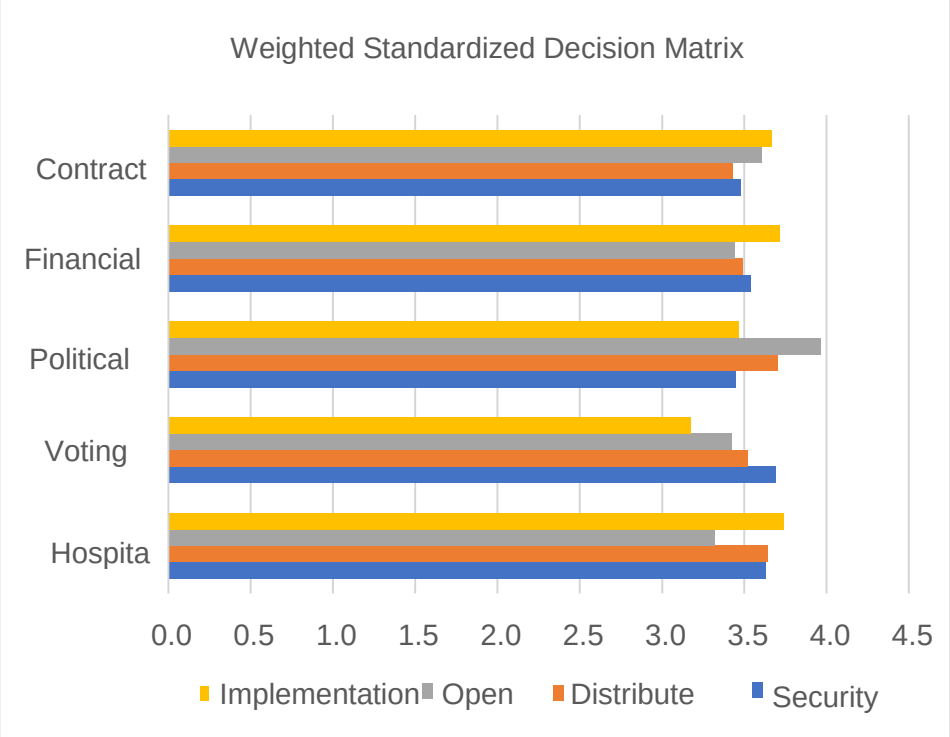

Figure 4 – Graphical representation of the weighted standardized decision matrix

These findings are significant as they indicate a shift in the public thinking towards the political scene within the country, with a greater demand for transparency of official documentation within the higher echelon of the government, and thus also indicate a better attitude towards the investment in technologies that cater to these specific needs such as Blockchain technology. Due to the fresh nature of the market, this allows a vastly diverse and superior investment opportunity for companies, which would also positively affect the country's economy. Transparency in the democratic process of the government shows a favorable movement towards a more stable democratic establishment within the government, which would lead to a more stable economy and a more stable currency, which also provides ground for more investment from outside sources.

An alternative explanation for the results may also be the current political scene within the government. Incidents such as the Panama Leaks of documents have led to more public outcry about the transparency of documents in possession of different government bodies and the accountability of the said government for better accessibility to these documents.

The study, though, acknowledges its limitations, as firstly, though quite large in relative size to the country's population, the sample size of both the general populace and the pool of experts is relatively small and may not cater to the opinions and ideology of the entire country. However, it does show noticeable trends and reveals meaningful information about the general mood within the country. The study also does not consider many other features of Blockchain technology. However, as mentioned earlier, it acknowledges the lack of public knowledge of the technology as it is still in its infancy.

Conclusions

The objective of this research is to examine the application of Blockchain technology in various sectors beyond finance within Pakistan. Being a developing nation, Pakistan presents an expansive and unexplored market for the emerging potential of this technology. Given its relatively recent and complex nature, Blockchain technology faces a lack of awareness and understanding among the general population in Pakistan. Consequently, the implementation of this technology across different sectors in the country is becoming progressively challenging.

The impact of this technology is extensive and crucial; however, there has not been any research exploring its application beyond the cryptocurrency realm in the dynamic shifts of the country's economy. This

study seeks to anticipate the trajectory of Blockchain technology in the nation, opening up a novel market for its utilization. This is accomplished by gauging public perceptions of the technology's attributes and incorporating expert opinions on the subject.

In conclusion, this study sets out to understand the public and expert perspectives on using Blockchain technology in other sectors of the country. It was achieved by applying the Multi-Criteria Decision-Making process known as The Technique for Order of Preference by Similarity to Ideal Solution, otherwise known as TOPSIS, by using responses from the general public and weighing them by expert opinions. As a result of this research work, it is concluded that government/political documentation presents an exciting market for implementing this technology.

These results are attributed to the ongoing political scene in the country, where heavy political competition between the major parties has recently resulted in many accusations against one another. Also, in the near past, there was a court case against the nation's prime minister regarding the proper disclosure of documents regarding assets held abroad, which resulted in his being removed from his office. These current happenings seem to have influenced a lot the public opinion on the use of Blockchain technology in Pakistan as a means of greater transparency towards their political representatives. It also predicted a shift towards a more transparent, democratic, and stable government, leading to an increasingly challenging economy for third-party investment. While this research work has its limitations, there are other features of the technology and other sectors in which it can be utilized effectively.

Furthermore, smart contracts are a booming industry and are in high demand as a secure means of agreement. Third-party investment in such technologies would lead to further research and development that would help the economy as a whole. Smart contracts would provide a very secure and legally enforceable method of making contracts between parties, which would increase the incentive for numerous and more extensive contracts and take away from the general public fear of entrepreneurship, leading to a healthier attitude towards further investment from the local population into the economy.

The study can be further extended by applying other decision-making techniques to evaluate different aspects of the Blockchain technology. It is recommended that Blockchain technology be investigated further in relation to government and political documentation applications. Applying a more secure yet open-source platform for distributing government policies and agreements would allow easier access to it for a wider population.

References

Angelou, G.N. & Economides, A.A. 2008. A Decision Analysis Framework for Prioritizing a Portfolio of ICT Infrastructure Projects. *IEEE Transactions on Engineering Management*, 55(3), pp.479-495. Available at: https://doi.org/10.1109/TEM.2008.922649.

Arsyad, A.A., Widayat, I.W. & Köppen, M. 2022. Supporting farming smart documentation system by modular blockchain solutions. *Decision Making: Applications in Management and Engineering*, 5(1), pp.1-26. Available at: https://doi.org/10.31181/dmame0326022022a.

Chen, C.-T. 2002. A decision model for information system project selection. In: *IEEE International Engineering Management Conference*, Cambridge, UK, 2, pp.585-589, August 18-20. Available at: https://doi.org/10.1109/IEMC.2002.1038501.

-DAWN. 2017. SBP mulls anti-cybercrime technology. *DAWN today's paper,* 20 April [online]. Available at: https://www.dawn.com/news/print/1328025 [Accessed: 01 January 2024].

Hsiao, J.-H., Tso, R., Chen, C.-M. & Wu, M.-E. 2017. Decentralized E-Voting Systems Based on the Blockchain Technology. In: Park, J., Loia, V., Yi, G. & Sung, Y. (Eds.) *Advances in Computer Science and Ubiquitous Computing. CUTE CSA 2017*. *Lecture Notes in Electrical Engineering*, 474, pp.305-309. Singapore: Springer. Available at: https://doi.org/10.1007/978-981-10-7605-3_50.

Hwang, C.-L., Lai, Y.-J. & Liu, T.-Y. 1993. A new approach for multiple objective decision making. *Computers & Operations Research*, 20(8), pp.889-899. Available at: https://doi.org/10.1016/0305-0548(93)90109-V.

Kuo, T.-T., Kim, H.-E. & Ohno-Machado, L. 2017. Blockchain distributed ledger technologies for biomedical and health care applications. *Journal of the American Medical Informatics Association*, 24(6), pp.1211-1220. Available at: https://doi.org/10.1093/jamia/ocx068.

Liu, N., Zhang, J., Zhang, H. & Liu, W. 2010. Security Assessment for Communication Networks of Power Control Systems Using Attack Graph and MCDM. *IEEE Transactions on Power Delivery*, 25(3), pp.1492-1500. Available at: https://doi.org/10.1109/TPWRD.2009.2033930.

Panisi, F. 2017. Blockchain and 'Smart Contracts': FinTech Innovations to Reduce the Costs of Trust. *SSRN*, 1 November. Available at: https://doi.org/10.2139/ssrn.3066543.

Puška, A., Stilić, A. & Stojanović, I. 2023. Approach for multi-criteria ranking of Balkan countries based on the index of economic freedom. *Journal of Decision Analytics and Intelligent Computing*, 3(1), pp.1-14. Available at: https://doi.org/10.31181/jdaic10017022023p.

Rezazadeh, J., Bagheri, R., Karimi, S., Nazarian-Jashnabadi, J. & Nezhad, M.Z. 2023. Examining the Impact of Product Innovation and Pricing Capability on the International Performance of Exporting Companies with the Mediating Role of Competitive Advantage for Analysis and decision making. *Journal of Operations Intelligence*, 1(1), pp.30-43. Available at: https://doi.org/10.31181/jopi1120232.

Sahoo, S.K. & Goswami, S.S. 2023. A Comprehensive Review of Multiple Criteria Decision-Making (MCDM) Methods: Advancements, Applications, and Future Directions. *Decision Making Advances*, 1(1), pp.25-48. Available at: https://doi.org/10.31181/dma1120237.

Tešić, D. & Marinković, D. 2023. Application of fermatean fuzzy weight operators and MCDM model DIBR-DIBR II-NWBM-BM for efficiency-based selection of a complex combat system. *Journal of Decision Analytics and Intelligent Computing*, 3(1), pp.243-256. Available at: https://doi.org/10.31181/10002122023t.

Trojan, F. & Morais, D.C. 2012. Prioritising alternatives for maintenance of water distribution networks: A group decision approach. *Water SA*, 38(4). Available at: https://doi.org/10.4314/wsa.v38i4.11.

Ul Haq, H.B., Irfan, M. & Saqlain, M. 2023. The Concept of Blockchain and its Application: A Review. T*heoretical and Applied Computational Intelligence*, 1(1), pp.49-57. Available at: https://doi.org/10.31181/taci1120236.

Velasco, P.R. 2017. Computing Ledgers and the Political Ontology of the Blockchain. *Metaphilosophy*, 48(5), pp.712-726. Available at: https://doi.org/10.1111/meta.12274.

Wang, Y. & Kogan, A. 2018. Designing confidentiality-preserving Blockchain-based transaction processing systems. *International Journal of Accounting Information Systems*, 30, pp.1-18. Available at: https://doi.org/10.1016/j.accinf.2018.06.001.

Aprovechar la tecnología Blockchain para acelerar la inclusión y el empoderamiento financiero y no financiero en los países en desarrollo

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CAMPO: matemáticas, ciencias de computación
TIPO DE ARTÍCULO: artículo científico original

Resumen:

Introducción/objetivo: Blockchain es una tecnología que surgió por primera vez para optimizar el área de las criptomonedas mediante la formación de una red descentralizada para transacciones en línea y la gestión de datos de los inversionistas. Con la llegada de la tecnología, han comenzado a tomar forma en las mentes de los expertos nuevas ideas sobre el potencial de esta tecnología si se utilizara en áreas distintas a las criptomonedas, principalmente Bitcoin. Algunas de sus características potenciales incluyen seguridad, datos distribuidos, mantenimiento de la integridad de los datos, anonimato y la falta de necesidad de participación de terceros. Esta investigación ha analizado el uso de la tecnología Blockchain en Pakistán, incluido su conocimiento entre los expertos técnicos y el público. Las áreas

de enfoque son el uso de la tecnología Blockchain en hospitales, así como para votaciones, documentos políticos, libros financieros y contratos. La investigación tuvo como objetivo investigar qué campo es más apropiado para utilizar la tecnología Blockchain según la creencia del público general.

Métodos: Se ha llevado a cabo una encuesta detallada recogiendo respuestas del público y recabando opiniones de expertos sobre el tema. Luego se aplicó el enfoque TOPSIS para determinar qué campos son los más favorecidos.

Resultados: Los resultados favorecieron el uso de la tecnología Blockchain en las áreas de documentación política. Según el estudio realizado, los expertos proporcionan recomendaciones y conocimientos importantes para facilitar la mejora del sistema en Pakistán.

Conclusión: En conclusión, este estudio se propone comprender las perspectivas del público y de los expertos sobre el uso de la tecnología Blockchain en otros sectores del país. Como resultado de este trabajo de investigación, se concluye que la documentación gubernamental/política presenta un mercado interesante para implementar esta tecnología.

Palabras claves: criptomoneda, bitcoin, blockchain, innovación empresarial, confianza computacional, MCDM.

Использование технологии блокчейн для ускорения финансовой и нефинансовой инклюзии и расширения прав и возможностей в развивающихся странах

Али Гоар

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РУБРИКА ГРНТИ: 20.23.00 Информационный поиск
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: Блокчейн - это технология, созданная для оптимизации сферы криптовалют путем формирования децентрализованной сети для онлайн-транзакций и управления данными инвесторов. С появлением этой технологии эксперты поняли насколько велик ее потенциал и стали развивать новые идеи относительно ее использования в других областях, а не только в области криптовалюты (в основном биткоин). Преимущества технологии блокчейн заключаются в безопасности, распределении данных, сохранении целостности данных, анонимности, а также в отсутствии необходимости привлекать посредников. В данном исследовании анализируется использование технологии блокчейн в Пакистане, а также уровень осведомленности технических экспертов и широкой

общественности о возможностях технологии блокчейна. Акцент делается на использовании технологии блокчейна в больницах, голосовании, политических документах, финансовых регистрах и контрактах. Цель исследования заключается в выявлении наиболее подходящей области для использования технологии блокчейн, по мнению общественности.

Методы: Был проведен подробный опрос среди населения, а также были собраны мнения экспертов по данной теме. Затем был применен подход TOPSIS для определения наиболее предпочтительных областей.

Результаты: По результатам опроса общественности применение технологии блокчейн предпочтительно в сфере политической документации. В то время как рекомендации и важные наблюдения экспертов, основанные на проведенном исследовании, будут способствовать совершенствованию системы в Пакистане.

Выводы: Целью данного исследования является определение мнения как экспертов, так и широкой общественности относительно использования технологии блокчейн в разных секторах экономики страны. На основании исследования сделан вывод, что государственные/политические документы являются главной областью для применения блокчейн технологии.

Ключевые слова: криптовалюта, биткоин, блокчейн, бизнес инновации, информационное доверие, MCDM.

Коришћење блокчејн технологије за убрзавање финансијске и нефинансијске инклузије и њен значај за земље у развоју

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Сажетак:

Увод/циљ: Блокчејн је технологија створена да оптимизује област криптовалута путем формирања децентрализоване мреже за онлајн трансакције и управљање подацима инвеститора. Уочивши њен потенцијал, стручњаци су почели да уобличавају нове идеје у вези с њеним коришћењем, не само код криптовалута (углавном биткоина) већ и у осталим областима. Нека од њених потенцијалних својстава су: сигурност, дистрибуирани подаци, одржавање интегритета података, анонимност, као и одсуство потребе за укључивањем посредника. Ово истраживање анализира

Gohar, A, Leveraging Blockchain technology to accelerate financial and nonfinancial inclusion and empowerment in developing countries, pp.630-650

коришћење блокчејн технологије у Пакистану, као и сазнања која о њој имају стручњаци и шира јавност. Тежиште је на коришћењу блокчејн технологије у болницама, при гласању, изради политичких докумената, финансијских књига и уговора. Циљ је да се истражи која област је најпогоднија за коришћење блокчејн технологије, по мишљењу шире јавности.

Методе: Спроведена је исцрпна анкета међу општом популацијом, а прикупљена су и мишљења стручњака о овој теми. Затим је примењен приступ TOPSIS како би се утврдило које су области најпожељније.

Резултати: Резултати показују да је примена блокчејн технологије најпожељнија у области политичке документације. На основу спроведеног истраживања, препоруке и важна запажања стручњака олакшаће побољшање система у Пакистану.

Закључак: Ова студија има за циљ да утврди какво је мишљење и стручњака и шире јавности у вези с коришћењем блокчејн технологије и у осталим областима у земљи. Закључује се да државна/политичка документација представља главну област за примену ове технологије.

Кључне речи: криптовалута, биткоин, блокчејн, пословне иновације, информатичко поверење, MCDM.

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Multivariate framework for introspecting the motivational factors for satisfaction in HR profession

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FIELD: mathematics, statistics
ARTICLE TYPE: original scientific paper

Abstract:

Introduction/purpose: Human Resource Management (HRM) has evolved as a strategic function for an organization, contributing significantly towards organizational development, business growth and societal development. The current work fills the gap in the literature by unveiling the higher order motivational needs driving the satisfaction of human resource (HR) professionals in their job roles. Further, it intends to delve into the causal relationship of the underlying factors.

Methods: A three stage detailed exploratory and mediation analysis is carried out. In the first stage, a focused group interview of 25 senior HR professionals was conducted. These professionals are all holding the role of Chief Human Resource Officers(CHROs) in their respective organizations. In the second stage, a large scale exploratory analysis is carried out based on the responses of 423 respondents. Stage three

confirms the interrelationship among the underlying factors obtained through the EFA.

Results: The results of the primary survey of 423 professionals reveal the three underlying factors such as identity, power and societal leadership (SL) that motivate HR professionals and drive their satisfaction in the job role. Further, it is observed that power mediates the interrelationship between identity and SL.

Conclusion: The results of the survey strongly suggest that there exists a high degree of correlation between identity, power, and societal relationships when it comes to HR professionals.

Key words: role satisfaction, human resource management, societal leadership, exploratory factor analysis, mediation.

Introduction

Human Resource Management (HRM) as a profession has undergone a transformational change over the years. From the traditional role of personnel management and industrial relations, HRM domain has been evolved as a strategic function for the organization contributing significantly towards organizational development, business growth and societal development (Carmeli et al, 2015). In general, employee motivation (EM) and employee satisfaction (ES) have been explored extensively by researchers. The current work fills the gap in the literature by unveiling the higher order motivational needs driving the satisfaction of human resource (HR) professionals in their job role. Uplifting the performance of an organization is one of the chief metrics of any organization's Human Resource Management (HRM) department (Shmailan, 2015; Vermeeren et al, 2014). HRM plays an important role as it engages in the search, collection, collation and utilization of Potential Manpower (PM) suitable for the given purpose. It helps the industry to survive, grow, and sustain. This can only be achieved when the quality of services offered is very good and meets the customer needs (Kehoe, 1996). The HR department is responsible for framing up HR practices thus creating required competitive advantage for the firm with the active and effective participation of its human capital that is unique and inimitable (Balgovind, 2007; Jena & Pradhan, 2014). In this context, existing literature mentions that HR practices play a crucial role towards the attainment of success by organizations (Condrey, 1995; Huselid, 1995; Koys, 2001). Managing human capital has gained higher significance as the growth of a country heavily depends on the tenets of motivation, capability, go-getting attitude, and effective deployment of its working force (Akinbode, 2011; Abdulkadir & Oladipo, 2011). It is proved beyond doubt

that the success of an organization has a direct relation with the effective productive mentality of the workforce (Pradhan et al, 2019). Any organization that is striving hard to reach its goal or set itself as an example in the related industry would only be capable of doing so if its HR practices are healthy and congenial to its workforce (Linna et al, 2010; Basit, 2019). Effective employee management provides strategic and cost leadership. Strategic leadership bridges the gap between management and employees to enhance employee performance (EP) (Zia-ud-Din et al, 2017). All of these functions are to be effectively carried out by HR professionals, which requires positive motivation from their end as they, in the end, also belong to the category of the workforce (Aristana et al, 2022).

It is generally believed that a self-motivated individual (in this case an employee) would be more productive for any organisation as he/ she would be prepared to walk that extra mile in realizing his/her goal and that of the organisation (Ghebregiorgis, 2018). Having said this, the world of academia has silently forgotten to take a departmentalized look at the organization, especially regarding the HR department. It cannot be accepted that all employees engaged in an organization have the same satisfaction level out of the HR practices prevalent in the organisation. Even if this logic is accepted for the sake of acceptance, the HR personnel would still not derive the same level of pleasure from the HR practices implemented by them as felt during this study. Unfortunately, literature in this micro field is missing, indicating the generalization of earlier studies. In a world where employee retention has become a big issue because firms offer hefty remuneration and smart promotion options (Blomme et al, 2010) to motivated and productive employees, we feel the time has come to take a fresh look into the subject of employee satisfaction in a departmentalized way.

Professional discussion with practicing HR people clearly identified that other than the established and documented extrinsic tenets of the lower-order motivational needs like handsome remuneration, employee-friendly HR practices, promotional ease (Blomme et al, 2010), job stability and sustainable after-retirement benefits (Hong et al, 2013), there are some more allied intrinsic factors termed as higher-order motivational needs connected with HR professionals which give them job satisfaction more than what the extrinsic factors can give (Alnuaimi, 2022) . Literature search drew flak in this particular field as nothing could be identified when it came to the motivational aspect of HR professionals. Hence, the need for this study was felt as this can bring about some degree of changes in the already pre-set mind of the research fraternity with some new inputs.

It is observed that there has been a number of attempts to discern the factors influencing the job satisfaction of employees in general vis-à-vis the

leadership styles and eventually their impacts on the performance. But there is a lack of scholarly activities in the field of employee motivation and job satisfaction in the last two decades focusing on HR profession. The existant literature shows that past studies have sufficiently considered employees in a generalized way but have not prioritized according to the functional role played by employees in HR profession. Some of the works have taken different fields like hospitality industry, service industry etc., to derive the motivational factors of these fields' employees. But nothing could be identified related to the motivational elements of HR professionals. Motivated by the aforesaid research gaps, the present work is centred on the following research objectives (RO):

RO 1. To identify the factors that drive HR professionals to be satisfied in their professional role.

RO 2. To delve into the interrelationship of the underlying factors driving the job satisfaction in the HR role.

The identified gap calls for the introspection of the related field with impunity. Higher-order motivational needs are also to be identified as a person can forego thinking about second-order motivational needs like compensation, monetary benefits, or promotion if his/her higher-order motivational needs, like recognition, power, authority, etc., are fulfilled. The principal purpose of this work is to identify the higher-order motivational needs of HR practitioners, which is yet to be specifically coined. In this regard, the study has taken a very close look at the elements of employee motivation available through existant literature in a generalized spectrum. On the other hand, the study has tried to investigate and identify the role of higher-order motivational needs of HR practitioners. It has tried to get an inkling of the reasons for the satisfaction of HR practitioners.

The current paper contributes the growing strand of the literature in mainly two ways. First, the present paper is an apparently rare one that intends to unfold the factors satisfying HR professionals in their role and subsequently, explore the interrelationship among the discovered factors. Secondly, from a technical point of view, concerning to the broad domain of the employee satisfaction and specifically, to HR professionals, the present study uses a detailed three stage research design consisting of exploratory and confirmatory analysis.The novelty of the paper stems from two aspects such as its application in deriving the underlying factors leading to satisfaction in HR profession and the three stage framework consists of expert opinion, exploratory mode and mediation analysis.

The rest of the paper is built in the following sections. In section 2, some of the past studies in the allied field are summarized. It may be noted that studies related to the factors influencing job satisfaction of HR professionals

are not amply available. Section 3 briefly outlines the research methodology. In section 4, the key findings are highlighted. Section 5 sketches the research implications of the current study. Section 6 concludes the paper while mentioning some of possible future scopes for further work.

Background

The growing strand of the literature is rife with a sizeable number of contributions related to motivation. For example, Baum et al (1997) defined motivation to be that guiding force that helps in energizing, sustaining and directing one's efforts in achieving one's goals. It is generally believed that a self-motivated individual (in this case an employee) would be more productive for any organisation as he/ she would be prepared to walk that extra mile in realizing his/her goal as well as that of the organisation (Ghebregiorgis, 2018). In an organisation set-up, public or private, EM is regarded to be the key element for its sustainability (Baldoni, 2005). The term EM refers to a set of processes undertaken by an organisation to encourage its workforce to set higher goals to achieve (Creswell et al, 2012), implying that employee performance (EP) is positively correlated to EM. Baldoni (2005) states that EM significantly contributes to raising EP in achieving the organisational goals (OG), proving that motivation is the sole driving force culminating in higher EP in any organisation (Amabile, 1997; Sharma & Raj, 2022).

Skudiene & Auruskeviciene (2012), reported that lack of EM affects the productivity of a firm to a great degree, reiterating Vroom's (1985) theory that the OG depends on the motivation level (ML) as well as on the long-term association (LTA) of the employees in that respective organisation. Employee attrition (EA), on the other hand, is considered to be a significant loss to an organisation as it loses the skill, expertise, experience, and aptitude of the MP (Wang et al, 2020), resulting in additional cost bearings, thereby affecting the organisation financially (Hackman and Oldham, 1976). Therefore, to discourage this and considerably bring down the EA rate, companies across the globe incentivize their employees with periodic performance-related bonuses', rewards, increments, fringe benefits, etc. to attain the OG's in due timeframe (Nyameh et al, 2013). Earlier works in this field indicate that the process of enhancing EM lies in the satisfaction quotient gained from the assigned task only. Employment growth depends on the degree of EM and their LTA with the organisation (Vroom, 1985), resulting in the reduction of cost of recruitment and employee maintenance, extending the advantage of expanding the vocation if the system can retain motivated employees for LTA (Nyameh et al, 2013). Therefore, EM refers to a procedure where organisations inspire their employees with the shape of

bonuses, rewards, increments, etc., to achieve organisational goals (Creswell et al, 2012).

The relationship between motivation, work satisfaction, and job performance is examined in Jalagat Jr (2016)'s study. It was shown that financial factors had a big impact on motivation. Herzberg's approach, however, cast doubt on the idea that money is the only factor in motivation. The research findings indicate that these variables function in a circular manner as opposed to a linear one. Furthermore, a correlation was found between improved performance and increased work satisfaction. Hence, it highlights how teamwork is necessary to accomplish goals at both the group and organizational levels.

Job satisfaction was shown to be negatively impacted by work motivation in a study by Hajiali et al (2022) that focused on employees. Specifically, poor employee motivation was found in the areas of existence, connectivity, and advancement, highlighting the need for improvements to increase job satisfaction. Employee performance was positively, although not significantly, impacted by competence. This suggested that innovation, technological integration, and career development needed to get more emphasis. It is interesting to note that, although being there, employee work satisfaction did not appear to be very effective in improving performance because of a perceived mismatch with directed abilities.

Ho et al (2022) found that a variety of factors, including career fit, career sacrifice, kinds of overseas workplaces (domestically vs internationally based organizations), and cross-cultural work adaptation, affect career happiness among professional accounting returnees. Interestingly, it was shown that the association between career fit, career sacrifice, and career happiness was somewhat mediated by cross-cultural work adaptation. These results provide important background for creating employee experiences that support job happiness for professionals entering the accounting sector again abroad.

Dodanwala et al (2023) looked at issues with staff retention in the construction sector in Sri Lanka. It made an effort to demonstrate how role conflict and ambiguity directly affect work satisfaction. Three factors have been found to be predictive of workplace stress: role conflict, work-family conflict, and job satisfaction. The study demonstrated how work satisfaction mediates the relationship between "role ambiguity, role conflict, and job stress". Furthermore, it was shown that work stress and job satisfaction were direct predictors of desire to leave. This demonstrates the complex links that exist between job role pressures, job satisfaction, job stress, and desire to leave the construction industry.

The effect of COVID-19 on Chinese teachers' work satisfaction was investigated in the Fute et al (2022) study. It was discovered that teachers' work values had a significant impact on job happiness, and that work engagement successfully mediated this link. There were noteworthy associations found between work values and job happiness as well as work engagement. The results shed light on the dynamics of teacher well-being in the difficult COVID-19 pandemic scenario and emphasize the critical roles that work values and work engagement play as determinants of job satisfaction.

Work discipline had no effect on employee performance, while empowerment was shown to greatly improve it in the Alfarizi et al (2022) study. Work discipline had a major beneficial impact on job satisfaction, and empowerment also had a good impact. Employee performance showed a favorable and substantial correlation with job satisfaction. Moreover, a partial mediator in the link between employee performance and empowerment was shown to be work happiness. Interestingly, it completely mitigated the impact of job discipline on worker productivity. These findings highlight the critical roles that work happiness and empowerment play in improving overall performance among workers. In a different work in this context, teacher empowerment and work satisfaction were found to have a substantial and favorable link in Ahrari et al (2021)'s thorough meta-analysis. Interestingly, self-efficacy and decision making showed strong positive effects on work satisfaction, and professional development followed suit. On the other hand, among instructors, autonomy, influence, and position showed a negative correlation with work satisfaction. These results highlight the critical role that teacher empowerment plays, highlighting the significance of decision making, self-efficacy, and professional development in promoting increased work satisfaction (Dmytriyev et al, 2021).

The expanding corporate awareness of social, ethical, and ecological goals beyond financial profits is highlighted by Chams & García-Blandón (2019). In line with the Sustainable Development Goals (SDGs), "green" firms have found that SHRM, or sustainable human resource management, is a catalyst. Key claims are revealed by Chams & García-Blandón (2019), the first of which is the Collective Sustainability Theory, which combines Parsons Social System theories with Social Learning. (2) Workers that have stronger environmental values are developing green competences, exhibiting green behaviors, and supporting SDGs 8 and 10. (3) Role rotation and green training are crucial for developing capabilities in line with SDG 12. (4) Characteristics and leadership style that create a green company culture for SDG 8. These claims provide a conceptual basis and paths for empirical investigation, directing future studies in sustainable management.

Human resource development (HRD) is essential to the advancement of ethics, sustainability, and corporate social responsibility (CSR), according to Garavan & McGuire (2010). The authors contend that while there is skepticism about HRD's connection with short-term business ambitions, Societal HRD (SHRD) should both challenge organizational efficiency and preserve a conscious business function. A thorough framework for SHRD initiatives to refocus agendas, hold companies responsible, and exercise leadership in CSR, sustainability, and ethics is presented in the report. While providing insights on SHRD's capacity to promote long-lasting beneficial impacts on societal and corporate well-being, it also acknowledges the contextual complexities impacting HRD's contribution.

Dirani et al (2020) examine leadership responsibilities both during and after COVID-19, stressing the skills necessary for crisis management. According to their research, a number of critical leadership qualities are necessary for an organization to thrive. These qualities include giving the company a purpose, delegating leadership, communicating effectively, facilitating technology access, putting emotional stability first, preserving financial stability, and encouraging resilience. In light of the ongoing epidemic, the report suggests that HRD plays a strategic role in assisting leaders by offering trustworthy data, building networks, encouraging innovation, allowing continuous learning, setting up frequent meetings, and setting up venues for employee celebrations. In order to solve the crisis of confidence in business, Stahl et al (2019) highlight the increasing necessity for firms to adopt corporate sustainability (CS) and social responsibility (CSR). In support of HRM's critical role in advancing CS/CSR initiatives, Stahl et al (2019) offer a multi-stakeholder sustainable HRM strategy. The radical framework expands the emphasis beyond the confines of the enterprise in order to question current HRM ideas while acknowledging prior accomplishments. HRM is encouraged to include CS/CSR concepts, promote stakeholder alignment, and navigate obstacles by collaborating, engaging, as well as harmonizing in the midst of the present crisis of confidence.

Herrera & de las Heras-Rosas (2020) investigate trends in Corporate Social Responsibility (CSR) and Human Resource Management (HRM) research by doing a bibliometric study of 314 articles from Web of Science journals. The survey shows that within the past ten years, there has been an increase in interest in these ideas. However, there are still many different ways to perceive what CSR and HRM are, as well as how they relate to one another. A few noteworthy rising topics include research methodologies analysis, "competitive advantage, satisfaction, performance, commitment, green management, and sustainability." The changing function of human

resource management (HRM) in the context of digital transformation is examined by Fenech et al (2019). A qualitative study of interviews conducted with HR professionals in the United Arab Emirates demonstrates that although digitalization has an influence on HR practices on a day-to-day basis, particularly on HR information systems, HR's strategic contribution to digitalization initiatives is viewed as lacking. In order to optimize the potential advantages of digitalization, the study highlights the necessity for HR to take a more central role in developing and coordinating digitalization plans.

From the review of the allied work it is seen that there is lack of focused work to figure out the factors that make HR professionals satisfied in their job role and fulfil their higher order motivational needs. It is noted that quite a number of studies are being conducted to understand the general motivational factors that influence the job performance and also, to establish various roles of the HR professionals in the current age. However, there is a need to connect the dots such as higher order motivational needs behind job satisfaction and the underlying factors driving the satisfaction of HR professionals.

Research methodology

The research has been carried out through three stages. In what follows are the brief descriptions of the stages.

Stage 1. Identification of the variables that drive the satisfaction of HR professionals in their roles. At this stage, a focused group interview of 25 senior HR professionals was conducted. These professionals are all holding the role of Chief Human Resource Officers (CHROs) in their respective organizations. Table 1 provides a brief outline of the profile of the professionals.

Table 1 – Respondents' profile (jn the CHRO role)

Profile	Number	Profile	Number
Industry		Years of experience	
Automobile	6	20-25	6
FMCG and FMCD	4	25-30	9
Service	3	Total	15
Technology/ IT	2		
Total	15		

Through a round of discussions with each of these professionals over 25-30 minutes on an average, it was found that they had not wanted to be HR professionals by choice. However, they became HR professional based on career progression and/or because of non-availability of other options. While answering to the question about what drives them to satisfaction, the following variables were found (Table 2).

Table 2 – List of the features that satisfy the HR professionals in their role

Variable	Statement
V1	HR as a profession has given me what I am today
V2	Identity achieved that I hardly dreamt of
V3	Credibility as an HR bringing people's respect within the organization
V4	Satisfaction of enjoying the power of employment
V5	Humble feeling as people refer candidates for employment
V6	Contributing to the cause of the people
V7	Confidence of colleagues soliciting help for their problems

Stage 2. Identification of the underlying factors

To further explore the features that act as the primary catalysts behind job satisfaction in the HR role, we proceeded to carry out a large scale exploratory analysis. For that purpose, a questionnaire was designed adopting the JES (Job Engagement Scale) developed by Rich et al (2010) and the same was circulated to potential participants. Email services were employed to gather data by creating online forms. An email was sent to participants multiple times asking them to fill out the questionnaire. 513 responses were collected from currently active human resource professionals of India across industries representing all the tiers of the hierarchy. A total of 423 responses were finally considered for the study, the rest dropped out because of incomplete data. Table 3 provides the profile of the respondents who took part in the survey.

Table 3 – Profile of the respondents took part in the survey

Profile	Number	Profile	Number	Profile	Number
Gender		Education (Graduate Level)		Years of experience	
Male	286	Science	97	Less than 5 years	27
Female	137	Engineering & Technology	37	5 - 10 years	82
Total	423	Commerce	117	10 - 20 years	184
Age (years)		Management	52	Above 20 years	130
Below 30	38	Arts and humanities	78	Total	423
31-40	179	Others	42	Origin place	
41-50	148	Total	423	Urban	366
Above 50	58			Non-urban	57
Total	423			Total	423

The reliability of the data set was ascertained with the help of Cronbach's alpha test as proposed by Shrestha (2021); it is considered as a measure of scale reliability and internal consistency (Tavakol et al, 2008).

$$\alpha = \frac{n\bar{r}}{\bar{v} + \bar{r}(n-1)} \quad (1)$$

Here, n is the number of items, $\bar{v}$ denotes the average variance and $\bar{r}$ is the average inter-item covariance among the items.

Next, the sample adequacy test was conducted using the KMO (Kaiser- Meyer-Olkin) measure. Expression (2) gives the definition of the KMO measure.

$$KMO_j = \frac{\sum_{i \neq j} R_{ij}^2}{\sum_{i \neq j} R_{ij}^2 + \sum_{i \neq j} U_{ij}^2} \quad (2)$$

Here, R_{ij} is the element of the correlation matrix and U_{ij} is the element of the partial covariance matrix.

The present study seeks to uncover the factors that influence HR professionals most to derive job satisfaction. The exploratory factor analysis (EFA) was performed on the data set to delve into the complex interrelationships existing among items and to find out the latent factors (Shrestha, 2021).

Stage 3. Confirm the interrelationship among the underlying factors obtained through the EFA and establish the theoretical and practical implications for explaining the job satisfaction of HR professionals.

Results

First, the reliability of the responses is examined. Cronbach's alpha was recorded at 0.764, hence it has been considered within the acceptable limit (DeVellis & Thorpe, 2021; Bland & Altman, 1997; Nunnally & Bernstein, 1994). The composite reliability (CR) of the instrument was measured at 0.781 which is acceptable as Fornell and Laker suggested that a CR value of 0.6 indicates that the convergent validity (CV) of the construct is adequate.

As a next step, the sample adequacy test was conducted using the KMO (Kaiser-Meyer-Olkin) test which resulted in 0.705 as shown in Table 4. Expression (2) gives the definition of the KMO measure.

Table 4 – Kaiser-Meyer-Olkin and Bartlett's Test of Sphericity

Kaiser-Meyer-Olkin (KMO) Measure of Sample Adequacy	0.705
Bartlett's Test of Sphericity – Approx. Chi-Square	1065.673
df.	21
Sig.	.000

A KMO value of > .6 is considered acceptable for a sample of > 300 (Tabachnick & Fidell, 2013; Kaiser, 1970, 1974; Guttman, 1954). Using EFA the model explained has been to the extent of 78.195 percent (ref. Table 5).

Table 5 – Explanation of the total variance

Factor	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2.954	42.204	42.204	1.883	26.896	26.896
2	1.402	20.023	62.227	1.69	24.141	51.037
3	1.118	15.968	78.195	0.858	12.252	63.289
4	0.541	7.733	85.928			
5	0.448	6.401	92.329			
6	0.304	4.347	96.676			
7	0.233	3.324	100			

The derived variance explained that the value of 78.195 conforms to the fit range for further investigation on the aspect. The variance-explained values > 60% are deemed fit and fall within the accepted range for further investigation in social science (Field, 2018; Stevens, 2009; Child, 2006; Kaiser, 1974). From here, the study proceeded to investigate and understand the nature of the constituent variables comprising the three factors thus formed (Table. 6).

Table 6 – Identification of the factors

	Factors		
Variables	1	2	3
V1	0.942		
V2	0.827		
V3	0.652		
V7		1.017	
V6		0.649	
V5			0.677
V4			0.668

It is evident from Table 6 that three factors (F1, F2, and F3) resulted in containing seven variables: V1 (HR as a profession has given me what I am today); V2 (Identity achieved that I hardly dreamt of); V3 (Credibility as an HR bringing peoples respect within the organisation); V4 (Satisfaction of enjoying the power of employment); V5 (Humble feeling as people refer candidates for employment); V6 (Contributing to the cause of the people); and V7 (Confidence of colleagues soliciting help for their problems). F1 has been termed as 'Identity', F2 has been termed as 'Power' (here power signifies authority of taking beneficial decisions for the benefit of the organisation), and F3 has been termed as 'Societal Leadership'.

From the exploratory analysis and the discussions with the focused group, it is apparent that HR professionals enjoy the trust and respect conferred on them by the people who eventually create an identity of the profession. They enjoy the power to create the employment opportunity, recruit and nurture the talents for the development of the individuals and the business as well. However, societal leadership is a dominant motivator for HR professionals. Hence, we surmise the following hypotheses:

H_a: The identity is positively influencing the societal leadership.

H_b: The identity is positively influencing the power.

H_c: Power plays a significant role as mediator to influence the relationship between identity and societal leadership.

Accordingly, we build the conceptual model for a further causal analysis as given in Figure 1.

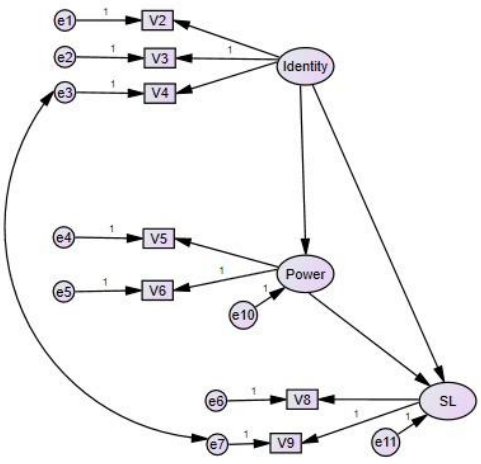

Figure 1 – Conceptual model and the path diagram

From the EFA results, the study proceeded to conduct the mediation analysis as it explores the series of bonding between a host of variables (Ballen & Salehi, 2021). In this case, the study investigates the relationship between the three constituent factors: F1, F2, and F3 containing eight variables. Table 7 suggests that F2 (power) acts as a mediating variable between F1 (identity) which acts as the independent variable, and F3 (societal leadership) which acts as the dependent variable. It is evident that F1 and F2 directly influence F3. Therefore, it can be suggested that F1 and F2 are significantly the major reason for HR professionals' job satisfaction as through F1 and F2 their higher order motivational needs get fulfilled. Thus, all the objectives taken up have been duly met in the course of the study.

Therefore, it is observed that all the hypotheses are supported. It is contended that Identity has a significant positive influence on SL and Power while the later plays a significant mediating role.

Table 7 – Estimation parameters of the model

Indices	Parameters	Permissible limits	Model
Goodness-of-fit	Chi-Square	As low as possible	17.07
Indices	Degree of Freedom (DOF)	As high as possible	10
	Normed Chi-Square (chi-Square/ DOF)	Between 2 to 5	1.707
	P- Value	Less than 0.01 or 0.05	0.073
Absolute- fit Indices	GFI	0 to 1	0.989
	Adjusted GFI	>0.80	0.969
	RMSEA	<0.08	0.041
	90% Confidence Interval	-	0.073
Incremental fit Indices	NFI	>0.9 or 0.95	0.984
	TLI or NNFI	>0.9 or 0.95	0.986
	CFI	>0.9 or 0.95	0.993
	IFI	>0.9 or 0.96	0.993
Hoelter Indices	PNFI	0.5	455
	PGFI	0.1	577

Research implications

Human Resources Profession has been continuously evolving, starting from industrial relation - legal framework towards people culture, human behavioural development. New generation organisations are more proactive in engaging quality human capital and in ensuring that a work place is happily productive and performance driven.

During this continuous transition and evolution from Industrial Relation to Human Resources development, the key driver was the "Humane Factor" inside the evolving organisation. Organisation Culture, Organisation Development, Learning and Development came out with a fast pace with a plethora of new knowledge in organisation behaviour. The role of Industrial Relationship also developed stronger into people development, where people and performance started getting measured for developing future organisation leadership and talent development. People started to recognise the most important resources for the organisation.

While introspecting continuous development in Human Resources as a profession, human resource professionals or practitioners (HRPT) should also require higher-order motivational needs (HOMN) which can satisfy and drive them to felicitate and enable People Work Force for performance and business profitability. During our national study with HR professionals and their satisfaction drivers, we identified and focussed on three key factors which were the professional motivation creators for the Human Resource Practitioners.

The research focus was to validate the hypotheses and the linkage of the factors like

i) Power (Authority) – Creating and giving employment, ownership of organisation's discipline and culture, authority to evaluate employees' performance and financial benefit;
ii) Identity: Respect and credibility from people by coaching, developing, mentoring, guiding employees for their success and developing their future; and
iii) Societal Leadership: Helping employees beyond, helping society by CSR, a human role model as a helping hand with fairness and trust.

The empirical study has significantly depicted that, for HR professionals, both Power (authority) and Identity (Respect and Credibility) are the major professional satisfaction drivers (higher order motivational needs). Both Power and Identity (Respect) drive HR professionals. The

power and identity factors converge to the societal leadership motivating HR professionals in their job roles.

From the managerial perspective, this work presents a significant contribution. It is revealed that HR professionals feel satisfied to contribute to the society. The entrusted authority enables the professionals to build credibility towards the societal contribution. These findings will provide a valuable impetus to organizations for talent management and for guiding aspirants to shape their careers in the HR profession.

The existing framework has some limitations. First of all, it unfolds underlying factors and thereby discovers the mediation effect. It does not prioritize the underlying factors. For that purpose, the framework used in this paper may be supported with the group decision-making models used in some of the recent work (Bairagi, 2022).

Conclusion and a future scope

Umpteen numbers of studies over decades have focused on decoding the tenets of employee motivation (EM) and employee satisfaction (ES). However, nothing significant has been done in this regard to the higher-order motivational needs of HR practitioners. This work has tried to unfold the mystery of the higher-order motivational needs driving the job satisfaction of HR professionals. It has tried to understand what makes HR professionals satisfied other than the prescribed lower-order motivational needs, such as handsome remuneration, employee-friendly HR practices, promotional ease, job stability, and sustainable after-retirement benefits that are common to the workforce. The principal objective of this study was to understand the specific issues of identity, power, and societal relationships, and their underlying role in forming the basis for higher-order motivation among HR professionals, if any. A quantitative primary survey was conducted in India among HR professionals, where n = 423. The results of the survey strongly suggest that there exists a high degree of correlation between identity, power, and societal relationships when it comes to HR professionals. Having identified the said higher order factors with the help of EFA, the study further employed a mediation approach constructing the path diagram to understand the relationship between the factors. The mediation strongly suggests that there exists a strong relationship between the factors where Power plays the role of the mediating variable, between Identity (independent variable) and Societal Leadership (dependent variable).

The current work has the following scope for further research opportunities. For example, a future study may be designed to discern the

antecedents of the selection of HRM as a career for professionals. The research question may be put as whether HRM as a career was thoughtfully opted for or it was selected as per availability under situation. Further, a future research may look into the inherent interests that dominate the choice of HRM as a career option and subsequently influence the satisfaction level. In another study, future researchers may investigate whether demographic variables have influences on the career selection and the satisfaction level. From the technical point of view, future work may think of developing uncertain models to carry out the causal analysis for exploring the underlying factors influencing the selection of a HRM career and success in it. Also, the present work uses the subjective opinions of the respondents which may suffer from inconsistencies. To better control the subjective bias, a future work may utilize the uncertain models using fuzzy or rough numbers. Nonetheless, the current work apparently provides a new perspective to shape up HRM as a career option and success thereof.

References

Abdulkadir, S.D. & Oladipo, J.A. 2011. Strategic Human Resource Management and Organizational Performance in the Nigerian Manufacturing Sector: An Empirical Investigation. *International Journal of Business and Management*, 6(9), pp.46-56. Available at: https://doi.org/10.5539/ijbm.v6n9p46.

Ahrari, S., Roslan, S., Zaremohzzabieh, Z., Mohd Rasdi, R. & Abu Samah, A. 2021. Relationship between teacher empowerment and job satisfaction: A Meta-Analytic path analysis. *Cogent Education*, 8, art.number:1898737. Available at: https://doi.org/10.1080/2331186X.2021.1898737.

Akinbode, G.A. 2011. Demographic and dispositional characteristics as predictors of organizational citizenship behaviour. *IFE PsychologIA: An International Journal,* 19(1), pp.375-404 [online]. Available at: https://hdl.handle.net/10520/EJC38841 [Accessed: 10 January 2024].

Alfarizi, A.W., Haryadi, D. & Syaechurodji, S. 2022. Mediating of Job Satisfaction in Improving Employee Performance with The Role Of Empowerment And Work Discipline. *Jurnal Mantik*, 6(2), pp.1892-1902 [online]. Available at: https://iocscience.org/ejournal/index.php/mantik/article/view/2612 [Accessed: 10 January 2024].

Alnuaimi, Y.M.A. 2022. Impacts of workplace factors on employee engagement in the public sector. *European Journal of Marketing and Economics*, 5(1), pp.57-70. Available at: https://doi.org/10.26417/969ouv25.

Amabile, T.M. 1997. Motivating Creativity in Organizations: On Doing What You Love and Loving What You Do. *California Management Review*, 40(1), pp.39-58. Available at: https://doi.org/10.2307/41165921.

Aristana, I.N., Arsawan, I.W.E. & Rustiarini, N.W. 2022. Employee loyalty during slowdown of Covid-19: Do satisfaction and trust matter? *International Journal of Tourism Cities*, 8(1), pp.223-243. Available at: https://doi.org/10.1108/IJTC-03-2021-0036.

Bairagi, B. 2022. A homogeneous group decision making for selection of robotic systems using extended TOPSIS under subjective and objective factors. *Decision Making: Applications in Management and Engineering*, 5(2), pp.300-315. Available at: https://doi.org/10.31181/dmame0304052022b.

Balgovind, P. 2007. *The relationship between human resource management practices and organisational performance in the manufacturing sector of the beer industry in South Africa*. MA thesis. Pretoria, South Africa: University of Pretoria [online]. Available at: https://repository.up.ac.za/bitstream/handle/2263/23343/dissertation.pdf [Accessed: 10 January 2024].

Baldoni, J. 2005. *Great Motivation Secrets of Great Leaders, 1st Edition*. New York: McGraw-Hill. ISBN: 978-0071447741.

Ballen, C.J. & Salehi, S. 2021. Mediation Analysis in Discipline-Based Education Research Using Structural Equation Modeling: Beyond "What Works" to Understand How It Works, and for Whom. *Journal of Microbiology & Biology Education*, 22(2), art.number:00108-21. Available at: https://doi.org/10.1128/jmbe.00108-21.

Basit, A.A. 2019. Examining how respectful engagement affects task performance and affective organizational commitment: The role of job engagement. *Personnel Review*, 48(3), pp.644-658. Available at: https://doi.org/10.1108/PR-02-2018-0050.

Baum, T., Amoah, V. & Spivack, S. 1997. Policy dimensions of human resource management in the tourism and hospitality industries. *International Journal of Contemporary Hospitality Management*, 9(5/6), pp.221-229. Available at: https://doi.org/10.1108/09596119710172615.

Bland, J.M. & Altman, D.G. 1997. Statistics notes: Cronbach's alpha. *BMJ*, 314, p.572. Available at: https://doi.org/10.1136/bmj.314.7080.572.

Blomme, R.J., Van Rheede, A. & Tromp, D.M. 2010. The use of the psychological contract to explain turnover intentions in the hospitality industry: A research study on the impact of gender on the turnover intentions of highly educated employees. *The International Journal of Human Resource Management*, 21(1), pp.144-162. Available at: https://doi.org/10.1080/09585190903466954.

Chams, N. & García-Blandón, J. 2019. On the importance of sustainable human resource management for the adoption of sustainable development goals. *Resources, Conservation and Recycling*, 141, pp.109-122. Available at: https://doi.org/10.1016/j.resconrec.2018.10.006.

Carmeli, A., Dutton, J.E. & Hardin, A.E. 2015. Respect as an engine for new ideas: Linking respectful engagement, relational information processing and creativity among employees and teams. *Human Relations*, 68(6), pp.1021-1047. Available at: https://doi.org/10.1177/0018726714550256.

Child, D. 2006. *The Essentials of Factor Analysis, 3rd Edition*. New York: London, UK: Bloomsbury Academic. ISBN: 978-0826480002.

Condrey, S.E. 1995. Reforming Human Resource Management Systems: Exploring the Importance of Organizational Trust. *The American Review of Public Administration*, 25(4), pp.341-354. Available at: https://doi.org/10.1177/027507409502500403.

Creswell, J.D., Irwin, M.R., Burklund, L.J., Lieberman, M.D., Arevalo, J.M., Ma, J., Breen, E.C. & Cole, S.W. 2012. Mindfulness-Based Stress Reduction training reduces loneliness and pro-inflammatory gene expression in older adults: A small randomized controlled trial. *Brain, behavior, and immunity*, 26(7), pp.1095-1101. Available at: https://doi.org/10.1016/j.bbi.2012.07.006.

DeVellis, R.F. & Thorpe, C.T. 2021. *Scale Development: Theory and Applications*. SAGE Publications, Inc [online]. Available at: https://us.sagepub.com/en-us/nam/scale-development/book269114#contents [Accessed: 10 January 2024].

Dirani, K.M., Abadi, M., Alizadeh, A., Barhate, B., Garza, R.C., Gunasekara, N., Ibrahim, G. & Majzun, Z. 2020. Leadership competencies and the essential role of human resource development in times of crisis: a response to Covid-19 pandemic. *Human resource development international*, 23(4), pp.380-394. Available at: https://doi.org/10.1080/13678868.2020.1780078.

Dmytriyev, S.D., Freeman, R.E. & Hörisch, J. 2021. The Relationship between Stakeholder Theory and Corporate Social Responsibility: Differences, Similarities, and Implications for Social Issues in Management. *Journal of Management Studies*, 58(6), pp.1441-1470. Available at: https://doi.org/10.1111/joms.12684.

Dodanwala, T.C., Santoso, D.S. & Yukongdi, V. 2023. Examining work role stressors, job satisfaction, job stress, and turnover intention of Sri Lanka's construction industry. *International Journal of Construction Management*, 23(15), pp.2583-2592. Available at: https://doi.org/10.1080/15623599.2022.2080931.

Fenech, R., Baguant, P. & Ivanov, D. 2019. The Changing Role of Human Resource Management in An Era of Digital Transformation. *Journal of Management Information and Decision Sciences,* 22(2), pp.166-175 [online]. Available at: https://www.abacademies.org/articles/the-changing-role-of-human-resource-management-in-an-era-of-digital-transformation-8154.html [Accessed: 10 January 2024].

Field, A. 2018. *Discovering Statistics Using IBM SPSS Statistics*. Thousand Oaks, CA, USA: AGE Publications Ltd. ISBN: 978-1526419521.

Fute, A., Oubibi, M., Sun, B., Zhou, Y. & Xiao, W. 2022. Work Values Predict Job Satisfaction among Chinese Teachers during COVID-19: The Mediation Role of Work Engagement. *Sustainability*, 14(3), art.number:1353. Available at: https://doi.org/10.3390/su14031353.

Garavan, T.N. & McGuire, D. 2010. Human Resource Development and Society: Human Resource Development's Role in Embedding Corporate Social Responsibility, Sustainability, and Ethics in Organizations. *Advances in*

Developing Human Resources, 12(5), pp.487-507. Available at: https://doi.org/10.1177/1523422310394757.

Ghebregiorgis, F. 2018. Factors Influencing Employee Performance in Hotel-A Comparative Study of Government and Privately Owned Hotels in Eritrea. *International Journal of Research in Business Studies and Management*, 5(11), pp.1-9 [online]. Available at: https://www.ijrbsm.org/papers/v5-i11/1.pdf [Accessed: 10 January 2024].

Guttman, L. 1954. Some necessary conditions for common-factor analysis. *Psychometrika*, 19(2), pp.149-161. Available at: https://doi.org/10.1007/BF02289162.

Hackman, J.R. & Oldham, G.R. 1976. Motivation through the design of work: test of a theory. *Organizational Behavior and Human Performance*, 16(2), pp.250-279. Available at: https://doi.org/10.1016/0030-5073(76)90016-7.

Hajiali, I., Fara Kessi, A.M., Budiandriani, B., Prihatin, E. & Sufri, M.M. 2022. Determination of Work Motivation, Leadership Style, Employee Competence on Job Satisfaction and Employee Performance. *Golden Ratio of Human Resource Management*, 2(1), pp.57-69. Available at: https://doi.org/10.52970/grhrm.v2i1.160.

Herrera, J. & de las Heras-Rosas, C. 2020. Corporate Social Responsibility and Human Resource Management: Towards Sustainable Business Organizations. *Sustainability*, 12(3), art.number:841. Available at: https://doi.org/10.3390/su12030841.

Ho, N.T.T., Hoang, H.T., Seet, P.-S., Jones, J. & Pham, N.T. 2022. Career satisfaction antecedents of professional accounting returnees in international workplaces: an employee experience perspective. *Employee Relations*, 44(5), pp.1014-1029. Available at: https://doi.org/10.1108/ER-06-2021-0258.

Hong, L.C., Abd Hamid, N.I.N. & Salleh, N.M. 2013. A Study on the Factors Affecting Job Satisfaction amongst Employees of a Factory in Seremban, Malaysia. *Business Management Dynamics*, 3(1), pp.26-40 [online]. Available at: https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=a59aa14350c38342792f473db9b8660f6beb9703 [Accessed: 10 January 2024].

Huselid, M.A. 1995. The Impact Of Human Resource Management Practices On Turnover, Productivity, And Corporate Financial Performance. *Academy of Management Journal*, 38(3), pp.635-672 [online]. Available at: https://journals.aom.org/doi/abs/10.5465/256741 [Accessed: 10 January 2024].

Jalagat Jr, R. 2016. Job Performance, Job Satisfaction, and Motivation: A Critical Review of their Relationship. *International Journal of Advances in Management and Economics*, 5(6), pp.36-43 [online]. Available at: https://www.managementjournal.info/index.php/IJAME/article/view/64 [Accessed: 10 January 2024].

Jena, L.K. & Pradhan, R.K. 2014. Deliverables towards HR Sustainability: A conceptual Review. *European Journal of Business Management*, 6(23), pp.95-102 [online]. Available at: https://iiste.org/Journals/index.php/EJBM/article/view/14775 [Accessed: 10 January 2024].

Kaiser, H.F. 1970. A second generation little jiffy. *Psychometrika*, 35, pp.401-415. Available at: https://doi.org/10.1007/BF02291817.

Kaiser, H.F. 1974. An index of factorial simplicity. *Psychometrika*, 39, pp.31-36. Available at: https://doi.org/10.1007/BF02291575.

Kehoe, D.F. 1996. *The Fundamentals Of Quality Management*. Springer Dordrecht. Available at: https://doi.org/10.1007/978-94-011-0545-3.

Koys, D.J. 2001. The effects of employee satisfaction, organizational citizenship behavior, and turnover on organizational effectiveness: A unit-level, longitudinal study. *Personnel psychology*, 54(1), pp.101-114. Available at: https://doi.org/10.1111/j.1744-6570.2001.tb00087.x.

Linna, P., Pekkola, S., Ukko, J. & Melkas, H. 2010. Defining and measuring productivity in the public sector: managerial perceptions. *International Journal of Public Sector Management*, 23(5), pp.479-499. Available at: https://doi.org/10.1108/09513551011058493.

Nunnally, J.C. & Bernstein, I.H. 1994. *Psychometric Theory, 3rd Edition.* New York: McGraw-Hill. ISBN: 9780070478497.

Nyameh, J., Douglas, H., Teru, S. & Titus, A. 2013. Do Motivation Drive Employee'S Performance in Public Sector Organization. *European Journal of Business and Management*, 5(17), pp.92-97 [online]. Available at: https://iiste.org/Journals/index.php/EJBM/article/view/6625 [Accessed: 10 January 2024].

Pradhan, R.K., Dash, S. & Jena, L.K. 2019. Do HR Practices Influence Job Satisfaction? Examining the Mediating Role of Employee Engagement in Indian Public Sector Undertakings. *Global Business Review*, 20(1), pp.119-132. Available at: https://doi.org/10.1177/0972150917713895.

Rich, B.L., Lepine, J.A. & Crawford, E.R. 2010. Job Engagement: Antecedents and Effects on Job Performance. *Academy of Management Journal*, 53(3), pp.617-635. Available at: https://doi.org/10.5465/amj.2010.51468988.

Sharma, A. & Raj, R. 2022. HR Practices and Employee Satisfaction: The Mediating Role of Employer Branding. *Journal of Positive School Psychology*, 6(2), pp.3488-3496 [online]. Available at: https://journalppw.com/index.php/jpsp/article/view/2312 [Accessed: 10 January 2024].

Shmailan, A.S.B. 2015. The relationship between job satisfaction, job performance and employee engagement: An explorative study. *Issues in Business Management and Economics*, 4(1), pp.1-8. Available at: https://doi.org/10.15739/IBME.16.001.

Shrestha, N. 2021. Factor Analysis as a Tool for Survey Analysis. *American Journal of Applied Mathematics and Statistics*, 9(1), pp.4-11. Available at: https://doi.org/10.12691/ajams-9-1-2.

Skudiene, V. & Auruskeviciene, V. 2012. The contribution of corporate social responsibility to internal employee motivation. *Baltic journal of management*, 7(1), pp.49-67. Available at: https://doi.org/10.1108/17465261211197421.

Stahl, G.K., Brewster, C., Collings, D.G. & Hajro, A. 2019. Enhancing the role of human resource management in corporate sustainability and social responsibility: A multidimensional, multi-stakeholder approach to HRM. *Human Resource Management Review*, 30(3), art.number: 100708. Available at: https://doi.org/10.1016/j.hrmr.2019.100708.

Stevens, J.P. 2009. *Applied Multivariate Statistics for the Social Sciences. 5th Edition*. New York: Routledge. Available at: https://doi.org/10.4324/9780203843130.

Tabachnick, B.G. & Fidell, L.S. 2013. *Using Multivariate Statistics (6th Edition).* London, UK: Pearson. ISBN: 978-0205849574.

Tavakol, M., Mohagheghi, M.A. & Dennick, R. 2008. Assessing the Skills of Surgical Residents Using Simulation. *Journal of Surgical Education*, 65(2), pp.77-83. Available at: https://doi.org/10.1016/j.jsurg.2007.11.003. .

Vermeeren, B., Steijn, B., Tummers, L., Lankhaar, M., Poerstamper, R.-J. & van Beek, S. 2014. HRM and its effect on employee, organizational and financial outcomes in health care organizations. *Human Resources for Health*, 12, art.number:35. Available at: https://doi.org/10.1186/1478-4491-12-35.

Wang, C., Xu, J., Zhang, T.C. & Li, Q.M. 2020. Effects of professional identity on turnover intention in China's hotel employees: The mediating role of employee engagement and job satisfaction. *Journal of Hospitality and Tourism Management*, 45, pp.10-22. Available at: https://doi.org/10.1016/j.jhtm.2020.07.002.

Zia-ud-Din, M., Shabbir, M.A., Asif, S.B., Bilal, M. & Raza, M. 2017. Impact of Strategic Leadership on Employee Performance. *International Journal of Academic Research in Business and Social Sciences*, 7(6), pp.8-22. Available at: https://doi.org/10.6007/IJARBSS/v7-i6/2938.

Marco multivariado para la introspección de los factores motivacionales para la satisfacción en la profesión de recursos humanos

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CAMPO: matemáticas, estadística
TIPO DE ARTÍCULO: artículo científico original

Resumen:

Introducción/objetivo: La Gestión de Recursos Humanos (HRM) ha evolucionado como una función estratégica para una organización,

contribuyendo significativamente al desarrollo organizacional, el crecimiento empresarial y el desarrollo social. El trabajo actual llena el vacío en la literatura al revelar las necesidades motivacionales de orden superior que impulsan la satisfacción de los profesionales de recursos humanos (RRHH) en sus funciones laborales. Además, pretende profundizar en la relación causal de los factores subyacentes.

Métodos: Se lleva a cabo un análisis exploratorio y de mediación detallado en tres etapas. En la primera etapa, se realizó una entrevista grupal focalizada a 25 profesionales senior de recursos humanos. Todos estos profesionales desempeñan el papel de directores de recursos humanos (CHRO) en sus respectivas organizaciones. En la segunda etapa, se lleva a cabo un análisis exploratorio a gran escala basado en las respuestas de 423 encuestados. La tercera etapa confirma la interrelación entre los factores subyacentes obtenidos a través de la EFA.

Resultados: Los resultados de la encuesta primaria de 423 profesionales revelan los tres factores subyacentes, como la identidad, el poder y el liderazgo social (SL), que motivan a los profesionales de RRHH e impulsan su satisfacción en el puesto de trabajo. Además, se observa que el poder media la interrelación entre identidad y SL.

Conclusión: Los resultados de la encuesta sugieren fuertemente que existe un alto grado de correlación entre identidad, poder y relaciones sociales cuando se trata de profesionales de recursos humanos.

Palabras claves: satisfacción del rol, gestión de recursos humanos, liderazgo social, análisis factorial exploratorio, mediación.

Многомерная структура для изучения мотивационных факторов, способствующих удовлетворенности специалистов по управлению человеческими ресурсами

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РУБРИКА ГРНТИ: 83.03.51 Прикладная математическая статистика
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: Управление человеческими ресурсами (HRM) развилось как стратегическая функция организации, которая вносит значительный вклад в ее развитие, а также в рост бизнеса и социальное развитие. Данная статья заполняет пробел в существующей литературе, раскрывая мотивационные потребности более высокого порядка, которые способствуют удовлетворенности менеджеров по персоналу своей работой. В статье также исследуется причинно-следственная связь факторов, которая способствует удовлетворенности.

Методы: Проведен трехэтапный подробный исследовательский и промежуточный анализы. На первом этапе была опрошена группа из 25 старших менеджеров по персоналу, каждый из которых был менеджером по персоналу в своих организациях. На втором этапе был проведен масштабный исследовательский анализ на основе ответов 423 респондентов. Третий этап подтвердил взаимосвязь основных факторов, полученную с помощью исследовательского факторного анализа (EFA).

Результаты: Результаты опроса 423 специалистов показали, что в основе их мотивации и удовлетворенности работой лежат три фактора (идентичность, власть и социальное лидерство). Также было выявлено, что власть представляет собой медианный элемент в отношениях между идентичностью и социальным лидерством.

Выводы: Результаты исследования убедительно свидетельствуют о высокой степени корреляции между идентичностью, властью и социальным лидерством в работе HR-специалистов.

Ключевые слова: удовлетворенность трудовой ролью, управление человеческими ресурсами, социальное лидерство, исследовательский факторный анализ, медиация.

Мултиваријантни оквир за испитивање мотивационих фактора који доприносе задовољству специјалиста у управљању људским ресурсима

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ОБЛАСТ: математика, статистика
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: Управљање људским ресурсима (ХРМ) развило се као стратешка функција организације која значајно доприноси њеном развоју, као и пословном расту и друштвеном развоју. Овај рад попуњава празнину у постојећој литератури тако што открива мотивационе потребе вишег реда које доприносе задовољству ХР менаџера у њиховим радним улогама. Такође, истражује се узрочно-последични однос фактора на којима то задовољство почива.

Методе: Извршена је детаљна експлоративна и медијациона анализа у три фазе. У првој фази интервјуисана је група од 25 виших ХР менаџера који су били на позицијама руководилаца служби за људске ресурсе у својим организацијама. У другој фази спроведена је експлоративна анализа великог обима на основу одговора 423 испитаника. Трећа фаза је потврдила међусобне односе основних фактора добијене експлоративном факторском анализом (ЕФА).

Резултати: Резултати анкетирања 423 стручњака откривају да су три фактора (идентитет, моћ и друштвено вођство) у основи њихове мотивације и задовољства на послу. Такође, уочено је да моћ представља медијациони елемент у односу између идентитета и друштвеног вођства.

Закључак: Резултати испитивања показују јаке индиције да постоји висок степен корелације између идентитета, моћи и друштвеног вођства када је реч о стручњацима из области људских ресурса.

Кључне речи: задовољство радном улогом, управљање људским ресурсима, друштвено вођство, експлоративна факторска анализа, медијација.

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Numerical investigation on the supersonic flow around a saboted bullet

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FIELD: mechanical engineering, fluid dynamics
ARTICLE TYPE: original scientific paper

Abstract:

Introduction/purpose: In this paper, the aerodynamic characteristics of a special bullet were investigated at supersonic conditions. A model of a handgun saboted bullet was selected for the study.

Methods: The method used in the research was computational fluid dynamic (CFD) simulation. The turbulence model k-ε was used for numerical calculation. The air model was selected as an ideal gas. For air viscosity, the Sutherland model was applied.

Results: The numerical simulation results show the behavior of the supersonic flow over the saboted bullet. By varying the petals opening angle and bullet velocity, their influences on the drags of the sabot and the penetrator were obtained to be used for later sabot separation study.

Conclusion: The study shows that the CFD simulation approach can be implemented to analyze the aerodynamic drags on the sabot and the penetrator after the saboted bullet leaving the gun barrel. The simulation results obtained in this work are important in designing saboted light armor-piercing bullets fired from handguns.

Key words: saboted bullets, handgun, aerodynamic characteristics, Ansys Fluent, CFD, numerical simulation.

Introduction

Increasing the performances of weapon systems is always necessary for any army in the world. Modern ballistic vests are effective against standard bullets (Odanović & Bobić, 2003; Stopforth & Adali, 2019; Yaneva, 2020; Zochowski et al, 2021). This fact prompts weapon

designers to find new ways to enhance the penetrating ability of bullets. One method is to use saboted bullets. This kind of bullets consists of a light-weight polymer sabot, an aluminum supporting base and a penetrator made of heavy-weight material (depleted uranium, tungsten carbide, etc.). After exiting the gun muzzle, the penetrator separates from the sabot and continues flying to the target alone. Due to high muzzle velocity and a small cross-sectional area, the penetrator delivers a very high penetrating performance (Abdelsalam & Fayed, 2022). Such a bullet structure has been successfully implemented in some weapon systems such as American 7.62x51mm M948 and 12.7x99mm M903 (Starek & Stepniak, 2021), 6.5x25mm CBJ (CBJ Tech, 2024) and Singaporean 12.7mm SLAP (Ministry of Defence, Singapore, 2016). Compared to standard bullets, saboted bullets own significant advantages: better penetrating performance; higher hit probability; longer range; higher impact velocity; lower levels of barrel wear and corrosion; and non-toxicity since they do not contain lead. They are effective against all targets of small arms, such as light ground vehicles, helicopters, etc. as well as highly protected troops. Their typical structure is presented in Figure 1.

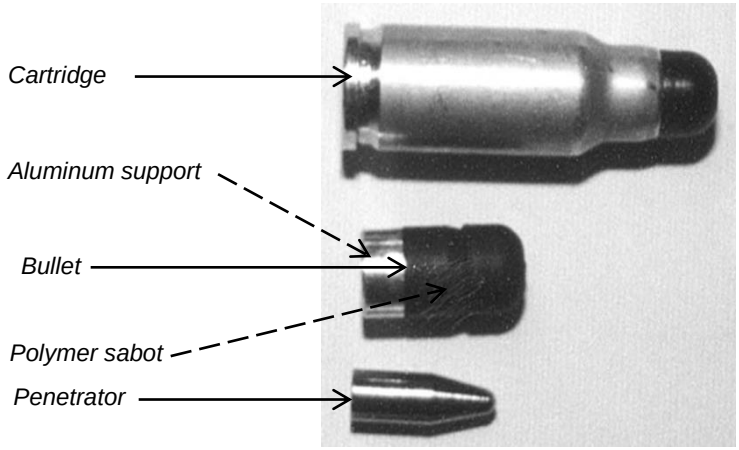

Figure 1 – Structure of the 6.5x25mm CBJ cartridge and the bullet

The working principle of the saboted bullet is as follows: after exiting the gun muzzle, under high centrifugal and aerodynamic forces, the sabot undergoes deformation when the sabot petals open at some angle increasing the sabot area exposed to air flow. Consequently, the drag on the sabot is much greater than the drag on the penetrator. Due to this drag difference, the penetrator gradually separates from the sabot. The sabot separation process is illustrated in Figure 2. After separating from the

penetrator, the sabot remains intact and continues on its intended course. Eventually, the sabot descends to the ground.

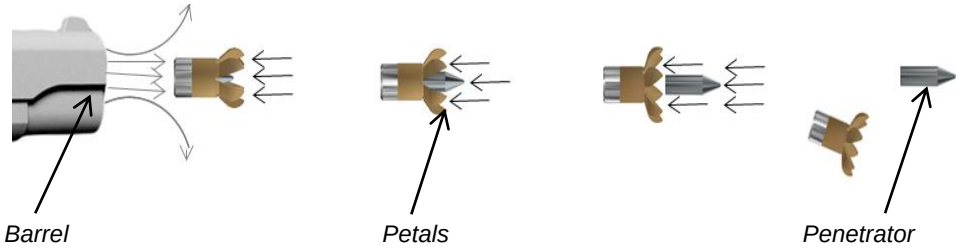

Figure 2 – Sabot separation process

In the saboted bullet designing process, one of the crucial problems is to investigate the interaction between the air and the bullet under different conditions. Although there is a significant number of studies on the separation process of the armour-piercing fin-stabilized discarding sabot (Lin & Lai, 1997; Huang et al, 2014; Lesage & Girard, 1996; Patanwala et al, 2023), the separation process of saboted bullets has not been appropriately studied. The present work aims at studying the aerodynamic characteristics of the supersonic flow around a saboted bullet, including the drags acting on the sabot and the penetrator at various muzzle velocities and petals opening angles. The muzzle velocity ranges from 500m/s to 600m/s with an increment of 20m/s. The petals opening angle changes in the interval from 50^0 to 80^0 with an increment of 10^0. The remaining structural parameters of the bullet are unchanged according to ballistic restrictions and designing requirements.

Numerical approach

Geometry model

In this research, a saboted bullet intended to be fired from 7.62mm caliber handguns has been considered for investigation. The bullet geometry details are presented in Figure 3. All the dimensions are presented in mm. The bullet consists of three components: a penetrator, a sabot with 6 petals, and an aluminium support as in the case of the 6.5x25mm CBJ structure.

The investigated air domain is shown in Figure 4. The domain length, width and height are 40L, 10L and 10L, respectively. Here, L is the overall length of the saboted bullet (L = 17.5mm in our case). The air domain was

created big enough to properly describe the turbulent flow behind the sabot.

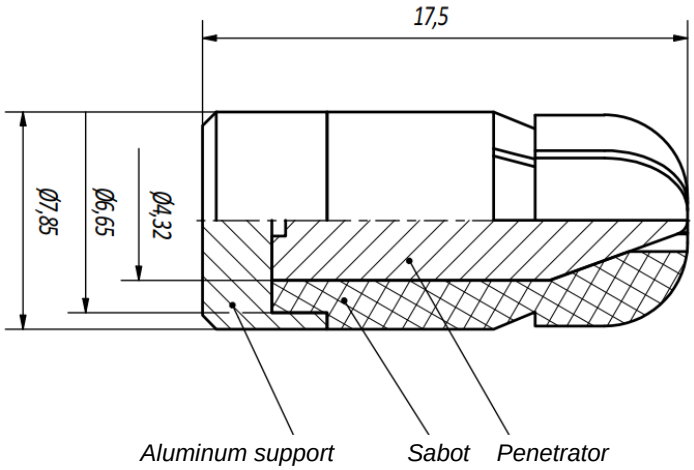

Figure 3 – Bullet dimensions (in mm)

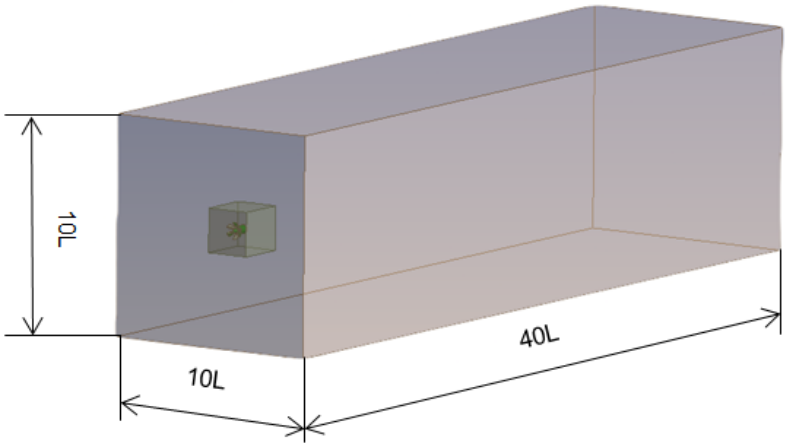

Figure 4 – Air domain dimensions

Mesh generation

In order to reduce burden on the mesh generation procudure, the aluminum support and the sabot were modeled as a unified object. This simplification does not affect the simulation accuracy since the aluminum support and the sabot are securely connected with each other and stay together for the whole separation process. Based on the bullet structure

and accuracy, the computational domain grid around the bullet was automatically generated. Figure 5 shows the mesh generation results on the bullet surface. There are a total of 3 365 498 mesh elements.

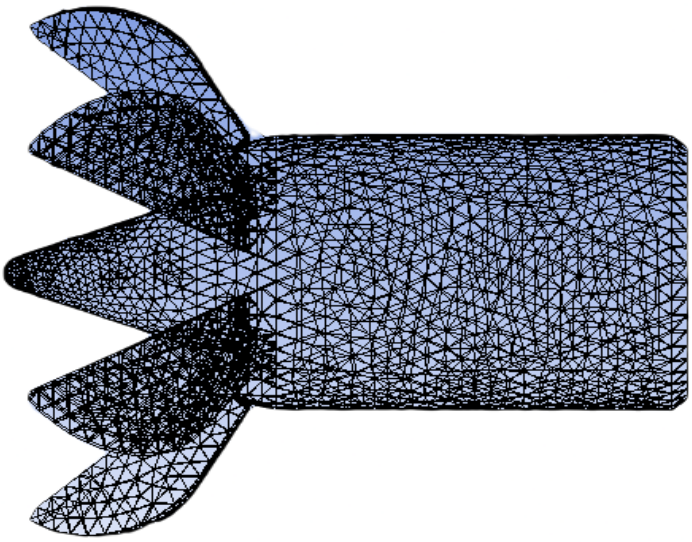

Figure 5 – Mesh around the bullet

Mathematical model

In this research, the Reynolds averaged Navier-Stokes (RANS) equations were selected to calculate the drag and analyze the flow fields around the bullet model. In the RANS methods, an averaged filter was applied to the Navier-Stokes equations. The Reynolds stresses are simulated by turbulent models. Despite only supporting averaged flow fields, the RANS approach is greatly effective at saving calculation time while maintaining a high level of accuracy. There are five Navier-Stokes equations: the first one expresses the law of conservation of mass, the next three describe the law of conservation of momentum, and the last one represents the law of conservation of energy (Matsson, 2023). They are as follows:

$$\frac{\partial p}{\partial t}+\frac{\partial(\rho u)}{\partial x}+\frac{\partial(\rho v)}{\partial y}+\frac{\partial(\rho w)}{\partial z}=0, \tag{1}$$

$$\frac{\partial(\rho u)}{\partial t}+\frac{\partial(\rho u^2)}{\partial x}+\frac{\partial(\rho uv)}{\partial y}+\frac{\partial(\rho uw)}{\partial z}= \\ =-\frac{\partial p}{\partial x}+\frac{1}{Re}(\frac{\partial(\tau_{xx})}{\partial x}+\frac{\partial(\tau_{xy})}{\partial y}+\frac{\partial(\tau_{xz})}{\partial z}), \tag{2}$$

$$\frac{\partial(\rho v)}{\partial t}+\frac{\partial(\rho uv)}{\partial x}+\frac{\partial(\rho v^2)}{\partial y}+\frac{\partial(\rho vw)}{\partial z}= \\ =-\frac{\partial p}{\partial y}+\frac{1}{Re}(\frac{\partial(\tau_{xy})}{\partial x}+\frac{\partial(\tau_{yy})}{\partial y}+\frac{\partial(\tau_{yz})}{\partial z}), \tag{3}$$

$$\frac{\partial(\rho w)}{\partial t}+\frac{\partial(\rho uw)}{\partial x}+\frac{\partial(\rho vw)}{\partial y}+\frac{\partial(\rho w^2)}{\partial z}= \\ =-\frac{\partial p}{\partial z}+\frac{1}{Re}(\frac{\partial(\tau_{xz})}{\partial x}+\frac{\partial(\tau_{yz})}{\partial y}+\frac{\partial(\tau_{zz})}{\partial z}), \tag{4}$$

$$\frac{\partial(E_T)}{\partial t}+\frac{\partial(uE_T)}{\partial x}+\frac{\partial(vE_T)}{\partial y}+\frac{\partial(wE_T)}{\partial z}= \\ =-\frac{\partial(up)}{\partial x}-\frac{\partial(vp)}{\partial y}-\frac{\partial(wp)}{\partial z}+ \\ +\frac{1}{Re}\left[\frac{\partial}{\partial x}\left(u\tau_{xx}+v\tau_{xy}+w\tau_{xz}\right)+\frac{\partial}{\partial y}\left(u\tau_{xy}+v\tau_{yy}+w\tau_{yz}\right)+\right. \\ \left.+\frac{\partial}{\partial z}\left(u\tau_{xz}+v\tau_{yz}+w\tau_{zz}\right)\right]-\frac{1}{Re}\frac{1}{Pr}\left(\left[\frac{\partial q_x}{\partial x}+\frac{\partial q_y}{\partial y}+\frac{\partial q_z}{\partial z}\right), \tag{5}$$

where u, v and w respectively are the velocity in the x, y and z directions; p is the pressure, t is the time, ρ is the air density, τ is the deviatoric stress tensor, E_T is the total energy, q is the heat flux, Re is the Reynolds number, and Pr is the Prandtl number.

In order to analyze the high-speed compressible flow around a saboted bullet, the k-ε turbulence model was applied. Introduced in 1974 (Launder & Spalding, 1974), this model quickly became one of the most popular models used in computational fluid dynamics to analyze aerodynamic characteristics for turbulent flow conditions. It is suitable for

high Reynolds numbers or free stream flow. Various authors have been successfully implementing the *k-ε* turbulence model to predict aerodynamic characteristics and analyze the flow around bodies with complicated geometry involving separation and strong pressure fluctuation (Do et al, 2022; Dolzhikov & Nikolaev, 2015; Ko et al, 2020; Trakic, 2020). The *k-ε* turbulence model enables turbulent eddy viscosity to be taken into account using the kinetic energy *k* and the dissipation rate *ε*. These additional parameters are determined through the following equations:

$$\frac{\partial(\rho k)}{\partial t}+u\frac{\partial(\rho k)}{\partial x}+v\frac{\partial(\rho k)}{\partial y}+w\frac{\partial(\rho k)}{\partial z}=\frac{\partial}{\partial x}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x}\right]+ \\ =\frac{\partial}{\partial y}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial y}\right]+\frac{\partial}{\partial z}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial z}\right]+P_k-\rho\varepsilon, \tag{6}$$

$$\frac{\partial(\rho\varepsilon)}{\partial t}+u\frac{\partial(\rho\varepsilon)}{\partial x}+v\frac{\partial(\rho\varepsilon)}{\partial y}+w\frac{\partial(\rho\varepsilon)}{\partial z}=\frac{\partial}{\partial x}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial \varepsilon}{\partial x}\right]+ \\ =\frac{\partial}{\partial y}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial \varepsilon}{\partial y}\right]+\frac{\partial}{\partial z}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial \varepsilon}{\partial z}\right]+P_k C_{1\varepsilon}\frac{\varepsilon}{k}-\rho C_{2\varepsilon}\frac{\varepsilon^2}{k}, \tag{7}$$

where the function P_k is defined as:

$$P_k=\tau_{xx}\frac{\partial u}{\partial x}+\tau_{xy}\frac{\partial u}{\partial y}+\tau_{xz}\frac{\partial u}{\partial z}+\tau_{yx}\frac{\partial v}{\partial x}+\tau_{yy}\frac{\partial v}{\partial y}+\tau_{yz}\frac{\partial v}{\partial z}+ \\ +\tau_{zx}\frac{\partial w}{\partial x}+\tau_{zy}\frac{\partial w}{\partial y}+\tau_{zz}\frac{\partial w}{\partial z}, \tag{8}$$

where *k* is the kinetic energy, *ε* is the dissipation rate, E_{ij} represents the component of the rate of deformation, and μ_t represents the eddy viscosity. *C1ε, C2ε,* σ_k and σ_ε are constant numbers: $C_{1\varepsilon}$ = 1.44, $C_{2\varepsilon}$ = 1.92, σ_k =1.00 and σ_ε = 1.30.

The turbulent viscosity μ_t is calculated using the equation below:

$$\mu_t=\rho C_\mu\frac{k^2}{\varepsilon}, \tag{9}$$

where the parameter C_μ is a constant number, C_μ = 0.0845.

Boundary condition and convergence criteria

The abovementioned Navier-Stokes equations from (1) to (9) were solved using Ansys Fluent numerical simulation software. The RANS equations with the k-ε turbulent model were applied in this research. The density-based solver was used. The finite volume method with the second order of numerical accuracy for pressure, density, momentum, and turbulent kinetic energy was employed for the investigation. The air model was an ideal gas. The Coupled algorithm was implemented for the calculation. The calculation domain was defined with the following boundary conditions: inlet, outlet, and wall. Velocity, static pressure, and static temperature were established for the inlet flow. For the outlet flow, static pressure was defined. Other setup parameters are presented in Table 1.

Table 1 – Ansys Fluent simulation settings

Parameter	**Value**
Inlet velocity	Bullet's muzzle velocity
Gauge pressure	0 Pascal
Side	Symmetry
Wall	No slip wall
Viscosity model	Sutherland
Temperature	300 K
Convergence criteria	10^{-6}

Validation

Although the numerical method and the simulation procedure have been carefully selected and carried out in this study, the obtained results should be compared with experimental data to verify the accuracy of the results. Since no relevant experimental data has been published in open literature so far, some limitations do exist regarding the result validation. However, the main objective of this research is to investigate the effect of the muzzle velocity of a bullet and the angle of petals opening on the drag trend of the sabot and the penetrator; hence, experimental tests can be conducted later as part of the continuation of this work to validate and verify the overall calculation model for the separation phenomenon.

Results and discussion

Flow field around the bullet

The pressure distribution around the bullet on the symmetric plane is presented in Figure 6. Obviously, the pressure is the highest in the forepart of the bullet while the pressure is significantly lower in the aftpart in comparison with that in the forepart. Figure 7 shows the velocity field around the bullet at a bullet velocity of 600 m/s and an angle of petals opening of 80^0. The flow separation takes place on the rear surface of the sabot petals. The turbulence intensity of the flow is presented in Figure 8. The most intense turbulence occurs in the space behind the opening petals.

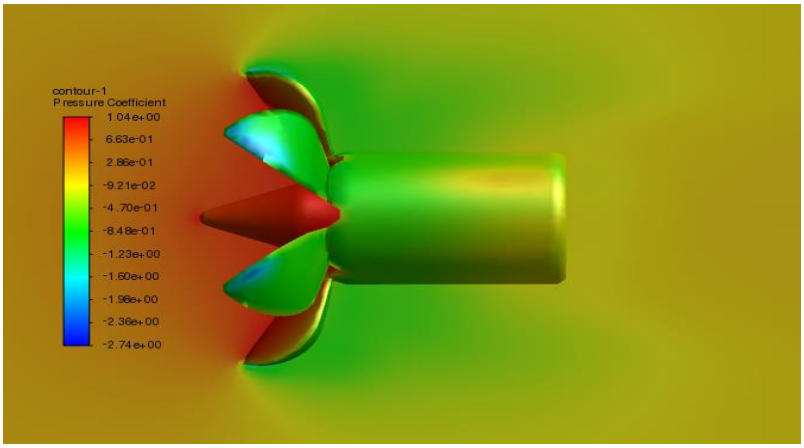

Figure 6 – Pressure distribution around the bullet (petals opening angle: 80^0, bullet velocity: 600 m/s)

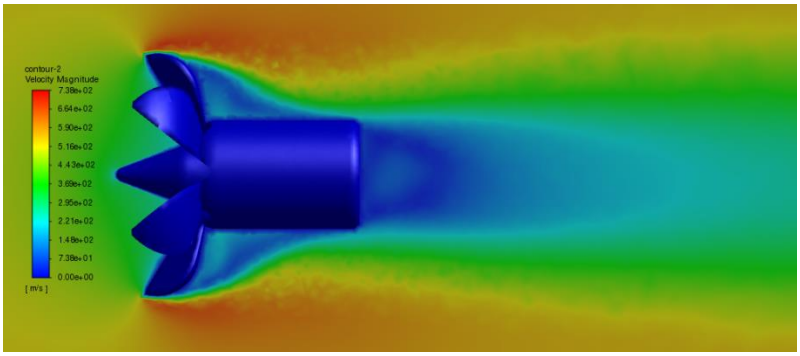

Figure 7 – Velocity distribution around the bullet (petals opening angle: 80^0, bullet velocity: 600 m/s)

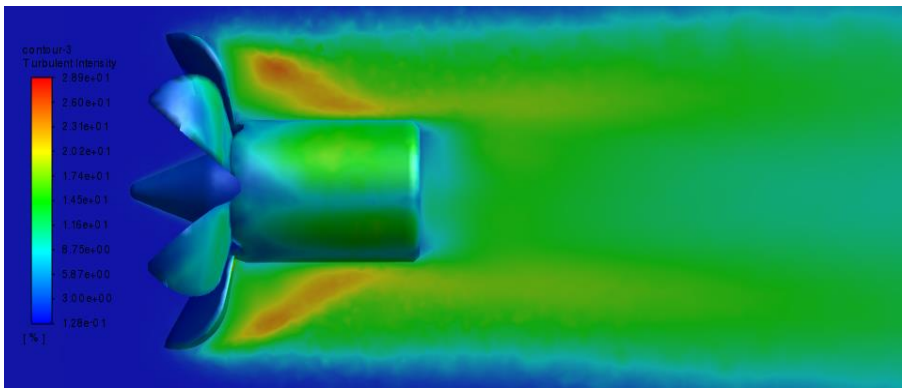

Figure 8 – Turbulence intensity around the bullet (petals opening angle: 80^0, bullet velocity: 600 m/s)

Influence of bullet velocity on drag

Since bullet velocity is a defining parameter for exterior ballistic fundamental problem solving, it is important to determine the drag of the sabot and the penetrator for different velocities.

Moreover, the muzzle velocity of the bullet is one of the defining parameters for the fundamental interior ballistic problem. In the penetrator-sabot separation process, the bullet velocity gradually changes and, as a consequence, the air drag acting on the sabot and the penetrator will change. In this study, the drag of the sabot and the drag of the penetrator were obtained for the velocity values ranging from 500 m/s to 600 m/s with different petals opening angles.

The influence of velocity on the drag of the sabot and the drag of the penetrator are shown in Figure 9, Figure 10, and Figure 11. Clearly, for all values of petals opening angles, an evident tendency can be seen: the greater bullet velocity, the greater the drags of the sabot and the penetrator; the greater bullet velocity, the greater difference of the drags on the sabot and the penetrator.

This means that the sabot and the penetrator leave each other quicker with a higher bullet velocity. Additionally, the drag-velocity dependency is almost linear for all the values of petals opening angles.

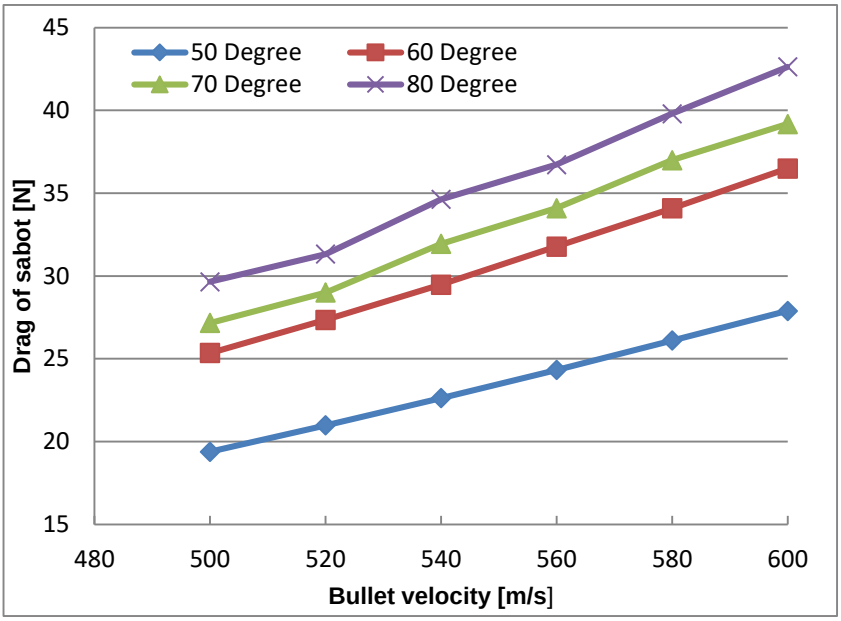

Figure 9 – Influence of bullet velocity on sabot drag for various petals opening angles

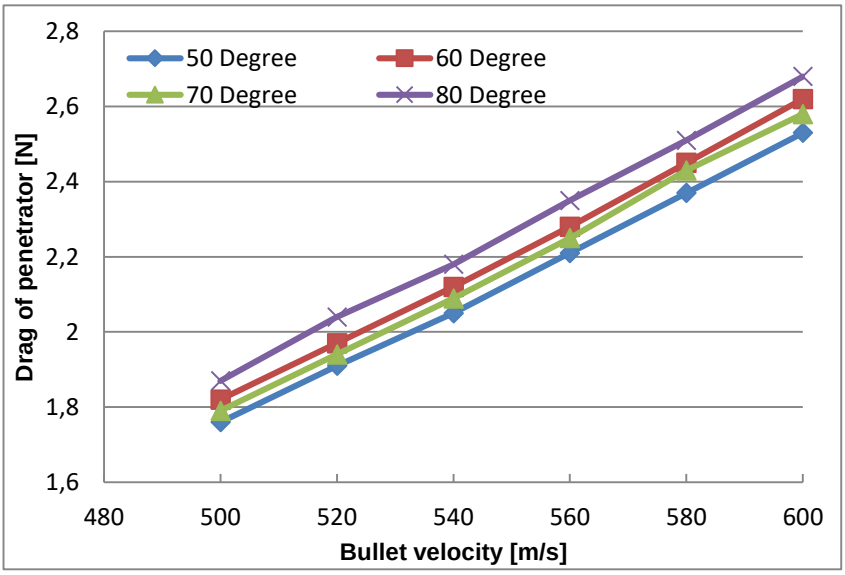

Figure 10 – Influence of bullet velocity on penetrator drag for various petals opening angles

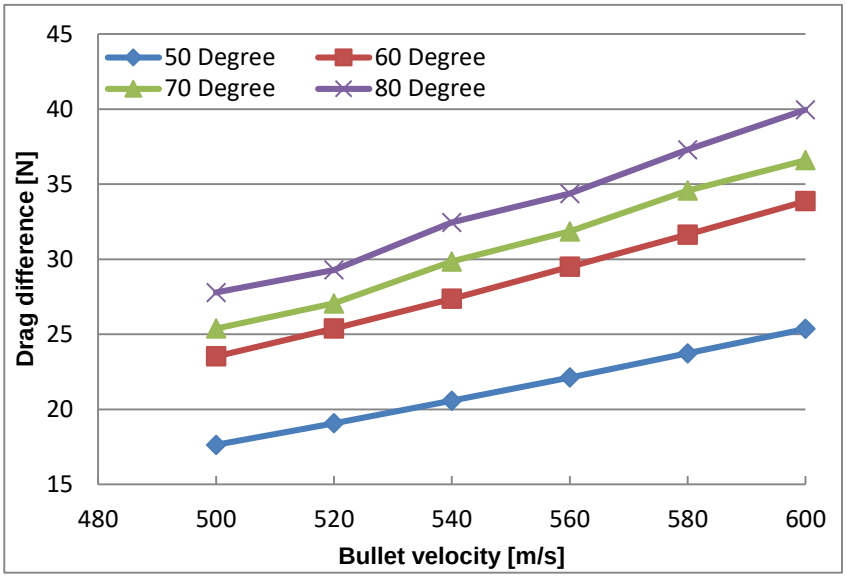

Figure 11 – Influence of bullet velocity on the difference of the drags of the sabot and the penetrator for various petals opening angles

Influence of petals opening angles on drag

In the sabot separation process, the petals opening angle graduallly changes affecting the air flow state around the bullet and the aerodynamic interference between the sabot and the penetrator. Consequently, the drag of the sabot and the drag of the penetrator change with time. Therefore, it is of great interest to investigate how the drag of the sabot and the drag of the penetrator change with the changes of petals opening angles. In this study, the petals opening angle varies from 50^0 to 80^0 with an increment of 10^0. Figure 12 - Figure 14 show the effect of petals opening angles on the drag of the sabot, the drag of the penetrator and their difference for various bullet velocities. Obvious tendencies can be observed. For any value of bullet velocity, the drag of the sabot, the difference between the drag of the sabot and the drag of the penetrator increase quickly with the increase of the angle of petals opening. Consequently, the greater the petals opening angle, the more quickly the sabot and the penetrator leave each other. Hence, one can vary the material or/and the structural parameters of the sabot, e.g. the sabot length, to influence the penetrator-sabot separation process.

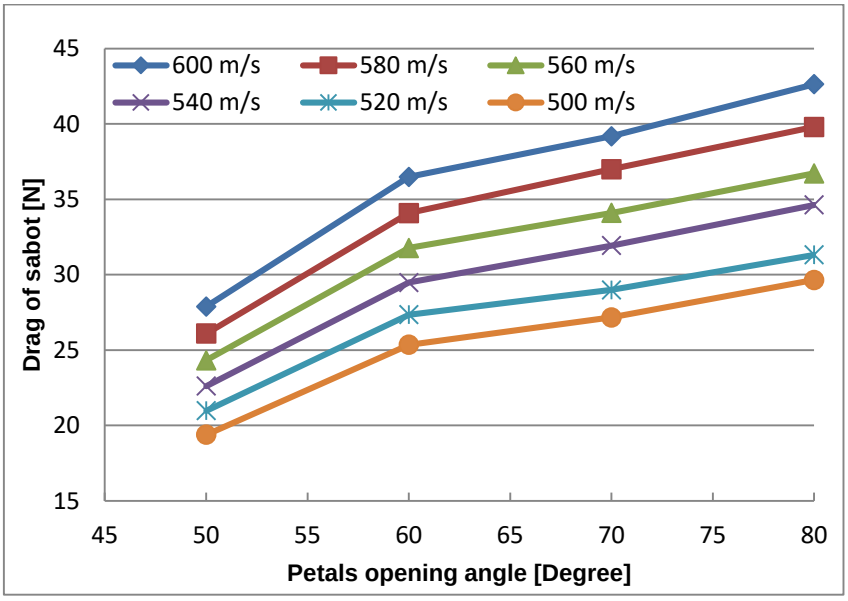

Figure 12 – Influence of the petals opening angle on the drag of the sabot for various bullet velocities

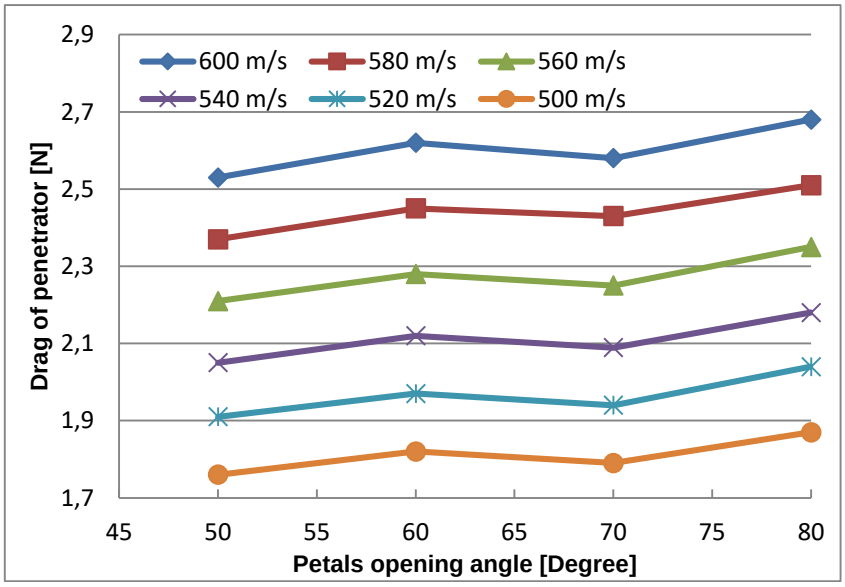

Figure 13 – Influence of the petals opening angle on the drag of the penetrator for various bullet velocities

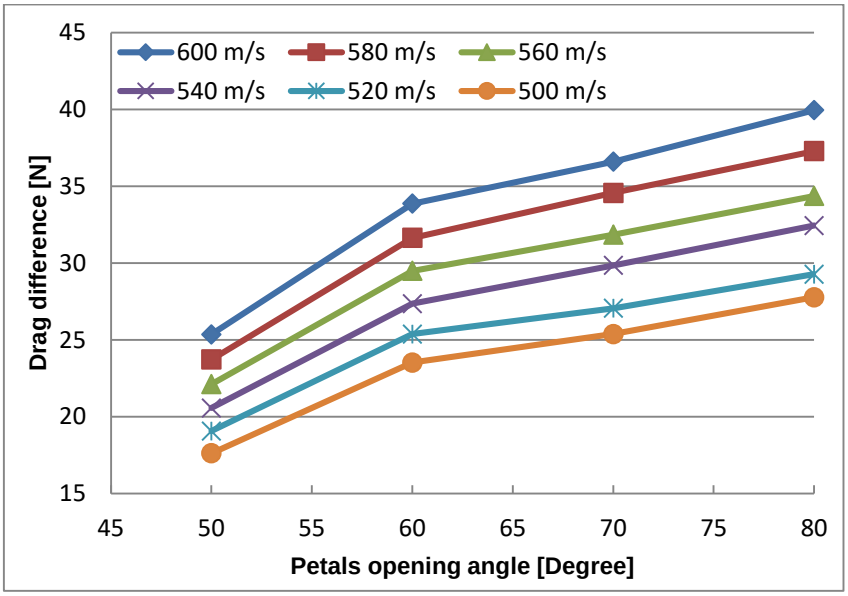

Figure 14 – Influence of the petals opening angle on the difference of the drags of the sabot and the penetrator for various bullet velocities

Conclusion

In this research, in order to save experimental time and resources, the numerical method was used to investagate the flow around a sub-caliber saboted bullet and analyze the effect of bullet velocity and the sabot petals opening angle on the drags of the sabot and the penetrator. The following are the main conclusions derived from the study:

The numerical method is a powerful and effective tool to study the air flow phenomenon around a complex body such as a saboted bullet, especially to predict the drags of the sabot and the penetrator under different conditions.

The pressure distribution around the bullet is complex: the pressure is the highest in the forepart and significantly lower in the aftpart.

The most intense turbulence takes place in the space behind the opening petals. The drag of the sabot, the drag of penetrator and their difference are almost linearly dependant on bullet velocity for any certain petals opening angle.

With increasing the petals opening angle, the drag of the sabot and the difference of the drag of the sabot and drag of the penetrator increase very quickly.

The overall tendency is that the greater bullet velocity or the petals opening angle are, the more quickly the penetrator leaves the sabot.

Eventually, the results obtained in this research work can be applied for further study and development of sub-calibre saboted bullets with similar geometries.

Future work

The following directions are recommended for further continuation of this study:

The first direction is to determine the drags of the sabot and the penetrator depending on their relative movement while the penetrator gradually leaves the sabot.

The second direction is to implement approximation techniques to present the drags of the sabot and the penetrator in form of continuous functions of velocity, opening angle and relative movement for further usage in sabot separation studies.

The third direction is to use continous functions of drags of the sabot and the penetrator in solving the fundamental exterior ballistic problem of a saboted bullet to determine not only the penetrator velocity at the moment it leaves the sabot but also the distance from the gun muzzle to the separation point and then to conduct experimental tests to verify the comprehensive calculation model.

References

Abdelsalam, O.R. & Fayed, A. 2022. Tungsten carbide core 12.7x99mm AP projectiles ballistic behavior against high hardness steel armor. *Journal of Physics: Conference Series,* 2299, art.number:012017. Available at: https://doi.org/10.1088/1742-6596/2299/1/012017.

-CBJ Tech. 2024. *6.5x25 CBJ APDS Tungsten core inside a discarding sabot. Cbjtech.com* [online]. Available at: https://www.cbjtech.com/ammunition/6-5x25-cbj/6-5x25-cbj-apds/ [Accessed: 21 December 2023].

Do, V.M., Tran, T.H., Bui, X.S. & Le, D.A. 2022. Influence of spike-nosed length on aerodynamic drag of a wing-projectile model. *Advances in Military Technology*, 17(1), pp.33-45. Available at: https://doi.org/10.3849/aimt.01542.

Dolzhikov, V.I. & Nikolaev, A.V. 2015. Determination of aerodynamic characteristics of rotating aircraft in the uncontrolled flight by means of engineering analysis systems. *Aerospace MAI Journal*, 22(3), pp.47-53 [online]. Available at: https://vestnikmai.ru/eng/publications.php?ID=58907&eng=Y (in Russian) [Accessed: 20 January 2024].

Huang, Z.-g., Wessam, M.E. & Chen, Z.-h. 2014. Numerical investigation of the three-dimensional dynamic process of sabot discard. *Journal of Mechanical Science and Technology*, 28, pp.2637-2649. Available at: https://doi.org/10.1007/s12206-014-0620-6.

Ko, A., Chang, K., Sheen, D.-J., Lee, C.-H., Park, Y. & Park, S.W. 2020. Prediction and Analysis of the Aerodynamic Characteristics of a Spinning Projectile Based on Computational Fluid Dynamics. *International Journal of Aerospace Engineering*, 2020, art.ID:6043721. Available at: https://doi.org/10.1155/2020/6043721.

Launder, B.E. & Spalding, D.B. 1974. The numerical computation of turbulent flows. *Computer Methods in Applied Mechanics and Engineering*, 3(2), pp.269-289. Available at: https://doi.org/10.1016/0045-7825(74)90029-2.

Lesage, F. & Girard, B. 1996. Wind tunnel and CFD investigation of aerodynamic interactions during sabot separation. In: *34th Aerospace Sciences Meeting and Exhibit*, Reno, NV, USA, January 15-18. Available at: https://doi.org/10.2514/6.1996-193.

Lin, H. & Lai, C.-L. 1997. Systematic study and numerical simulation of sabot projectile aerodynamics. *Journal of the Chinese Institute of Engineers*, 20(3), pp.275-284. Available at: https://doi.org/10.1080/02533839.1997.9741831.

Matsson, J.E. 2023. *An Introduction to Ansys Fluent 2023*. Mission, KS, USA: SDC Publications. ISBN: 978-1-63057-648-6.

-Ministry of Defence, Singapore. 2016. *Engineering land systems*. Singapore: Ministry of Defence [online]. Available at: https://www.mindef.gov.sg/oms/dam/publications/eBooks/DTC50/Engineering-Land-Systems.pdf [Accessed: 20 January 2024]. ISBN: 978-981-11-1490-8.

Odanović, Z. & Bobić, B. 2003. Ballistic protection efficiency of composite ceramics/metal armours. *Scientific Technical Review*, 53(3), pp.30-38 [online]. Available at: http://www.vti.mod.gov.rs/ntp/rad2003/3-03/odan/odan.pdf [Accessed: 20 January 2024].

Patanwala, H., Suresh, C. & Pawar, V. 2023. Computational Study of Safe Separation of Sabot from Penetrator in APFSDS. In: Edwin Geo, V. & Aloui, F. (Eds.) *Energy and Exergy for Sustainable and Clean Environment*, Volume 2, Green Energy and Technology, pp.279-294. Singapore: Springer. Available at: https://doi.org/10.1007/978-981-16-8274-2_19.

Starek, W. & Stepniak, W. 2021. Analysis and evaluation of small arms and ammunition with the reference to known foreign developments. *Problemy Techniki Uzbrojenia/Issues of Armament Technology,* R.35, z.99 pp.65-89. Available at: https://yadda.icm.edu.pl/baztech/element/bwmeta1.element.baztech-article-PWAA-0025-0007 (in Polish) [Accessed: 20 January 2024].

Stopforth, R. & Adali, S. 2019. Experimental study of bullet-proofing capabilities of Kevlar, of different weights and number of layers, with 9 mm projectiles. *Defence Technology*, 15(2), pp.186-192. Available at: https://doi.org/10.1016/j.dt.2018.08.006.

Trakic, A. 2020. Axial force coefficient of APFSDS projectile. *Defense and Security Studies*, 1(1), pp.1-15. Available at: https://doi.org/10.37868/dss.v1.id63.

Yaneva, S. 2020. Ballistic resistance of bulletproof vests level IIIA. Development of testing methodology. *MATEC Web of Conferences,* 317, art.number:06003. Available at: https://doi.org/10.1051/matecconf/202031706003.

Zochowski, P., Bajkowski, M., Grygoruk, R., Magier, M., Burian, W., Pyka, D., Bocian, M. & Jamroziak, K. 2021. Ballistic Impact Resistance of Bulletproof Vest Inserts Containing Printed Titanium Structures. *Metals,*11(2), art.number:225. Available at: https://doi.org/10.3390/met11020225.

Investigación numérica sobre el flujo supersónico alrededor de una bala saboteada

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CAMPO: mecánica, dinámica de fluidos
TIPO DE ARTÍCULO: artículo científico original

Resumen:

Introducción/objetivo: En este artículo, se investigaron las características aerodinámicas de una bala especial en condiciones supersónicas. Para el estudio se seleccionó un modelo de bala saboteada por pistola.

Métodos: El método utilizado en la investigación fue la simulación de dinámica de fluidos computacional (CFD). Para el cálculo numérico se utilizó el modelo de turbulencia k-ε. Se seleccionó el modelo aire como gas ideal. Para la viscosidad del aire se aplicó el modelo de Sutherland.

Resultados: Los resultados de la simulación numérica muestran el comportamiento del flujo supersónico sobre la bala saboteada. Al variar el ángulo de apertura de los pétalos y la velocidad de la bala, se obtuvo su influencia en las resistencias del casquillo y del penetrador para su posterior estudio de separación del casquillo.

Conclusión: El estudio muestra que el enfoque de simulación CFD se puede implementar para analizar las resistencias aerodinámicas en el casquillo y el penetrador después de que la bala saboteada sale del cañón del arma. Los resultados de la simulación obtenidos en este trabajo son importantes en el diseño de balas perforantes ligeras saboteadas disparadas con pistolas.

Palabras claves: balas saboteadas, pistola, características aerodinámicas, Ansys Fluent, CFD, simulación numérica.

Численное исследование сверхзвукового обтекания подкалиберной пули с отделяющимся поддоном

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РУБРИКА ГРНТИ: 30.17.33 Газовая динамика,
30.17.53 Прикладная аэродинамика
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: В данной статье исследованы аэродинамические характеристики гиперзвукового патрона. Для исследования была выбрана модель пистолетного патрона с отделяющимся поддоном.

Методы: В исследовании использовался метод компьютерного моделирования гидродинамики (CFD). Для численного моделирования использовалась модель k-ε турбулентности. Формула Сазерленда использовалась для определения вязкости воздуха как модели идеального газа.

Результаты: Результаты численного моделирования показывают поведение сверхзвукового обтекания патрона с отделяющимся поддоном. Путем изменения углов открытия лепестков поддона и изменения скорости патрона было выявлено их влияние на аэродинамическое сопротивление, действующее на поддон и сердечник. Это влияние необходимо учитывать в последующих расчетах процесса отделения сердечника и поддона.

Выводы: Исследование показало, что вычислительная аэродинамика может быть использована для получения аэродинамического сопротивления корпуса и сердечника после выхода пули из ствола пистолета. Результаты моделирования, полученные в данной статье, важны для проектирования бронебойных патронов с отделяющимся поддоном.

Ключевые слова: патроны с отделяющимся поддоном, сердечник, аэродинамические характеристики, Ansys Fluent, CFD, численное моделирование.

Nguyen, Q.T. et al, Numerical investigation on the supersonic flow around a saboted bullet, pp.676-694

Нумеричко испитивање надзвучног струјања око поткалибарног пројектила са одвојивим носачем (саботом)

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ОБЛАСТ: машинство, динамика флуида
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: У овом раду проучавају се аеродинамичке карактеристике специјалног метка при надзвучној брзини. Модел одабран за студију био је пиштољски метак са одвојивим носачем (саботом).

Методе: Коришћен је метод компјутерски симулиране динамике флуида (CFD), а за нумеричку симулацију к-ε модел турбуленције. За вискозност ваздуха, као модела идеалног гаса, примењена је Сатерландова формула.

Резултати: Резултати нумеричке симулације показују понашање надзвучног струјања око метка са одвојивим саботом. Варирањем углова отварања сегмената носача, као и брзине пројектила, утицало је на њихов аеродинамички отпор који делује на носач као и на пенетратор за коришћење у каснијим прорачунима процеса одвајања језгра/пенетратора од носача.

Закључак: Студија показује да се компјутерска аеродинамика може користити за добијање аеродинамичког отпора на носачу и језгру након што метак напусти цев пиштоља. Резултати симулације важни су за пројектовање противоклопних метака са одвојивим носачем.

Кључне речи: противоклопни метак, пиштољ, аеродинамичке карактеристике, Ansys Fluent, CFD, нумеричка симулација.

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Rheology properties of bitumen binders with various fillers

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FIELD: chemical technology, chemical industry, construction
ARTICLE TYPE: original scientific paper

Abstract:

Introduction: The resistance of road surfaces to the formation of a longitudinal wear mark from passing vehicles at the present stage is one of the most pressing problems in the field of asphalt concrete coatings. Therefore, the search for a solution to this problem constantly continues, including studying the behavior of various components of asphalt concrete mixtures when they are loaded.

Methods: The studies were carried out under static load in three temperature modes: 25°C, 40°C and 50°C, as well as using the standard DSR (dynamic shear rheometer) method at temperatures above 70°C. Two types of bitumen were used as binders: semi-blown petroleum road bitumen BND 100/130 and polymer bitumen binder PmB 90. Various fine fillers were introduced into their composition: marble dust, rubber crumbs and modified powder obtained by simultaneous grinding of marble with polyethylene.

Results: It was found that a fine filler has a stronger effect on creep than a change in the grade of asphalt concrete binder. The lowest creep and the greatest shear resistance in the entire temperature range of measurements were shown by an asphalt binder based on a powder obtained by joint grinding of marble and polyethylene.

Conclusions: The effect of a fine filler on the creep of a bitumen binder may exceed the effect associated with a change in the type of bitumen binder. It is obvious that it is the fine filler that has a greater effect on the stability of asphalt concrete to the formation of ruts than conventional semi-blown bitumen binders.

Keywords: rheology properties, asphalt-concrete, bitumen binders, asphalt binder, fillers, mineral powder, rutting, shear resistance, creep of an asphalt binder.

Introduction

The rutting resistance of the pavement surface is one of the most pressing problems in the field of asphalt concrete road construction. The annual increase in speed, traffic intensity and weight of vehicles (Olsson et al, 2019; Hou et al, 2015) indicates the increasing relevance of this problem in the future. Therefore, the search for a solution to this problem continues. To date, numerous studies have identified various factors influencing the formation of rutting in asphalt concrete pavements (Lira et al, 2019; Ai et al, 2017; Bodin, 2017; Ma et al, 2018). These include the influence of bitumen viscosity: hard grades of bitumen have a lower penetration degree and improve the resistance, whereas liquid grades worsen it (Alekseenko et al, 2019). However, other less important factors are suggested to affect rutting resistance. They may be roughly divided into two classes:

- structural factors, which include: grain size distribution and mixture homogeneity of mineral fillers, the maximum size and shape of crushed rock, and the porosity of a mineral aggregate (Akisetty et al, 2009; Qian et al, 2020);
- rheological properties of the binder: asphalt binder grade, the behavior of binder properties in the reaction with a finedispersed filler (mineral powder), the asphalt binder/mineral powder ratio, and the concentration of a binder in asphalt concrete (Ibrahim, 2019; Arun Kumar & Satyanarayana, 2015; Okhotnikova et al, 2019; Abdulmajeed & Muniandy, 2017).

As noted earlier, the viscosity of bitumen depending on the asphalt binder type has a considerable influence on the rutting resistance of asphalt concrete. The question arises: what other factors besides the bitumen grade might be relevant to the viscosity of bitumen? In our opinion, one of the most important factors is the type and amount of fine-dispersed filler. In most asphalt concrete compositions, this role is played by mineral marble dust. In asphalt concrete, approximately 90% of the total area occupied by mineral particles is the area of the mineral powder surface.

Selective adsorption of bitumen components onto the surface of particles or even inside them in modified powders of fine-dispersive fillers may considerably change the viscosity of the bitumen mixture if compared with the reference material. Therefore, the research into a bitumen composite with a fine-dispersed filler will make an important contribution to the field of asphalt binders. Therefore, it seems necessary to study the mixture of bitumen and fine-dispersive filler.

Purpose and problem statement

This study examines changes on the rheological properties of asphalt binders when mixed with a variety of fine-dispersed fillers. The properties of this composite differ considerably from the reference binder, so the term “an asphalt binder” is used throughout this paper as suggested in scientific literature. It is the asphalt binder that bonds coarse particles of asphalt concrete, and its properties are important for the rutting resistance of an asphalt concrete pavement, but only in that part that depends on the asphalt binder. Other structural factors influencing rutting resistance are beyond the scope of this study.

To assess the shear resistance and tensile strength of asphalt concrete, it is necessary to know the rheological properties of the asphalt binder in the contact zone of two mineral filler particles. At the same time, the speed of force application in real conditions of interaction of a car wheel with an asphalt concrete surface can vary greatly. Under rapidly changing loads on an asphalt concrete pavement, the main rheological property is the complex dynamic shear modulus (G*) which is stated by the equation:

$$G^*=G'+i^*G''= G^*\cos(\delta)+i^* G^*\sin(\delta) \quad (1)$$

where G’ is the storage shear modulus, G’’ is the loss shear modulus, δ is the phase angle, (in radians), defining the delay between sinusoidal deformation and sinusoidal stress during tests with controlled deformation. The value G/sin(δ) is called resistance to shear deformation and it determines the contribution of bitumen to the shear resistance of asphalt concrete. For rapidly changing forces, there is a standard method AASHTO T315-10 "Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer (DSR)" which allows to measure the shear stress of not only bitumen, but also asphalt binders.

Under slowly changing loads, for example, stopping a car, the creep stiffness of asphalt concrete will make a large contribution to the deformation.

The term “creep” refers to the deformation changing over time at a constant pressure. At the same time, the creep of asphalt concrete, if the fracture and rubbing of crushed mineral filler are ignored, is related to the deformation of the asphalt binder ΔX(t); its dependence upon the applied force P(t) and the impact time is stated in the equation:

$$\Delta X(t) = P(t)/k + fa(t) \quad (2)$$

where P(t) – the stress caused by external forces, k – the hardness of the asphalt binder, t – the time, and fa(t) – the function of the asphalt binder type and temperature. The constant k and the function fa(t) may be estimated either experimentally or by a computer-assisted experiment when fracturing asphalt concrete samples (Alekseenko et al, 2019). The creep measurements were carried out on a Kinexus DSR device using a special technique described below.

This study seeks to examine the creep and shear resistance of the asphalt binder. These experiments are far less difficult (cost-demanding) than measuring the creep (rutting) of asphalt concrete. In addition, the results obtained may be used in the future for the computer-assisted modeling of any physical and mechanical parameters of asphalt concrete.

Objects and materials for research

The study was carried out using two typical asphalt binders: petroleum road semi-blown bitumen grade BND 100/130 (BND) and polymer- modified bitumen grade PmB 90 (PmB). The three filler grades were used: a standard mineral powder from marble flour (MM), crumb rubber of automobile tires (RC), and a powder produced of marble dust and modified by polymers, which was a joint grinding of marble and polyethylene (MP).

These fillers were selected for some reasons:

- a standard powder from marble flour represents an etalon of an asphalt binder,
- crumb rubber is associated with an urgent problem of recycling waste tires; moreover, there is a vast body of literature on bitumen and rubber binders (Akisetty et al, 2009; Qian et al, 2020);
- a powder modified by polymers may resolve a problem of polymer recycling (Ibrahim, 2019; Arun Kumar & Satyanarayana, 2015; Okhotnikova et al, 2019), wherein the rutting resistance of asphalt concrete might be improved dramatically if the polymer and the powder modification method are selected appropriately.

Mineral powder from marble dust satisfied the Russian State Standard (GOST) 32761-2014, and the crumb rubber of waste tires (100%) was sieved (1 mm). The modified powder was a product of intergrinding marble powder with 10% (to the mass of mineral powder from marble) granulated high-density polyethylene. It took 4 hours to grind materials in a laboratory ball mill.

All samples of the asphalt binders for the creep research were prepared by heating and mix-ing bitumen binder and powder for 2 hours at a temperature of 175°C. The amount of filler in the bitumen binders was as follows: marble dust and bitumen binders were taken 1:1, 15% crumb rubber was added to BND and 10% to PmB, and modified powder and bitumen binders were in a ratio of 1:1. In this way, 8 samples of asphalt binders were obtained to study creep (Table 1).

Table 1 – Characteristics of the asphalt binder samples for creep research

№	The composition of the asphalt binder		Short name of the binder
	Bitumen type	Fillers (Mineral powder)	
1	BND 100/130	no filler	BND
2	PmB 90	no filler	PmB
3	BND 100/130	mineral powder from marble flour (MM)	BND/MM
4	PmB 90	mineral powder from marble flour (MM)	PmB/MM
5	BND 100/130	15% crumb rubber of automobile tires (RC)	BND/15RC
6	PmB 90	10% crumb rubber of automobile tires (RC)	PmB/10RC
7	BND 100/130	powder produced of marble dust and modified by polymers (MP)	BND/MP
8	PmB 90	powder produced of marble dust and modified by polymers (MP)	PmB/MP

Table 2 – Characteristics of the asphalt binder samples for the study of shear stability

№	The composition of the asphalt binder		Short name of the binder
	Bitumen type	Fillers (Mineral powder)	
1	BND 100/130	no filler	BND
2	PmB 90	no filler	PmB
3	BND 100/130	100% mineral powder from marble flour (MM)	BND/100MM
4	PmB 90	100% mineral powder from marble flour (MM)	PmB/100MM
5	BND 100/130	90% mineral powder from marble flour (MM) + 10% rubber crumb from car tires (RK)	BND/90MM/10RC
6	BND 100/130	90% mineral powder from marble flour (MM) + 10% polymer modified powder from marble flour (MP)	BND/90MM/10MP
7	PmB 90	90% mineral powder from marble flour (MM) + 10% polymer modified powder from marble flour (MP)	PmB/90MM/10MP

The filler amount in bitumen binders during shear resistance tests was as follows: the powder was mixed with the bitumen binders in a ratio of 1:1, while the powder consisted of 90% marble powder and 10% modifier by weight. Such a small amount of modifier was caused by the fact that dynamic measurements are more sensitive to changes in viscosity than creep measurements. Thus, 7 samples of asphalt binders were obtained for creep testing (Table 2).

Method for measuring shear resistance and creep research

The asphalt binder creep measurement was carried out using the standard procedure described below on a DSR instrument which is used to measure the creep of asphalt binders. The measurements were carried out at temperatures of 25 °C, 40 °C and 50°C for eight types of asphalt binders, the characteristics of which are given in Table 1. This temperature range is typical for real asphalt concrete pavements. In addition, at lower temperatures, the creep of the asphalt binder is too small; at higher temperatures, the difference in the creep of various asphalt binders is increasingly leveled out. The measurement of the complex shear modulus of the asphalt binder was carried out according to the standard methods when determining the grade of bitumen according to PG (Performance Grade). The temperature range of the measurement in this case corresponded to the expected softening temperature of the asphalt binder.

Measuring creep and shear resistance by Kinexus DSR

The measurements were carried out for a spindle of 25 mm, a space of 1 mm, and a shear force of 50 kPa. Once the temperature was stabilized, a shear force was applied for 60 seconds (20 seconds at high temperatures and low shear resistance of the asphalt binder), and the curve presenting the rotational displacement of a spindle vs. time was analyzed. It is apparent that the deformation is linear for all types of asphalt binders at all temperatures under consideration, so the creep function may be stated in the equation:

$$fa(t) = \alpha \cdot t \qquad (3)$$

where the constant α is related to the asphalt binder type and temperature. In some tests, the creep demonstrated non-linear behavior over the first seconds, so Table 3 below provides the data for the linear section of the

creep. To compare, the creep of the bitumen binders without fillers was measured at low temperatures. The measurement failed at a temperature of 50 °C and a shear force of 50 kPa because bitumen binders without fillers have low shear resistance.

Results

The speed of the spindle phase angle change characterizes the creep of the asphalt binder at a constant shear force. The results of its measurement are presented in Table 3.

Table 3 – The rate of the change of the spindle rotation angle (rad/s) at different temperatures

№	Short name of the binder	Temperature		
		25,°C	40,°C	50,°C
1	BND	0.325	605	*
2	PmB	0.030	2.400	*
3	BND/MM	0.028	3.333	1200
4	PmB /MM	0.013	0.188	890
5	BND/15RC	0.011	0.183	667
6	PmB/10RC	0.003	0.140	625
7	BND /MP	0.00014	0.0035	0.057
8	PmB/MP	0.00002	0.0015	0.011

*- no data, because bitumen binders without fillers have low shear resistance

Thus, any fine-dispersed filler decreases dramatically the creep of the bitumen binder. Furthermore, a PmB-based asphalt binder has lower creep than a BND-based material; however, a modified mineral powder provides the best creep reduction effect. Rubber crumb at temperatures of 25 °C and 40 °C has a stronger effect on the bitumen binder than marble dust, while at 50 °C it is vice versa.

The results of testing the shear resistance of asphalt binders (the parameters of the dynamic modulus of elasticity of asphalt binders), carried out according to the standard method, which is performed when determining the grade of binder according to PG (Performance Grade), are shown in Figure 1.

From Figure 1 it is obvious that, as in the experiments measuring creep, fine powders noticeably change the viscosity of the binder. The strongest effect on the change in viscosity is provided by mineral powder obtained by jointly grinding the mineral part and polyethylene.

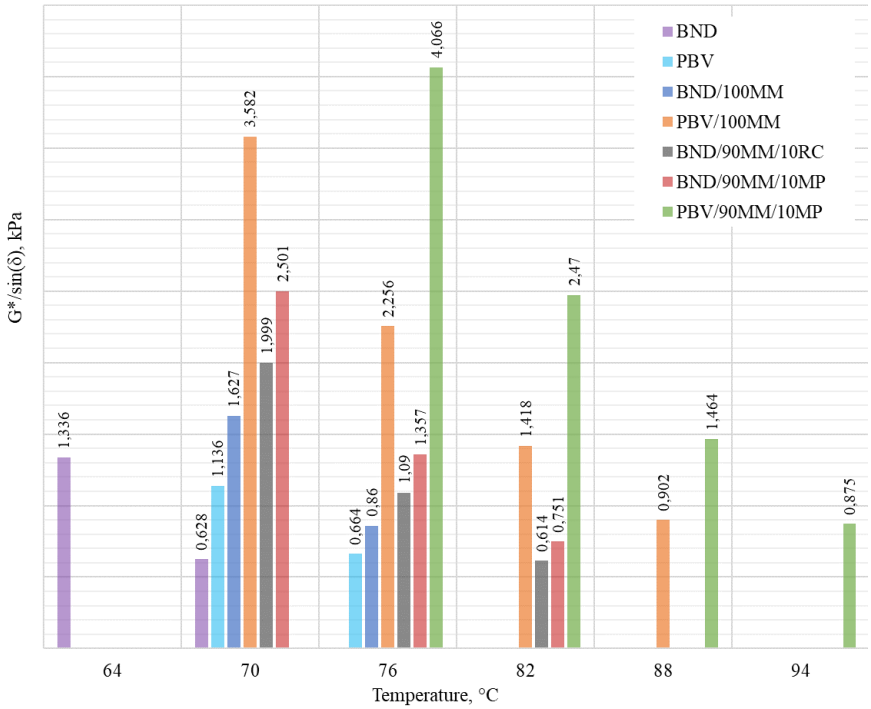

Figure 1 – Parameters of the dynamic modulus of elasticity of asphalt binders

Conclusion

The study showed that fine-dispersed fillers have a strong influence on the creep and shear stability of bitumen binders. This influence is far more significant than the behavior of bitumen if SBS grades are dissolved. Moreover, the influence of fine-dispersed fillers is equally pronounced in bitumen and polymer bitumen binders. The least creep and the highest shear resistance over the entire temperature range were shown in the asphalt binder produced by joint intergrinding marble and polyethylene.

The technology for improving the shear resistance of asphalt concrete through the use of modified mineral powders has a significant advantage compared to the technology for modifying bitumen by dissolving polymers. When using modified mineral powders, there is no problem of storage, change in properties and delamination of the binder. When modifying bitumen with various polymer and inorganic modifiers, the problem of binder degradation as a result of delamination, oxidation and other factors is always relevant.

It should also be noted that the estimation of the rheological parameters of asphalt binders is the quickest and most reliable method to assess the strength and shear resistance of asphalt concrete.

References

Abdulmajeed, S.G. & Muniandy, R. 2017. The Effect of Binder Type and Temperature Differential on The Rutting Performance of Hot Mix Asphalt. *International Journal of Applied Engineering Research*, 12(17), pp.6841-6852 [online]. Available at: https://www.ripublication.com/ijaer17/ijaerv12n17_73.pdf [Accessed: 20 December 2023].

Ai, U., Sharp, K.G. & Trevorrow, N. 2017. Heavy vehicle horizontal stresses and pavement surface performance. *TRID* [online]. Available at: https://trid.trb.org/View/1485226 [Accessed: 20 December 2023]. ISBN: 9781925671001.

Akisetty, C.K., Lee, S.-J. & Amirkhanian, S.N 2009. High temperature properties of rubberized binders containing warm asphalt additives. *Construction and Building Materials*, 23(1), pp.565-573. Available at: https://doi.org/10.1016/j.conbuildmat.2007.10.010.

Alekseenko, V.V., Vabishchevich, K.Yu. & Verkhoturova, E.V. 2019. Modeling of Asphalt Concrete While Using Discrete Element Method. *Science and Technique*, 18(2), pp.171-180. Available at: https://doi.org/10.21122/2227-1031-2019-18-2-171-180.

Arun Kumar, U. & Satyanarayana, P.V.V. 2015. Comparison of the Polyethylene and SBS Polymer Modi-fied Bitumen's Effect – A Case Study. *International Journal of Engineering Trends and Tech-nology (IJETT)*, 22(7), pp.325-330. Available at: https://doi.org/10.14445/22315381/IJETT-V22P268.

Bodin, D. 2017. Improved laboratory characterisation of the deformation properties of granular materials. *TRID* [online]. Available at: https://trid.trb.org/View/1485223 [Accessed: 20 December 2023]. ISBN: 9781925451993.

Hou, S., Zhang, D., Huang, X. & Zhao, Y. 2015. Investigation of micro-mechanical response of asphalt mixtures by a three-dimensional discrete element model. *Journal of Wuhan University of Technology-Mater. Sci. Ed.,* 30, pp.338-343. Available at: https://doi.org/10.1007/s11595-015-1150-5.

Ibrahim, A.-H.A. 2019. Laboratory investigation of aged HDPE-modified asphalt mixes. *International Journal of Pavement Research and Technology*, 12, pp.364-369. Available at: https://doi.org/10.1007/s42947-019-0043-y.

Lira, B., Ekblad, J. & Lundström, R. 2019. Evaluation of asphalt rutting based on mixture aggregate gradation. *Road Materials and Pavement Design*, 22, pp.1-18. Available at: https://doi.org/10.1080/14680629.2019.1683061.

Ma, T., Zhang, D., Zhang, Y., Wang, S. & Huang, X. 2018. Simulation of wheel tracking test for asphalt mixture using discrete element modelling. *Road Materials and Pavement Design*, 19(2), pp.367-384. Available at: https://doi.org/10.1080/14680629.2016.1261725.

Okhotnikova, E.S., Frolov, I.N., Ganeeva, Yu.M., Firsin, A.A. & Yusupova, T.N. 2019. Rheological behavior of recycled polyethylene modified bitumens. *Petroleum Science and Technology*, 37(10), pp.1136-1142. Available at: https://doi.org/10.1080/10916466.2019.1578796.

Olsson, E., Jelagin, D. & Partl, M. 2019. New discrete element framework for modelling asphalt com-paction. *Road Materials and Pavement Design*, 20, pp.5604-5616. Available at: https://doi.org/10.1080/14680629.2019.1633750.

Qian, C., Fan, W., Yang, G., Han, L., Xing, B. & Lv, X. 2020. Influence of crumb rubber particle size and SBS structure on properties of CR/SBS composite modified asphalt. *Construction and Building Materials*, 235, art.number:117517. Available at: https://doi.org/10.1016/j.conbuildmat.2019.117517.

Propiedades reológicas de aglutinantes bituminosos con diversos rellenos

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CAMPO: tecnología química, industria química, construcción
TIPO DE ARTÍCULO: artículo científico original

Resumen:

Introducción/objetivo: La resistencia de las superficies de las carreteras a la formación de marcas de desgaste longitudinal por el paso de vehículos es en la actualidad uno de los problemas más apremiantes en el campo de los revestimientos de hormigón asfáltico. Por lo tanto, la búsqueda de una solución a este problema continúa constantemente, incluido el estudio del comportamiento de los diversos componentes de las mezclas de hormigón asfáltico cuando se cargan.

Métodos: Los estudios se llevaron a cabo bajo carga estática en tres modos de temperatura: 25°C, 40°C y 50°C, así como utilizando el método estándar DSR (reómetro de corte dinámico) a temperaturas superiores a 70°C. Como aglutinantes se utilizaron dos tipos de betún: betún de petróleo semi - soplado para carreteras BND 100/130 y aglutinante de betún polimérico PmB 90. En su composición se introdujeron diversos rellenos finos: polvo de mármol, virutas de caucho y polvo modificado obtenido mediante trituración simultánea de mármol con polietileno.

Resultados: Se encontró que un relleno fino tiene un efecto más fuerte sobre la fluencia que un cambio en el grado del ligante de concreto asfáltico. La menor fluencia y la mayor resistencia al corte en todo el rango de temperaturas de medición las mostró un aglutinante asfáltico a base de un polvo obtenido mediante la trituración conjunta de mármol y polietileno.

Conclusión: El efecto de un relleno fino sobre la fluencia de un ligante bituminoso puede exceder el efecto asociado con un cambio en el tipo de ligante bituminoso. Es obvio que es el relleno fino el que tiene un mayor efecto sobre la estabilidad del hormigón asfáltico ante la formación de surcos que los aglutinantes bituminosos semi - soplados convencionales.

Palabras claves: propiedades reológicas, asfalto-concreto, ligantes bituminosos, ligante asfáltico, rellenos, polvo mineral, ahuellamientos, resistencia al corte, fluencia de un ligante asfáltico.

Реологические характеристики битумных вяжущих с различными наполнителями

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РУБРИКА ГРНТИ: 67.15.00 Технология производства строительных материалов и изделий,
67.15.49 Производство материалов на основе органических вяжущих. Производство асфальтобетона

ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение: Устойчивость дорожных покрытий к образованию колеи от проезжающих транспортных средств на современном этапе является одной из наиболее актуальных проблем в области асфальтобетонных покрытий. Увеличение скоростей движения автотранспорта и увеличение нагрузки на ось автомобиля делает эту задачу из года в год все более важной. Поэтому поиск решения этой проблемы постоянно продолжается, в том числе путем изучения поведения различных компонентов асфальтобетонных смесей под нагрузкой.

Методы: Данное исследование отражает экспериментальные данные по измерению реологических свойств битумных вяжущих

при различных скоростях деформации. Исследования проводились при статической нагрузке в трех температурных режимах: 25°C, 40°C и 50°C, а также с использованием стандартного метода DSR (динамический реометр сдвига) при температурах выше 70°C. В качестве двухкомпонентных вяжущих были использованы два вида битума: окисленный нефтяной дорожный битум БНД 100/130 и полимерно-битумное вяжущее ПБВ 90. В их состав были введены различные мелкодисперсные наполнители: мраморная пыль, резиновая крошка и модифицированный порошок, полученный путем взаимного измельчения мрамора с полиэтиленом.

Результаты: Показано, что мелкий наполнитель оказывает более сильное влияние на ползучесть асфальтобетонного вяжущего, чем изменение марки асфальтобетонного вяжущего. Наименьшую ползучесть и наибольшую устойчивость к сдвигу во всем диапазоне температур измерений продемонстрировало асфальтовое вяжущее на основе порошка, полученного совместным измельчением мрамора и полиэтилена.

Выводы: Показано, что влияние мелкодисперсного наполнителя на ползучесть битумного вяжущего может превышать эффект, связанный с изменением типа битумного вяжущего. Этот результат указывает на то, что именно мелкодисперсный наполнитель оказывает большее влияние на устойчивость асфальтобетона к образованию колеи, чем обычные битумные вяжущие.

Ключевые слова: реологические свойства, асфальтобетон, битумные вяжущие, асфальтовяжущее, наполнители, минеральный порошок, колееобразование, сопротивление сдвигу, ползучесть асфальтовяжущего.

Реолошке карактеристике битуменских везива са различитим филерима

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ОБЛАСТ: хемијске технологије, хемијска индустрија, грађевинарство
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод: Један од горућих проблема у области превлака од асфалтног бетона јесте отпорност површина путева на формирање уздужних трагова хабања од точкова возила. Решење се још увек тражи, а обухвата и проучавање понашања различитих компоненти мешавина асфалтног бетона при оптерећењу.

Методе: Испитивања су вршена под статичким оптерећењем у три температурна режима (25°C, 40°C и 50°C), као и помоћу стандардне методе ДСР (реометар за динамичко смицање) на температурама изнад 70°C. Две врсте битумена коришћене су као везива: битумен за путеве од ваздухом продуване нафте БНД 100/300 и полимер модификовани битумен ПмБ 90. У мешавину су уведене различите ситне фракције – филери: мермерни прах, мрвице гуме и модификовани прах добијен истовременим млевењем мермера и полиетилена.

Резултати: Утврђено је да ситна фракција има већи утицај на течење од промене степена везива асфалтног бетона. Показало се да најнижу вредност течења и највећу отпорност на смицање у свим испитиваним температурним режимима има асфалтно везиво на бази праха добијеног заједничким млевењем мермера и полиетилена.

Закључак: Утицај ситне фракције филера на течење битуменског везива може да буде значајнији од утицаја промене врсте битуменског везива. Очигледно је да ситна фракција – филер има већи ефекат на стабилност асфалтног бетона при формирању колотрага од конвенционалних битуменских везива добијених удувавањем ваздуха.

Кључне речи: реолошка својства, асфалтни бетон, битуменска везива, асфалтно везиво, филери, минерални прах, формирање колотрага, отпорност на смицање, течење асфалтног везива.

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Recycling of shredded printed circuit boards (PCBs) by two-phase moving wave conveyors

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FIELD: mechanical engineering, materials, chemical technology
ARTICLE TYPE: original scientific paper

Abstract:

Introduction/purpose: The aim of this study is to demonstrate the viability of electrostatic separation of mixtures from shredded printed circuit boards (PCBs), in association with the X-ray fluorescence analysis, and simultaneously to examine how the efficiency of this method is influenced by the supply voltage, both in terms of amplitude and nature.

Methods: The electrostatic separation technique is used by means of a two-phase moving wave conveyor with characterisation analysis using X-ray fluorescence in order to justify the efficiency of the process studied.

Results: The results of this study can have practical implications for improving the recycling process of electronic waste, especially from printed circuit boards (PCBs). By optimizing the high voltage and understanding its effects on the electrostatic separation process, it may be possible to increase the efficiency and effectiveness of recycling valuable materials from electronic waste while reducing environmental impact.

Conclusion: The XRF analysis of the samples reveals their distinct compositions. The variations observed are even more marked if the influence of the voltages applied on the electrostatic separation process is considered.

Key words: recycling, environment, waste electrical and electronic equipment, two-phase moving wave conveyor, x-ray fluorescence, high voltage.

Introduction

Waste Electrical and Electronic Equipment (WEEE) is increasing rapidly globally and has become one of the most important types of solid

waste (Lu et al, 2018, p.83). In the context of recycling electronic boards, it can be used to separate different components or materials based on their electrical characteristics. The separation effectiveness relies on the ability to control particle tribocharging (Iuga et al, 2005, p.937).

The triboelectric separation represents a solution for the sorting of plastics mixtures, whenever the components have a similar size, shape, magnetic permeability and electrical conductivity (Mimouni et al, 2017, p.2).

Metals represent a significant part of this waste, both in volume and in material value (UNEP, 2013). The recycling market for old electronic devices is essentially based on recovered metals, recycling chains for plastics, glass and ceramics being more limited. Printed circuit boards are among the most economically relevant waste materials in this category. Various processing units recycle Waste Printed Circuit Boards (WPCB) to capture metals of value, such as Cu, Ag, or Au (Ghosh et al, 2015, p.5).

Traveling-wave conveyors or electric curtains are generally used for the displacement of micronized insulating particles such as plastic granules and dust, among others. They consist of parallel electrodes separated by a small inter-electrodes gap of the order of 1 mm and powered by a polyphase voltage; the resulting dielectrophoretic and Coulomb forces then cause the movement of particles (Louati et al, 2020, p.2).

The study aims to investigate how the efficiency of the electrostatic separation process is influenced by high voltage. This includes variations in both the amplitude (intensity) and nature (AC or DC) of the voltage applied to the process. This variation in voltage can impact the electrostatic forces acting on particles, potentially affecting the separation efficiency. The study likely involves conducting experiments where shredded printed circuit boards (PCBs)are subjected to electrostatic separation using different high voltage settings. The separated materials are then analyzed using X-ray fluorescence to assess the effectiveness of the process in terms of sorting and recycling different components from electronic boards.

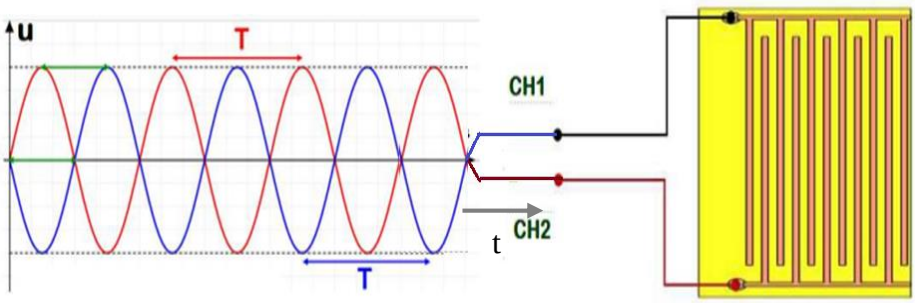
The results of this study can have practical implications for improving the recycling process of electronic waste, especially from PCBs. By optimizing high voltage and understanding its effects on the electrostatic separation process, it may be possible to increase the efficiency and effectiveness of recycling valuable materials from electronic waste while reducing environmental impact.

Experimental

Concept of moving wave conveyors

The moving wave method is an electrical phenomenon that causes particles to move by exploiting the interaction between a polarized particle and a polyphaser electric field. This electric field is generated by a set of parallel electrodes arranged in a common plane and subjected to 2, 3 or 4-phase alternating potentials as presented in Figure 1.

(a)



(b)

Figure 1
a) Experimental set-up for a sinusoidal power supply:
1) HV amplifiers, 2) Digital oscilloscope, 3) Function generator, 4) Vibrator with a regulator, 5) HV transformer,6) Two-phase, double-sided conveyor inclined at 20°, 7) Recovery tank; 8) HV connectors
b) Descriptive diagram of the two-phase conveyor feeder

When a particle is exposed to an electric field E, this induces an electric dipole moment within it. In the presence of a uniform electric field, the particle is subjected to two equal and opposite forces, which cancel out the net force, called the electrophoretic force, exerted on the particle. Unlike the polarity of the voltage, this force can be observed with AC or DC voltages. It is the dominant force in the "moving wave conveyor" type of devices.

The moving wave conveyor uses two-phase bilateral vibration excitation. This means that the conveyor electrodes are supplied with a two-phase periodic voltage, with a phase shift between them equal to π. The number of phases is denoted by "n=2". These periodic voltages generate a progressive electric field called "moving waves" in the direction perpendicular to the axes of the electrodes. This moving wave is responsible for lifting the particles deposited on the conveyor and moving them progressively.

The conveyor was mounted on an electromagnetic vibrator with the type designation "LEV2-220V-50/60HZ S3000-0.25A-37W MAX-IP66". This designation cannot be used to determine the specific type of vibratory actuator without further information.

The "220V-50/60HZ" part indicates the AC motor supply voltage, with the possibility of operating at a frequency of 50 or 60 Hz. S3000-0.25A-37W MAX" may provide information on the model or specific electrical characteristics of the motor, including rated current (0.25A), maximum power (37W), and other potential specifications. Finally, "IP66" indicates the level of protection against ingress of dust and water.

The mechanical operating frequency may be different from the mains frequency, as some vibratory conveyor systems can be designed to operate at specific frequencies depending on separation process requirements or design preferences.

For our study we varied only the material flow rate that causes the plastic granules to move and keeps the metal particles on the surface (D=0.5 g/s).

This is a set of identical parallel electrodes separated by a gap. The assembly is then coated with an insulating layer of varnish to prevent breakdown between the electrodes. Electrodes belonging to the same phase are connected together. The phases are supplied with periodic voltages with a phase shift of π, which generate a progressive field called "moving waves" in the direction perpendicular to the axes of the electrodes . The 2-phase electric field charges the deposited particles, lifts them from the substrate by electrostatic forces and propels the particle layer off the conveyor surface by a progressive wave which is none other

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than the moving wave. The dynamic forces of the non-uniform field wave thus generated overcome the adhesion and gravitational forces acting on the charged particles and transport them in a direction in the plane perpendicular to the electrodes in a progressive manner from one electrode to the other. The particle charging process is primarily a surface-dominated process and is described as follows: Particles on the interface of the thin insulating film above the embedded field electrodes are either triboelectrically charged by contact friction for non-conductive objects when placed on the surface, or inductively charged by the application of voltages to the electrodes for conductive objects. This particle separation device is an electronic printed circuit board measuring 200 x 165 mm^2, on which parallel copper electrodes 1 mm wide and 100 mm long have been made. The electrodes were made on both sides of the printed circuit, separated by the thickness of the printed circuit itself, equal to 1.5 mm. (Louhadj, 2021, p.52).

In this study, we used a mixture of crushed electronic boards recovered from cathode ray tube television sets, Figure 2. These boards are printed circuits that hold and electrically connect a set of electronic components together. In the whole world, more than 50 million tons of e-waste is generated yearly. PCBs represent the most economically attractive portion of e-waste and account for 3-5% by weight (Kaya, 2016, p.2). Waste PCBs constitute a heterogeneous mixture of metals, nonmetals and some toxic substances. A PCB assembly contains many electronic components (ECs) and organic plastic board. Waste PCBs have a metal content of nearly 30% (Cu: 10–20%, Pb: 1–5%, Sn: 1-6%, Ni: 1–3%, Fe:1-3%, Ag: 0.05%, Au: 0.03% and Pd: 0.01%), especially the purity of precious metals in PCBs is more than 10 times that of ore minerals (Zhou & Qui, 2010, p.823).

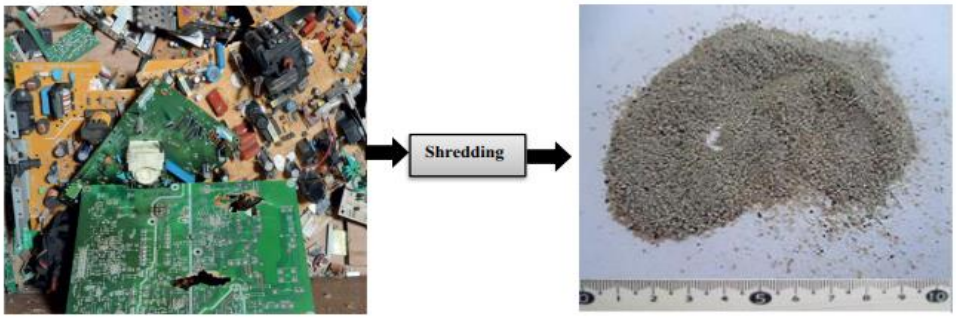

Figure 2 – Photographs of the electronic boards of a cathode ray tube before and after shredding

The experimental procedure was divided into two parts to determine the influence of the type of supply voltage and its amplitude on the attractive force applied by the moving-wave conveyors.

Experimental set-up

Sinusoidal AC high voltage:

The experimental set-up used is illustrated by the schematic description in Figure 1 .The voltage amplifier (Trek, model 2220) is one of many types in the Trek 2200 series. This series of 40 W high-voltage amplifiers offers high performance. The Model 2220 (Fig.2-7) provides precise control of output voltages in the range 0 to ± 2 kV DC or peak AC with an output current range of 0 to ± 20 mA peak AC and a wide DC bandwidth at 7.5 kHz (3 dB).

The study of variations in one quantity as a function of another requires a very rapid recording of a series of points to obtain a curve. The GDS-3000 series digital memory oscilloscope makes it possible to plot the curves corresponding to the evolution of the measurement signal directly on the screen in an experimental study with the single-sided conveyor. A mid-point transformer is used to provide a "symmetrical" voltage.

The angle of inclination of the vibrating conveyor is currently set at 20°. Parametric studies carried out by scientific researchers have shown that the optimum angle of inclination for this actuator is between 10° and 20°.

A vibrating conveyor is elastically supported by standard springs. It is designed for conveying and handling small quantities of bulk material over short distances. These feeders are ideal for applications such as dosing, mixing, weighing or continuous in-process feeding. Vibratory feeders are controlled via a 220 V - 50 Hz control box with a potentiometer in the standard configuration for precise flow rate adjustment. The chutes are made of painted sheet metal as standard.

Continuous high voltage:

For this part, a DC voltage was applied to the two-phase conveyor that varied from 0 - 30 kV with a current of 9 mA (Spellman, 30 kV, 9 mA). Using a single positive DC high voltage supply, one phase was supplied with the positive voltage and the other phase was earthed. The conveyor was attached to an electromagnetic vibrator to facilitate the movement of particles that did not stick to the conveyor surface.

Fluorescence spectrometry analysis can be used to characterize and identify the different materials present in a mixture of waste electrical and

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electronic equipment that has been separated using a moving wave conveyor.

Detecting breakdown voltage is usually a critical aspect of high-voltage systems to prevent failure or damage. Common methods of detecting breakdown voltage include the use of voltage sensors, monitoring devices, or predefined thresholds that trigger safety actions when voltage reaches critical levels.

To eliminate breakdowns in our system, we optimised the system parameters such as voltage, frequency and pulse duration to minimise the risk of breakdowns.

Coordination between the arrival of the material from the vibrating conveyor and the intensity of the discharge in this electrostatic separation system can be achieved by manual control.

The discharge intensity can be manually adjusted according to the material arrival. This can be done using manual controls or adjustable parameters on the electrostatic discharge device.

TORNADO M4 compact X-ray micro-fluorescence spectrometer:

For the analyses, X-ray fluorescence microscopy was used to identify and determine most of the chemical elements making up the samples (equipment available at the research technology platform (Algeria). This technique can be used for a wide variety of materials: minerals, ceramics, cements, metals, oils, water, glass, etc. in the solid or liquid form.

Bruker's M4 TORNADO is an advanced characterization tool that uses the small spot X-ray micro- fluorescence technique to analyze a variety of samples. This technique provides detailed information on the elemental composition and distribution of elements in samples, even at depths below the surface. Each separate material was placed individually in the excitation zone of the fluorescence spectrometer and the corresponding fluorescence spectra recorded. These are graphs representing the intensity of light emitted as a function of wavelength.

Results and discussion

Analysis of the results at high sinusoidal AC voltage:

It is possible to discern various constituents present in a waste mixture by examining their distinct spectral characteristics by applying a high sinusoidal AC voltage of 2kV. Fluorescence proves useful for detecting the presence of precious metals such as iron and copper, as well as other specific components of electronic devices, such as plastic and

glass. We used the experimental set-up illustrated in Figure 1 to obtain two samples:

Sample 1: Separated product and adhered to the surface of the moving wave conveyor.

Sample 2: The second sample of the product is separated and analyzed also in the M4 TORNADO spectrometer.

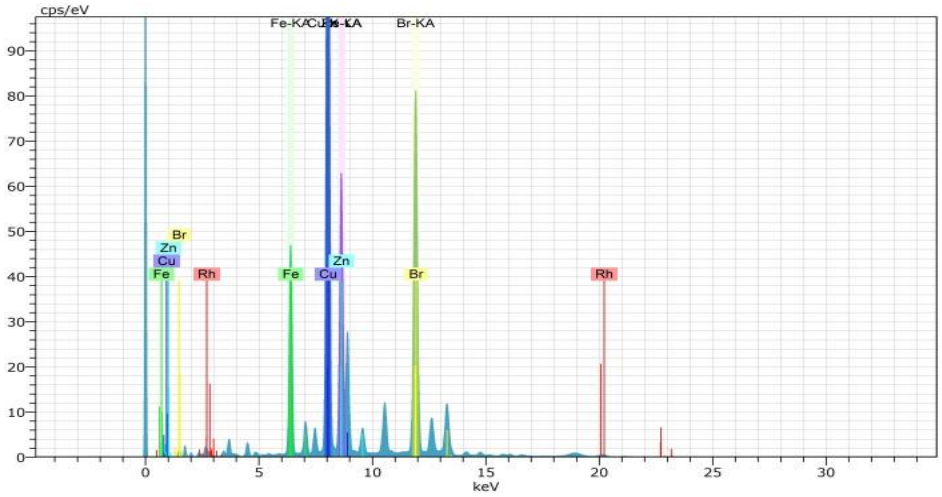

Figure 3 – X-ray fluorescence spectrum of the sample (conductor material)

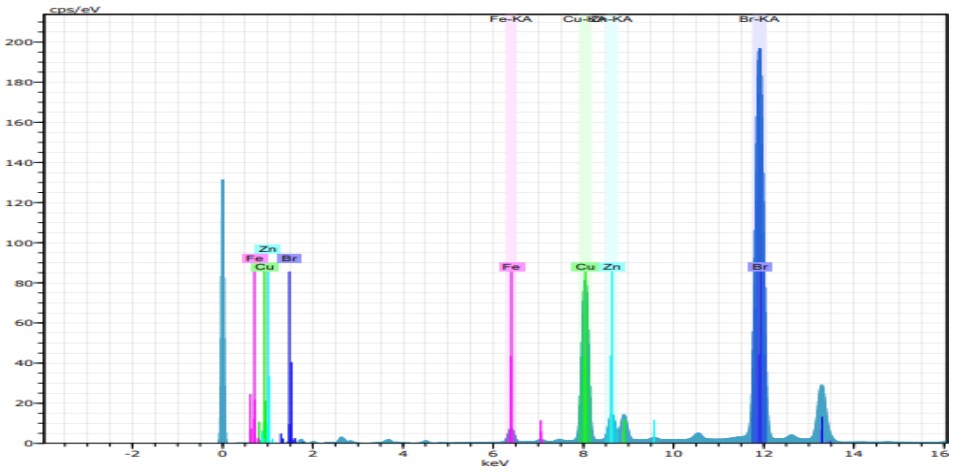

Figure 4 – X-ray fluorescence spectrum of the sample (non-conductor material)

The XRF spectra of the different samples show the elements present in each sample (Figs. 3 and 4). The intensity of the lines in the XRF spectra is associated only with the intensity of the energy, which means that the radiation is more intense for the highest lines. These lines are attributed to bromine (Br) and copper (Cu) in both samples. The elemental analysis and therefore the mass percentage of the elements present in our samples were calculated using XRF analysis software.

Table 1 – Chemical composition of samples 1 and 2 at high sinusoidal AC voltage (%)

Element	Voltage [kV]	Conductivity	Rh [%]	Fe [%]	Cu [%]	Zn [%]	Re [%]	Br [%]
Sample 1	2	Conductor	6.03	9.29	36.30	11.93	0.13	36.33
Sample 2	2	Non-conductor	<Lod	1.83	12.91	1.49	<Lod	83.77

Table 1 shows the results of the XRF analysis of the samples (1 and 2).The spectrum presented in Figure 3 shows that the sample studied is mainly composed of different chemical elements, with the following percentages: 36.30% copper (Cu), 11.93% zinc (Zn), 9.29 % iron (Fe) and 36.33% bromine (Br). It also fluoresces due to the presence of 0.34% rhodium (Rh). The spectrum shown in Figure 4 demonstrates that the sample is predominantly bromine (Br), accounting for 83.77% of its composition, while the metals copper, zinc and iron account for 15%.

In the light of the results, it appears that bromine is the predominant constituent in the chemical composition of sample 2, while sample 1 is rich in metals such as copper, zinc and iron.

Analysis of the results at high DC voltage:

By using a high DC voltage ranging from 2 kV to 8 kV, it becomes possible to distinguish different constituents present in a waste mixture by observing distinct spectral properties. To achieve this, we set up the experimental setup described in the second part, generating two samples for each test.

Further on, we present two spectra for each experiment:

Samples 3, 5, 7 and 9: of particles stuck to the conveyor surface after separation for U=2 kV, 4 kV, 6 kV and 8 kV, respectively.
Samples 4, 6, 8 and 10: of particles detached from the conveyor after vibration for U=2 kV, 4 kV, 6 kV and 8 kV, respectively.

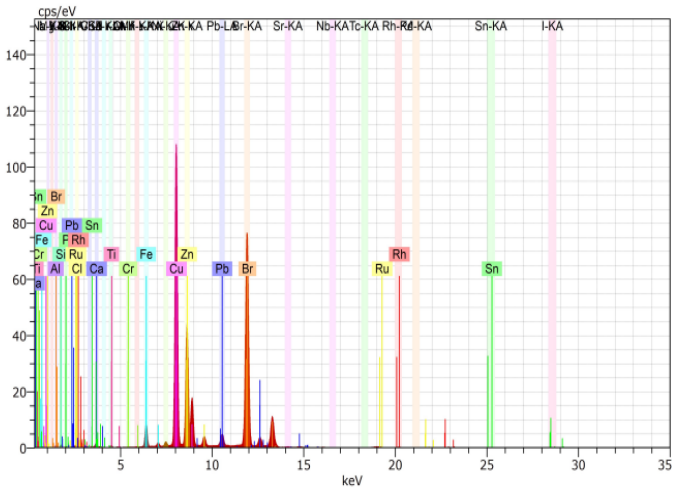

Figure 5 – X-ray fluorescence spectrum of sample 3 for U=2kV (conductor material)

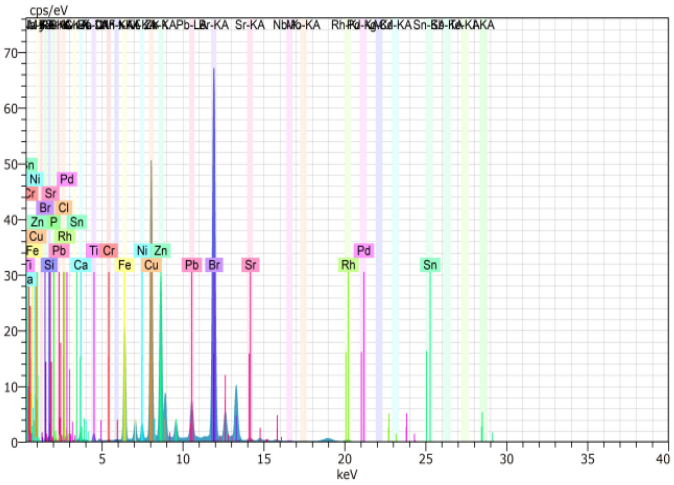

Figure 6 – X-ray fluorescence spectrum of sample 4 for U=2kV (non-conductor material)

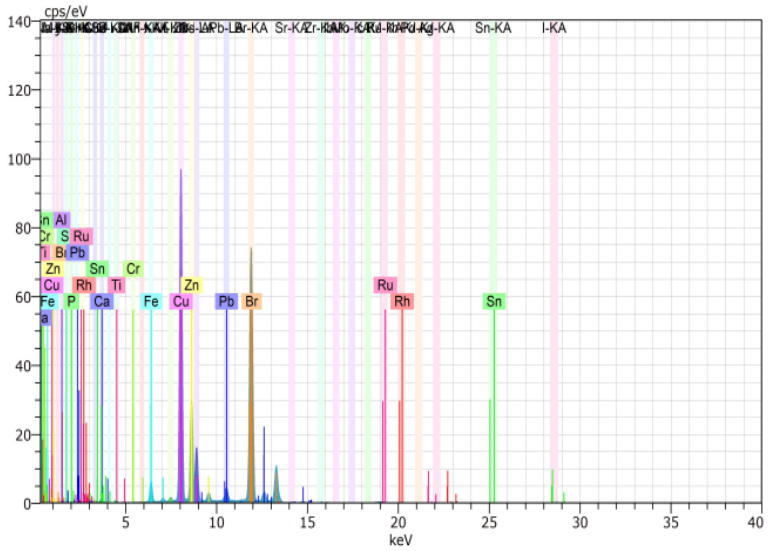

Figure 7 – X-ray fluorescence spectrum of sample 5 for U=4kV (conductor material)

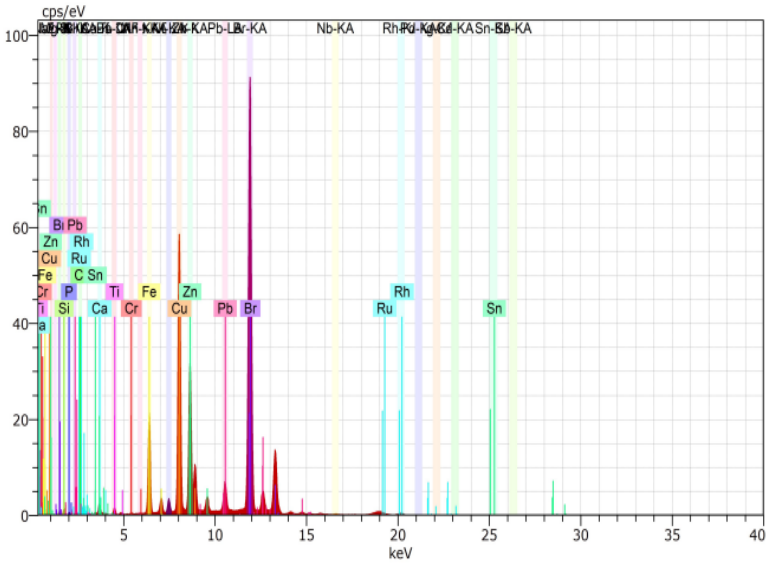

Figure 8 – X-ray fluorescence spectrum of sample 6 for U=4 kV (non-conductor material)

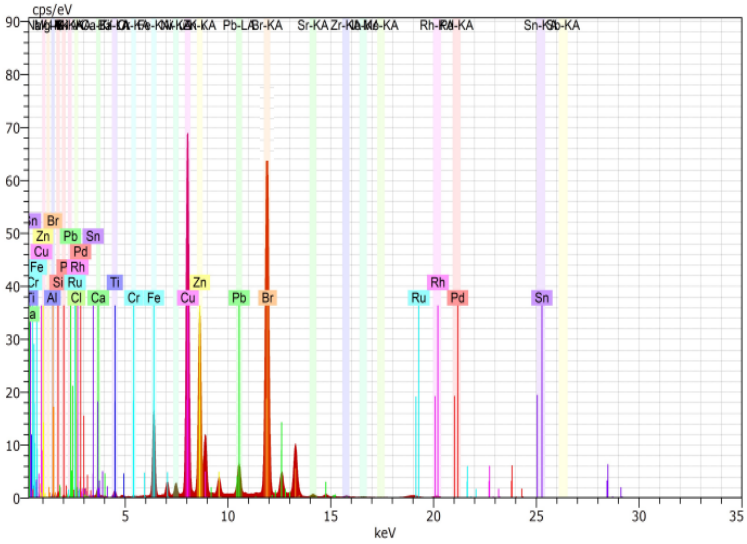

Figure 9 – X-ray fluorescence spectrum of sample 7 for U=6 kV (conductor material)

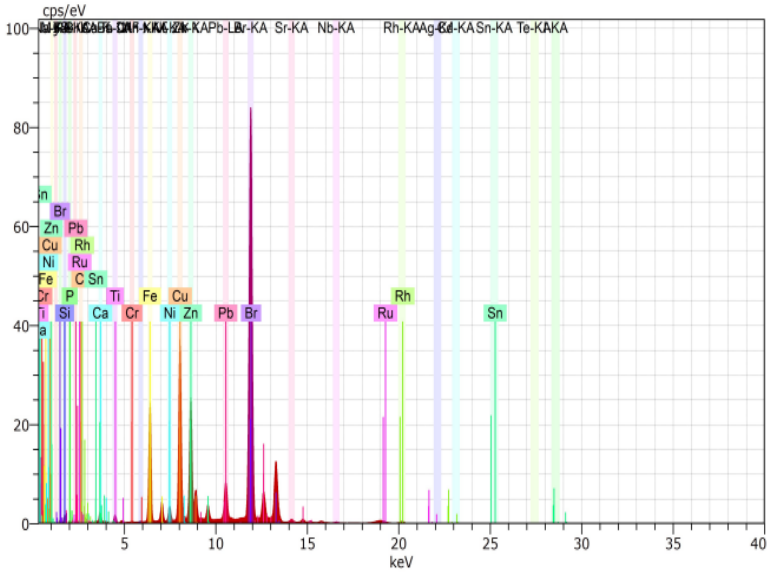

Figure 10 – X-ray fluorescence spectrum of sample 8 for U=6 kV (non-conductor material)

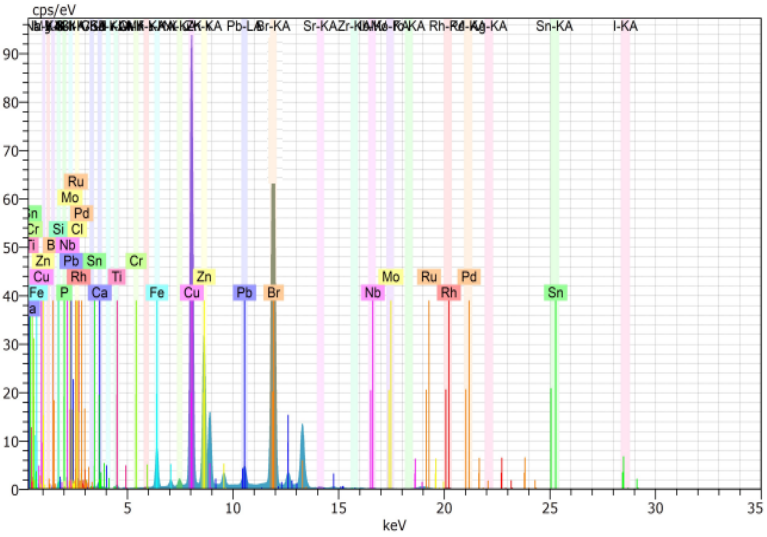

Figure 11 – X-ray fluorescence spectrum of sample 9 for U=8 kV (conductor material)

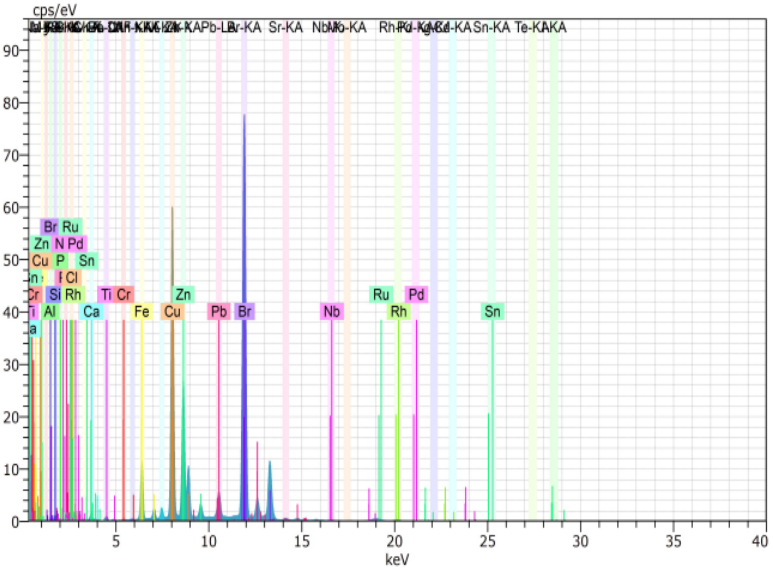

Figure 12 – X-ray fluorescence spectrum of sample for 10 for U=8 kV (non-conductor material)

The results shown in Table 2 represent the X-ray fluorescence (XRF) analyses of the samples taken after electrostatic separation of shredded TV electronic boards, followed by the application of a high DC voltage ranging from 2 to 8 kV.

The samples are divided into two categories according to their conductivity: conductive and non-conductive.Percentages indicate the relative amount of each element in the samples. Elements such as copper (Cu), iron (Fe), bromine (Br), zinc (Zn), etc., may come from electronic boards.The "<Lod" values indicate that the quantity of certain elements is below the detection limit of the analysis method used. This is due to the low concentration of these elements in the samples.

The XRF spectra of the various samples reveal the elements present in each of them. The intensity of the peaks observed in the XRF spectra is directly related to the energy emitted, meaning that the most intense lines correspond to the highest energy levels. In this context, the lines observed are attributed to copper in samples 3, 5, 7 and 9 (Figures: 5, 7, 9 and 11), while bromine is identified in samples 4, 6, 8 and 10 (Figures: 6, 8, 10 and 12).

The elemental analysis, including determination of the mass percentages of the elements present in our samples, was carried out using XRF analysis software. The results of this XRF analysis of the samples recovered from the DC electrostatic separation experiments are presented in Table 2, covering samples 3 to 10.

Table 2 – Chemical composition of samples for 3 to 10 at a high DC voltage (%)

Element	Voltage [kV]	Conductivity	Rh [%]	Fe [%]	Cu [%]	Zn [%]	Re [%]	Br [%]	Si [%]	P [%]	Pb [%]
Sample 3	2	Conductor	<Lod	13.26	57.36	6.56	0.29	19.32	3.21	<Lod	<Lod
Sample 4	2	Non-conductor	<Lod	4.02	14.61	3.25	<Lod	74.77	3.35	<Lod	<Lod
Sample 5	4	Conductor	0.33	10.98	60.55	7.28	<Lod	17.33	3.25	<Lod	0.28
Sample 6	4	Non-conductor	<Lod	4.05	10.91	3.01	<Lod	78.27	2.98	0.23	0.55
Sample 7	6	Conductor	<Lod	8.1	64.02	6.93	0.84	16.33	3.33	0.45	<Lod
Sample 8	6	Non-conductor	<Lod	3.83	10.61	2.98	<Lod	80.02	2.23	0.38	<Lod
Sample 9	8	Conductor	<Lod	7.23	68.25	6.33	<Lod	14.85	3.23	<Lod	0.11
Sample 10	8	Non-conductor	<Lod	2.95	9.91	2.03	<Lod	82.35	2.33	<Lod	0.43

The analysis of the compositions as a function of the voltages applied offers important insights into the efficiency of the electrostatic separation process applied to samples obtained from the shredding of television circuit boards. Looking at the results, significant variations in the distribution of elements are apparent. Samples subjected to higher voltages, such as those at 8 kV, show important percentages of certain conductive elements, notably copper (Cu) 68.25%, while for non-conductors there is a significant recovery of bromine which exceeds 82%.

This observation suggests that the application of a higher voltage promotes more efficient separation of conductive components from electronic boards, resulting in a higher concentration of these elements in the samples. This correlation between the applied voltage and the composition of the samples offers valuable indications for optimizing the electrostatic separation process, highlighting the possibility of adjusting the voltage to improve the specific recovery of precious metals or other valuable elements. These results provide a useful basis for refining the process parameters and maximizing the efficiency of electrostatic separation in the recycling of electronic waste.

Conclusion

In conclusion, the XRF analysis of the samples reveals distinct compositions, shedding light on the elemental makeup of shredded printed circuit boards (PCBs) subjected to electrostatic separation.

The observed variations in the composition are further emphasized when considering the influence of the applied voltages on the electrostatic separation process. Notably, higher DC voltages, such as 8 kV, result in a more efficient recovery of conductive elements, particularly copper (68.25%), while non-conductive elements, such as bromine, are significantly recovered, exceeding 82%. This correlation between voltage and composition provides crucial insights for process optimization, indicating the potential to tailor voltage parameters for enhanced recovery of precious metals and valuable elements.

The influence of the amplitude and the nature of the supply voltage to the travelling wave conveyor revealed promising results. Sinusoidal voltages of 2 kV showed superior performance compared with DC voltages, even at high values (from 2 kV to 8 kV). For example, an AC voltage of 2 kV recovered around 65% of conductors and 83% of non-conductors, exceeding the proportions obtained with a DC voltage of 8 kV. In conclusion, AC voltage appears to offer significant advantages in this context. These findings lay a solid foundation for refining electrostatic separation processes, contributing to the efficient recycling of electronic waste.

References

Ghosh, B., Ghosh, M.K., Parhi, P., Mukherjee, P.S., Mishra, B.K. 2015. Waste Printed Circuit Boards recycling: an extensive assessment of current status. *Journal of Cleaner Production*, 94, pp.5-19. Available at https://doi.org/10.1016/j.jclepro.2015.02.024

Iuga, A., Calin, L., Neamtu, V., Mihalcioiu, A. & Dascalescu, L. 2005. Tribocharging of plastics granulates in a fluidized bed device. *Journal of Electrostatics*, 63(6-10), pp.937-942. Available at: https://doi.org/10.1016/j.elstat.2005.03.064.

Kaya, M. 2016. State of the art in printed circuit board (PCB) recycling technology. In: *15th International Mineral Processing Symposium*, Istanbul, Turkey, pp.1182-1219, October 19-21 [online]. Available at: https://www.researchgate.net/publication/309576564_State_of_the_Art_in_Printed_Circuit_Board_PCB_Recycling [Accessed: 20 December 2023].

Louati, H., Tilmatine, A., Ouiddir, R., Alibida,, A. & Zouzou, N. 2020. New separation technique of metal/polymer granular materials using an electrostatic sorting device. *Journal of Electrostatics*, 103, art.number:103410. Available at: https://doi.org/10.1016/j.elstat.2019.103410.

Louhadj, S. 2021. *Contribution to the study of the separation of micronized particles using mobile wave conveyors*. PhD thesis. Sidi Bel Abbès, Algeria: Djillali Liabes University [online]. Available at: http://rdoc.univ-sba.dz/handle/123456789/3514 [Accessed: 20 December 2023].

Lu, B., Yang, J., Ijomah, W., Wu, W. & Zlamparet, G. 2018. Perspectives on reuse of WEEE in China: Lessons from the EU. *Resources, Conservation and Recycling*, 135, pp.83-92. Available at: https://doi.org/10.1016/j.resconrec.2017.07.012.

Mimouni, C., Tilmatine, A., Rahou, F.Z. & Dascalescu, L. 2017. Numerical simulation of a tribo-aero-electrostatic separator of ternary plastic granular mixture. *Journal of Electrostatics*, 88, pp.2-9. Available at https://doi.org/10.1016/j.elstat.2017.01.015.

Zhou, Y. & Qiu, K. 2010. A new technology for recycling materials from waste printed circuit boards. *Journal of Hazardous Materials*, 175(1-3), pp.823-828. Available at: https://doi.org/10.1016/j.jhazmat.2009.10.083.

Reciclaje de placas de circuito impreso (PCB) trituradas mediante transportadores bifásicos de ondas móviles de dos fases

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CAMPO: ingeniería mecánica, materiales, tecnología química
TIPO DE ARTÍCULO: artículo científico original

Resumen:

Introducción/objetivo: El objetivo de este estudio es demostrar la viabilidad de la separación electrostática de mezclas de placas de circuitos impresos (PCB) trituradas, en asociación con el análisis de fluorescencia de rayos X, y examinar simultáneamente cómo influye en la eficienciade este método por el suministro de voltaje, tanto en términos de amplitud como de naturaleza.

Métodos: Se utiliza la técnica de separación electrostática mediante un transportador bifásico de ondas móviles con análisis de caracterización mediante fluorescencia de rayos X para justificar la eficacia del proceso estudiado.

Resultados: Los resultados de este estudio pueden tener implicaciones prácticas para mejorar el proceso de reciclaje de desechos electrónicos, especialmente de placas de circuitos impresos (PCB). Mediante la optimización de la alta tensión y la comprensión de sus efectos en el proceso de separación electrostática, puede ser posible aumentar la eficiencia y la eficacia del reciclaje de materiales valiosos de los desechos electrónicos, reduciendo al mismo tiempo el impacto ambiental.

Conclusión: El análisis XRF de las muestras revela composiciones distintas. Las variaciones observadas son aún más marcadas si se considera la influencia de los voltajes aplicados en el proceso de separación electrostática.

Palabras claves: reciclaje, medio ambiente, residuos de aparatos eléctricos y electrónicos; transportador bifásico de ondas móviles; fluorescencia de rayos x, alta tensión.

Переработка измельченных печатных плат (ПП) с помощью двухфазных волновых конвейеров

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Университет Мохамеда Бен Ахмеда д'Орана 2, Институт технического обслуживания и промышленной безопасности,
г. Оран, Алжирская Народная Демократическая Республика

РУБРИКА ГРНТИ: 47.59.49 Печатные платы. Печатные узлы
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: Цель этого исследования − продемонстрировать возможность электростатической сепарации измельченных печатных плат (ПП) в сочетании с рентгенофлуоресцентным анализом а также изучить, как на эффективность этого метода влияют колебания и характер питающего напряжения.

Методы: Для подтверждения эффективности исследуемого процесса используется метод электростатической сепарации с помощью двухфазного волнового конвейера с подвижным потоком и анализ характеристик с использованием рентгеновской флуоресценции.

Результаты: Результаты данного исследования могут использоваться на практике для улучшения процесса переработки электронных отходов, особенно печатных плат (ПП). Оптимизация высокого напряжения и понимание его влияния на процесс электростатической сепарации способствуют эффективности и результативности переработки ценных материалов из электронных отходов, одновременно снижая негативное воздействие на окружающую среду.

Выводы: Рентгенофлуоресцентный анализ образцов выявил различия в их составе. Наблюдаемые различия становятся еще более заметными, если учесть влияние напряжения, используемого в процессе электростатической сепарации.

Ключевые слова: рециклинг, окружающая среда, отходы электрического и электронного оборудования, двухфазный волновой конвейер, рентгенофлуоресценция, высокое напряжение.

Рециклирање уситњених штампаних плоча (ПЦБ) помоћу двофазне таласне покретне траке

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ОБЛАСТ: машинство, материјали, хемијске технологије
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: Ова студија има за циљ да демонстрира изводљивост електростатичког одвајања елемената смеша насталих од уситњених штампаних плоча (ПЦБ), заједно са рендгенском

Mimouni, C, Recycling of shredded printed circuit boards (PCBs) by two-phase moving wave conveyors, pp.708-726

флуоресцентном анализом, као и да испита како на ефикасност ове методе утичу амплитуда и природа напона напајања.

Методе: У техници електростатичког одвајања користи се двофазна таласна покретна трака са рендгенском флуоросцентном анализом с циљем да се образложи ефикасност проучаваног процеса.

Резултати: Резултати ове студије могу бити значајни за побољшање процеса рециклирања електронског отпада, нарочито оног насталог од штампаних плоча (ПЦБ). Оптимизација високог напона и разумевање његовог утицаја на процес електростатичког одвајања могу да повећају ефикасност и ефективност рециклирања вредних материјала из електронског отпада, уз истовремено смањивање утицаја на животну средину.

Закључак: Рендгенска флуоресцентна анализа узорака открива њихове карактеристичне саставе. Уочене варијације су још приметније ако се узме у обзир утицај напона коришћеног у процесу електростатичког одвајања.

Кључне речи: рециклирање, животна средина, опрема за електрични и електронски отпад, двофазна таласна покретна трака, рендгенска флуоресценција, високи напон.

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Supervised machine learning algorithms for brain signal classification

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FIELD: biomedical engineering
ARTICLE TYPE: original scientific paper

Abstract:

Introduction/purpose: The brain wave application is widespread in recent years, especially in the applications that aid the impaired people suffered from amputation or paralysis. The objective of this research is to assess how well different supervised machine learning algorithms classify brain signals, with an emphasis on improving the precision and effectiveness of brain-computer interface applications.

Method: In this work, brain signal data was analyzed using a number of well-known supervised learning models, such as Support Vector Machines (SVM) and Neural Networks (NN). The data set was taken from a previous study. Twenty five participants imagined moving their right arm (elbow and wrist) while the brain signals were recorded during that process. The dataset was prepared for the analysis by the application of meticulous pre-processing and feature extraction procedures. Then the resulting data were subjected to classification.

Results: The study highlights how crucial feature selection and model modification are for maximizing classification results. Supervised machine learning methods have great potential for classifying brain signals, particularly SVM and NN.

Conclusion: The use of SVM and NN has the potential to completely transform the creation of cutting-edge brain-computer interfaces. The integration of these models with real-time data should be investigated in future studies.

Keywords: supervised machine learning, EEG, brain signals, classifications, feature extraction.

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Introduction

The field of electroencephalography (EEG) signal processing lies at the crossroads of neuroscience and machine learning, with far-reaching implications for comprehending and interpreting complicated cerebral activities. This work describes a game-changing breakthrough in the categorization of EEG data accomplished by the methodical use of supervised machine learning techniques. The research expands on a dataset from a prior study, in which the categorization accuracy of EEG signals was 65%. This study effectively increased classification accuracy to 95% by utilizing sophisticated algorithms such as Support Vector Machines (SVM), K-Nearest Neighbors (KNN), and Optimized Ensemble techniques. This large improvement in accuracy not only contributes significantly to the study of neural signal analysis, but it also opens up new pathways for practical applications in medical diagnostics, neurotherapeutic methods, and the creation of complex brain-computer interfaces. The improved capacity to identify EEG data with such high precision is critical in interpreting the complicated patterns of brain activity, with implications for understanding and treating neurological illnesses, improving cognitive capacities, and building adaptive neurotechnology.

The brain signals are oscillating electrical impulses occurring in the brain tissue; these impulses have different frequencies depending on the mental state or the activity. Slow waves are related to deep sleep while fast waves are associated with active thoughts and speech. The brain is connected to the rest of the organs through nerves; these nerves are just like telephone wires that connect homes together all around the world. When a human being wants to move an organ, let us say the hands, the brain sends signals to the hands to inform the muscles to contract. In fact, the nerves send a lot of electrical impulses called action potentials to different muscles in the hands allowing the movement in extreme precision.

A Brain-Computer interface (BCI) or Brain-Machine interface (BMI) is a device that is designed to read or decode a signal from the brain to directly control external devices such as Prosthetics, Wheelchair, or a robot. The BCI system acquires signals from the brain and, with the help of the signal processing techniques, translates them into control commands that provide real-time feedback to the user.

The chain process of the common BCI (Figure 1) system has several stages starting with:

- Amplification and digitizing of the analogue signal collected from the electrodes using analogue-to-digital conversion,

- Signal processing of the signal (removing noise and artifacts),
- Feature Extraction, and
- Classification.

The BCI has several types depending on the signal recording methods: Invasive, Semi-Invasive, and Non-Invasive. The Invasive and Semi-Invasive methods provide more accurate signals, higher bandwidth, better spatial resolution, and less artifacts than the Non-Invasive one. The Non-Invasive method is generally easier in signal recordings and does not require surgical intervention as the previous two methods.

Machine Learning (ML) algorithms are programs that can learn the hidden patterns from the data, predict the output and improve the performance. There are different types of algorithms used in ML as shown in Figure 2. This figure shows three types of algorithms: Supervised, Unsupervised and Reinforcement learning.

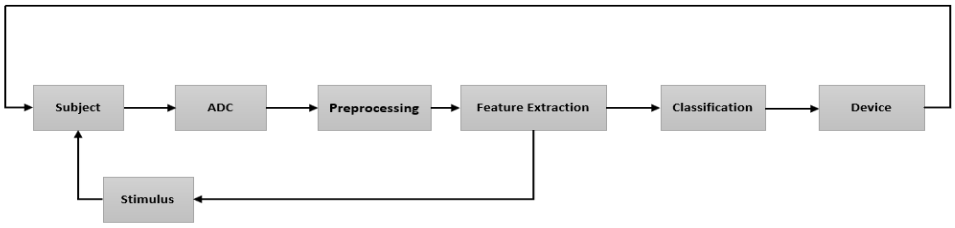

Figure 1 – BCI system components

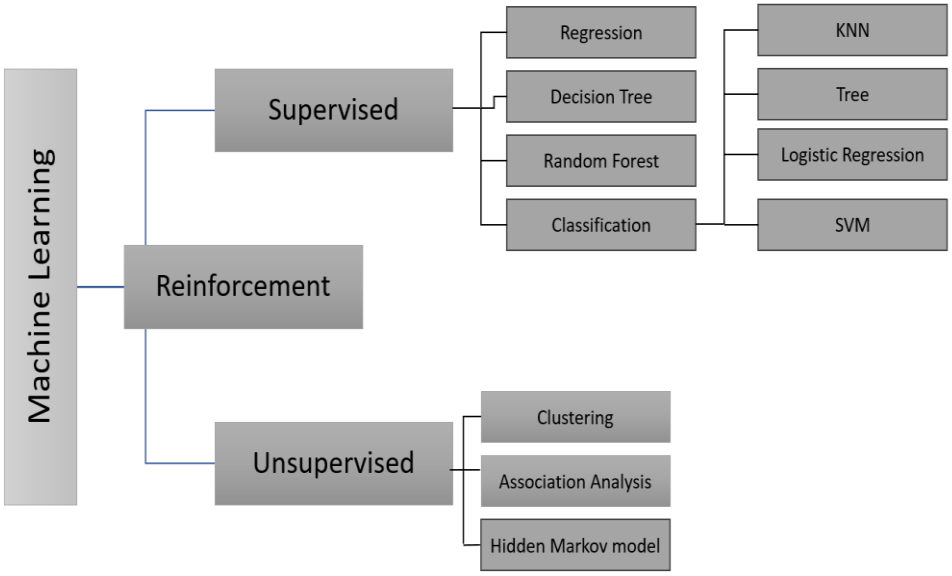

Figure 2 – ML types

In Supervised learning, as indicated by the name, the machine needs external supervision to learn. The Supervised learning models are trained using labeled datasets. Once training and processing are done, the model is tested by providing sample test data to check whether it predicts the correct output or not. Supervised learning is divided into: Classification and Regression. Unsupervised learning is the type where the machine does not need external supervision to learn from the data. The unsupervised model can be obtained using the unlabeled dataset that is not classified, nor categorized and the algorithm needs to act on that data without any supervision. The types of unsupervised algorithms are Clustering and Association. Reinforcement learning is a type where the agent interacts with the environment by performing actions and learn with the help of feedback. There are several studies regarding using ML algorithms for the classification of brain data. Amin et al (2017) proposed a pattern recognition approach. They used four types of classifiers: K-nearest neighbors (KNN), Support Vector Machine (SVM), Multi-layer Perceptron (MLP), and Naïve Bayes (NB). For low frequencies 0-3.91 Hz, the accuracy achieved using SVM for A5 approximate coefficient was 99.11%. For detailed coefficients D5, two algorithms were used: SVM and KNN with the accuracy of 98.57% and 98.39%, respectively. For higher frequencies, 3.91-7.81 Hz, the other algorithms were used for A5 and D5 coefficients. MLP(A5-D5) with 97.11-89.63%, respectively, and NB(A5-D5) with 91.6-81.07%, respectively. De Brito Guerra et al (2023) developed a machine learning model based on the Random Forest algorithm to classify EEG signals from subjects performing real and imagery motor activities. In another work by Ramírez-Arias et al (2022), they used 9 machine learning algorithms to classify a signal related with a real motor movement. They indicate that medium Artificial Neural Network was the best algorithm with the area under the curve of 0.9998 and losses with 0.0147. Huang et al (2020) presented a classification methodology using sparse representation and Fast Compression Residual Convolutional Neural Networks (FCRes-CNNs). Their work achieved the accuracy of 98.82%. Wen et al (2021) proposed a deep network model for autonomous learning and the classification of EEG signals. The model can self-adapt to classify EEG signals with different frequencies. Despite the artificial design feature, the extraction method was not able to obtain stable classification results; the model had a better classification accuracy with short length signals. Paez-Amaro et al (2022) used four algorithms: Common Spatial Patterns (CSP) combined with Linear Discriminant Analysis (LDA), Deep Neural Network (DNN), Convolutional Neural Network (CNN), and finally

Riemannian Minimum Distance to Mean (RMDM). The mean accuracy for these algorithms were 8%, 66%, 60% and 80%, respectively.

In this study, six ML algorithms were used to increase the accuracy of the former study from Ma et al (2020). The algorithms used were: Optimal SVM, Fine SVM, Optimal KNN, Optimal Decision Tree, Optimal NN, and optimized Ensemble.

Methodology

Dataset

The data for this work was made available by Ma et al (2020) and each trial had been approved by the ethics board at the Institute of Automation, Chinese Academy of Sciences. A total of 25 healthy, right-handed subjects were polled. (19 males, 6 females). The participant had no Mi-based BCI knowledge. It is important to mention that all the experiments were approved by the Ethical Committee of the Institute of Automation, Chinese Academy of Sciences.

Method of recording signals

The data signals were selected from Ma et al (2020), as mentioned in the previous section. In order to completely comprehend the scenario, it is critical to describe the way by which the signals were recorded. The subjects reclined in a comfortable chair, their hands naturally resting on their legs, and looked at the screen from one meter away, Figure 3(a). Every trial lasted 8 seconds and began with a white circle in the middle of the screen for two seconds, as illustrated in Figure 4.

Then, a red circle flashed for one second as a signal to assist people focus on the coming goal. Before the desired reaction was required, the "Hand" or "Elbow" cue was presented for 4s. The participants were instructed to visualize doing the needed activity with their entire bodies, rather than simply their eyes, during this time. The participants were told to relax their limbs and think about whatever they wished. EMGs were recorded from the right hands and forearms of the subjects, Figure 3(b), to ensure they were not acting on their own initiative. (The EMG signals were eliminated during the EEG preprocessing.

Finally, the "Break" for 1s was enough to put an end to the 8s experiment and relax. During the interval, patients were instructed to relax and reduce ocular and muscular activity.

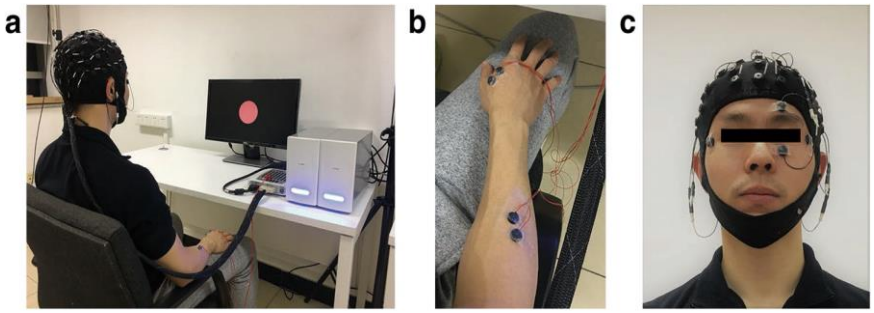

Figure 3 – Data recording

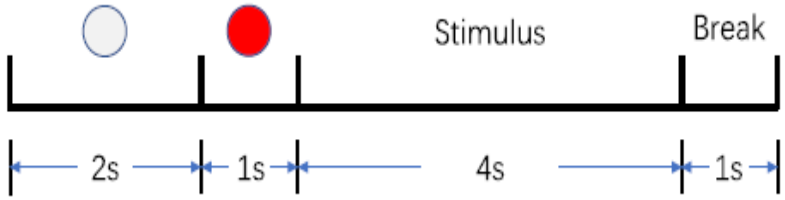

Figure 4 – Time period of one trial

The motor-related processes alpha (8-13 Hz) and beta (14-30 Hz) are associated with event-related synchronization and desynchronization (ERS/ERD). When the actual action is performed or anticipated, ERD manifests as a decrease in a certain frequency component associated with an increase in brain activity. What makes any enhanced frequency sensitive, or ERS, is an increase in a certain frequency component. Because it is connected to the suppression of brain activity, it can sometimes be detected even when no actual action is being done or imagined.

Researchers have recently uncovered a strong correlation between a specific sensory brain area and the ability to envisage moving certain parts of the body (as shown in Figure 5). In the picture, the dark blue region in the middle of the brain is in charge of directing the motion of the limbs. The pale cyan area is in charge of guiding hand movement.

After everything is said and done, the region above the ears is in charge of moving things like the cheekbones and the lips. ERD in the dominant brain and ERS in the nondominant hemisphere can be caused by motor imagery. Figure 6 depicts the spectrum strength of the brain frequency ranges (indicated in red).

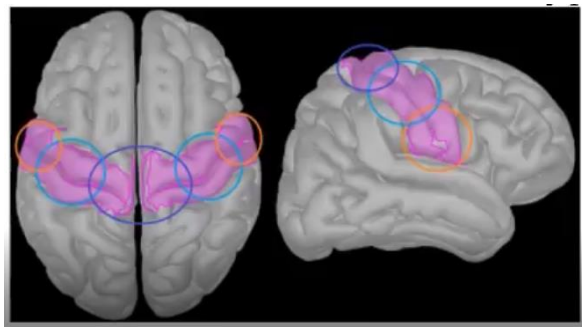

Figure 5 – Regions of motor imagery

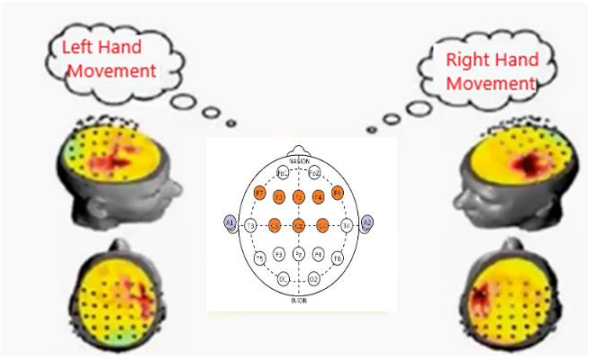

Figure – 6 BCI System for motor imagery signal recording

Using a Neuroscan SynAmps2 amplifier and a 64-channel electrode cover, the conventional 10/20 system was utilized to acquire EEG data at a sampling rate of 1000 Hz. For the electroencephalogram (EEG) recordings, the left mastoid was employed as a reference. Throughout the trial, the electrode impedances were maintained below 10 k ohm. The acquired data was cleaned up in MATLAB (R2015a) using the EEGLAB toolbox (v14.1.1_b). We used a common average reference (CAR) in the early phases of processing. A low-pass filter with a frequency of 40 hertz and a high-pass filter with a frequency of 0.1 hertz were installed. To save processing expenses, the input was down sampled to 200Hz. The EEG was cleaned of anomalies associated to the eyes and muscles using automatic artifact removal (AAR). The data set was preprocessed in [7] and became ready for feature extraction. The wavelet transform is a non-stationary time-scale analytic method that may be used with EEG data. It is extremely useful to be able to evaluate non-stationary signals and break them down into discrete frequency components over a wide range of

timeframes. WT allows researchers to condense complicated biological signals comprised of several time-varying data sets into a digestible collection of diagnostic variables (Amin et al, 2017).

The continuous and discrete Wavelet transform formula are both given in equations (1) and (2).

$$WT_x(a,\tau) = \frac{1}{\sqrt{a}}\int_{-\infty}^{\infty} x(t)\psi * \frac{(t-\tau)}{a}\,dt \quad (1)$$

Continuous Wavelet Transform

where a represents scale displacement, τ represents time displacement, and ψ is a wavelet basis function, including Hear, db.Series, Coiflet, etc.

$$WT_x(j,k) = \int x(t)\psi^*_{j,k}(t)dt \quad (2)$$

Discrete Wavelet Transform

The DWT (Discrete Wavelet Transform) is used to discretize scale and displacement by limiting the end of the wavelet basis function (a,). Figure 7 displays the DWT breakdown of the EEG signal x(n). Convolution is a two-function multiplication method that uses the low-pass or high-pass filter coefficients and is then processed using own sampling. To down sample, the sample signal must be cut in half (reduced). Wavelet signals are classified into two types: approximation signals and detail signals. An approximation is a signal produced by the convolution of the original signal with a low-pass filter, whereas a detail is produced by the convolution of the original signal with a high-pass filter. Figure 7 shows that each output generates a detailed signal D and an approximation signal A, with the more recent one acting as the input for the phase that follows. The main frequency component of the EEG data dictates how many layers the wavelet decomposes.

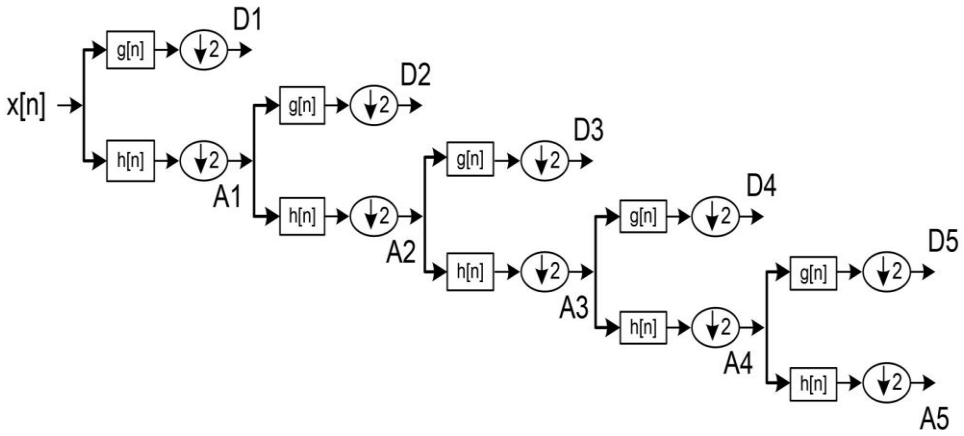

Figure 7 – Wavelet decomposition

The formula of WT and the filter h, is a low pass and can be formulated in the formulation as follows:

$$H\ (z)\ H\ (z-1)\ +\ H\ (-z)\ H\ (-z-1)\ =\ 1 \quad (3)$$

In the above formula, $H\ (z)$ is used to represent the h, z-transform filter and the complement transformation of this high-pass filter is expressed as:

$$G\ (z)\ =\ zH\ (-z-1). \quad (4)$$

According to the Section above, DWT is used to evaluate the spectrum components of EEG data. The EEG signal analysis relies heavily on WT, specifically the careful selection of a wavelet and the optimal number of breakdown stages. The number of thresholds is calculated based on the primary frequency component of the EEG data. In order to classify signals, the levels are chosen such that the wavelet coefficients maintain a strong connection between the various parts of the signals and the requisite frequencies. The analysis was performed using five distinct degrees of decomposition. Therefore, the EEG data is segmented into D1-D5 details and a final method, A5.

Multiple wavelet varieties are typically tested to find the most effective combination for a particular application. As a result of its Daubechies wavelet feature, second order (db2) filtering is more adept at detecting variations in the input signal. Therefore, wavelet coefficients were generated using db2 for this study.

For the Daubechies wavelet of the second order (db2), the band frequencies are as follows, with a sampling frequency of 256 Hz: D1 (64-128 Hz); D2 (32-64 Hz); D3 (16-32 Hz); D4 (8-16 Hz); D5 (4-8 Hz); and A5 (2-4 Hz). (0 - 4 Hz). To determine discrete wavelet values, MATLAB is used. Because even the most effective classifier will fail with a badly selected input feature, this is a crucial factor in the design of artificial neural networks based on pattern categorization. Determining the wavelet discontinuous coefficient provides a representation of the signal's energy across time and frequency. For this reason, the discontinuous wavelet coefficient calculated from the EEG signal of each record serves as the feature vector used to characterize the signal. The size of the recovered feature vector is reduced by using statistics on top of the collection of wavelet coefficients. The temporal frequency distribution of the signals under study is represented by the statistical characteristic listed below:

- Means and standard deviation value,
- Variance,
- Skewness,
- Kurtosis, and
- Root Mean Square.

In this paper, the data needed for the right arm is collected from C3 channel as explained in Section 3. In order to retrieve the features for the EEG data prior to classification, a code is developed in MATLAB for this wavelet.

Means and Standard Deviation Value

The definition of the mean is very simple as it is the sum of all the signals divided by the number of the signals.

$$\mu = \frac{1}{N}\sum_{i=0}^{N-1} X_i \quad (5)$$

The expression |X_i-μ| indicates the difference between the deviation of the sample and their mean. The average deviation can be found by the sum of all the derivative of the sample signals and dividing by the total number of samples. The standard deviation is similar but the average is done by power instead of amplitude as shown in equation (6).

$$\sigma = \sqrt{\frac{1}{N-1}\sum_{i=0}^{N-1}(x_i - \mu)^2} \quad (6)$$

Variance

It is the variability measure. In order to determine the variance, the average cubed departure from the mean is used as the denominator. The extent of dispersion in a data collection can be better understood by examining its variance. The variance from the mean increases as data spreads out.

$$\sigma^2 = \frac{1}{N-1}\sum_{i=0}^{N-1}(X(i) - \mu)^2 \quad (7)$$

Skewness

Skewness is a statistical measure of the degree to which a signal deviates from its mean value. To compute it, divide the cubed standard deviation by the cubed mean variation.

$$\gamma = \frac{1}{(N-1)\sigma^3}\sum_{n=0}^{N-1}(x_n - \mu)^3 \quad (8)$$

Kurtosis

It is the Kurtosis of the signal that determines its Peakedness. More peaks in the waveform correspond to a greater kurtosis number.

$$K = \frac{\frac{1}{N-1}\sum_{i=0}^{N-1}(x_i^4)}{(\frac{1}{N-1}\sum_{i=0}^{N-1}(x_i^2))^2} \quad (9)$$

Root Mean Square

It is a quantitative representation of the signal's intensity. The signal's magnitude is determined using the root-mean-square formula. The strength is represented by the range. The root-mean-square deviation provides a measure of the variability in the system's response to external factors.

$$R.M.S = \sqrt{\frac{1}{N-1}\sum_{i=0}^{N-1} x_i^2} \quad (10)$$

Machine learning algorithms

Machine learning algorithms are a critical component of the fast-evolving science of artificial intelligence. These algorithms allow computers to learn from data and make predictions or choices without the need of human instructions. Here is a quick rundown of some of the most common types of machine learning algorithms:

1. Supervised learning: In this sort of learning, algorithms are trained using labeled training data—that is, data that has already been assigned the right answer. Based on this data, the algorithm predicts things and is adjusted if it gets it wrong. For continuous outputs, common examples include logistic regression or support vector machines for classification methods, and for categorical outputs, linear regression.
2. Unsupervised learning: In this type of learning, data is sent to the algorithm without clear instructions on how to handle it. Finding some organization in the data through exploration is the aim. Clustering methods like K-means or hierarchical clustering, as well as dimensionality reduction algorithms like Principal Component Analysis (PCA), are examples of common unsupervised learning algorithms.
3. Semi-Supervised learning: This method falls in between unsupervised and supervised learning. Here, both labeled and unlabeled data are used to train the algorithm. When obtaining a properly labeled dataset is costly or time-consuming, this approach might be helpful.
4. Reinforcement learning: In this method, an algorithm gains decision-making skills by acting in a way that advances its objective in the environment. Rather than being informed directly of its errors, it learns from the results of its actions. This method is frequently applied in gaming, navigation, and robotics.

5. Deep learning: A branch of machine learning that makes use of multi-layered neural networks, or "deep networks," to assess different aspects of data. Deep learning is very effective for voice and picture recognition applications.

Every kind of machine learning algorithms has advantages and disadvantages, and it may be used to many kinds of jobs. The type of data and the particular needs of the work are major factors in selecting an algorithm. In this paper, the supervised machine learning algorithms were applied to the data for classification. The main idea of Supervised ML is mapping between the input output of that data. In order to accomplish this task, the algorithm receives training data. Training data consists of input and output pairs. Inputs are multidimensional vectors that represent relevant information about the signal states (which in our case are the brain signal states) or activities to be decoded. Typically, raw data is used to create features which are then manually optimized through feature engineering to identify the most promising or relevant ones. Training involves learning the mapping between features and desired outcomes. The response variable, also known as the dependent variable, refers to the output of interest linked with these traits, such as brain state or behavior. During the training phase, the model learns to map the input characteristics to target variables by optimizing model parameters, which can be achieved through minimizing the cost function. The model performance is indicated by the loss or error estimated by the cost function. There are several algorithms that have the ability to minimize the cost function, but the most common one is gradient descent. An acceptable machine algorithm model consists of training and testing sets. The testing set should never be evaluated by the algorithm during the training phase. It should accurately depict the model's actual setting. The testing results should be as good as the training sets. Figure 8 represents the machine learning architecture.

The algorithms used were Support Vector Machine and Neural Network.

Support Vector Machine

Although it may also be used for regression, Support Vector Machine (SVM) is a strong and adaptable supervised machine learning technique that is mostly utilized for classification problems. Given that it can handle both linear and non-linear data, many difficult classification tasks benefit greatly from its use. SVM tends to find the most adequate dividing boundary (Linear or Hyperplane). SVM locates the hyperplane with the

highest margin for a two-class classification issue, which indicates that it is the farthest from the closest data points in each class. Support vectors, which are these closest points, are essential for establishing the hyperplane (Ahmed et al, 2022; Al-Hamadani, 2023).

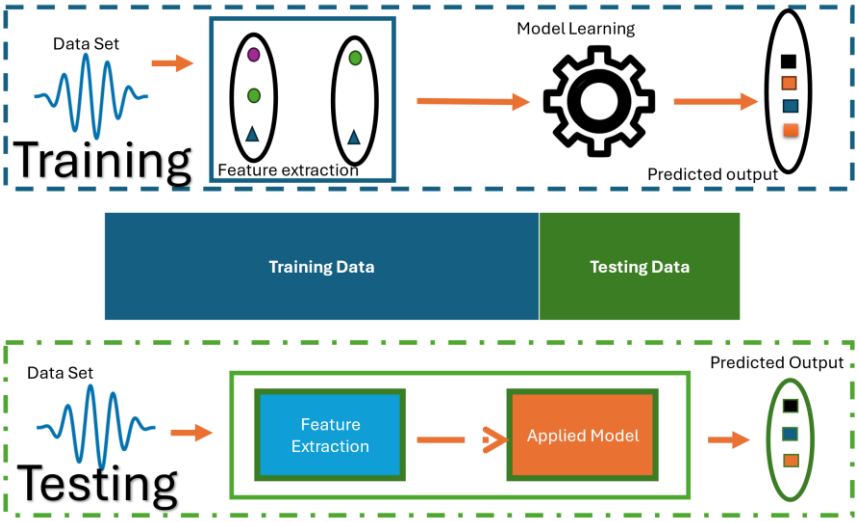

Figure 8 – Architecture of machine learning

Neural Network

A neural network that is intended to be optimized or enhanced over time is referred to as an "optimizable neural network". A neural network's optimization often focuses on enhancing its performance in certain tasks, such as predictive modeling, language processing, or image recognition (Ortega-Fernandez et al, 2024) Below are some key concepts related to optimizable neural networks:

1- Learning algorithm: An optimizable neural network's learning algorithm is its most important component. This approach, which is frequently a variation of gradient descent, modifies the network's weights in response to input. The objective is to reduce the deviation, sometimes referred to as the cost or loss, between the network's predicted and actual results.

2- Backpropagation: Backpropagation is a common optimization technique in neural networks, particularly in deep learning models. It is a technique for quickly calculating the gradients of the loss

function in relation to the network weights. The weights are then updated using this knowledge to lessen the loss.

3- Hyperparameters: These are the configurations or settings that control the neural network's general behavior but are left alone while it learns. Learning rate, batch size, and the number of network layers are a few examples. An essential step in neural network optimization is fine-tuning of these hyperparameters.
4- Regularization and Overfitting: Overfitting is the process by which a network gets excessively specialized to the training set and underperforms when exposed to fresh, untested data. Through the use of regularization techniques like dropout, weight decay, or early halting, overfitting is prevented, improving the network's generalizability and real-world performance.
5- Data Preprocessing: The performance of the network can be greatly impacted by the way data is prepared and displayed. Normalization, standardization, and augmentation are some of the techniques that can improve the effectiveness and efficiency of network training (Al-Aziz et al, 2021).
6- Transfer Learning: Using a pre-trained model on a sizable dataset and then honing it for a particular job is a common method used to enhance neural networks. This strategy can result in substantial performance gains, particularly when there is a dearth of data available for the particular job.
7- Evolutionary Algorithms: To optimize neural networks, certain cutting-edge techniques include evolutionary algorithms. By producing a population of networks, picking the top-performing ones, and then using those networks to build a new generation of networks, these techniques iteratively enhance the performance of the network (Kuptsov & Stankevich, 2024).
8- Hardware Optimization: Lastly, employing GPUs (Graphics Processing Units) or TPUs (Tensor Processing Units) for quicker processing—a critical step in the effective training of big networks—the performance of neural networks may also be enhanced at the hardware level.

In the recent years, the development of artificial intelligence presented an efficient opportunity in the enhancement of the lives of disabled individuals. However, ethical considerations must be pointed out. To begin, we must recognize the importance of ethics in AI research. When

designing technology to aid disabled people, it is critical to examine the possible implications for their privacy, autonomy, and well-being. Failure to effectively address ethical issues can cause harm to the very people these technologies are intended to serve. Thus, ethical monitoring and thought are essential in AI research. Furthermore, privacy and data security considerations are critical when dealing with sensitive personal information about disabled people. Data anonymization, encryption, and rigorous access restrictions must be applied to ensure the confidentiality of personal data. Furthermore, gaining informed consent and guaranteeing individuals' ownership over their data are critical ethical issues for protecting autonomy and privacy rights. Addressing the ethical concerns in AI research targeted at enhancing the everyday activities of disabled people is critical to ensuring the appropriate and useful deployment of technology. Researchers can uphold ethical values and maximize the positive impact of AI technologies on the lives of disabled people by recognizing potential risks such as bias, privacy concerns, and dependency, as well as implementing mitigation strategies such as fairness principles, data security measures, and stakeholder engagement. Ethical monitoring and reflection must be integrated into AI research to promote inclusion, autonomy, and dignity for all humans.

Results

The study's findings are provided in this section. The methods and goals described in the preceding sections are followed in the organization and detail of the results. To make sure that the data was fully understood, a variety of analytical approaches were used. The purpose of this part is to lay the foundation for the debate and interpretation of the study findings by offering an objective and factual summary of the findings. As the analysis and ramifications of these findings will be fully addressed in the discussion section that follows, it is crucial to highlight that the data is provided without prejudice or subjective interpretation.

The feature extraction explained in the previous sections aims to find the best features of the data that can be used in classification later. Figure 9 shows the feature extracted using equations 5 – 10.

The features extracted help the classification algorithms to train in order to find a pattern that can predict the outcome for each trial. The data was labeled as 1 and 2 which represents if the subject imagined moving his elbow or his wrist. Figures 10 and (11-12) show the SVM and NN algorithms respectively for classifications.

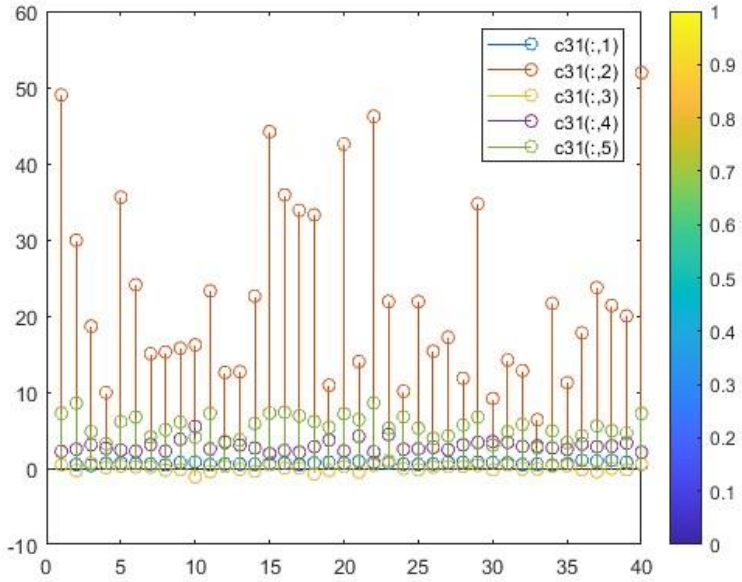

Figure 9 – Features extracted

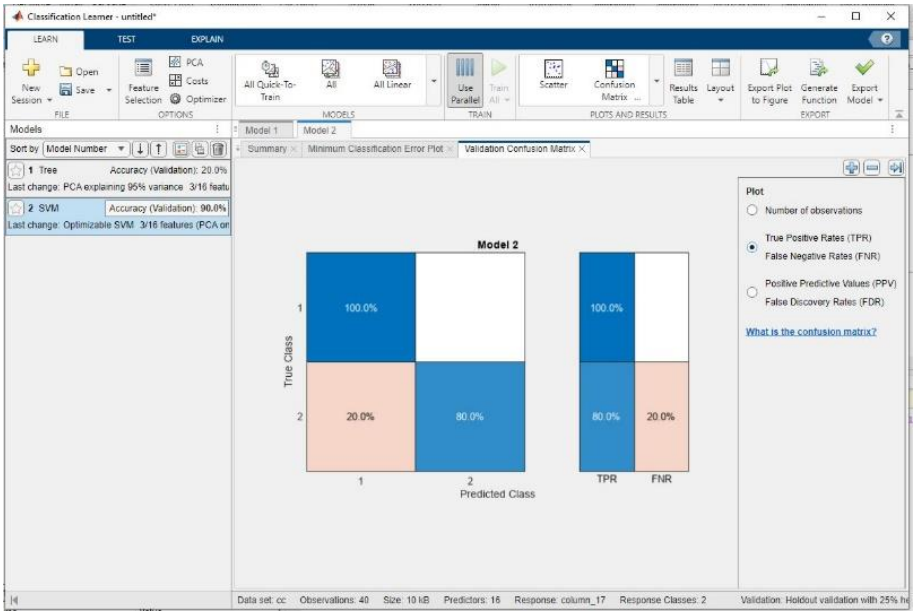

Figure 10 – SVM

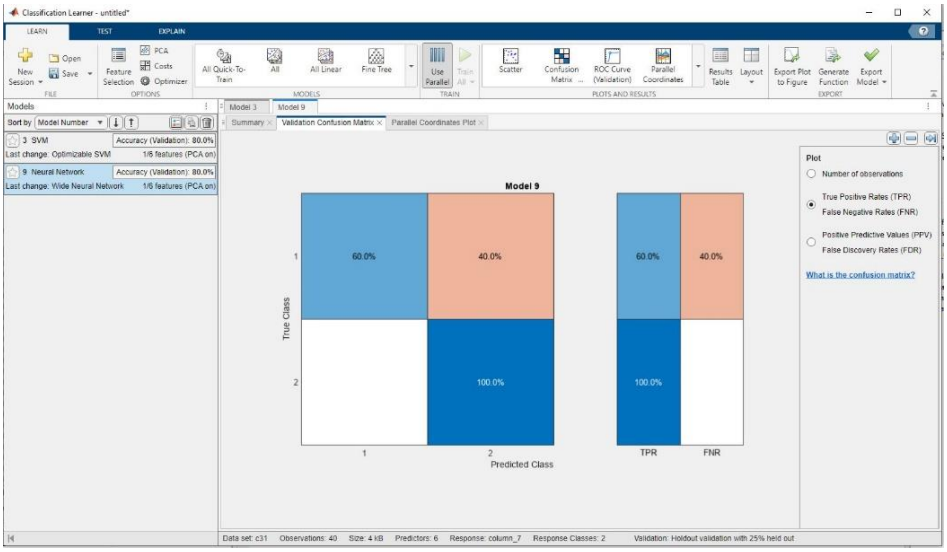

Figure 11 – Neural network 1

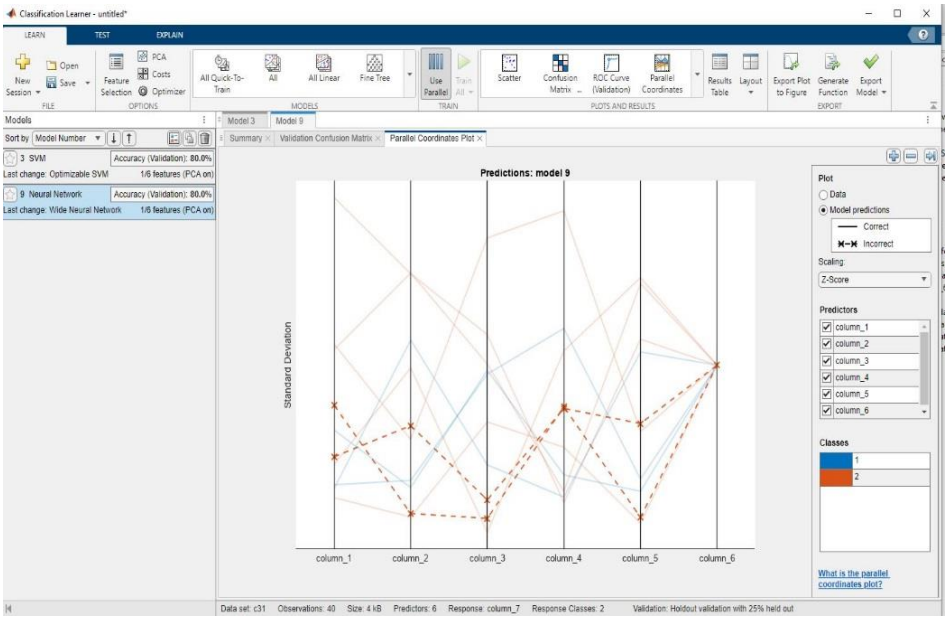

Figure 12 – Neural Network 2

The figures show the results for only one subject. Table 1 present all subjects' results after applying the same signal processing, feature extraction and classifications.

Table 1 – Classification accuracy

No	Accuracy	
	SVM	NN
1	90.00%	80.00%
2	85.00%	84.00%
3	85.00%	82.00%
4	80.00%	80.00%
5	84.00%	81.00%
6	82.00%	82.50%
7	75.00%	84.00%
8	80.00%	83.00%
9	79.00%	84.00%
10	76.00%	87.00%
11	85.00%	80.00%
12	80.00%	80.00%
13	77.00%	80.00%
14	85.00%	81.00%
15	73.00%	86.00%
16	78.00%	90.00%
17	88.00%	85.00%
18	84.00%	81.00%
19	86.00%	83.00%
20	91.00%	81.00%
21	96.00%	81.00%
22	98.00%	81.00%
23	85.00%	85.00%
24	96.00%	82.00%
25	82.00%	81.00%

Figure 13 shows the difference between the SVM, and NN results compared to the results shown in Ma et al (2020). The improvement made in this study shows a good step up in classifying the signals.

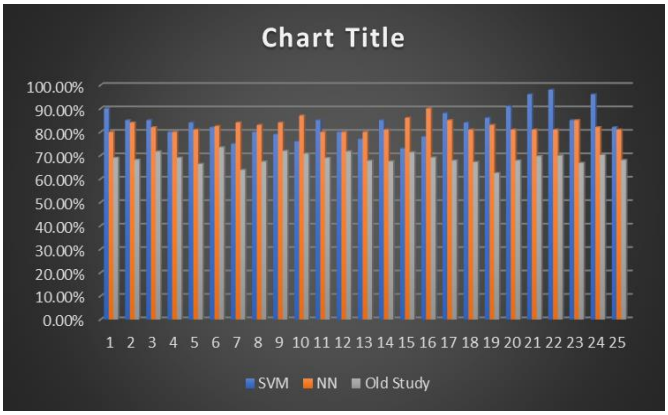

Figure 13 – Comparison of the results

Conclusion

The applications of brain waves has become widespread in recent decades. The usage of these programs enhances the daily activities of disabled individuals. Achieving high levels of accuracy is essential. The non-invasive method of signal recording is the most commonly used in this sort of application. In this procedure, EEG electrodes are used to record signals from various areas of the brain while the brain is functioning in response to a stimulus. This work improved a prior study's classification accuracy of brain signals. Different algorithms are employed to analyze signals, extract features, and classify them. The findings demonstrate how the algorithms improved the classification accuracy of the prior study, indicating that the work was on the right path. Achieving this accuracy percentage leads to the development of new approaches for future accuracy increase. There are several sorts of algorithms that may be used for classification, but in our study, we only employed two since they produced the best results. The findings obtained were based on the type of characteristics extracted.

References

Ahmed, A.H., Al-Hamadani, M.N.A. & Satam, I.A. 2022. Prediction of COVID-19 disease severity using machine learning techniques. *Bulletin of Electrical Engineering and Informatics*, 11(2), pp.1069-1074. Available at: https://doi.org/10.11591/eei.v11i2.3272.

Al-Hamadani, M.N. 2023. Classification and analysis of the MNIST dataset using PCA and SVM algorithms. *Vojnotehnički glasnik/Military Technical Courier*, 71(2), pp. 221-238. Available at: https://doi.org/10.5937/vojtehg71-42689.

Amin, H.U., Mumtaz, W., Subhani, A.R., Saad, M.N.M. & Malik, A.S. 2017. Classification of EEG Signals Based on Pattern Recognition Approach. *Frontiers in Computational Neuroscience*, 11, art.number:103, pp.1-12. Available at: https://doi.org/10.3389/fncom.2017.00103.

Al-Aziz, A., Muntakim, A.-H. & Ahmed, K. 2021. No Regular Behavior Pattern in Neural Network Execution – A Matlab Experience. *International Journal of Computer Application*, 174(19), pp.39-46. Available at: https://doi.org/10.5120/ijca2021921087.

de Brito Guerra, T.C., Nóbrega, T., Morya, E., de M. Martins, A. & de Sousa, V.A. 2023. Electroencephalography Signal Analysis for Human Activities Classification: A Solution Based on Machine Learning and Motor Imagery. *Sensors*, 23(9), art.number:4277. Available at: https://doi.org/10.3390/s23094277.

Huang, J.-S., Li, Y., Chen, B.-Q., Lin, C. & Yao, B. 2020. An Intelligent EEG Classification Methodology Based on Sparse Representation Enhanced Deep Learning Networks. *Frontiers in Neuroscience*, 14, art.number:808. Available at: https://doi.org/10.3389/fnins.2020.00808.

Kuptsov, P.V. & Stankevich, N.V. 2024. Modeling of the Hodgkin–Huxley neural oscillators dynamics using an artificial neural network. *Izvestiya VUZ Applied Nonlinear Dynamics,* 32(1), pp.72-95. Available at: https://doi.org/10.18500/0869-6632-003079.

Ma, X., Qiu, S. & He, H. 2020. Multi-channel EEG recording during motor imagery of different joints from the same limb. *Scientific Data*, 7, art.number:191, pp.1-9. Available at: https://doi.org/10.1038/s41597-020-0535-2.

Ortega-Fernandez, I., Sestelo, M. & Villanueva, N.M. 2024. Explainable generalized additive neural networks with independent neural network training. *Statistics and Computing,* 34, art.number:6. Available at: https://doi.org/10.1007/s11222-023-10320-5.

Páez-Amaro, R.T., Moreno-Barbosa, E., Hernández-López, J.M., Zepeda-Fernández, C.H., Rebolledo-Herrera, L.F. & de Celis-Alonso, B. 2022. EEG motor imagery classification using machine learning techniques. *Revista Mexicana de Fisica*, 68(4), art.number:041102. Available at: https://doi.org/10.31349/RevMexFis.68.041102.

Ramírez-Arias, F.J., García-Guerrero, E.E., Tlelo-Cuautle, E., Colores-Vargas, J.M., García-Canseco, E., López-Bonilla, O.R., Galindo-Aldana, G.M. & Inzunza-González, E. 2022. Evaluation of Machine Learning Algorithms for Classification of EEG Signals. *Technologies,* 10(4), art.number:79. Available at: https://doi.org/10.3390/technologies10040079.

Wen, T., Du, Y., Pan, T., Huang, C. & Zhang, Z. 2021. A Deep Learning-Based Classification Method for Different Frequency EEG Data. *Computational and Mathematical Methods in Medicine*, 2021, art.ID:1972662. Available at: https://doi.org/10.1155/2021/1972662.

Algoritmos de aprendizaje automático supervisados para la clasificación de señales cerebrales

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CAMPO: Bioingeniería
TIPO DEL ARTÍCULO: artículo científico original

Resumen:

Introducción/objetivo: La aplicación de las ondas cerebrales está muy generalizada en los últimos años, especialmente en las aplicaciones que ayudan a las personas discapacitadas que han sufrido alguna amputación o parálisis. El objetivo de esta investigación es evaluar qué tan bien diferentes algoritmos de aprendizaje automático supervisado clasifican las señales cerebrales, con énfasis en mejorar la precisión y efectividad de las aplicaciones de interfaz cerebro-computadora.

Métodos: En este trabajo, los datos de las señales cerebrales se analizaron utilizando varios modelos bien conocidos de aprendizaje supervisado, como las máquinas de vectores de soporte (SVM) y las redes neuronales (NN). El conjunto de datos se tomó de un estudio anterior. Veinticinco participantes imaginaron mover su brazo derecho (codo y muñeca) mientras se registraban las señales cerebrales durante ese proceso. El conjunto de datos se preparó para el análisis mediante la aplicación de meticulosos procedimientos de preprocesamiento y extracción de características. Luego los datos resultantes fueron sometidos a clasificación.

Resultados: El estudio destaca cuán cruciales son la selección de características y la modificación del modelo para maximizar los resultados de clasificación. Los métodos de aprendizaje automático supervisados tienen un gran potencial para clasificar señales cerebrales, particularmente SVM y NN.

Conclusión: El uso de SVM y NN tiene el potencial de transformar completamente la creación de interfaces cerebro-computadora de vanguardia. La integración de estos modelos con datos en tiempo real debería investigarse en estudios futuros.

Palabras claves: aprendizaje automático supervisado, EEG, señales cerebrales, clasificaciones, extracción de características.

Контролируемые алгоритмы машинного обучения в классификации сигналов мозга

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РУБРИКА ГРНТИ: 34.57.00 Биоинженерия
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: Применение BrainWave в последние время сильно возросло, особенно в области приложений, которые помогают людям с ограниченными возможностями, перенесшим ампутацию или паралич. Цель данного исследования − оценить, насколько точно различные контролируемые алгоритмы машинного обучения классифицируют сигналы мозга с акцентом на повышение точности и эффективности при взаимодействии мозга и компьютера.

Методы: В данной статье проанализированы данные о сигналах мозга с использованием ряда хорошо известных моделей контролируемого обучения, таких как методы опорных векторов (МОВ) и нейронные сети (НС). Данные заимствованы из предыдущего исследования. Двадцать пять респондентов представляли, как двигают правой рукой (локоть и запястье), а одновременно записывались сигналы мозга. Набор данных был подготовлен для анализа путем тщательной предварительной обработки и выявления признаков. Затем полученные данные были подвергнуты классификации.

Результаты: Исследование подчеркивает значимость выбора признаков и модификации модели для получения наилучших результатов классификации. Методы контролируемого машинного обучения имеют большой потенциал в классификации сигналов мозга, особенно методы МОВ и НС.

Выводы: Применен*ие методов* МОВ *и* НС *может полностью изменить процесс* разработки *современных интерфейсов «мозг-компьютер».* А внедрение *этих моделей с данными*, полученными *в реальном времени, должно стать предметом дальнейших исследований.*

Ключевые слова: контролируемое машинное обучение, ЭЭГ, сигналы мозга, классификация, выявление признаков.

Надгледани алгоритми машинског учења за класификацију можданих сигнала

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ОБЛАСТ: биоинжењеринг
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: Мождани таласи имају све чешћу примену, наричито у области апликација за помоћ особама са ампутацијом или парализом. Циљ овог истраживања јесте процена успешности класификовања можданих сигнала различитих надгледаних алгоритама машинског учења, са тежиштем на побољшању прецизности и ефикасности интерфејса између мозга и рачунара.

Методе: У раду су анализирани подаци можданих сигнала помоћу неколико познатих надгледаних модела учења, попут метода потпорних вектора (SVM) и неуралних мрежа (NN). Подаци су узети из претходне студије. Двадесет пет испитаника је замишљало да покреће десну руку (лакат и ручни зглоб) док су истовремено снимани мождани сигнали. Скуп података је припремљен за анализу коришћењем детаљних поступака претходне обраде и екстракције карактеристика.

Резултати: Студија наглашава суштински значај селекције карактеристика и модификације модела за добијање што бољих резултата класификације. Надгледане методе машинског учења имају велики потенцијал за класификовање можданих сигнала, нарочито методе SVM и NN.

Закључак: Коришћење метода SVM и NN има потенцијал да потпуно трансформише креирање најсавременијих интерфејсова између мозга и рачунара. Интеграција ових модела са подацима добијеним у реалном времену треба да буде предмет будућих истраживања.

Кључне речи: надгледано машинско учење, ЕЕГ, мождани сигнали, класификације, екстракција карактеристика.

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Comparative analysis of the specific motor skills of cadets by classes after the second year of education

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FIELD: physical education
ARTICLE TYPE: original scientific paper

Abstract:

Introduction/purpose: Despite the era of digitization, the assessment of the combat readiness of modern army members has always been associated with good physical fitness. When it comes to the specific physical abilities of the Military Academy cadets, their previous tests indicate that the values are within the expected limits. The aim of this work is to compare the values of the results in the specific motor skills of cadets by classes (groups) after the second year of schooling. It is hypothesized that there are differences in the results of the cadets by groups.

Methods: The sample consisted of a total of 932 male cadets within nine groups, after the second year of study, starting from the 2012/2013 school year. Four variables related to specific motor skills were included: pull-ups on a bar for 2 minutes, crunches for 2 minutes, 3200 m running, and overcoming infantry obstacles. Using statistical programs, the results of these four variables were processed through central and dispersion parameters. The univariate analysis of variance (ANOVA) was used to determine the differences between the groups in the achieved results. The multivariate analysis of variance (MANOVA) determined the differences in the system of variables with spaces.

Results: The analysis of the results of the specific motor abilities by groups after the second year of study determined that there are statistically significant differences in the variables "pull-ups on a bar" and "crunches", while there are no statistically significant differences in the variables "3200 m running" and "overcoming infantry obstacles".

Conclusions: The values of the results of the cadets in these four specific motor abilities are obviously within the limits provided by the Instructions

and standards for evaluating cadets by age, so it was determined that there are no greater deviations than expected.
Key words: ANOVA, MANOVA, combat readiness, motor skills, pull-ups, crunches, infantry obstacles.

Introduction

The previous research studies on the specific physical abilities of the cadets of the Military Academy indicate that the results are within the expected limits. There are numerous worldwide studies related to motor abilities, morphological characteristics and functional abilities and they were conducted on a sample of respondents consisting of cadets of military academies or professional persons aged 18 to 24. The Military Academy in Norway performed testing on 260 male and 29 female cadets with the aim of examining changes in anthropometry and physical fitness during 3 years of schooling (Aandstad et al, 2020). The results showed that the most of the observed changes were very small. During the research of cadets (197 male cadets and 31 female cadets) of the Military Academy in Poland, in addition to somatic development, they were also tested in physical abilities (Jamro et al, 2021). A statistical difference was established, where male cadets showed better results in practical military subjects, while female cadets had better results in theoretical military subjects. The results of physical fitness indicate differences between the male and female sexes and point to the need for specialized training aimed at bridging large differences in physical fitness, especially in the development of muscle strength.

At the Military Academy in Romania (Melnykov et al, 2018), research was conducted on 112 cadets in physical preparation in the first two years of schooling. Eurofit tests for physical education and military training were used. The results indicate that the structure of changes in physical preparation in the experimental groups differs significantly in relation to the years of study. The obtained results should be aimed at developing the physical abilities of cadets.

Many studies indicate that good physical abilities of cadets or soldiers enable better execution of operational tasks as well as reduced musculoskeletal injuries (Vaara, 2017).

The analysis of the results of the motor skills of the cadets of the Military Academy in Belgrade during schooling shows that the best results were achieved after the second academic year (Marić, 2011). The exper-

imental treatment included the entire curriculum in the subject of Physical Education (PE) during the education at the Military Academy. The number of hours was 60+30 hours. The course content includes: wrestling, swimming, overcoming infantry obstacles with gymnastics, general physical preparation, skiing and theory. Based on the principle of systematicity and gradualness, each specialty goes from the known to the unknown and from the easier to the more difficult. "The best average results for the assessment of motor skills were achieved after the second year of study." (Marić et al, 2013).

The aim of this work is to compare the values of the results in the specific motor abilities of cadets by classes (groups) after the second year of study. It is hypothesized that there are differences in the results of (male) cadets by groups. The concept of experimental treatment is included in the entire curriculum in the subject of Physical Education (PE) related to the education of cadets in the Military Academy.

Results

Table 1 shows the descriptive parameters of the motor variable "pull-ups on a bar" for 2 minutes. Based on the minimum and maximum values of the results of the motor variable "pull-ups on a bar" by groups, it is observed that they range from a minimum of 5 (except in the 8^{th} group, where the minimum value is 6 repetitions) to a maximum of 21. The coefficient of variation indicates a greater heterogeneity of the results by groups when the values are maximal. It is obvious that the subjects were prepared differently in mastering this motor task. Based on testing the symmetry of the curve, the skewness values indicate a negative curvature, while the kurtosis values show a certain heterogeneity of the results by groups.

Table 1 – Descriptive indicators of the variable "pull-ups on a bar" by groups

Group	No. cad.	Min	Max	Aver.	SD	COV. V. %	Skew.	Kurt.
I	121	5	21	11.26	3.68	32.7	-0.204	-1.015
II	107	5	15	12.63	3.07	24.3	-1.178	0.168
III	142	5	15	12.66	2.98	23.5	-1.039	-0.133
IV	99	5	20	13.03	3.25	24.9	-0.968	0.144
V	123	5	17	12.33	3.22	26.1	-0.783	-0.760
VI	94	5	15	12.02	3.21	26.7	-0.717	-0.803
VII	85	5	20	11.61	3.78	32.6	-0.370	-1.146
VIII	63	6	18	13.13	3.20	24.4	-0.679	-0.394
IX	98	5	16	12.57	3.28	26.1	-1.114	-0.051

The motoric variable “crunches for 2 minutes” by groups is shown in Table 2. From the descriptive parameters of this motor ability, it can be seen that the minimum values range mostly from 40 repetitions, except in the 8th group and the 6^{th} group, where the minimum numbers of repetitions are 67 and 46, respectively.

Table 2 – Descriptive indicators in the variable “crunches for 2 min” by groups

Group	No. cad.	Min	Max	Aver.	SD	COV. V. %	Skew.	Kurt.
I	121	40	90	72.27	11.08	15.33	-1.209	0.861
II	107	40	91	72.08	10.38	14.40	-1.175	1.135
III	142	41	100	75.50	8.34	11.05	-1.633	3.382
IV	99	40	100	74.56	10.98	14.73	-0.982	1.178
V	123	44	90	73.74	8.43	8.44	-1.170	0.374
VI	94	46	100	76.65	10.84	14.14	-0.884	1.015
VII	85	40	115	70.74	14.15	20.00	-0.356	0.406
VIII	63	67	110	81.37	6.93	8.51	1.031	4.219
IX	98	40	90	70.49	12.10	17.16	-0.986	-0.122

The maximum values indicate that the best result was achieved in the seventh group with 115 crunches for 2 minutes. On the basis of the coefficient of variation, it was determined that the results in this motor ability are mostly homogeneous, which is mostly reflected in the 8^{th} group (cov.v.= 8.44 %). The greatest heterogeneity is in the 7^{th} group, where the values of the results of crunches for 2 minutes range from a minimum of 40 repetitions to a maximum of 115 repetitions (cov. v.= 20.00 %).

Based on the skewness value, the curvature of the curve is negative for all groups by years of education, except for the 8^{th} group, which has a high degree of homogeneity.

In Table 3, the descriptive indicators in the variable “3200 meters running” by classes are shown in seconds. For some cadets, the maximum results are slightly higher than the limit based on the PE Instructions, but these are the results they achieved at the end of the school year in this discipline.

The worst result was achieved by a cadet in the 7^{th} group, in the 3200 m running, with a time of 990 seconds, and the best time was achieved by some cadets from the 3^{rd} and 5^{th} groups with 678 seconds (11 min. and 18 sec.). On the basis of the coefficient of variation, one can observe a great homogeneity by classes. These values are possible, because the results are limited, according to the tables for the 3200 m running. In most cases,

Table 3 – Descriptive indicators in the variable "3200 meters running" by groups

Group	No. cad.	Min	Max	Aver.	SD	COV. V. %	Skew.	Kurt.
I	121	684	985	837.21	73.57	8.79	-0.041	-0.704
II	107	690	959	831.96	62.85	7.55	-0.013	-0.807
III	142	678	980	825.45	67.45	8.17	0.293	-0.471
IV	99	701	950	835.43	69.82	8.36	0.299	-0.462
V	123	678	980	826.07	68.63	8.30	0.301	-0.421
VI	94	722	980	828.34	73.31	8.62	0.274	-0.437
VII	85	699	990	861.33	71.02	8.24	-0.124	-0.675
VIII	63	690	938	815.71	61.67	7.56	-0.172	-0.699
IX	98	704	968	854.15	56.54	6.62	0.108	-0.566

the results by group move towards higher values, but the homogeneity is equally good, and the highest value is in the ninth group (cov.v.= 6.62 %).

Table 4 – Descriptive indicators in the variable "overcoming infantry obstacles" by groups

Group	No. cad.	Min	Max	Aver.	SD	COV. V. %	Skew.	Kurt.
I	121	98	176	141.72	21.28	15.0	-0.018	-0.921
II	107	96	176	140.38	18.77	13.4	0.144	-0.628
III	142	87	176	140.64	20.89	14.8	-0.177	-0.654
IV	99	92	176	139.92	19.73.82	14.1	-0.156	-0.728
V	123	101	176	144.45	21.47	14.9	-0.125	-1.197
VI	94	103	176	144.83	20.87	14.4	0.028	-0.678
VII	85	93	176	141.63	21.01	14.8	-0.412	-0.341
VIII	63	85	176	141.50	24.09	17.6	-0.003	-0.124
IX	98	95	176	142.21	19.46	13.7	-0.347	-0.377

Table 4 shows the descriptive parameters of the motor variable of overcoming infantry obstacles. For the assessment of the motor ability "overcoming infantry obstacles", after the second year of studying and by analyzing the mean values, it can be said that the results are within the possibility limits, based on the minimum and maximum values of the results of the motor variable. It can be seen that the best time (result) was in the 8^{th} group with 85 sec. (1 min. and 25 sec.) and in the 3^{rd} group with 87 sec. (1 min. and 27 sec.), which means that some cadets had really outstanding results. Based on the coefficient of variation, it was determined that the results in this motor skill are mostly homogeneous and approximately equal. The maximum (worst) results are the same in all groups, because this is the result that is recognized for the grade that cadets should achieve based on the Physical Education instructions. Based on testing the symmetry of

the curve, the skewness values indicate mostly negative asymmetry and the curve is stretched towards higher scores.

Differences between the respondents in mastering the motor skills of cadets

During the analysis of the descriptive indicators in the mastery of the motor skills tested (pull-ups on a bar for 2 minutes, crunches for 2 minutes, 3200 m running, and overcoming infantry obstacles), numerical differences in the average results in certain variables for the assessment of motor skills were observed. The statistical significance of the observed differences between groups (classes) in relation to these four variables was determined by statistical analysis, the multivariate analysis of variance (MANOVA), and the univariate analysis of variance (ANOVA).

Regarding the pull-up test, from Table 5, it can be said that there are statistically significant differences in the results between the nine groups, based on the multivariate analysis of variance (MANOVA), where p=0.012.

Table 5 – Statistically significant differences between the groups in the variable "pull-ups on a bar"

MANOVA	n	F	p
	9	1.334	0.012

The analysis of the results obtained by the univariate analysis of variance (ANOVA), in Table 6, shows that, in the variable "pull-ups on a bar", there are no statistically significant differences between the respondents by groups, except in the 4^{th} group (.033), the 8^{th} group (.004), and the 7^{th} group (.079), but with an increased risk of inference.

The results achieved by the cadets by groups were as expected. However, there are cadets who achieved better results than expected, which may be the result of their greater commitment during the school year, apart from regular classes. In the variable "2-minute crunches", by the MANOVA analysis (Table 7), within 9 different groups, it is observed that there are statistically significant differences, where p=0.001.

The univariate analysis of variance ANOVA, Table 8, showed that there are statistically significant differences in the 3^{st} group (0.029), the 6^{th} group (0.031), and the 8^{th} group (0.037), which was not observed in other groups.

The results of this test indicate that even in these groups there is a different level of preparedness, but which can be influenced by practice. Regard-

Table 6 – Statistically significant differences between the groups in the variable "pull-ups on a bar"

Group	F	p
I	1.084	0.409
II	1.496	0.133
III	0.773	0.755
IV	1.952	**0.033**
V	0.887	0.625
VI	1.252	0.266
VII	1.669	**0.079**
VIII	2.635	**0.004**
IX	1.311	0.226

Table 7 – Statistically significant differences between the groups in the variable "crunches"

MANOVA	n	F	p
	9	1.591	0.001

ing the analysis of the statistically significant differences within 9 groups, the multivariate analysis of variance in the 3200 m running variable, Table 9, indicates that there are no differences, where p=0.798.

The univariate analysis of variance ANOVA, Table 10, showed no statistically significant differences by groups.

Having in mind that the cadets successfully mastered the teaching content after two years of studying, the obtained results are not surprising.

The analysis of the variable "overcoming infantry obstacles" based on the MANOVA (Table 11), shows that no statistically significant differences were found (p=0.233).

Table 8 – Statistically significant differences in the variable "2-minute crunches"

Group	F	p
I	2.473	**0.029**
II	0.939	0.587
III	1.272	0.314
IV	1.757	0.117
V	1.211	0.355
VI	2.451	**0.031**
VII	1.223	0.347
VIII	2.353	**0.037**
IX	1.594	0.163

Table 9 – Statistically significant differences between the groups in the 3200 m running variable

MANOVA	n	F	p
	9	0.660	0.798

Table 10 – Statistically significant differences in the 3200 m running variable

Group	F	p
I	2.453	0.333
II	0.331	0.943
III	3.803	0.230
IV	3.194	0.269
V	3.722	0.221
VI	4.931	0.258
VII	0.901	0.664
VIII	0.398	0.933
IX	1.067	0.603

Table 11 – Statistically significant differences between the classes in the variable "overcoming infantry obstacles"

MANOVA	n	F	p
	9	1.225	0.233

Based on the analysis of individual results (ANOVA) to determine statistically significant differences within 9 groups (Table 12), it can be observed that there are no differences here either.

Table 12 – Statistically significant differences in the variable "overcoming infantry obstacles"

Group	F	p
I	0.789	0.713
II	1.947	0.204
III	1.029	0.547
IV	1.571	0.299
V	1.006	0.562
VI	1.755	0.247
VII	0.903	0.630
VIII	0.911	0.624
IX	2.752	0.101

The achieved results are expected, because the cadets mastered these skills, which is mandatory during the evaluation within the Curriculum. Individual differences among cadets by groups in specific motor abilities may

be a consequence of different individual preparation. In these tests, motor skills are developed, mostly strength and endurance, and less speed, coordination, flexibility, etc. Cadets, with their extracurricular involvement, can achieve even better results during the schooling.

Conclusion

The achieved results in the motor skills of the cadets of the Military Academy are within the limits specified by the tables for checking physical abilities. The planned program corresponds to the set norms, but it is obvious that there is room to improve the results through afternoon physical activities - sections (Marić et al, 2015). A number of cadets are not sufficiently engaged in extracurricular physical activities, and it may also be a consequence of genetic predispositions, so they achieve minimal results. Depending on the period of development, certain factors that act on the body during exercise can cause different effects. Monitoring cadets by groups gives the opportunity to change and supplement the teaching process in military physical education.

References

Aandstad, A., Sandberg, F., Hageberg, R. & Kolle, E. 2020. Change in Anthropometrics and Physical Fitness in Norwegian Cadets During 3 Years of Military Academy Education. *Military Medicine*, 185(7-8), pp. e1112–e1119. Available at: https://doi.org/10.1093/milmed/usz470.

Jamro, D., Zurek, G., Lachowicz, M. & Lenart, D. 2021. Influence of Physical Fitness and Attention Level on Academic Achievements of Female and Male Military Academy Cadets in Poland. *Healthcare*, 9(10, art.number:1261). Available at: https://doi.org/10.3390/healthcare9101261.

Marić, L., Krsmanović, B., Mraović, T., Gogić, A., Sente, J. & Smajić, M. 2013. The effectiveness of physical education of the Military Academy cadets during a 4-year study. *Vojnosanitetski pregled*, 70(1), pp. 16–20. Available at: https://doi.org/10.2298/VSP1301016M.

Marić, L.D., Marinković, M.D. & Ćorić, M.M. 2015. Assessment of the effectiveness of physical education classes based on weight index during cadets' education at the Military Academy. *Vojno delo*, 67(4), pp. 186–194. Available at: https://doi.org/10.5937/vojdelo1504186M.

Marić, L. 2011. *The development of the motor capabilities and its relations to the motor efficiency of the students at the Military Academy*. Ph.d. thesis, Novi Sad, Serbia: University of Novi Sad.

Melnykov, A., Iedynak, G., Galamandjuk, L., Blavt, O., Duditska, S., Koryagin, V., Balatska, L. & Mazur, V. 2018. Factors that influence changes in cadets' physical preparation during the first half of study at a military academy. *Journal of Physical Education and Sport*, 18(2), pp. 781–786. Available at: https://doi.org/10.7752/jpes.2018.02115.

Vaara, J. 2017. Physical fitness trends in soldiers – Implications for recruitment and combat readiness. *Journal of Science and Medicine in Sport*, 20(2), p. S11. Available at: https://doi.org/10.1016/j.jsams.2017.09.029.

Análisis comparativo de las habilidades motoras específicas de los cadetes por clases a partir del segundo año de educación

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CAMPO: educación física

TIPO DE ARTÍCULO: artículo científico original

Resumen:

Introducción/objetivo: A pesar de la era de la digitalización, la evaluación de la preparación para el combate del ejército moderno siempre ha estado asociada con una buena condición física. En cuanto a las capacidades físicas específicas de los cadetes de la Academia Militar, sus pruebas previas, indican que los valores se encuentran dentro de los límites esperados. El objetivo de este trabajo es comparar los valores de los resultados en las habilidades motoras específicas de los cadetes por clases (grupos) después del segundo año de escolarización. Se hipotetiza que existen diferencias en los resultados de los cadetes por grupos.

Métodos: La muestra estuvo compuesta por un total de 932 cadetes varones dentro de nueve grupos, después del segundo año de estudio, a partir del año escolar 2012/2013. Se incluyeron cuatro variables relacionadas con habilidades motoras específicas: dominadas en barra durante 2 minutos, abdominales durante 2 minutos, carrera de 3200 m y superación de obstáculos de infantería. Mediante programas estadísticos se procesaron los resultados de estas cuatro variables a través de parámetros centrales y de dispersión. Se utilizó el análisis de la varianza (ANOVA) para determinar las diferencias entre los grupos en los resultados obtenidos. El análisis multivariado de varianza (MA-

NOVA) determinó las diferencias en el sistema de variables con espacios.

Resultados: El análisis de los resultados de las habilidades motoras específicas por grupos después del segundo año de estudio, determinó que existen diferencias estadísticamente significativas en las variables "dominadas en barra" y "abdominales", mientras que no existen diferencias estadísticamente significativas. en las variables "3200 m corriendo" y "superación de obstáculos de infantería".

Conclusión: Los valores de los resultados de los cadetes en estas cuatro habilidades motoras específicas obviamente se encuentran dentro de los límites previstos por el Instructivo y estándares para la evaluación de cadetes por edades, por lo que se determinó que no existen desviaciones mayores a las esperadas.

Palabras claves: ANOVA, MANOVA, preparación para el combate, habilidades motoras, dominadas, abdominales, obstáculos de infantería.

Сравнительный анализ специфических двигательных навыков курсантов после второго курса обучения

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РУБРИКА ГРНТИ: 77.03.17 Профессионально-прикладная физическая подготовка

ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: Оценка боеготовности современной армии всегда была связана с хорошей физической подготовленностью и, несмотря на цифровизацию, до сих пор является основой оценки боевой готовности армии. Ранние исследования специфических физических способностей курсантов Военной академии свидетельствуют о том, что значения их физической подготовки соответствуют норме. Целью данной статьи является сравнение значений результатов конкретной двигательной активности курсантов (по группам) после второго курса обучения. Выдви-

гается гипотеза о наличии различий в результатах курсантов в зависимости от группы.

Методы: Выборка состояла из 932 курсантов мужского пола, окончивших второй курс в девяти разных группах, начиная с 2012/2013 учебного года. Были включены четыре переменные, связанные с конкретными двигательными навыками, а именно: подтягивания на турнике - 2 минуты, подъем корпуса от пола за 2 минуты, бег на 3200 м и преодоление полосы препятствий. Используя статистические программы, результаты этих четырех переменных были обработаны с помощью центральных и дисперсионных параметров. Для определения различий между группами в достигнутых результатах использовался одномерный дисперсионный анализ (ANOVA). Многомерный дисперсионный анализ (МАНОВА) выявил различия в системе переменных по пространствам.

Результаты: Анализируя результаты отдельных двигательных способностей курсантов, окончивших второй курс в разных группах, установлено, что имеются статистически значимые различия по показателям подтягиваний на турнике и подъема корпуса от пола, в то время как статистически значимых различий по переменным бега на 3200 м и преодоления препятствий не обнаружено.

Выводы: Значения результатов тестирования курсантов по этим четырем конкретным двигательным способностям находятся в пределах, предусмотренных Инструкцией и стандартами оценки курсантов по возрасту. Установлено, что больших отклонений, чем ожидалось, нет.

Ключевые слова: ANOVA, MANOVA, физическая подготовка, моторика, подтягивания, приседания, полоса препятствий для пехоты.

Упоредна анализа специфичних моторичких способности кадета по класама после друге године школовања

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ОБЛАСТ: физичко васпитање
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: Процена борбене готовости савремене војске, упркос дигитализацији, одувек је била повезана са добром физичком оспособљеношћу и њена је основа. Досадашња истраживања специфичних физичких способности кадета Војне академије, указују на то да се вредности крећу у предвиђеним границама. Циљ овог рада јесте да се упореде вредности резултата који се односе на специфичне моторичке способности кадета по класама (групе) после друге године школовања. Поставља се хипотеза да постоје разлике у резултатима кадета по групама.

Методе: Узорак чине укупно 932 кадета мушког пола у оквиру девет група, након друге године школовања почевши од школске 2012/ 2013. године. Обухваћене су четири варијабле које се односе на специфичне моторичке способности: згибови на вратилу за 2 мин, подизање трупа са тла за 2 мин, трчање на 3200 m и савладавање пешадијских препрека. Применом статистичких програма обрађени су резултати ове четири варијабле кроз централне и дисперзионе параметре. За утврђивање разлика између група у постигнутим резултатима коришћена је универијантна анализа варијансе (АНОВА). Мултиваријантном анализом варијансе (МАНОВА) утврђене су разлике у систему варијабли по просторима.

Резултати: Анализирајући резултате специфичних моторичких способности кадета по групама после друге године школовања, утврђено је да статистички значајне разлике постоје у варијаблама згибови на вратилу и подизање трупа са тла, док у варијаблама трчање на 3200 m и савладавање пешадијских препрека нема статистички значајних разлика.

Закључак: Вредности резултата кадета у ове четири специфичне моторичке способности очигледно се крећу у границама предвиђеним Упутством и стандардима за оцењивање кадета по годинама, па је утврђено да не постоје већа одступања од предвиђених.

Кључне речи: АНОВА, МАНОВА, физичка оспособљеност, моторне способности, згибови, трбушњаци, полигон пешадијских препрека.

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REVIEW PAPERS

Review of RF-based drone classification: techniques, datasets, and challenges

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FIELD: computer sciences, telecommunications
ARTICLE TYPE: review paper

Abstract:

Introduction/purpose: This article analyzes the publicly available literature on drone classification in the radio frequency domain, focusing on detection and identification. Drones are increasingly used for illegal purposes, making classification techniques crucial. This review paper covers passive radio frequency sensors, classification techniques, and datasets that highlight the challenges.

Methods: Researchers are developing antidrone solutions because drones have become valuable tools and targets for illegal activities. Due to the scope of the subject matter, the review included only the classification of drones via passive radio frequency sensors with a description of the classification techniques (set of algorithms, methods, and procedures) and

NOTE: This work, with a similar title (Drone classification based on radio frequency: techniques, datasets, and challenges), has been presented at the 10th International Scientific Conference on Defensive Technologies OTEH 2022, Belgrade, Serbia, pp.314-320, October 13-14.

the datasets used for performance testing. This study introduces a new categorization and offers deeper insights into publicly available drone classification techniques.

Results: Based on the results of this study, it is apparent that deep learning algorithms are presently the most effective approach to addressing the challenge of drone classification within the radio frequency domain. One of the primary obstacles is the absence of a comprehensive standard for classifying drones in the radio frequency domain, which should be based on end-user requirements. Additionally, the results of two ablative experiments highlight the preprocessing of raw I/Q radio signals as an essential step in drone classification.

Conclusion: In summary, the proposed categorization provides a valuable tool for literature review. Deep learning is the most effective technique for drone classification, but publicly available datasets with drone radio signals are limited. The key strength of this study is that it represents the first review of publicly available datasets with drone radio signals.

Keywords: deep learning, drone, detection, classification, identification, radio frequency.

Introduction

Unmanned aerial systems (UAS), primarily commercial off-the-shelf (COTS) ones, have become increasingly popular due to their numerous applications, ranging from commercial to military purposes. However, as technology continues to improve and UAS become more affordable, they have also become more susceptible to criminal and terrorist activities. This has made it vital to have effective antidrone (ADRO) systems in place to protect sensitive areas and critical infrastructure. ADRO systems use a combination of sensors, including optoelectronic, acoustic, radar, and radio frequency devices, to monitor and detect UAS. These systems have three core subsystems: monitoring, mitigation, and command and control (C2). To ensure maximum protection against UAS threats, ADRO systems must incorporate different procedures such as detection, spoofing, jamming, and mitigation (Hassanalian & Abdelkefi, 2017; Ding et al, 2018). In summary, ADRO systems are essential for safeguarding against the potential harm that UAS can cause. By incorporating various sensors and procedures, these systems can effectively detect and neutralize UAS threats, making them a critical tool for security forces. The ongoing military operations in Ukraine and the Gaza Strip serve as evidence that the engagement of UAS worth less than tens of thousands of dollars can effectively neutralize crucial weapons and military assets of the enemy.

The ADRO system relies on various sensors combined with detection or warning procedures to detect UAS, also known as drones. These procedures serve two purposes - early warning (detection) and identification of the detected drones, with optional tracking, which provides inputs for the next stage of the ADRO system. Spoofing is one of the approaches used in the next phase but is not compulsory. The ADRO system can deceive drones by sending false radio signals, typically an emergency landing signal. If the spoofing fails, the ADRO system can engage in jamming procedures, where the drone control and navigation signals are disturbed by posing substantial interference. Finally, the ADRO system can use the mitigation procedure to destroy or capture malicious drones.

Although ADRO systems use various strategies and sensors, radar and radio frequency (RF) sensors are the most practical applications for primary drone detection. RF sensors have several advantages over radar technology. One of the most significant benefits is that they do not emit electromagnetic radiation, making them a safer and covert option. Additionally, RF sensors have a more extensive detection range and can be used to counteract UAS that use jamming techniques. RF sensors are passive devices that only receive RF signals from UAS, which are present in almost every scenario. In contrast, radar is an active device that emits electromagnetic energy, making it unsuitable for specific situations. The detection range of RF sensors depends on the environment and the transmitter power of the UAS but is usually comparable to radar. Another advantage of RF sensors is that they can combine with jammers, which can be used for spoofing and jamming if required. RF sensors are also more versatile than other sensors, as they can be utilized for various purposes such as communication protocol detection, drone MAC address detection, feature extraction, or direct use with multiple classification algorithms.

The characteristics mentioned above, especially those offered by RF sensors, have been verified through a quantitative comparative analysis based on data from (Drone Industry Insights UG, 2023) and (Butterworth-Hayes, 2023). The results of such analysis are shown in Figure 1 and include 295 different antidrone (ADRO) systems. Notably, most ADRO systems engage optoelectronic sensors (35.8%), RF sensors (31.24%), and radars (28.13%), while acoustic sensors (4.83%) are the least represented. The availability of cameras and the variety of computer vision (CV) algorithms are the main reasons that optoelectronic sensors (OES) take the first place. However, a more comprehensive and quality data analysis determines that RF sensors and radars are the primary choice for

modern ADRO systems due to their better characteristics. Indeed, this means that cutting-edge ADRO systems have an RF sensor and radar to detect the drone, while the OES is used mainly for closer identification of the drone type.

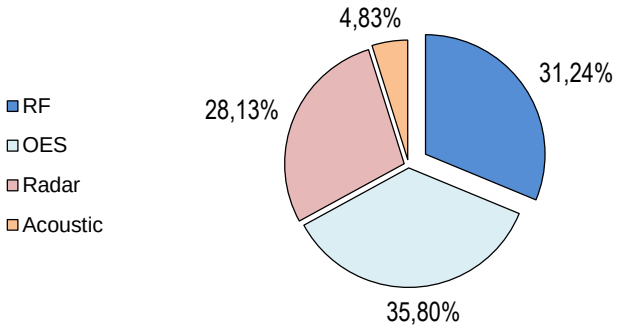

Figure 1 – Quantitative comparison of sensor types in ADRO systems

RF-based ADRO systems can extract valuable information by intercepting signals between drones and ground controllers. This information can be used to detect and identify drones based on their communication protocols and MAC addresses. However, a significant drawback of such systems is that they require prior knowledge of the protocols and addresses which may not be available for custom-made drones. The ADRO system can also extract features from intercepted RF signals for detection and uses frequency or joint time-frequency signal representation (TFSR) of I/Q data to prepare inputs for the classification algorithm.

Unfortunately, ambient RF noise, multipath, and customized drones that operate autonomously without a communication link between the drone and the ground controller can make RF-based detection difficult. Real-time monitoring of RF signals can also be challenging due to the complexity of the RF domain. Moreover, it is worth pointing out that drone RF communication can be categorized into three main groups: command and control (uplink), telemetry and video (downlink), and guidance communications. The first two groups use various frequencies, while global navigation signals are used for guidance and navigation. In such a complex environment, RF sensors must be agile, have high-speed scanning performance, be susceptible, and have a high dynamic range within the whole frequency range.

Section 2 of the paper categorizes and describes the literature to provide a comprehensive overview of relevant studies. Section 3

compares different classification techniques, and section 4 presents the results of the comparative analysis of the most relevant papers. Finally, section 5 provides the conclusion.

Review of literature and RF techniques categorization

Available studies introduced different classification techniques (approaches) based on the RF sensors. We created a new categorization of these RF techniques for classification according to the following:

- The method of input data processing:
  - classic engineering techniques require prior feature extraction in combination with a decision threshold mechanism;
  - advanced engineering techniques engage procedures for classification purposes without prior feature extraction (feature extraction is implemented in AI-based algorithms together with the learning process); and
  - hybrid engineering techniques present a combination of the previous ones.

- The type of input data:
  - techniques with classification algorithms that use the MAC address information as input data;
  - techniques with classification algorithms that use the protocol information as input data;
  - techniques with classification algorithms that use the features of RF signals as input data; and
  - techniques with classification algorithms that use the entire received I/Q RF signal as input data.

It is important to note that both rules can categorize one technique, specifically, a classic engineering approach that uses protocol information as input. The categorization presented in this research paper is based on the most significant research papers available in the literature over the past five years.

A comprehensive literature dataset on counter-unmanned aircraft systems (C-UAS) is available for review in (Sazdic-Jotic, 2024a). This dataset offers information and insights into C-UAS technology, applications, and trends. The framework for this literature review was adopted from (Alzubaidi et al, 2021), starting from the identification, screening, and selection stages, which included almost two hundred (199) research papers in the last five years from publishers such as IEEE,

Nature, Springer, ACM, Elsevier, and MDPI. All reviewed papers have tackled the drone classification problem (detection and identification) using RF sensors. Each paper was categorized as a novel approach, survey/review, dataset description, or regulation/standard, with mandatory remarks explaining specific ADRO procedures (e.g., jamming, spoofing, direction finding).

RF techniques according to the method of input data processing

In classical engineering techniques, extracting features from intercepted RF signals is mandatory for data preparation and processing. This step is crucial as only features extracted with a decision threshold mechanism can be used for classification. However, the feature extraction process can be complex and time-consuming, requiring profound engineering skills and adaptation to the nature of the input data. Authors (Lv & Wang, 2019) used standard deviation analysis, maximum slope analysis, and accumulation in azimuth direction as statistical features for drone detection and direction finding. They also employed principal component analysis (PCA) and empirical mode decomposition (EMD) based wavelet transform (WT) methods to cope with additive Gaussian white noise. A similar approach was presented in (Ezuma et al, 2020) involving fifteen (15) different statistical features of RF signals. On the other hand, (Fu et al, 2018) presented the cyclostationarity signature of the drone RF signal and the pseudo-Doppler principle for the classification issue with a single-channel universal software radio peripheral (USRP) receiver. Authors (Nguyen et al, 2018) described a passive drone detection system (Matthan) based on two critical physical signatures of drones: body shifting and vibration. However, the Matthan approach faces a range of constraints, making it impractical for implementation. Another unique way is the received signal strength indicator (RSSI) ratio that engages various factors, such as propagation channels and fading effects, and can help accurately determine the location of a drone.

Artificial intelligence (AI) algorithms, particularly deep learning (DL), provide an alternative approach to the problem of drone classification. Unlike classical engineering techniques, advanced engineering techniques such as DL algorithms use the entire received I/Q RF signal, perform preprocessing steps, and send all data to the learning process without prior feature extraction. This approach is more robust and scalable, but a significant amount of input data is required for the training process, which can sometimes be a disadvantage. Fully connected deep neural networks (FC-DNN) and convolutional neural networks (CNN) are two

prominent DL algorithms for drone classification in the publicly available literature. In addition, transformer models - a distinctive DL algorithm with an attention mechanism - are increasingly utilized to attain outstanding outcomes. Authors (Al-Sa'd et al*,* 2019; Sazdić-Jotić et al*,* 2022) employed FC-DNN for this purpose, while (Al-Emadi & Al-Senaid, 2020; Allahham et al, 2020; Ozturk et al, 2020; Basak et al, 2021; Mokhtari et al, 2021, 2022; Nguyen et al, 2021) used CNN. Authors (Basak et al, 2023) proposed a unique deep residual network-based autoencoder framework for known drone signal classification, novelty detection, and clustering (DE-FEND).

The quantitative comparison of the techniques that exploit RF sensors according to the method of processing input data is presented in Figure 2.

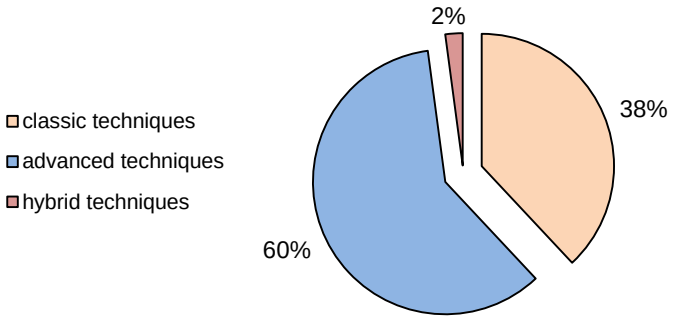

Figure 2 – Quantitative comparison of RF techniques according to the method of input data processing

Notably, more than half (60%) of all research studies rely on advanced techniques, while 38% use classic engineering techniques. The reason behind the absence of classical engineering techniques in the analysis is that only studies from the last five years were considered. This time frame shows a significant increase in advanced techniques, now preferred over classical methods. Hence, it is not unsurprising that there is a lack of classical engineering techniques in the analysis. In the overall research, advanced engineering techniques such as DL and machine learning (ML) algorithms account for 47% and 13% of all research. Compared to the results presented in (Sazdić-Jotić et al, 2023), this is a growth of 9.3% for advanced techniques in favor of classic techniques.

It is also worth mentioning that the authors (Abeywickrama et al, 2018; Shi et al, 2018; Shorten et al, 2018; Basak & Scheers, 2019; Bisio et al, 2021; Bhattacherjee et al, 2022; Lofu et al, 2023) present classical and advanced engineering techniques in combination with direction-finding (DF) methods. The specific hardware and software implementation of the RF-based DF of UAS is presented in (Abeywickrama et al, 2018) because

the authors used a single-channel RF sensor and a four-element antenna array in combination with a sparse denoising autoencoder deep neural network (SDAE-DNN). However, it is essential to note that some authors (Zhang et al, 2018; Ezuma et al, 2020; Swinney & Woods, 2021; Medaiyese et al, 2022) use a hybrid engineering technique or a combination of classical and advanced techniques. In (Zhang et al, 2018), the authors used extracted features (the slope, kurtosis, and skewness) of the drone RF signal as an input for an FC-DNN. Moreover, in (Medaiyese et al, 2022), the authors performed feature extraction and used ML algorithms (Logistic Regression). An interesting approach was presented by (Ezuma et al, 2020), where the authors extracted fifteen statistical features from the UAS RF signal and engaged them with five different ML classifiers at various SNR levels.

While advanced techniques may offer a broader range of benefits than classical techniques, they also have certain drawbacks that must be considered. It is essential to thoroughly assess the advantages and disadvantages of each approach before deciding which one to use in a particular situation. Advanced engineering techniques often need help with several challenges that can hinder their successful implementation. One of the most significant obstacles is the requirement for unique training scenarios, which means that engineers must develop customized training models for each specific use case. Additionally, the availability of datasets can be limited, making it challenging to train models effectively. Finally, the transfer learning process can be complex, especially when applying previously learned knowledge to new scenarios. These factors can make it tricky to implement advanced engineering techniques successfully. Moreover, a fusion of different sensor data is also a particular solution to the drone classification problem. This approach involves fusing information from multiple sensors, such as radar, cameras, RF, and acoustic sensors, to create a more comprehensive view of the drone characteristics. This method can provide a more reliable drone classification by analyzing the drone shape, size, movement, and RF signals. It is a promising solution gaining traction in the drone detection and defense industry.

RF techniques according to the type of input data

RF sensors receive an RF signal from a UAS for various purposes. Four techniques exist for detecting and identifying drones based on the input data type. The first technique uses classification algorithms to detect and identify the MAC address of the transceiver device in a drone. In contrast, the second technique employs classification algorithms to detect and identify the communication protocol between drones and ground

control devices. These techniques are the least represented in the literature because they have significant limitations and shortcomings. Both approaches use received and demodulated RF signals to obtain information about the MAC address of the RF transceiver installed in the drone and the type of communication protocol unique to certain types of drones. The information obtained is used for the detection and identification of drones. (Schiller et al, 2023) analyzed the security and privacy of the DJI's tracking protocol (DroneID), presenting sixteen vulnerabilities that can be adopted. In addition, there are more hardware implementations of ADRO systems based on this technique. Authors (Haluza & Čechák, 2016) performed device and protocol identification through data format analysis. In (Sciancalepore et al, 2020), features such as packet inter-arrival time and size were analyzed, while (Stoica et al, 2020) studied eight protocols to classify UAS. The technique with classification algorithms based on protocol recognition is more efficient than the previous one, proven by practical implementations of such ADRO systems. (Oh et al, 2020) also proposed long-range (LoRa) modulation exploiting wireless communication protocol for drone identification.

Furthermore, techniques with classification algorithms that use features of RF signals as input data are more present in the literature. Essential studies that exploited features have been mentioned because this is a mandatory step for classical engineering techniques. Nevertheless, an increasing number of research papers in the literature deal with the entire intercepted I/Q RF signal. Faster hardware and improved computing power have allowed it to exploit the full power of DL algorithms created for a considerable amount of data. As a result, the techniques with algorithms that classify the entire received I/Q RF signal as input data are becoming widely present solutions providing excellent results. RF sensors are used to record the raw I/Q RF signal, and different preprocessing steps are taken to prepare input data for the classifier. Some authors (Al-Sa'd et al, 2019; Sazdić-Jotić et al, 2022) calculated the magnitude or phase spectrum to obtain 1-D (vector) data with corresponding labels, while others (Ozturk et al, 2020; Basak et al, 2021; Nguyen et al, 2021; Mandal & Satija, 2023) used more complex TFSRs, such as spectrograms or scalograms, to obtain 2-D (image) representations of intercepted I/Q RF signals with corresponding labels for classification purposes. Figure 3 illustrates one 2-D TFSR obtained from RF activities in the 2.4 GHz range.

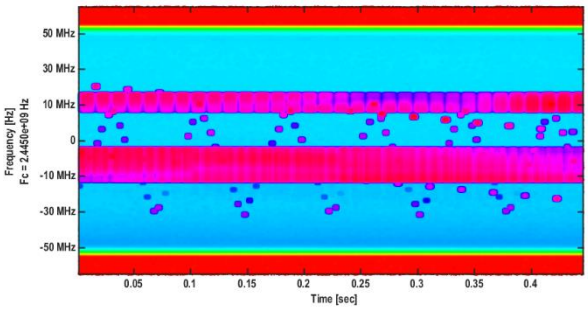

Figure 3 – Spectrogram of two RF drone signals

This TFSR is a spectrogram of the RF signal when two drones operate simultaneously at 2.4 GHz. Two emissions are visually distinctive in Figure 3: the command and control (fixed frequency, FF) and telemetry and video (frequency hopping, FH) emissions. Subsequent image processing techniques based on morphological operations of the obtained spectrograms can extract all emissions. Moreover, it is possible to determine the technical parameters of the detected radio signals (the number of the detected radio signals, the total width of the frequency range, and the width of the frequency range of one channel). The technical parameters estimation of the detected radio signals must be divided into two branches, i.e., analysis of FH or FF emissions. This way, the channel raster, the FH hop durations, and the time between two successive FH hops can be estimated. In the case of the DJI Phantom IV Pro drone, one FF and FH emission was detected with a total band of 75 MHz in the spectral domain. This drone has the highest hop duration (6 ms) with a simple FH emission comparable to a sweep frequency signal. In contrast, the DJI Mavic 2 Zoom and Enterprise drones have three types of FH emissions, which depend on operation modes (a drone is connecting to the flight controller, a drone is hovering, a drone is flying, and a drone is flying with recording) (Sazdić-Jotić, 2024b).

Different DL models are used depending on the preparation method of input data. In (Mokhtari et al, 2021; Sazdić-Jotić et al, 2022), the authors used an FC-DNN and CNN for single drone classification (detection and type identification) and multiple drone detection. Moreover, (Ozturk et al, 2020) examined CNN accuracy with SNR dependency, showing that classification is feasible. The quantitative comparison of the techniques that exploit RF sensors according to the type of input data is presented in Figure 4.

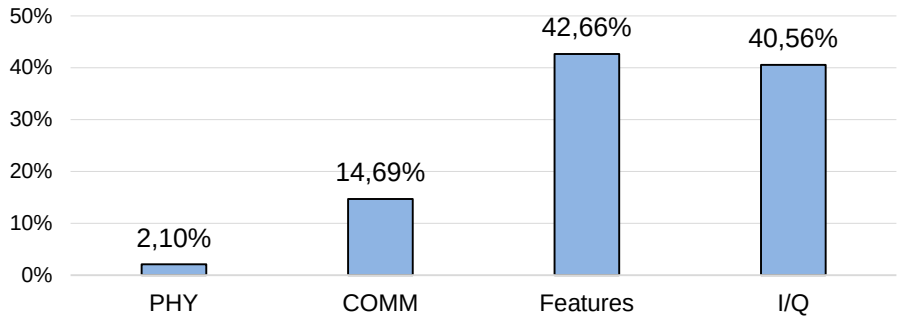

Figure 4 – Quantitative comparison of the RF techniques according to the type of input data

It is important to note that the techniques that use features and raw I/Q RF signals as input data are the most exploited, with 42.66% and 40.56%, respectively. The techniques that use MAC addresses (PHY) and communication protocols (COMM) for drone classification are the least concurrent in the reviewed literature. Compared to the results presented in (Sazdić-Jotić et al, 2023), this is an increase of 10.8% for the I/Q RF signal as input data. This fact is unsurprising due to the expansion of the DL and ML research papers. More interesting is that more than 95% of all papers that use the whole received I/Q RF signal as input data use advanced engineering techniques.

Datasets and comparison of RF techniques

The main goal of this research was to review and categorize all available RF-based drone classification research papers and datasets. Extensive research was conducted to support and highlight the best RF-based drone detection technique by performing a comprehensive comparative analysis. The most relevant research papers were utilized, and the comparison was made based on the dataset used and engineering techniques. The publicly available studies verified on the DroneRF dataset, and the VTI_DroneSET were presented and classified according to our categorization and results from three experiments. This method was intentionally employed to compare different approaches to detecting or identifying the same number of classes.

It is worth noting that only a few publicly available datasets contain drone RF signals. Only two datasets have the records of RF signals from industrial, scientific, and medical (ISM) radio bands, but only one has multiple drones that operate simultaneously. Additionally, some authors

(Ezuma et al, 2021) and (Vuorenmaa et al, 2020) used ground controllers for classification, which can be valuable in various research. Furthermore, RF receivers generate vast amounts of data during the recording process, leading to massive datasets. It is essential to consider that such an amount of information can be a disadvantage in certain situations due to the requirement for excellent computers, storage, and GPUs - Table 1 lists publicly available datasets containing RF signals from UAS.

Table 1 – The RF drone publicly available datasets

Reference	Number of UAS	Multiple drones	2.4 GHz	5.8 GHz	Size [GB]
(Allahham et al, 2019)	3	-	+	-	3.75
(Soltani et al, 2020)	unknown	-	+	-	4.5
(Vuorenmaa et al, 2020)	10	-	+	+	3,800
(Sazdic-Jotic et al, 2021)	3	+	+	+	3.35
(Ezuma et al, 2021)	17	-	+	-	124.13
(Medaiyese et al, 2023)	unknown	-	+	-	66.26
(Swinney & Woods, 2022)	7	-	+	-	65.76

It is worth mentioning that there are additionally publicly available RF fingerprinting datasets (Al-Shawabka et al, 2020) and (Soltani et al, 2020) that can be used for automatic modulation classification in ADRO systems. Such datasets can be used to train the ADRO system to filter out non-interesting RF signals (Wi-Fi, Bluetooth) and concentrate on drone RF signal classification procedures.

Authors (Allahham et al, 2019) presented a DroneRF dataset incorporating three drones, recorded in four operating modes in only one ISM band (2.4 GHz). This dataset was used in over 60% of the reviewed literature. The studies whose results were verified on the DroneRF dataset are presented in Table 2.

The inscription "H" stands for hybrid and "A" for advanced engineering techniques. The inscription "F" stands for features and "R" for raw I/Q RF signal. It is important to note that no classic engineering techniques are employed on the DroneRF dataset. Moreover, for drone detection, there

are several approaches with excellent results that are lower for drone identification and flight mode identification.

Table 2 – Comparative analysis of publicly available studies verified on the DroneRF dataset

Reference	Technique	Features	Drone detection	Type identification	Flight mode identification
(Al-Sa'd et al, 2019)	A	R	99.7	84.5	46.8
(Allahham et al, 2020)	A	R	100.0	94.6	87.4
(Al-Emadi & Al-Senaid, 2020)	A	R	99.8	85.8	59.2
(Akter et al, 2020)	A	R	-	92.5	-
(Swinney & Woods, 2020)	A	F	100.0	90.4	87.5
(Zhang, 2021)	A	R	100.0	98.7	79.2
(Kılıç et al, 2022)	A	F	100.0	98.6	95.1
(Huynh-The et al, 2022)	A	R	99.9	98.6	95.3
(Donatus et al, 2023)	A	R	99.7	94.2	81.5
(Mohammed et al, 2023)	A	R	99.6	96.9	96.0

Similarly, (Sazdic-Jotic et al, 2021) introduced a dataset with three drones recorded in four operating modes in two ISM bands (2.4 and 5.8 GHz). Moreover, this dataset contains records of multiple (two and three) drones operating at the same time simultaneously.

Such data makes the VTI_DroneSET unique because there is no such dataset in the available literature.

Three studies whose results were verified on the VTI_DroneSET are presented in Table 3.

Table 3 – Comparative analysis of publicly available studies verified on the VTI_DroneSET

Reference	Technique	Features	Drone detection		Type identification		Multiple drone detection	
			2.4GHz	5.8GHz	2.4GHz	5.8GHz	2.4GHz	5.8GHz
(Sazdić-Jotić et al, 2022)	A	R	98.6	99.8	96.1	95.7	96.2	97.3
(Mokhtari et al, 2021)	A	R	-	-	100.0	-	-	-
(Mokhtari et al, 2022)	A	R	-	-	99.9	-	-	-
(Sazdić-Jotić et al, 2023)	A	R	98.6	100.0	98.8	95.7	99.0	99.2

It is worth mentioning that the VTI_DroneSET provides multiple drone detection on real RF signals rather than simulated RF signals. It is essential to note that authors (Sazdić-Jotić et al, 2022) engaged FC-DNN while (Mokhtari et al, 2021), (Mokhtari et al, 2022) and (Sazdić-Jotić, 2024b) investigated CNN and CNN with recurrent layers (CRNN), respectively.

It is crucial to consider the input data and the corresponding preprocessing steps for adequate results of comparative analysis. Authors (Sazdić-Jotić et al, 2022) used power spectrum data obtained from raw I/Q radio signals for TFSR. Other authors engaged spectrograms as images for input data and achieved better results because they kept more valuable features for CNN/CRNN learning and testing. Moreover, through ablative analysis, it is possible to establish which TFSR is the best for processing raw I/Q radio signals when CNN is engaged as a neural network. The accuracy results of such an experiment are presented in (Sazdić-Jotić, 2024b) and shown in Table 4. The ablative experiment was performed with the AlexNet model introduced by (Krizhevsky et al, 2017) for the 2.4 GHz frequency band.

The results shown in Table 4 show that TFSR choice is essential for CNN accuracy. Moreover, the Short-Time Fourier Transform (STFT) method outperformed the Continuous Wavelet Transform (CWT) and the Wigner-Ville Decomposition (WVD) methods for all scenarios in the presented ablative experiment.

Table 4 – Comparative analysis of accuracy for different TFSRs in 2.4 GHz in ablative experiments

the AlexNet / TFSR	Drone detection	Type identification	Multiple drone detection
STFT	97.3	96.6	99.1
CWT	95.3	96.2	97.9
WVD	86.6	86.0	96.6

An additional ablative experiment compares CNN accuracy with the radio signal segment length on which TFSR is performed. The accuracy results of such an ablative experiment for drone detection are presented in (Sazdić-Jotić, 2024b) and shown in Table 5.

Table 5 – Comparative analysis of the accuracy for different lengths of input data in ablative experiments

Segment length [samples]	Segment duration [ms]	Drone detection (the AlexNet model / 2.4 GHz frequency band)
100,000	0.67	97.3
200,000	1.34	100.0
700,000	4.69	100.0

This ablative experiment was performed within the AlexNet model, the STFT method, with radio signals in the 2.4 GHz frequency band and with three-segment lengths (100,000, 200,000, and 700,000 samples). It can be observed that with the increase in the segment length of the drone radio signal, the accuracy improves. Moreover, the detection accuracy is 100% when a segment length is bigger than 200,000 samples.

Challenges in RF-based drone classification

Drone classification procedures encounter a complex challenge regardless of the sensor type and input data. As discussed in the paper (Aledhari et al, 2021), one solution, such as optoelectronic and radio sensors, uses sensor fusion. However, sensor fusion is not widely utilized in this application due to its complex implementation. Moreover, radio sensors are often paired with diverse DL algorithms to navigate the

complex and frequently unpredictable RF environment. Such a robust combination enables the ADRO system to classify and identify drones accurately, even in challenging conditions.

At (Ozturk et al, 2020; Medaiyese et al, 2022; Noh et al, 2022; Mohammed et al, 2023), great emphasis is placed on signal preprocessing as a crucial step in enhancing the accuracy and reliability of detecting and identifying drones. By carefully processing and analyzing incoming signals, it is possible to uncover hidden patterns and extract valuable information that would have otherwise been missed. This meticulous approach enables researchers to deliver superior results and stay ahead of the curve in the fast-evolving field of drone technology with improved accuracy of DL algorithms.

Finally, the multistage classification presented in (Medaiyese et al, 2022) is often employed to enhance the accuracy of the classification process and minimize the inclusion of superfluous input data. Typically, the initial stage entails detecting the drones and classifying the specific drone types. The final stage of identifying drone behavior is generally not required in practical applications.

Conclusion

This study provides a comprehensive analysis of the existing research on drone classification in the radio frequency domain and explores the potential of deep learning algorithms in addressing this issue. According to the findings, the proposed algorithms exhibit promising results in effectively resolving the problem of drone classification. However, further research is necessary to evaluate their practical implementation and testing in real-world antidrone systems. According to the findings in our review, the most effective method for categorizing drones in the radio frequency domain is through deep learning techniques. Nonetheless, it is crucial to remember that most of the research in this area is still in the experimental phase and needs to be implemented practically. One of the significant challenges is the need for a general specification of a drone classification system based on real-world requirements and experience from combat engagement.

Future research should focus on merging multiple datasets or evaluating classification techniques on different datasets to address this issue. Additionally, it is crucial to investigate the new multimodal deep learning algorithm that combines various features and raw I/Q radio signals for more accurate drone classification. Overall, this study contributes to drone classification in the radio frequency domain and highlights the need for further research.

References

Abeywickrama, S., Jayasinghe, L., Fu, H., Nissanka, S. & Yuen, C. 2018. RF-based Direction Finding of UAVs Using DNN. In: *2018 IEEE International Conference on Communication Systems (ICCS),* Chengdu, China, pp.157-161, December 19-21. Available at: https://doi.org/10.1109/ICCS.2018.8689177.

Akter, R., Doan, V-S., Tunze, G.B., Lee, J.-M. & Kim, D.-S. 2020. RF-Based UAV Surveillance System: A Sequential Convolution Neural Networks Approach. In: *2020 International Conference on Information and Communication Technology Convergence (ICTC)*, Jeju, South Korea, pp.555-558, October 21-23. Available at: https://doi.org/10.1109/ICTC49870.2020.9289281.

Aledhari, M., Razzak, R., Parizi, R.M. & Srivastava, G. 2021. Sensor Fusion for Drone Detection. In: *2021 IEEE 93rd Vehicular Technology Conference (VTC2021-Spring),* Helsinki, Finland, pp.1-7, April 25-28. Available at: https://doi.org/10.1109/VTC2021-Spring51267.2021.9448699.

Allahham, M.S., Al-Sa'd, M.F., Al-Ali, A., Mohamed, A., Khattab, T. & Erbad, A. 2019. DroneRF dataset: A dataset of drones for RF-based detection, classification and identification. *Data in Brief*, 26, art.number:104313. Available at: https://doi.org/10.1016/j.dib.2019.104313.

Allahham, M.S., Khattab, T. & Al-Sa'd Mohamed, A.M. 2020. Deep Learning for RF-Based Drone Detection and Identification: A Multi-Channel 1-D Convolutional Neural Networks Approach. In: *2020 IEEE International Conference on Informatics, IoT, and Enabling Technologies (ICIoT),* Doha, Qatar, pp.112-117, February 02-05. Available at: https://doi.org/10.1109/ICIoT48696.2020.9089657.

Al-Emadi, S. & Al-Senaid, F. 2020. Drone Detection Approach Based on Radio-Frequency Using Convolutional Neural Network. In: *2020 IEEE International Conference on Informatics, IoT, and Enabling Technologies (ICIoT),* Doha, Qatar, pp.29-34, February 02-05. Available at: https://doi.org/10.1109/ICIoT48696.2020.9089489.

Al-Sa'd, M.F., Al-Ali, A., Mohamed, A., Khattab, T. & Erbad, A. 2019. RF-based drone detection and identification using deep learning approaches: An initiative towards a large open source drone database. *Future Generation Computer Systems*, 100, pp.86-97. Available at: https://doi.org/10.1016/j.future.2019.05.007.

Al-Shawabka, A., Restuccia, F., D`Oro, S., Jian, T., Rendon, B.C., Soltani, N., Dy, J., Ioannidis, S., Chowdhurz, K. & Melodia, T. 2020. Exposing the Fingerprint: Dissecting the Impact of the Wireless Channel on Radio Fingerprinting. In: *IEEE INFOCOM 2020 - IEEE Conference on Computer Communications*, Toronto, ON, Canada, pp.646-655, July 06-09. Available at: https://doi.org/10.1109/INFOCOM41043.2020.9155259.

Basak, S., Rajendran, S., Pollin, S. & Scheers, B. 2021. Drone classification from RF fingerprints using deep residual nets. In: *2021 International Conference on COMmunication Systems & NETworkS (COMSNETS),* Bangalore, India, pp.548-555, January 05-09. Available at: https://doi.org/10.1109/COMSNETS51098.2021.9352891.

Basak, S., Rajendran, S., Pollin, S. & Scheers, B. 2023. Autoencoder based framework for drone RF signal classification and novelty detection. In: *2023 25th International Conference on Advanced Communication Technology (ICACT)*, Pyeongchang, South Korea, pp.218-225, February 19-22. Available at: https://doi.org/10.23919/ICACT56868.2023.10079363.

Basak, S. & Scheers, B. 2019. Passive radio system for real-time drone detection and DoA estimation. In: *2018 International Conference on Military Communications and Information Systems (ICMCIS),* Warsaw, Poland, pp.1-6, May 22-23. Available at: https://doi.org/10.1109/ICMCIS.2018.8398721.

Bhattacherjee, U., Ozturk, E., Ozdemir, O., Guvenc, I., Sichitiu, M.L. & Dai, H. 2022. Experimental Study of Outdoor UAV Localization and Tracking using Passive RF Sensing. In: *WiNTECH '21: Proceedings of the 15th ACM Workshop on Wireless Network Testbeds, Experimental evaluation & CHaracterization*. New Orleans, USA, pp.31-38, January 31 - February 04. Available at: https://doi.org/10.1145/3477086.3480832.

Bisio, I., Garibotto, C., Haleem, H., Lavagetto, F. & Sciarrone, A. 2021. On the Localization of Wireless Targets: A Drone Surveillance Perspective. *IEEE Network*, 35(5), pp.249-255. Available at: https://doi.org/10.1109/MNET.011.2000648.

Butterworth-Hayes, P. 2023. The Counter UAS Directory and Buyer's Guide. *Unmanned Airspace* [online]. Available at: https://www.unmannedairspace.info/wp-content/uploads/2023/04/Counter-UAS-directory.-April-2023.v2.pdf [Accessed: 05.12.2023].

Ding, G., Wu, Q., Zhang, L., Lin, Y., Tsiftsis, T.A. & Yao, Y.D. 2018. An Amateur Drone Surveillance System Based on the Cognitive Internet of Things. *IEEE Communications Magazine*, 56(1), pp.29-35. Available at: https://doi.org/10.1109/MCOM.2017.1700452.

Donatus, R.E., Dere, M.D., Donatus, I.H., Chiedu, U.O., Abdulrazaq, M.B. & Ohemu, M.F. 2023. Development of an Optimised Neural Network Model for RF Based UAV Detection and Identification. *Dutse Journal of Pure and Applied Sciences*, 8(4b), pp.82-91. Available at: https://doi.org/10.4314/dujopas.v8i4b.10.

Drone Industry Insights UG. 2023. Commercial Drone Reports. *Droneii.com* [online]. Available at: https://droneii.com/drone-reports [Accessed: 28.12.2023].

Ezuma, M., Erden, F., Anjinappa, C.K., Ozdemir, O. & Guvenc, I. 2020. Detection and Classification of UAVs Using RF Fingerprints in the Presence of Wi-Fi and Bluetooth Interference. *IEEE Open Journal of the Communications Society*, 1, pp.60-76. Available at: https://doi.org/10.1109/OJCOMS.2019.2955889.

Ezuma, M., Erden, F., Anjinappa, C.K., Ozdemir, O. & Guvenc, I. 2021. Drone remote controller RF signal dataset. *IEEEDataPort,* 11 February. Available at: https://doi.org/10.21227/ss99-8d56.

Fu, H., Abeywickrama, S., Zhang, L. & Yuen, C. 2018. Low-Complexity Portable Passive Drone Surveillance via SDR-Based Signal Processing. *IEEE Communications Magazine*, 56(4), pp.112-118. Available at: https://doi.org/10.1109/MCOM.2018.1700424.

Haluza, M. & Čechák, J. 2016. Analysis and decoding of radio signals for remote control of drones. In: *2016 New Trends in Signal Processing (NTSP),* Demanovska dolina, Slovakia, pp.1-5, October 12-14. Available at: https://doi.org/10.1109/NTSP.2016.7747781.

Hassanalian, M. & Abdelkefi, A. 2017. Classifications, applications, and design challenges of drones: a review. *Progress in Aerospace Sciences*, 91, pp.99-131. Available at: https://doi.org/10.1016/j.paerosci.2017.04.003.

Huynh-The, T., Pham, Q.-V., Nguyen, T.-V., Da Costa, D.B. & Kim, D.-S. 2022. RF-UAVNet: High-Performance Convolutional Network for RF-Based Drone Surveillance Systems. *IEEE Access*, 10, pp.49696-49707. Available at: https://doi.org/10.1109/ACCESS.2022.3172787.

Krizhevsky, A., Sutskever, I. & Hinton, G.E. 2017. ImageNet classification with deep convolutional neural networks. *Communications of the ACM*, 60(6), pp.84-90. Available at: https://doi.org/10.1145/3065386.

Kılıç, R., Kumbasar, N., Oral, E.A. & Ozbek, I.Y. 2022. Drone classification using RF signal based spectral features. *Engineering Science and Technology, an International Journal*, 28, art.number:101028. Available at: https://doi.org/10.1016/j.jestch.2021.06.008.

Lofu, D., Di Gennaro, P., Tedeschi, P., Di Noia, T. & Di Sciascio, E. 2023. URANUS: Radio Frequency Tracking, Classification and Identification of Unmanned Aircraft Vehicles. *IEEE Open Journal of Vehicular Technology*, 4, pp.921-935. Available at: https://doi.org/10.1109/OJVT.2023.3333676.

Lv, X. & Wang, Z. 2019. An Improved RF Detection Algorithm Using EMD-based WT. *KSII Transactions on Internet and Information Systems*, 13(8), pp.3862-3879. Available at: https://doi.org/10.3837/tiis.2019.08.003.

Mandal, S. & Satija, U. 2023. Time-Frequency Multiscale Convolutional Neural Network for RF-Based Drone Detection and Identification. *IEEE Sensors Letters*, 7(7), art.number:7003304. Available at: https://doi.org/10.1109/LSENS.2023.3289145.

Medaiyese, O., Ezuma M., Lauf, A. & Adeniran, A. 2023. Cardinal RF (CardRF): An Outdoor Uav/Uas/Drone RF Signals With Bluetooth And Wifi Signals Dataset. *IEEEDataPort,* 08 May. Available at: https://doi.org/10.21227/1xp7-ge95.

Medaiyese, O.O., Ezuma M., Lauf, A.P. & Guvenc, I. 2022. Wavelet transform analytics for RF-based UAV detection and identification system using machine learning, *Pervasive and Mobile Computing*, 82, art.number:101569. Available at: https://doi.org/10.1016/j.pmcj.2022.101569.

Mohammed, K.K., El-Latif, E.I.A., El-Sayad, N.E., Darwish, A., & Hassanien, A.E. 2023. Radio frequency fingerprint-based drone identification and classification using Mel spectrograms and pre-trained YAMNet neural. *Internet of Things*, 23, art.number:100879. Available at: https://doi.org/10.1016/j.iot.2023.100879.

Mokhtari, M., Bajčetić, J., Sazdić-Jotić, B. & Pavlović, B. 2021. RF-based drone detection and classification system using convolutional neural network. In: *2021 29th Telecommunications Forum (TELFOR)*, Belgrade, Serbia, pp.1-4,

November 23-24. Available at: https://doi.org/10.1109/TELFOR52709.2021.9653332.

Mokhtari, M. Bajčetić, J., Sazdić-Jotić, B. & Pavlović, B. 2022. Developing a convolutional recurrent neural network for drone classification. In: *9th Small Systems Simulation Symposium*, Niš, Serbia, pp.85-89, February 28 - March 02 [online]. Available at: http://ssss.elfak.rs/proceedings-2022/ [Accessed: 25.12.2023].

Nguyen, H.N., Vomvas, M., Vo-Huu, T. & Noubir, G. 2021. Spectro-Temporal RF Identification using Deep Learning. *arXiv:2107.05114*. Available at: https://doi.org/10.48550/arXiv.2107.05114.

Nguyen, P., Truong, H., Ravindranathan, M., Nguyen, A., Han, R. & Vu, T. 2018. Cost-Effective and Passive RF-Based Drone Presence Detection and Characterization. *GetMobile: Mobile Computing and Communications*, 21(4), pp.30-34. Available at: https://doi.org/10.1145/3191789.3191800.

Noh, D.-I., Jeong, S.-G., Hoang, H.-T., Pham, Q.-V., Huynh-The, T., Hasegawa, M., Sekiya, H., Kwon, S.-Y., Chung, S.-H. & Hwang, W.-J. 2022. Signal Preprocessing Technique With Noise-Tolerant for RF-Based UAV Signal Classification. *IEEE Access*, 10, pp.134785-134798. Available at: https://doi.org/10.1109/ACCESS.2022.3232036.

Oh, J., Lim, D.-W. & Kang, K.-M. 2020. Unmanned Aerial Vehicle Identification Success Probability with LoRa Communication Approach. In: *2020 IEEE 31st Annual International Symposium on Personal, Indoor and Mobile Radio Communications*, London, UK, pp.1-6, August 31 - September 03. Available at: https://doi.org/10.1109/PIMRC48278.2020.9217172.

Ozturk, E., Erden, F. & Guvenc, I. 2020. RF-Based Low-SNR Classification of UAVs Using Convolutional Neural Networks. *arXiv:2009.05519*. Available at: https://doi.org/10.48550/arXiv.2009.05519.

Sazdic-Jotic, B. 2024a. CUAS_Literature_DataSet. *Mendeley Data,* 20 February. Available at: https://doi.org/10.17632/6jc6w2v5nf.2.

Sazdić-Jotić, B. 2024b. *Klasifikacija dronova u radio-frekvencijskom domenu primenom algoritama dubokog učenja*. Ph.D. thesis. Belgrade, Serbia: University of Defence in Belgrade, Military Academy (in Serbian).

Sazdic-Jotic, B., Pokrajac, I., Bajcetic, J., Bondzulic, B., Joksimović, V., Šević, T. & Obradović, D. 2021. VTI_DroneSET_FFT. *Mendeley Data*, 04 January. Available at: https://doi.org/10.17632/s6tgnnp5n2.3.

Sazdić-Jotić, B., Bondžulić, B., Pokrajac, I., Bajčetić, J. & Mohammed, M. 2023. Drone classification based on radio frequency: techniques, datasets, and challenges. In: *10th International Scientific Conference on Defensive Technologies, OTEH 2023*, Belgrade, Serbia, pp.314-320, October 13-14 [online]. Available at: http://www.vti.mod.gov.rs/oteh/elementi/rad/031.pdf [Accessed: 05.02.2024].

Sazdić-Jotić, B., Pokrajac, I., Bajčetić, J., Bondžulić, B. & Obradović, D. 2022. Single and multiple drones detection and identification using RF based deep learning algorithm. *Expert Systems with Applications*, 187, art.number:115928. Available at: https://doi.org/10.1016/j.eswa.2021.115928.

Schiller, N., Chlosta, M., Schloegel, M., Bars, N., Eisenhofer, T., Scharnowski, T., Domke, F., Schönherr, L. & Holz, T. 2023. Drone Security and the Mysterious Case of DJI's DroneID. In: *Network and Distributed System Security (NDSS) Symposium,* San Diego, CA, USA, pp.1-17, February 27 - March 03. Available at: https://doi.org/10.14722/ndss.2023.24217.

Sciancalepore, S., Ibrahim, O.A., Oligeri, G. & Di Pietro, R. 2020. PiNcH: an effective, efficient, and robust solution to drone detection via network traffic analysis. *Computer Networks*, 168, art.number:107044. Available at: https://doi.org/10.1016/j.comnet.2019.107044.

Shi, X., Yang, C., Xie, W., Liang, C., Shi, Z. & Chen, J. 2018. Anti-Drone System with Multiple Surveillance Technologies: Architecture, Implementation, and Challenges. *IEEE Communications Magazine*, 56(4), pp.68-74. Available at: https://doi.org/10.1109/MCOM.2018.1700430.

Shorten, D., Williamson, A., Srivastava, S. & Murray, J.C. 2018. Localisation of Drone Controllers from RF Signals using a Deep Learning Approach. In: *PRAI 2018: Proceedings of the International Conference on Pattern Recognition and Artificial Intelligence*, Union Township, NJ, USA, pp.89-97, August 15-17. Available at: https://doi.org/10.1145/3243250.3243272.

Soltani, N., Reus-Muns, G., Salehi, B., Dy, J., Ioannidis, S. & Chowdhury, K. 2020. RF Fingerprinting Unmanned Aerial Vehicles with Non-Standard Transmitter Waveforms. *IEEE Transactions on Vehicular Technology*, 69(12), pp.15518-15531. Available at: https://doi.org/10.1109/TVT.2020.3042128.

Stoica, P., Basak, S., Molder, C. & Scheers, B. 2020. Review of Counter-UAV Solutions Based on the Detection of Remote Control Communication. In: *2020 13th International Conference on Communications (COMM)*, Bucharest, Romania, pp.233-238, June 18-20. Available at: https://doi.org/10.1109/COMM48946.2020.9142017.

Swinney, C.J. & Woods, J.C. 2020. Unmanned Aerial Vehicle Flight Mode Classification using Convolutional Neural Network and Transfer Learning. In: *2020 16th International Computer Engineering Conference (ICENCO),* Cairo, Egypt, pp.83-87, December 29-30. Available at: https://doi.org/10.1109/ICENCO49778.2020.9357368.

Swinney, C.J. & Woods, J.C. 2021. RF Detection and Classification of Unmanned Aerial Vehicles in Environments with Wireless Interference. In: *2021 International Conference on Unmanned Aircraft Systems (ICUAS)*, Athens, Greece, pp.1494-1498, June 15-18. Available at: https://doi.org/10.1109/ICUAS51884.2021.9476867.

Swinney, C.J. & Woods, J.C. 2022. DroneDetect Dataset: A Radio Frequency Dataset Of Unmanned Aerial System (UAS) Signals For Machine Learning Detection & Classification. *IEEEDataPort* 17 May. Available at: https://doi.org/10.21227/5jjj-1m32.

Vuorenmaa, M., Marin, J., Heino, M., Turunen, M., Riihonen, T. & Pärlin, K. 2020. Radio-Frequency Control and Video Signal Recordings of Drones. *Zenodo*, 05 November. Available at: https://doi.org/10.5281/zenodo.4264467.

Zhang, H., Cao, C., Xu, L. & Gulliver, T.A. 2018. A UAV Detection Algorithm Based on an Artificial Neural Network. *IEEE Access*, 6, pp.24720-24728. Available at: https://doi.org/10.1109/ACCESS.2018.2831911.

Zhang, Y. 2021. RF-based Drone Detection using Machine Learning. In: *2021 2nd International Conference on Computing and Data Science (CDS)*, Stanford, CA, USA, pp.425-428, January 28-29. Available at: https://doi.org/10.1109/CDS52072.2021.00079.

Revisión de la clasificación de drones basada en RF: técnicas, conjuntos de datos y desafíos

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CAMPO: ciencias de computación, telecomunicación
TIPO DE ARTÍCULO: artículo de revisión

Resumen:

Introducción/objetivo: Este artículo analiza la bibliografía disponible públicamente sobre la clasificación de drones en el dominio de la radiofrecuencia, centrándose en la detección e identificación. Los drones se utilizan cada vez más con fines ilegales, lo que hace que las técnicas de clasificación sean cruciales. Este artículo de revisión cubre sensores pasivos de radiofrecuencia, técnicas de clasificación y conjuntos de datos que destacan los desafíos.

Métodos: Los investigadores están desarrollando soluciones anti drones porque los drones se han convertido en herramientas valiosas y objetivos para actividades ilegales. Debido al alcance del tema, la revisión incluyó solo la clasificación de drones mediante sensores pasivos de radiofrecuencia con una descripción de las técnicas de clasificación (conjunto de algoritmos, métodos y procedimientos) y los conjuntos de datos utilizados para las pruebas de rendimiento. Este estudio introduce una nueva categoría y ofrece información más profunda sobre las técnicas de clasificación de drones disponibles públicamente.

Resultados: Con base en los resultados de este estudio, es evidente que los algoritmos de aprendizaje profundo son actualmente el enfoque más eficaz para abordar el desafío de la clasificación de drones dentro del dominio de la radiofrecuencia. Uno de los principales obstáculos es la ausencia de un estándar integral para clasificar los drones en el dominio de la radiofrecuencia, que debería basarse en los requisitos del usuario final. Además, los resultados de dos experimentos ablativos destacan el

preprocesamiento de señales de radio I/Q sin procesar como un paso esencial en la clasificación de drones.

Conclusión: En resumen, la clasificación propuesta proporciona una herramienta valiosa para la revisión de la bibliografías. El aprendizaje profundo es la técnica más eficaz para la clasificación de drones, pero los conjuntos de datos disponibles públicamente con señales de radio de drones son limitados. La fortaleza clave de este estudio es que representa la primera revisión de conjuntos de datos disponibles públicamente con señales de radio de drones.

Palabras claves: aprendizaje profundo, drone, detección, clasificación, identificación, radiofrecuencia.

Обзор классификации дронов на основании радиочастотного диапазона: методы, наборы данных и вызовы

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ВИД СТАТЬИ: обзорная статья

Резюме:

Введение/цель: За последнее десятилетие многократно возросло использование беспилотных летательных аппаратов или дронов как в коммерческих (гражданских или любительских), так и в функциональных (военных или промышленных) целях. В связи с этим в данной статье представлен всесторонний обзор общедоступной и актуальной литературы по классификации (обнаружению и идентификации) дронов и их радиочастотного спектра. Особое внимание уделено алгоритмам глубокого обучения и результатам, полученным из общедоступного набора данных VTI_DroneSET.

Методы: Благодаря значительному прогрессу дроны стали полезным инструментом в осуществлении различных целей. Дополнительным преимуществом является то, что они стали дешевле и доступнее, вследствие чего увеличилась опасность от использования дронов в противозаконной деятельности. Такое развитие событий вызвало повышенное вовлечение исследователей в разработку решений по борьбе с дронами. С учетом большого объема общедоступных исследований в данной статье рассматривается исключительно вид дронов,

собирающих данный с помощью пассивных радиочастотных датчиков с описанием используемых методов (набора алгоритмов, методов и процедур) и наборов данных, используемых в испытаниях эффективности. Для понимания проблемы классификации дронов был проведен количественный и качественный анализы методами технического анализа и обработки радиосигналов. Количественные показатели с графическим изображением использовались в систематизации собранных статей, в то время как для определения возможности классификации дронов по радиочастотному диапазону использовались алгоритмы глубокого обучения. Помимо этого, в данной статье представлены вызовы и ограничения классификации дронов на основании радиосигналов.

Результаты: Результаты данного исследования доказывают, что алгоритмы глубокого обучения в настоящее время являются наиболее эффективным подходом к решению проблемы классификации дронов по радиочастотному диапазону. Однако следует отметить, что большинство современных исследований имеют экспериментальный характер, следовательно, они ограничены в практическом применении. Главной проблемой является отсутствие общей спецификации в классификации дронов по радиочастотному диапазону, основанной на требованиях, исходящих из ежедневной практики.

Выводы: Вклад данного исследования заключается в систематизации всех доступных работ, посвященных классификации дронов по радиочастотному диапазону, и представлении некоторых возможностей алгоритмов глубокого обучения. Можно сделать вывод, что предложенные алгоритмы могут быть использованы в решении этой проблемы, а в ближайшем будущем можно будет испытать на практике в реальных сценариях антидрон систему защиты от беспилотных летательных аппаратов.

Ключевые слова: глубокое обучение, дроны, обнаружение, классификация, идентификация, радиочастоты.

Преглед класификације дронова у радио-фреквенцијском домену: технике, скупови података и изазови

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Сажетак:

Увод/циљ: Коришћење беспилотних ваздухоплова – дронова, током последње деценије многоструко се увећало, како за комерцијалне (цивилне или аматерске), тако и за функционалне (војне или индустријске) потребе. У овом истраживачком раду представљен је свеобухватан преглед јавно доступне и актуелне литературе о класификацији (детекција и идентификација) дронова у радио-фреквенцијском домену. Посебан аспект представљају алгоритми за дубоко учење и резултати који су добијени са јавно доступним скупом (базом) података VTI_DroneSET.

Методе: Захваљујући значајним унапређењима дронови су постали корисна средства за различите намене. Додатна погодност јесте што су јефтинији и приступачнији за коришћење, што представља опасност од њихове злоупотребе. Стога је појачано ангажовање истраживача на развоју антидрон решења. Због обима јавно доступних истраживања, овај рад је обухватио само класификацију дронова путем пасивних радио-фреквенцијских сензора са описом коришћених техника (скуп алгоритама, метода и процедура) и скупова података који се користе за тестирање перформанси. Ради разумевања проблема класификације дронова извршена је квантитативна и квалитативна анализа са методама техничке анализе и обраде радио-сигнала. Квантитативни показатељи са графичким илустрацијама коришћени су за систематизацију прикупљених радова, док су за утврђивање могућности класификације дронова у радио-фреквенцијском домену коришћени алгоритми дубоког учења. Штавише, представљени су изазови и ограничења класификације дронова на основу радио-сигнала.

Резултати: Показано је да су алгоритми дубоког учења тренутно најбоље решење за решавање питања класификације дронова у радио-фреквенцијском домену. Међутим, већина савремених истраживања је експериментална и има ограничену практичну имплементацију. Посебан проблем представља недостатак опште спецификације за класификацију дронова у радио-фреквенцијском домену на основу захтева из свакодневног искуства.

Закључак: Допринос овог истраживања је у систематизацији свих доступних радова који се баве класификацијом дронова у радио-фреквенцијском домену, као и у приказу неких могућности алгоритама дубоког учења. Може се закључити да се предложени алгоритми могу искористити за наведену примену, те да је у

наредном периоду могуће тестирати практичне имплементације, као и вршити тестирање у реалним сценаријима употребе антидрон система.

Кључне речи: дубоко учење, дрон, детекција, класификација, идентификација, радио-фреквенција.

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Direct sequence spread spectrum: history, principles and modern applications

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Abstract:

Introduction/purpose: Direct sequence spread spectrum modulation is widely used in many radiocommunications systems. At the first time, this modulation technique was used in military communications and navigation systems. Later, applications became diverse in civil communication systems as well. Today, there are many systems where direct sequence spread spectrum modulation is implemented as a part of the system. This article aims to sublimate knowledge about the direct sequence spread spectrum modulation technique and its applications.

Methods: The article presents a review of the historical development of the direct sequence spread spectrum modulation technique, its principles and the most important current applications.

Results: Based on a large number of references, this article summarizes the historical development, basic principles and modern applications of the direct sequence spread spectrum modulation in military and commercial communication systems.

Conclusion: Direct sequence spread spectrum modulation is widely used in modern wireless and satellite radiocommunications. It is expected to be part of future global communication systems.

Key words: radiocommunications, military communications, cellular mobile systems, spread spectrum, direct sequence, global positioning system, underwater acoustic communications, unmanned aerial vehicles, wireless fidelity, ZigBee.

Introduction

Spread Spectrum (SS) modulation has been developed in the middle of the 20th century. In the beginning, this modulation was developed for military purposes. Today, there are many reasons for commercial applications of SS modulation, such as: anti-jamming capability, interference rejection, low probability of intercept, multiple access capability, improved multipath and diversity reception, high resolution ranging, and accurate universal timing (Fazel & Kaiser, 2003). Also, these systems cause relatively minor interference with other systems operating in the same frequency band (Torrieri, 2015). There are also promising possibilities for its implementation in future global communication systems (Todorović et al, 2024).

In radiocommunication systems with SS modulation, the transmitted signal requires a much wider frequency bandwidth than the minimum bandwidth needed to transmit information in classical communication systems. The pseudonoise (PN) sequence is used for signal spreading at the transmitter and signal despreading at the receiver. The PN sequence, or code sequence as it is also called in SS, is independent of the data signal.

The two most commonly used SS modulations are: Direct Sequence Spread Spectrum (DS-SS) and Frequency Hopping Spread Spectrum (FH-SS) (Torrieri, 2015).

In the transmitter, a data signal arriving at the input of the transmitter is multiplied by the PN sequence generated locally. The PN sequence must have a much higher rate than the data signal. In this way, the data signal is spread. At the receiver, the incoming spread signal is multiplied by the same locally generated PN sequence which is synchronized with the PN sequence contained in the incoming signal. In that way, the spectrum of the transmitting signal is despread. In other words, the removal of the PN sequence at the receiver results in spectrum despreading and it is exploited by appropriate filtering to remove a large portion of the interference.

This paper presents: (1) the history of the DS-SS modulation technique and its application to radiocommunication systems, (2) the operating principles of the DS-SS modulation technique, and (3) an overview of modern systems, both military and commercial, using the DS-SS modulation technique. At the end of this paper, some conclusions are given.

History of DS-SS modulation technique

The first system which looks like today's DS-SS modulation appeared in 1935. Two Telefunken engineers, Paul Kotowski and Kurt Dannehl, made a device for masking voice signals. The voice was masked by combining it with a broadband noise signal produced by a rotating generator. The U.S. version of this patent (Kotowski & Dannehl, 1940), which was published in 1940, was considered as the forerunner of the DS-SS modulation technique. Kotowski and Dannehl had an idea to create a device that used key-stream generators for discrete data encryption. This patent did not mention the spreading spectrum, although there were some concepts of DS-SS modulation. These principles were implemented in radio devices in Very High Frequency (VHF) and Ultra High Frequency (UHF) bands during World War II (Scholtz, 1982).

The occurrence of DS-SS modulation is connected with the occurrence of Shannon's theory of information (Shannon, 1948). The idea was how to suppress interference and jamming signals (Scholtz, 1994).

In August 1954, a transcontinental system project called F9C (Green, 1954) commenced. The transmitter was located in Davis, California, and the receiver in Deal, New York, and based on DS-SS modulation. The system operated in a High Frequency (HF) band. A further test of the F9C system was performed in February 1955. The improvement of the system was tested in situations with and without jammers. In December 1956, the manuals for the new advanced F9C system named F9C-A were published. It was planned to make 16 pairs of transmitters and receivers and put them in final testing, but because of the limited funds of the project, only six were produced. The devices were installed in a couple of places around the world, and the testing lasted until 1959. The last version of this system was F9C-A/Rake. It had the additional implementation of a rake receiver, as a solution for ionospheric multipath propagations. The F9C-A/Rake was tested until 1962, between Hawaii and Tokyo. That system is no longer on-site, operational and supported by the United States Army (Scholtz, 1982).

The COded DOppler, RAnging, and Command (CODORAC) system was developed by Eberhardt Rechtin, Richard Jaffe, and Walt Victor

(Scholtz, 1982). In 1952, the Jet Propulsion Laboratory (JPL) of the California Institute of Technology was attempting to construct a radio command link for remote control of rocket systems. In 1953, DS-SS modulation began to be used in this project. In the period from 1954 to 1958, the radio guidance system for the Sergeant and Jupiter space programs (Mudgway, 2001) was developed from that project. In October 1958, the National Aeronautics and Space Administration (NASA) was officially established to consolidate the separately developing space-exploration programs of the United States Army, United States Navy, and United States Air Force into one civilian organization. That was the beginning of the deep space network (Scholtz, 1982).

In the NASA Apollo program, which lasted from 1969 to 1974, it was necessary to determine the precise position of the spacecraft during the journey to the Moon. Due to a great distance, frequently used pulse radars were not good enough due to excessive attenuation. To overcome that problem, a PN sequence was generated using a linear shift register with a length of up to 127 chips (the symbol of the data signal is called a bit, while a symbol of the PN sequence is called a chip). This method of signal transmission was chosen because it was easy to extract a significantly attenuated signal from the noise on the receiver, which is a very useful feature of the DS-SS modulation technique. The basic principles applied in this system are applied today in satellite communications, more precisely in the Global Positioning System (GPS) (Shirriff, 2022).

For the communication between fighter planes, the ARC-50 project was launched in 1953. The researchers who were on the CODORAC project proposed the use of DS-SS modulation for that communication. Before that time, the tactic of aero units was to keep planes in radio silence when they were in the range of radars or radio eavesdroppers. Then it was realized that upon entering the radar range, it was not necessary for aircraft to be in radio silence and therefore it was important to avoid possible radio signal interference, where the good characteristics of DS-SS modulation could be expressed. This system initially used PN sequences generated by linear shift registers with 31 registers. Later, Bob Gold proposed a way to generate PN sequences with very good cross-correlation characteristics, which was finally implemented (Scholtz, 1982).

The Joint Tactical Information Distribution System (JTIDS) was founded in 1973. It was created by the Department of Defence of the United States as a joint program office with the Air Force as an executive agent. In the beginning, their work on communication systems for military purposes was based on DS-SS modulation. Later, they also often used FH-SS in their radiocommunication solutions. The JTIDS solutions are

also used by allies of the United States. Frequency Shift Keying (FSK) and Phase Shift Keying (PSK) are used both in their network radio systems and in a combination with SS to reduce susceptibility to noise, jamming, and interception. Their equipment is highly survivable radio and meets the most stringent requirements of modern combat, providing reliable situational awareness for fast-moving forces. Great performances were shown during the Desert Storm operation. Even today, JTIDS solutions are implemented in the radio infrastructure of the North Atlantic Treaty Organization (NATO) (DTIC, 1988).

A project called SECRAL, which was realized during the 1950s, was based on DS-SS modulation and was intended for missile guidance. This project was terminated as a failure. This is only one of the known examples, and there were certainly others that were unsuccessful, but that information never reached the general public (Scholtz, 1982).

Major advances in the field of SS systems were made during the 1950s, 1960s and 1970s. Almost all researchers from that period were shrouded in secrecy because these systems were exclusively for military purposes. Some of these systemic solutions were later fully disclosed to the general public, while some never were (Malik, 2001).

Operating principles of the DS-SS modulation technique

The DS-SS modulation technique has great resistance to interference and multipath propagation. Also, it can operate in the environment of low Signal to Noise plus Interference Ratio (SNIR). Using the orthogonal code, sequences can create a system with multiple access, named Code Division Multiple Access (CDMA) in which all channels operate on the same frequency bandwidth simultaneously (Todorović, 2021).

Figure 1 shows a block diagram of the DS-SS transmitter. The spectrum is spread by the direct multiplication of the data signal, $u_m(t)$, and the PN sequence, $c(t)$, generated in the PN generator. The data signal in this case is assumed to be polar. The product of multiplication of the data signal and the PN sequence is labeled as $u_c(t)$, and that signal is further fed to the classic modulator. In the classic modulator, some of the classic digital modulation techniques are applied. PSK modulation techniques are most often used in applied systems. After the classic modulation, a DS-SS signal is obtained, and it is denoted with $u_{DS}(t)$ (Todorović, 2021).

Since the interval of the PN sequence chip is much shorter than the interval of the data bit, the chip rate defines the transmitting bandwidth.

Hence, the transmitted signal needs a much wider bandwidth than it would be necessary when only classical modulation is used.

Figure 2 shows the waveforms of the signals during the processing in the transmitter. In the example, Binary PSK (BPSK) modulation is applied.

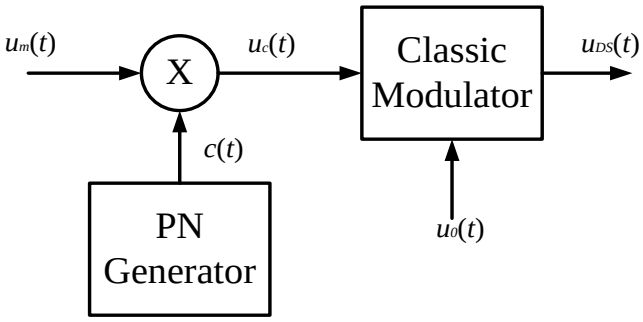

Figure 1 – Block diagram of the direct sequence spread spectrum transmitter

The processing gain or spreading ratio is an important system parameter in DS-SS systems. The processing gain is defined as:

$$PG = \frac{T_b}{T_c}, \tag{1}$$

where T_c is the PN sequence chip interval and the T_b is the data bit interval. It can be calculated also as:

$$PG = \frac{B_{DS-SS}}{B_{class}}, \tag{2}$$

where B_{class} is the frequency bandwidth necessary for signal transmission used only with the classic modulation technique and the $B_{DS\text{-}SS}$ is the frequency bandwidth necessary for signal transmission in SS. The processing gain is more often expressed in dB as follows:

$$PG_{dB} = 10\log\left(PG\right). \tag{3}$$

The processing gain determines the level of interference protection. In modern devices, the processing gain value varies between 20 and 60 dB (Todorović, 2021).

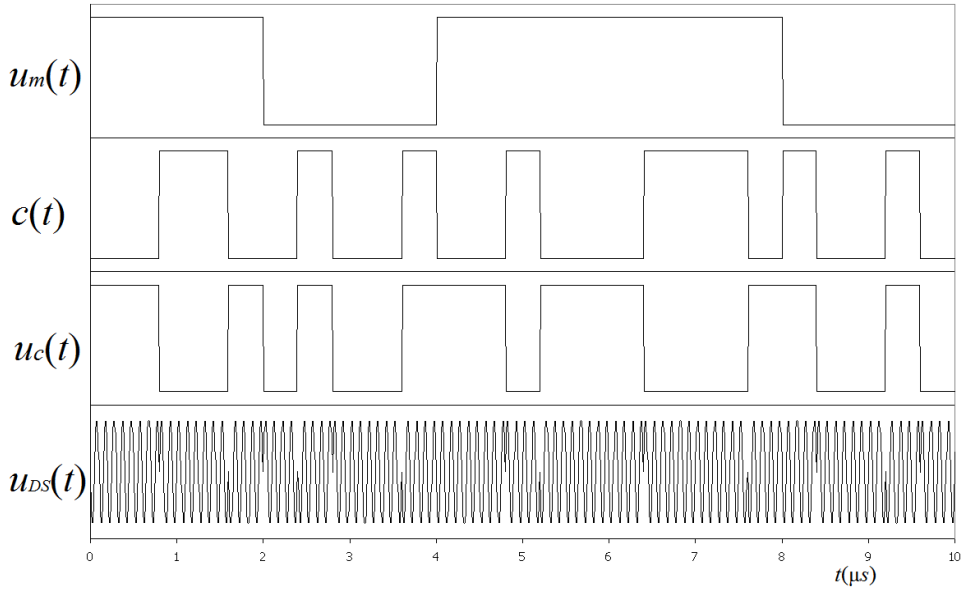

Figure 2 – Signals waveforms in the direct sequence spread spectrum transmitter

The block diagram of the DS-SS receiver is shown in Figure 3. At the receiver, the received spread spectrum signal is despread by the multiplication of signals $u_{DS}(t)$ and $c(t)$. The locally generated PN sequence has to be synchronized with the PN sequence contained in the received signal. If the two PN sequences are synchronized, the original data signal after correlation can be recovered. The aim of a bandpass (BP) filter is to remove the undesirable frequency components. Finally, classic demodulation is applied (Todorović, 2021).

Figure 4 presents the power spectral densities of the DS-SS data signal and interference before and after signal despreading at the receiver. In Figure 4 (a), the data signal is spread and its power spectral density is below the power spectral density of the narrowband interference. In the receiver, the data signal is despread by multiplying with the locally generated and synchronized PN sequence. In addition to the data signal, interference is also multiplied by the same PN sequence, thereby spreading the interference signal. The result is shown in Figure 4 (b). The data signal is despead to the bandwidth before spreading, while the interference is spread and its impact on the data signal is significantly reduced.

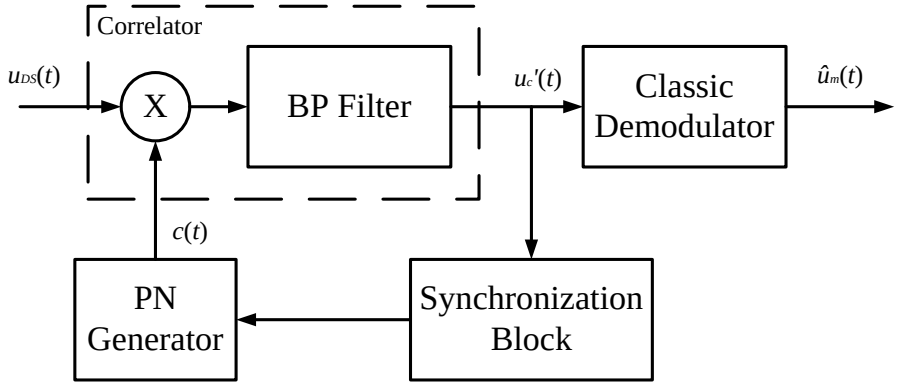

Figure 3 – Block diagram of the direct sequence spread spectrum receiver

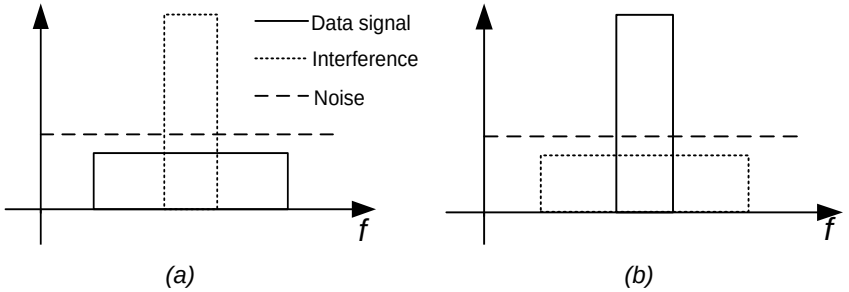

Figure 4 – Data signal and interference in the frequency domain at the receiver: (a) before and (b) after spectrum despreading

Modern applications

DS-SS modulation has been implemented in many modern radiocommunication systems. In the text which follows, eight applications of DS-SS modulation in commercial and military radiocommunication systems are described.

Interim standard 95

The Interim Standard 95 (IS-95) is the first commercial cellular radiocommunication system based on the DS-SS modulation technique and Frequency Division Duplex (FDD). This system was developed and implemented in the United States just after the introduction of the Global System for Mobile Telecommunications (GSM) in Europe (Fazel & Kaiser, 2003). It is also known as CDMAOne.

The IS-95 operates in two frequency bandwidths. The first frequency bandwidth is from 824-849 MHz for uplink and from 869-894 MHz for

downlink. The second uses a frequency bandwidth from 1850-1910 MHz for uplink and from 1930-1990 MHz for downlink (Fazel & Kaiser, 2003).

The channel bandwidth is 1.25 MHz. Without guard bands, the channel bandwidth is 1.23 MHz. The processing gain of the system is 19.3 dB. The modulation scheme for the downlink is coherent Quadrature Phase Shift Keying (QPSK). The convolutional code is used for error protection with a code rate of 1/2 and nine memory elements. In the uplink, noncoherence Offset QPSK (OQPSK) is used. For error protection, the convolutional code with a code rate of 1/3 and nine memory elements is used after which the Walsh-Hadamard (6, 64) code is implemented. Spectrum is spreading using the short and long codes. For the short code, the Walsh-Hadamard orthogonal code is used and for the long code, the PN code is used. Timeshift offset of the same PN sequence is used. The maximal throughput is 14.4 kbit/s for data and 9.6 kbit/s for voice. The system chip rate is 1.2288 Mchip/s (Fazel & Kaiser, 2003), (Garg, 2007).

CDMA2000

The CDMA2000 was created as the evolution of the CDMAOne (IS-95) standard. It represents the family of third Generations (3G) of mobile communications. The common feature of these two technologies is that they are based on the same type of short (Walsh-Hadamard orthogonal code) and long (PN code) codes for spreading. The same channel width of 1.25 MHz and the same chip rate of 1.2288 Mchip/s are used to enable backward compatibility with CDMAOne systems. Some transmission modes in CDMA2000 use the same chip rate and carrier spacing as CDMAOne, but different spreading factors and channel coding schemes. In contrast to CDMAOne, the Walsh codes are not fixed but of variable length to offer a variety of data rates (Schullze & Lüders, 2005).

Some modifications have been introduced to offer more flexibility with the data rate and the chip rate. In the uplink, the CDMA2000 uses the DS-SS modulation technique. The chip rate is a multiple of 1.2288 Mchip/s. That multiple factor can be 3, 6, 9 or 12. Also, the channel width is a multiple of 1.25 MHz. The QPSK modulation scheme and fast closed loop power control are used here. For the downlink, a multicarrier concept has been defined. The number of carriers is also a multiple that can have values of 3, 6, 9 or 12. The width of each subchannel is 1.25 MHz and the chip rate is 1.2288 Mchip/s for each subcarrier (Schullze & Lüders, 2005; Garg, 2007).

Wideband CDMA

The wideband CDMA (WCDMA) is the heart of 3G Universal Mobile Telecommunication Systems (UMTS). This system is very similar to the CDMA2000 and it is implemented in Europe and Japan (Prasad & Ojanpera, 1998).

Compared to GSM, the improvement refers to higher data rates transmission as well as the ability to send better quality multimedia content and to enable video calls. Transmission rates reach up to 2 Mbit/s. Frequency bandwidths are defined for the uplink and downlink: for uplink from 1920 to 1980 MHz, and downlink from 2110 to 2170 MHz. The DS-SS modulation technique is used in both links. Possible channel bandwidths are 1.25 MHz, 5 MHz, 10 MHz and 20 MHz, depending on the transmission rate and the number of users at the moment (Garg, 2007).

Three-structured orthogonal variable spreading factor codes as short codes and PN codes as long codes are used for spectrum spreading. For user separation, contrary to CDMA2000, different PN sequences are used instead of time shifts of the same PN sequence. The chip rate of the system is 3.84 Mchip/s (Prasad & Ojanpera, 1998).

A coherent QPSK modulation scheme is used for both the downlink and uplink. Several types of correction codes are used to control errors. While transmitting voice, convolutional codes with a code ratio of 1/3 and nine memory elements are used. A combination of the concatenated Reed Solomon code and the convolutional code is used for data transmission. For a high rate of data transmissions and services that require high quality, convolutional turbo codes are used (Fazel & Kaiser, 2003).

Global positioning system

The Global Positioning System (GPS) is the first satellite navigation system. The GPS program started in the early 1970s and was put into operation status in 1995. This system nominally has 24 satellites in the Medium-altitude Earth Orbit (MEO), (Hegarty, 2017).

The GPS consists of three segments: (1) satellite constellation, (2) ground-control/monitoring network, and (3) user receiving equipment (Kaplan & Hegarty, 2006). The GPS was developed for military purposes by the Department of Defense of the United States. Later, it was opened to civil applications. The GPS offers two types of services: (1) Precise Positioning Service (PPS) and (2) Standard Positioning Service (SPS) which is less accurate than the PPS. The positioning is based on trilateration. A GPS device measures the propagation delay of the signal received from the three satellites. As the positions of the satellites are

known, the position of the GPS terrestrial device is obtained as the intersection of the three spheres. If more than three satellites are used during the determining of the position, a more precise position is obtained (Schullze & Lüders, 2005).

The GPS uses two frequency bandwidths. The first frequency bandwidth is labeled as L1 and its carrier frequency is 1575.42 MHz. The other frequency bandwidth is labeled as L2 with a carrier frequency of 1227.6 MHz. The SPS uses only the first carrier, while the PPS requires both carriers. The modulation scheme that is used in the GPS is BPSK. The system processing gain is around 60 dB.

Two types of codes are used for the signal spreading. The first is Coarse/Acquisition or Clear/Access codes (C/A code) whose chip rate is 1.023 Mchip/s. The second is Precision or Protected code (P code) with a chip rate of 10.23 Mchip/s.

The C/A codes are Gold sequences generated in two 10-stage shift registers. These codes are used only with the first frequency carrier for SPS. These codes also divide the users who consume this service at the same time in nearby locations. The P code is used on both frequency bandwidths mainly for military applications. The determination of the user position with this code is more precise than with C/A codes (Schullze & Lüders, 2005).

The accuracy of the determined position became higher during the time and after the enhancements and modernizations of the system. The specified accuracy of the SPS is 13 m in 95% of cases for horizontal positioning and 22 m in 95% of cases for vertical positioning. These specification data are valid in an ideal environment. The performance of the system is typically better than the specification. Errors can be greater than specification due to atmosphere processes, multipath propagation and different user equipment. The PPS gives much better results than the SPS. In 95% of cases, the position precision is 1-2 m for both horizontal and vertical positioning. Advanced user equipment and modern positioning techniques can achieve accuracies better than 1 cm.

GPS transceivers are embedded in everyday devices such as smartphones. The performance of some smartphones' GPS and some sophisticated GPS devices were compared. Sophisticated GPS devices give better results than GPSs on smartphones, but the performance of smartphones is accurate enough for everyday life for fast positioning requirements (Zandbergen & Barbeau, 2011).

Wireless Fidelity

Wireless Local Area Network (WLAN) is a network type that is developed based on the IEEE 802.11 standard. This technology is also known as Wireless Fidelity (Wi-Fi). WLAN connects a small group of devices on short distances via the wireless access point. During the evolution of the IEEE 802.11 standard, several types of that standard were created (Schullze & Lüders, 2005). In the early beginning of Wi-Fi, DS-SS and FH-SS were planned to be used for transmission, but only products using DS-SS modulation have been established on the market. Today, there are several releases of IEEE 802.11 standards such as: IEEE 802.11a, IEEE 802.11b, IEEE 802.11g, IEEE 802.11n, IEEE 802.11ac, etc. (IEEE802.11, 2024).

The DS-SS modulation technique is implemented in the IEEE 802.11b and IEEE 802.11g standards. IEEE 802.11b was released in 1999. The system operates on a frequency of 2.4 GHz with a channel bandwidth of 22 MHz. Transmission data rates are going from 1 to 11 Mbit/s. The maximum ranges from the access point are from 35 m in the indoor environment to 140 m in the outdoor environment (Abdelrahman et al, 2015).

The available frequency bandwidth of 2.4 GHz has actually 83.5 MHz and it is from 2.4 GHz to 2.4835 GHz. In the United States in this bandwidth, there are thirteen channels, and in Europe, there are fourteen channels. According to the bandwidth of one channel, in order to avoid inter-channel interference, it is recommended to use three non-overlapping channels at the same time: in the United States, the first, sixth and eleventh channel, and in Europe the first, seventh and thirteen channel (Al Agha et al, 2016). In Figure 5, channel allocations are illustrated with the markation of non-overlapped channels in the United States. IEEE 802.11b is the longest, well-supported, stable, and cost-effective technique, but security is the main disadvantage. It has a limited number of access points. Sometimes the IEEE 802.11b devices are affected by interference from other products that operate in the 2.4 GHz bandwidth (Garg, 2007). Devices operating in the 2.4 GHz frequency are microwave ovens, bluetooth devices, baby monitors and cordless telephones.

Four years later, in 2003, IEEE 802.11g was released. In this release, the transmission data rates are significantly higher relative to IEEE 802.11b and it can be from 6 Mbit/s to 54 Mbit/s. This system also operates on a 2.4 GHz frequency range and has a narrower bandwidth of 20 MHz. The maximum ranges from the access point are from 38 m in the indoor

environment to 140 m in the outdoor environment (Abdelrahman et al, 2015). It is compatible with the IEEE 802.11b standard.

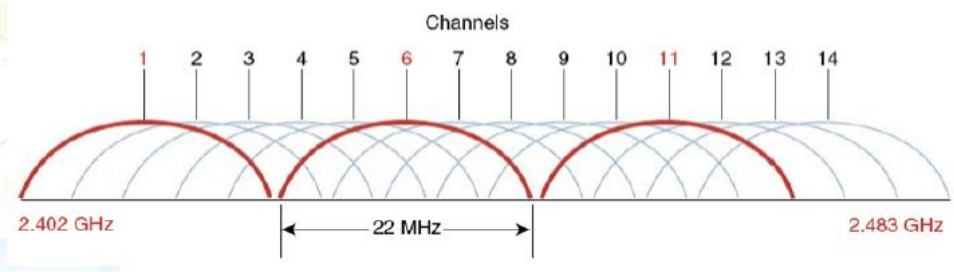

Figure 5 – Channel allocation of the IEEE 802.11b standard

Wi-Fi found a place in many applications like Internet distribution, Voice over Internet Protocol (VoIP) phone access, gaming and connecting consumer electronics devices. It is used as a radio interface for the sensor devices in the Internet of Things (IoT), especially in smart home solutions (Guo et al, 2012).

The latest IEEE 802.11 standards use Orthogonal Frequency Division Multiplexing (OFDM) instead of DS-SS modulation.

ZigBee

ZigBee is a set of specifications for Wireless Personal Area Networking (WPAN) or short-distance wireless networks. ZigBee is an often used standard in Wireless Sensor Networks (WSN). WSN request node devices with low power, low data rate, low cost and short time delay characteristics. The ZigBee standard got its name from the zigzagging patterns of honey bees between flowers which represent the communication between nodes in a mesh network (Ramya et al, 2011).

ZigBee is a standard based network protocol developed by the ZigBee Alliance that uses the transport services of the IEEE 802.15.4 network specification (ZigBee Alliance, 2024). The reasons why ZigBee is used are: low cost, easy to deploy, secure and reliable communication, open standards protocol, low power, low maintenance, very long battery life, supports a large number of nodes, etc (Ramya et al, 2011).

ZigBee found applications in areas like home automation, telecommunication services, healthcare, remote control, etc. (Challoo et al, 2012).

The physical layer of the communication process is based on the DS-SS modulation technique. It operates in three frequency bandwidths. The first frequency bandwidth is between 868-868.6 MHz. Only one channel

labeled with 0 operates in this frequency bandwidth. This frequency bandwidth is used in Europe. The maximum throughput is 20 kbit/s. The modulation sheme is BPSK. The chip rate for spectrum spreading is 300 kchip/s.

The second frequency bandwidth is used in America. It encompasses a band from 902-928 MHz. Ten channels operate in this frequency bandwidth, labeled from 1 to 10. The maximum throughput is 40 kbit/s. The modulation scheme is BPSK and the chip rate is 600 kchip/s.

The third frequency bandwidth is used globally and that is the frequency bandwidth from 2400-2483.5 MHz. This frequency bandwidth is for industrial, scientific and medical (ISM) purposes. In this frequency bandwidth, there are 16 channels labeled from 11 to 26. The modulation type that is used is OQPSK. The maximum throughput in this frequency bandwidth is 250 kbit/s. The chip rate for spectrum spreading is 2000 kchip/s.

The transmission range can be between 10 meters and 75 meters, depending on power output and environmental characteristics, but in ideal conditions, it can achieve a distance of 150 meters in an outdoor environment (Ramya et al, 2011).

There are also some other standards similar to ZigBee which are used in WPAN and WSN based on DS-SS modulation such as IPv6 over Low-Power Wireless Personal Area Networks (6LoWPAN) (Mulligan, 2007), (Ma & Luo, 2008). However, ZigBee is still the most popular choice.

Unmanned aerial vehicles

The Unmanned Aerial Vehicle (UAV) represents an aircraft without a crew. These aircraft are also called drones. UAVs come in two varieties: some are controlled from a remote location while others fly autonomously based on pre-programmed flight plans. If UAVs are controlled remotely, wireless communication can be direct, which can significantly affect the control range, or by using the infrastructure of some of wireless technologies, such as mobile cellular systems, satellite communications, etc. If a UAV flies autonomously based on the pre-programmed flight plan, it uses the GPS or computer vision, where the camera or appropriate sensors detect obstacles and, if necessary, bypass them (Zhao et al, 2018).

The very beginning of using UAVs was for military purposes. Later, UAVs began to be used in various civilian applications (Miličević & Bojković, 2021). UAVs are extremely important in modern military operations (Milic et al, 2019; Radovanović et al, 2022).

UAVs use two types of communication channels. One is used for the transmission of command and control data. Control data is sent in both directions, from the control station to the UAV (uplink) and from the UAV to the control station (downlink). The data sent through this channel is related to the control of the aircraft, whether it is generated by the operator by issuing commands or collected by the UAV during flight using the sensors it is equipped with. The data that the UAV sends to the control station is intended to provide a flight as reliable as possible. The second communication channel serves to collect the main data depending on the purpose of the UAV itself. It is mainly used for the transmission of video signals in the downlink (Miličević & Bojković, 2021).

Due to the need for high reliability and resistance to interference, the use of DS-SS modulation was suggested (Todorović & Orlić, 2010). Different vendors use DS-SS and FH-SS modulation techniques because of difficult interception and high resistance to interference. The most commonly used frequency bandwidth is the unlicensed band around 2.4 GHz. A brief overview of the vendors and the SS modulation techniques used is given in (Ristić et al, 2022).

Underwater acoustic communications

Underwater acoustic communications are used in military, scientific and civilian applications. Some of the applications are control of underwater vehicles and military facilities under the sea and on the seabed, instrument monitoring, pollution control, climate monitoring, prediction of natural changes, search and rescue missions, etc. (Song et al, 2019).

Underwater acoustic channels are time-frequency and spatially variable channels with limited bandwidth and interference that occurs due to multiple propagations (Du et al, 2019; Singer et al, 2009). These channels are bandwidth limited due to the increased attenuation at higher frequencies (Yang & Yang, 2008).

In this specific kind of communication, the DS-SS modulation technique is commonly used because of its excellent anti-interference ability, antichannel fading ability, and low Signal to Noise Ratio (SNR) performance. However, DS-SS modulation is limited by the narrow bandwidth of the underwater acoustic channel and has a low transmission rate (Chitre et al, 2008; Yang et al, 2021).

The biggest influence on the gain of an SS modulation is the fluctuation of the carrier phase. Fluctuation of the carrier phase directly affects the receiver to, for example, detect and decide which symbol was sent, which can lead to the inability to despread the signal. Carrier

fluctuation is caused by the appearance of the Doppler effect. Multiple signal propagation in underwater communications can lead to the loss of orthogonality characteristics of the PN sequence, thus reducing decoding performance. The core of DS-SS underwater acoustic communication is to obtain the matched filter processing gain and the fast carrier phase fluctuation interference caused by the Doppler effect is the most important factor affecting the matched filter processing gain (Du et al, 2019).

Underwater acoustic communications are used to send control signals and commands to Autonomous Underwater Vehicles (AUVs) and underwater sensors. Due to their nature, controlling signals and short commands often require high reliability (Qu et al, 2009).

Since the very beginning of the use of underwater acoustic communications, DS-SS modulation has been used at low frequencies and small channel bandwidths. These communications were first tested for military purposes (Loubet et al, 1997).

In (Loubet et al, 1997), tests of DS-SS signal transmission at carrier frequencies from 1.5 kHz to 2 kHz are described. Channel bandwidths are very narrow, up to 500 Hz with the maximum transmission rates of 80 bit/s. For the purposes of spread spectrum, Gold and Kasami sequences are used with the system process gains of 9 dB and 18 dB, depending on the sequence duration.

In (Yang & Yang, 2008) the DS-SS modulated signals had a carrier frequency of 17 kHz with a channel bandwidth of 4 kHz. The transmitted symbols are spread with an m-sequence with 511 chips. The sequence of chips is then transmitted using BPSK modulation. The obtained processing gain is around 27 dB.

Other realizations using DS-SS modulation for underwater acoustic communications are presented in (Yang et al, 2021) and (Qu et al, 2009).

Conclusion

The DS-SS modulation technique is based on direct spectrum spreading by multiplying a data signal with the PN sequence defined in the PN sequence generator. The DS-SS modulation technique has been successfully implemented in many military and commercial applications, due to its high protection against interference, making communication difficult for reconnaissance and eavesdropping, and its ability to provide code division multiple access. The history, principles and modern applications of the DS-SS modulation technique are presented in this article.

Historically, the first developed DS-SS systems were used in military radiocommunications, since it requires a technique that has good resistance to various forms of electronic attacks. Later, DS-SS modulation found its applications in commercial radiocommunication systems.

Mobile phones, wireless sensor networks, wireless local area computer networks, radio-relay and satellite communications are just some of the applications. Communication links for UAVs control are very important, so they need to use technology that is difficult to interfere with. Applications to control signals of UAVs and underwater acoustic communications are promising in the near future.

References

Abdelrahman, R.B.M., Mustafa, A.B.A. & Osman, A.A. 2015. A Comparison between IEEE 802.11 a, b, g, n and ac Standards. *IOSR Journal of Computer Engineering (IOSR-JEC)*, 17(5), pp.26-29 [online]. Available at: https://www.iosrjournals.org/iosr-jce/papers/Vol17-issue5/Version-3/D017532629.pdf [Accessed: 15 February 2024].

Al Agha, K., Pujolle, G. & Yahiya, T.A. 2016. *Mobile and Wireless Networks*. Wiley-ISTE. ISBN: 978-1-84821-714-0.

Challoo, R., Oladeinde, A., Yilmazer, N., Ozcelik, S. & Challoo, L. 2012. An Overview and Assessment of Wireless Technologies and Co- existence of ZigBee, Bluetooth and Wi-Fi Devices. *Procedia Computer Science*, 12, pp.386-391. Available at: https://doi.org/10.1016/j.procs.2012.09.091.

Chitre, M., Shahabudeen, S., Freitag, L. & Stojanovic, M. 2008. Recent advances in underwater acoustic communications & networking. In: *OCEANS 2008*, Quebec City, QC, Canada, pp.1-10, September 15-18. Available at: https://doi.org/10.1109/OCEANS.2008.5152045.

-DTIC. 1988. Joint Tactical Information Distribution System (JTIDS) Cost and Training Effectiveness Analysis (CTEA). *DTIC Defense Technical Information Center*, 01 November [online]. Available at: https://apps.dtic.mil/sti/citations/ADA221656 [Accessed: 10 February 2024].

Du, P., Wang, L., Zhang, H. & Xie, Z. 2019. Performance analysis of direct-sequence spread-spectrum underwater acoustic communications based on at-sea data. In: *MATEC Web of Conerences - The 2nd Franco-Chinese Acoustic Conference (FCAC 2018)*, Le Mans, France, 283, art.number:07006, October 29-31. Available at: https://doi.org/10.1051/matecconf/201928307006.

Fazel, K. & Kaiser, S. 2003. *Multi-Carrier and Spread Spectrum Systems.* Chichester, West Sussex, England: John Wiley & Sons Ltd. ISBN: 0-470-84899-5.

Garg, V.K. 2007. *Wireless Communications and Networking.* Elsevier. ISBN: 978-0-12-373580-5.

Green, P.E.Jr. 1954. The Lincoln F9C radioteletype system. *Massachusetts Institute of Technology, Lincoln Laboratory, Technical Memorandum,* 61, May 14.

Guo, Y., Zhang, S. & Xiao, D. 2012. Overview of Wi-Fi technology. In: *Proceedings of the 2012 International Conference on Computer Application and System Modeling (ICCASM 2012)*, Taiyuan, Shanxi, China, pp.1293-1296, July 27-29. Available at: https://doi.org/10.2991/iccasm.2012.330.

Hegarty, C.J. 2017. The Global Positioning System (GPS). In: Teunissen, P.J. & Montenbruck, O. (Eds.) *Springer Handbook of Global Navigation Satellite Systems*, pp.197-218. Cham: Springer. Available at: https://doi.org/10.1007/978-3-319-42928-1_7.

-IEEE802.11. 2024. Wireless Local Area Networks: The Working Group for WLAN Standards. *IEEE802.org/11* [online]. Available at: https://www.ieee802.org/11/ [Accessed: 10 February 2024].

Kaplan, E.D. & Hegarty, C.J. 2006. *Understanding GPS: Principles and Applications, Second Edition.* Aptech House. ISBN: 1-58053-894-0.

Kotowski, P. & Dannehl, K. 1940. Patent US2211132A: Method of transmitting secret messages. *GooglePatents* [online]. Available at: https://patents.google.com/patent/US2211132A/en [Accessed: 15 February 2024].

Loubet, G., Capellano, V. & Filipiak, R. 1997. Underwater spread-spectrum communications. In: *Oceans' 97.MTS/IEEE Conference Proceedings*, Halifax, Canada, pp.574-579, October 6-9. Available at: https://doi.org/10.1109/OCEANS.1997.634429.

Ma, X. & Luo, W. 2008. The Analysis of 6LoWPAN Technology. In: *2008 IEEE Pacific-Asia Workshop on Computational Intelligence and Industrial Application,* Wuhan, China, pp.963-966, December 19-20. Available at: https://doi.org/10.1109/PACIIA.2008.72.

Malik, R. 2001. Spread Spectrum - Secret Military Technology to 3G. In: *IEEE History of Telecommunications Contest*, St. John's, Newfoundland, Canada, pp.1-5, July 25-27 [online]. Available at: https://ethw.org/2001_IEEE_Conference_on_the_History_of_Telecommunications [Accessed: 15 February 2024].

Milic, A., Ranđelović, A. & Radovanović, M. 2019. Use of drones in operations in the urban environment. In: *Proceedings of 5th International Scientific-Professional Conference - Security and Crisis Management - Theory and Practice SeCMan,* Belgrade, Serbia, pp.124-130 [online]. Available at: https://bekmen.rs/zbornik/2019/2019-Zbornik-ENG.pdf [Accessed: 15 February 2024]. ISBN: 978-86-80692-04-3.

Miličević, Z. & Bojković, Z. 2021. From the early days of unmanned aerial vehicles (UAVs) to their integration into wireless networks. *Vojnotehnički glasnik/Military Technical Courier*, 69(4), pp.941-962. Available at: https://doi.org/10.5937/vojtehg69-33571.

Mudgway, D.J. 2001. *Uplink-Downlink: A History of the Deep Space Network, 1957-1997*. Washington DC: NASA SP-2001-4227, The NASA History Series [online]. Available at: https://www.nasa.gov/wp-content/uploads/2023/04/sp-4227.pdf [Accessed: 15 February 2024].

Mulligan, G. 2007. The 6LoWPAN architecture. In: *EmNets '07: Proceedings of the 4th workshop on Embedded networked sensors,* New York, USA, pp.78-82, June 25-26. Available at: https://doi.org/10.1145/1278972.1278992.

Prasad, R. & Ojanpera. T. 1998. A survey on CDMA: evolution towards wideband CDMA. In: *1998 IEEE 5th International Symposium on Spread Spectrum Techniques and Applications - Proceedings. Spread Technology to Africa (Cat. No.98TH8333),* Sun City, South Africa, pp.323-331, September 4. Available at: https://doi.org/10.1109/ISSSTA.1998.726251.

Qu, F., Yang, L. & Yang, T.C. 2009. High reliability direct-sequence spread spectrum for underwater acoustic communications. In: *OCEANS 2009*, Biloxi, MS, USA, pp.1-6, October 26-29. Available at: https://doi.org/10.23919/OCEANS.2009.5422362.

Radovanović, M., Petrovski, A., Jokić, Z. & Aleksić, A. 2022. Use of Unmanned Aerial Vehicles Integrated Into the C4IRS System in Modern Combat Operations. In: *8th International Forum "Safety for the Future" 2022: 8th Scientific-professional conference Security and Crisis Management - Theory and Practice (SeCMan)*, Sremska Kamenica, Serbia, pp.88-98, September 29-30. ISBN: 978-86-80692-09-8.

Ramya, C.M., Shanmugaraj, M. & Prabakaran, R. 2011. Study on ZigBee technology. In: *2011 3rd International Conference on Electronics Computer Technology*, Kanyakumari, India, pp.297-301, April 8-10. Available at: https://doi.org/10.1109/ICECTECH.2011.5942102.

Ristić, V., Todorović, B. & Stojanović, N. 2022. Frequency hopping spread spectrum: History, principles and applications. *Vojnotehnički glasnik/Military Technical Courier*, 70(4), pp.856-876. Available at: https://doi.org/10.5937/vojtehg70-38342.

Scholtz, R. 1982. The Origins of Spread-Spectrum Communications. *IEEE Transactions on Communications*, 30(5), pp.822-854. Available at: https://doi.org/10.1109/TCOM.1982.1095547.

Scholtz, R.A. 1994. The evolution of spread-spectrum multiple-access communications. In: *Proceedings of IEEE 3rd International Symposium on Spread Spectrum Techniques and Applications (ISSSTA'94)*, Oulu, Finland, pp.4-13, July 6-8. Available at: https://doi.org/10.1109/ISSSTA.1994.379623.

Schullze, H. & Lüders, C. 2005. *Theory and Applications of OFDM and CDMA: Wideband Wireless Communications.* John Wiley & Sons Inc. ISBN: 978-0-470-85069-5.

Shannon, C.E. 1948. A mathematical theory of communication. *The Bell System Technical Journal*, 27(3), pp.379-423. Available at: https://doi.org/10.1002/j.1538-7305.1948.tb01338.x.

Shirriff, K. 2022. The digital ranging system that measured the distance to the Apollo spacecraft. *Righto.com* [online]. Available at: https://www.righto.com/2022/04/the-digital-ranging-system-that.html [Accessed: 15 February 2024].

Singer, A.C., Nelson, J.K. & Kozat, S.S. 2009. Signal processing for underwater acoustic communications. *IEEE Communications Magazine*, 47(1), pp.90-96. Available at: https://doi.org/10.1109/MCOM.2009.4752683.

Song, A., Stojanovic, M. & Chitre, M. 2019. Editorial Underwater Acoustic Communications: Where We Stand and What Is Next? *IEEE Journal of Oceanic Engineering*, 44(1), pp.1-6. Available at: https://doi.org/10.1109/JOE.2018.2883872.

Todorović, B.M. 2021. *Osnove telekomunikacija*. Belgrade: Akademska misao (in Serbian). ISBN: 978-86-7466-864-1.

Todorović, B. & Orlić, V. 2010. Analysis and optimization of direct sequence spread spectrum scheme for an unmanned aerial vehicle PPM control signal. *Facta universitatis - series: Electronics and Energetics,* 23(3), pp.319-332. Available at: https://doi.org/10.2298/FUEE1003319T.

Todorović, B.M., Stojanović, N.M. & Velikić, G.S. 2024. Is Direct Sequence Spread Spectrum Modulation Promising for AI-Based Design of 6G Networks? *IEEE Consumer Electronics Magazine*. Early Access. Available at: https://doi.org/10.1109/MCE.2024.3349458.

Torrieri, D. 2015. *Principles of Spread-Spectrum Communication Systems*. Cham: Springer. Available at: https://doi.org/10.1007/978-3-319-70569-9.

Yang, G., Zhou, F., Lou, Y., Qiao, G., Ahmed, N. & He, Y. 2021. Double-differential coded M-ary direct sequence spread spectrum for mobile underwater acoustic communication system. *Applied Acoustics*, 183, art.number:108303. Available at: https://doi.org/10.1016/j.apacoust.2021.108303.

Yang, T.C. & Yang, W.-B. 2008. Performance analysis of direct-sequence spread-spectrum underwater acoustic communications with low signal-to-noise-ratio input signals. *The Journal of the Acoustical Society of America*, 123(2), pp.842-855. Available at: http://doi.org/10.1121/1.2828053.

Zandbergen, P.A. & Barbeau, S.J. 2011. Positional Accuracy of Assisted GPS Data from High-Sensitivity GPS-enabled Mobile Phones. *The Journal of Navigation*, 64(3), pp.381-399. Available at: https://doi.org/10.1017/S0373463311000051.

Zhao, J., Gao, F., Ding, G., Zhang, T., Jia, W. & Nallanathan, A. 2018. Integrating Communications and Control for UAV Systems: Opportunities and Challenges. *IEEE Access*, 6, pp.67519-67527. Available at: http://doi.org/10.1109/ACCESS.2018.2879637.

-ZigBee Alliance. 2024. ZigBee Specification FAQ. *Zigbee.org* [online]. Available at: https://web.archive.org/web/20130627172453/http://www.zigbee.org/Specifications/ZigBee/FAQ.aspx [Accessed: 15 February 2024].

Espectro ensanchado de secuencia directa: historia, principios y aplicaciones modernas

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CAMPO: telecomunicación
TIPO DE ARTÍCULO: artículo de revisión

Resumen:

Introducción/objetivo: La modulación de espectro ensanchado de secuencia directa se utiliza ampliamente en muchos sistemas de radiocomunicaciones. Al principio, esta técnica de modulación se utilizó en sistemas de navegación y comunicaciones militares. Posteriormente, las aplicaciones también se diversificaron en los sistemas de comunicación civiles. Hoy en día, existen muchos sistemas en los que se implementa modulación de espectro ensanchado de secuencia directa como parte del sistema. Este artículo tiene como objetivo sublimar el conocimiento sobre la técnica de modulación de espectro ensanchado de secuencia directa y sus aplicaciones.

Métodos: El artículo presenta una revisión del desarrollo histórico de la técnica de modulación de espectro ensanchado de secuencia directa, sus principios y las aplicaciones actuales más importantes.

Resultados: Basado en una gran cantidad de referencias, este artículo resume el desarrollo histórico, los principios básicos y las aplicaciones modernas de la modulación de espectro ensanchado de secuencia directa en sistemas de comunicaciones militares y comerciales.

Conclusión: La modulación de espectro ensanchado de secuencia directa se utiliza ampliamente en las radiocomunicaciones modernas inalámbricas y por satélite. Se espera que forme parte de futuros sistemas de comunicación globales.

Palabras claves: radiocomunicaciones, comunicaciones militares, sistemas móviles celulares, espectro ensanchado, secuencia directa, sistema de posicionamiento global, comunicaciones acústicas submarinas, vehículos aéreos no tripulados, fidelidad inalámbrica, ZigBee.

Спектр распространения прямой последовательности: история, принципы и современные применения

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РУБРИКАГРНТИ: 49.27.00 Система передачи,
49.43.00 Радиосвязь и радиовещание
ВИД СТАТЬИ: обзорная статья

Резюме:

Введение/цель: Модуляция расширение спектра методом прямой последовательности широко используется во многих системах радиосвязи. Впервые этот метод модуляции был использован в военных системах управления, связи и навигации. Затем применение распространилось и на системы гражданской связи. В современном мире существует множество систем, в которых модуляция расширенного спектра методом прямой последовательности стала частью системы. Целью данной статьи является обобщение знаний о методе модуляции с расширенным спектром методом прямой последовательности и его применении.

Методы: В статье представлен обзор исторического развития модуляции с расширенным спектром методом прямой последовательности, его принципов и наиболее важных в настоящее время приложений.

Результаты: В данной статье, основанной на большом количестве литературы, обобщаются историческое развитие, основные принципы и современное применение модуляции с расширенным спектром методом прямой последовательности в военных и коммерческих системах связи.

Вывод: Модуляция с расширенным спектром методом прямой последовательности широко используется в современной беспроводной и спутниковой радиосвязи. Можно предположить, что он станет частью будущих глобальных коммуникационных систем.

Ключевые слова: радиосвязь, военная связь, сотовые мобильные системы, расширенный спектр, прямая последовательность, глобальная система позиционирования, подводная акустическая связь, беспилотные летательные аппараты, Wi-Fi, ZigBee.

Пренос у проширеном спектру – директна секвенца: историја, принципи и савремене примене

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ОБЛАСТ: телекомуникације
КАТЕГОРИЈА (ТИП) ЧЛАНКА: прегледни рад

Сажетак:

Увод/циљ: Многи системи радио-комуникација користе систем преноса у проширеном спектру помоћу директне секвенце. На почетку, ова техника се користила у војним и навигационим системима, док се касније примењује за различите сврхе и у цивилним телекомуникационим системима. Данас постоје многи системи где је техника директне секвенце имплементирана у неком њиховом делу. Циљ овог рада јесте да сублимира знања о техници проширеног спектра са директном секвенцом и њеним применама.

Методе: Представљени су историјски развој технике проширеног спектра са директном секвенцом, принципи рада и најважније савремене примене.

Резултати: На основу доступне литературе, рад сумира историјски развој, основне принципе и савремене примене проширеног спектра са директном секвенцом у војним и комерцијалним телекомуникационим системима.

Закључак: Систем преноса проширеног спектра са директном секвенцом је у широкој примени у модерним бежичним и сателитским радио-комуникацијама. Очекује се да буде део будућих глобалних телекомуникационих система.

Кључне речи: радио-комуникације, војне телекомуникације, ћелијски мобилни системи, проширени спектар, директна секвенца, глобални систем позиционирања, подводне акустичне комуникације, беспилотне летелице, Wi-Fi, ZigBee.

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SMART monitoring and treatment of fracture healing: Piezoelectric transducers and stepper motor actuators

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Abstract:

Introduction/purpose: SMART orthopedic systems use fixators with remote monitoring, processing, and communication capabilities to leverage healing progression data for personalized, real-time monitoring of a healing process. The fixators incorporate small and compact piezoelectric sensors that generate electrical signals upon the application of force to the piezoelectric diaphragm. This enables doctors to remotely guide fixation devices using indirectly and remotely controlled stepper motors known for their precision and accuracy. Reliability of stepper motors makes them a viable alternative for the mechanical tools traditionally used by doctors for fixator extension.

Methods: This study focuses on the evaluation of sensor-based technology in orthopedic applications. The paper presents a theoretical framework for the application of SMART devices in the bone fracture healing process. It delves into the structure and functionality of piezoelectric transducers,

offering a comprehensive insight into this technology and various engineering aspects of SMART systems.

Results: The implementation of SMART systems has significantly enhanced doctor-patient communication. This improvement is facilitated through a dual-phase process involving gathering, processing, and transmitting the data wirelessly from the patient's (sensor) interface to the doctor who uses specialized software for data analysis and wireless transmission to the stepper motor actuator. Subsequently, the data is forwarded to the decoder at the motor site, where a motor controller generates the control signal for the stepper motor driver.

Conclusion: SMART implants can provide doctors with quantitative data that can be used in directing a rehabilitation plan. The sensor-based technology offers insights into the stress induced by the callus formation enabling bidirectional communication between the doctor and the patient. The stepper motor is a tool that aids in personalized treatment from the distance.

Key words: SMART implant, piezoelectric sensor, fracture healing, stepper motor.

Introduction

Traditional technologies used to monitor fracture healing mostly rely on imaging techniques such as radiography, computed tomography (CT) scans, magnetic resonance imaging (MRI), and ultrasound, which are subjective, involve radiation, and expensive (Bizzoca et al, 2023; Nicholson et al, 2021; Coneicao et al, 2023). Efforts in improving bone healing were firstly focused on measuring fracture stiffness based on external fixation (Pelham et al, 2017). However, internal fixation is now the preferred method for treating lower limb fractures due to the drawbacks associated with external fixation, such as patient discomfort, prolonged recovery time, and infection risks (Friis et al, 2017; Sellei et al, 2015; Antic et al, 2023a). To monitor interfragmentary movement, implanted devices with internal power sources and instrumented bone plates are commonly used (Ernst et al, 2020). Recent advancements in long bone healing involve innovative methodologies using both external and internal fixators, introducing new remote detection, processing, and communication systems. The development of multifunctional Self-Monitoring Analysis and Reporting Technology (SMART) implants incorporating various sensing, actuation, processing, and power systems, represents an emerging trend in this field (Soares dos Santos & Bernardo, 2022). SMART implants have the potential to provide personalized, real-time monitoring of the healing process even after the patient has been discharged from the hospital

(Antic et al, 2023a). In their study, Borchani et al. (2016) describe sensor-based monitoring devices equipped with an internal power source and an instrumented bone plate for monitoring interfragmentary movement. At the site of a bone fracture, these devices gather data on the patient's activity. The collected raw data is subjected to statistical processing, storage, and/or transmission. A significant challenge arises from the fact that sensor packages are too large to be integrated into small orthopedic components such as fracture fixation plates, microcontroller units, and power sources (Sun, R. et al, 2018). The design based on piezoelectric sensors eliminates the need for an external power source, which simplifies the construction and implementation of fixators.

Piezoelectric materials have the ability to generate electrical signals without external stimulation. The distortion of the internal dipole caused by applied mechanical force generates surface charge, resulting in the generation of electrical signals (Tandon et al, 2018). When a force is applied to the piezoelectric diaphragm, an electric charge is generated across the crystal faces. The output is measured as voltage that is directly proportional to applied pressure (Antic et al, 2023b). Consequently, piezoelectric sensors can function as self-powered, battery-free sensors with inherent mechano-electric energy capabilities. These sensors enable the accurate capture of various information from the environment. Parameters such as fracture stiffness, void geometry deformation, bending moment, and other relevant factors can be monitored to facilitate the healing process of a fractured bone (Claes & Cunningham, 2009; Antic et al, 2023a).

The SMART sensor system must be designed to utilize data related to healing progression in order to provide doctors with information about fracture healing, which necessitates that it incorporates acquisition and processing systems capable of detecting electrical changes in various stages of fracture healing including not only sensors but also analogue-to-digital (A/D) and digital-to-analog (D/A) converters, data processing and storage devices, as well as communication system for data transmission (Coneicao et al, 2023).

The use of remote data monitoring and acquisition of the fracture activity profile is considered a distinguishing feature of the SMART sensor-based concept compared to passive techniques for in vivo monitoring (Green & Gianchandani, 2009). Through remote monitoring, doctors can guide fixation devices from a distance, if necessary, to align bone fragments and facilitate the formation of new callus tissue. This can be achieved using indirectly and remotely controlled devices such as miniaturized stepper motors known for their precise and accurate

movements, fine resolution, low noise, high torque capabilities, reliability, and durability. Stepper motors translate electrical pulses into precise mechanical movements, while the controller keeps track of the number of steps taken. Their excellent dynamic characteristics enable quick starts and stops, making stepper motors widely used in medical applications for controlling critical aspects of patient care, such as infusion pumps, systolic pumps, respiratory devices, dialysis machines, CT scanners, MRI machines, surgical instruments, and medical robots (Kumar, 2021). The reliability of stepper motors makes them suitable for replacing mechanical tools used by doctors to extend fixators.

This article highlights the use of SMART implant systems consisting of the piezoelectric sensor and data processing, storage, and transmission units. It is shown that communication between the sensor transmitter and the receiver at the doctor's site can enhance the personalized healing process. Furthermore, the use of stepper motors is discussed, demonstrating their ability to adjust external fixators without the doctor's physical presence.

SMART orthopedic implant systems

Bones form a solid structure known as the skeleton which provides the support and protection of internal organs (Andrew, 2024). The bones contain one of the hardest tissues that make up the human body representing a suitable medium for biomechanical analysis, the results of which could be applied in the treatment of bone fractures. The healing process of bone fractures is governed by the achieved mechanical stability and maintenance of broken bone fragments in a specific position to ensure smoot progression of the healing process (Sheen et al, 2023). Minimal distance between bone fragments as well as minimal movement between them is essential until a solid new bone tissue (callus) is formed. There are two basic methods of bone fracture fixation. The internal method involves placing the entire fixation implant beneath the skin (Friis et al, 2017; Sellei et al, 2015). The external fixator entails the use of pins and needles inserted into the bone, passing through skin and soft tissues and attached externally to a fixator frame (Pelham et al, 2017). External fixators are commonly used for open fractures and where the postoperative corrections may be necessary.

SMART implants

Orthopedic implants that are considered SMART are typically small and compact electrically powered devices used for the purpose of

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diagnosis, monitoring, and treatment (Ledet et al, 2018). These implants have the capability to measure pressure, force, strain, displacement, proximity, and temperature, in addition to other physical stimuli that can assist in the process of fracture fixation (Ledet et al, 2018). Fracture fixation can be achieved through the use of fracture plates, intramedullary rods and external fixators. Loads are transmitted through both the bone and the fixator when a bone is loaded. During the acute postoperative period, the forces are transmitted solely to the fixator since the fracture cannot withstand loads. As the bone callus forms and the fracture heals, the bone gradually begins to bear some load, thereby reducing the force on the fixator. The SMART implant system typically comprises a sensor chip, a reader unit, and a battery (Antic et al, 2023b). Electrochemical monitoring is made possible through on-chip microelectrodes. The sensor readout unit is built upon an application specific integrated circuit. The sensor reading and bi-directional data transmission between the implant and the interface is enabled by a microcontroler integrated into the reader unit. All the components of the system are designed to operate on low power.

Implant materials

Despite significant advancement in the technology of SMART implants, there are still several obstacles that need to be addressed such as implant failure mechanisms, toxicity, infection, corrosion of metal implants, design, and effectiveness of implants used in fracture fixation (Shayesteh Moghaddam et al, 2016).

Metals have unique and valuable characteristics in terms of their extensive surface areas and biological properties which encompass biocompatible loading and heat transfer. Due to the high mechanical stress resistance and fracture toughness of cobalt, iron, nickel and titanium, these were the pioneering materials used for implants, and continue to be extensively used (Binyamin et al, 2006; Shekhawat et al, 2021). Additionally, metal alloys like cobalt, magnesium, stainless steel, and titanium alloys are frequently used for implants to attain specific properties such as corrosion resistance, elasticity, and strength (Poinem et al, 2012; Shekhawat et al, 2021). Stainless steel is the most frequently used in metallic implants due to its affordability and ease of production. However, its high stiffness compared to bone can result in bone resorption from stress shielding. Stainless steel may also trigger an inflammatory response as its oxide becomes conductive (Jacobs et al, 1998). On the other hand, cobalt-based alloys surpass stainless steel in terms of biocompatibility, corrosion resistance and strength, albeit at higher manufacturing costs

(Brogini et al, 2021; Solanke et al, 2021). Titanium and its alloys are characterized by low density, excellent biocompatibility, and an oxide layer for bone progenitor cells attachment (Xu et al, 2020; Anene et al, 2021). Nickel-titanium, commonly used in orthodontic wires and vascular stents, has the lowest elastic modulus among biocompatible metals having bone-like biomechanical properties (Taheri Andani et al, 2014). Titanium-based materials, although very expensive, are reserved for patients with hypersensitivity reactions to cobalt-based or stainless-steel alloys. Magnesium, with a density slightly lower than that of the bone, can serve as an osteo-conductive and biodegradable implant material in load-bearing applications. However, controlling its high corrosion rate is crucial to ensure its suitability for biomedical applications (Findik, 2020).

In decades, synthetic materials have progressed from biocompatible substances to bioactive materials. By adjusting the composition, polymeric compounds can mimic the structure of different tissues while retaining their mechanical characteristics. Among synthetic materials, polyurethane (PE) is recognized as one of the most versatile substances suitable for orthopedic implants (Francis, 2021). The increasing use of polymers is driven by their costs-effectiveness and adaptability. The key benefits of using PE include low friction resistance, resistance to abrasion and impact, good biocompatibility, favorable tensile properties, tensile strength and flexural rigidity (Jefferies et al, 2021). However, its drawbacks include the generation of heat and the release of methyl methacrylate monomer during the in-situ polymerization process (Rohani Shirvan et al, 2021; Allizond et al, 2022). With the rise in the life expectancy and surgical procedures, there is a growing demand for implants that are highly reliable and resistant to fractures. Bio-ceramics are a type of wear-resistant materials with high fracture toughness. They are categorized into three groups: bioinert materials that do not react with the living tissue and are non-toxic, showcasing exceptional stability and mechanical properties, but with high manufacturing costs (zirconia, alumina); biodegradable substances that are absorbed by the body; and bioactive materials capable of forming bioactive glass (Piconi, 2017).

SMART orthopedic fixation

Movements around the fractured area and the natural muscle tension tend to dislocate the fracture. When external fixation is utilized, these movements can strain the pins and the frame of the external fixator, causing micromovements and micro-deformations. This effect is particularly noticeable in cases of external fixation involving weight-bearing bones of the lower extremities. The forces from lower extremity

movements, muscle tension, and the body's weight during standing and walking all contribute to the issue. As the callus hardens, more of the load is gradually transferred through the bone and less through the external fixator, resulting in a reduction of micromovements and micro-deformations. SMART fixators have the capability to provide objective data that can assist doctors in guiding patient rehabilitation strategies at various stages of treatment. Monitoring loads during weight-bearing is typically used to indicate the process of fracture consolidation and healing (Borchani et al, 2016). SMART internal fixators using bone plates have shown promising results in comparison to other surgical methods. Studies describe postoperative fracture monitoring by electrical impedance spectroscopy (Lin et al, 2019), and the measurement of physical stimuli achieved through application-specific technology of the implant (Ledet et al, 2018). In addition, the integration of intelligent features into orthopedic implants containing wireless transceivers and microsensors has significantly improved implant capabilities. However, certain challenges such as ensuring the reliability of wireless links, downsizing implants, providing adequate power supply, high measurement accuracy, affordability, and low complication rates, still need to be addressed (Naghdi et al, 2023). The main advantages, challenges, and future perspectives of the SMART concept are listed in Table 1.

Table 1 – Advantages, disadvantages, and expectations of the SMART concept

Advantages	Disadvantages	Future perspectives
Data analytics Data integration Information exchange Interoperability IoT Remote monitoring and controlling Target audience Wearable sensor technologies/Portability Wireless/wired transmission	Accuracy Battery life Complexity Discomfort High costs Reliability of wireless links Security Stability	Affordability Artificial intelligence Biomedical sensing Cost effectiveness Decentralized medicine Mobile health Personalized health care User friendly Time effectiveness

Sensor-based diagnostic

The sensor system serves as an active device that not only possesses the capability to make automatic decisions but also has the ability to control actuators based on those decisions. The system comprises several key components, including excitation control, amplifiers, converters, and analog filters. These components work together to convert mechanical stimuli into electrical signals determined by responses to mechanical strain (Kausar, 2022). Among various types of

stretchable strain sensors, capacitive and resistive sensors have received significant attention among researchers. Capacitive strain sensors are constructed by placing an insulating foil between two stretchable electrodes (Amjadi et al, 2016). When subjected to strain, the capacitance of these sensors increases due to geometric changes in the capacitive region, independent of the resistance value of the electrodes. Resistive sensors are designed in the stretchable format. When stretched or compressed, the electrical resistance of these sensors changes in response to the applied mechanical stress.

In terms of sensors system diagnostics, there are two types of measurements: external and internal. Both types incorporate sensing and active devices that facilitate real-time monitoring of bone fracture healing. Pelham et al. (2017) discuss external measurements which involve indirect measurements of fracture stiffness as an indicator of bone union, as well as the monitoring of the mechanical response of external fixation devices. Furthermore, Chiurazzi et al. (2020) explore the functions of capacitive sensors in relation to relative rotation and translation of external fixator pins used to determine the status of bone healing. Borchani et al. (2016) discuss an internal approach to long-term measurement that includes a microprocessor.

Devices most commonly used for measuring strain in SMART sensor orthopedic devices are strain gauges. Strain gauges are metallic transducers used for accurate measurements of forces, loads, weight, or tension. The resistance in a strain gauge varies in direct proportion to the level of strain. A strain gauge consists of a small wire or a metallic foil arranged in a grid pattern, which is bonded to a thin carrier attached to a bone and undergoes a linear change in its electrical resistance when the bone experiences strain (Button et al, 2013). Strain gauges have the advantage of being able to be directly attached to the object being measured, streamlining the measurement procedure. They are particularly suitable for extended periods of measurements making them ideal for long-term monitoring. Furthermore, the simplified process of extracting relevant information from the gathered data facilitates data analysis. Additionally, strain gauges exhibit a high capability to adjust for variations in temperature, enhancing their overall utility. Piezoelectric force sensors or force transducers used in SMART orthopedic systems are typically installed directly at the measurement point allowing for immediate readiness of conducted measurements. They are designed for precise measurements, strategically positioned and calibrated to take into account factors such as the structure geometry, the material modulus of elasticity, and the mechanical stress (Sirohi & Chopra, 2000). These transducers

capture electrical charge through the application of force on a piezoelectric crystal which is then converted into a voltage signal using the charge amplifier. Due to atomic-level shifts that cause charge effects, the deformation is extremely small. This allows for the creation of highly rigid structures with high natural frequencies. Such characteristics are particularly advantageous for capturing fast and high-frequency measurements. The disadvantages encompass the high volatility of electric charge captured by the crystal and its tendency to decrease over time, along with the vulnerability of piezoelectric transducers to temperature fluctuation.

Piezoelectric transducers

Piezoelectric transducers generate an electrical charge in response to applied mechanical stress. These transducers are commonly used in systems that measure various physical stimuli, including force, pressure, strain, and temperature (Jacobs et al, 1998). The transducer circuit comprises internal resistance, an inductor connected to generate inductance due to the inertia of the sensor, and capacitance that is inversely proportional to the elasticity of the sensor material. Unlike other transducers, piezoelectric transducers do not require an external voltage source as they directly generate an electrical signal based on the applied strain. Consequently, these transductors function as piezoelectric sensors. Moreover, transducers can also convert electrical signals into mechanical energy or physical movement, thereby operating as piezoelectric actuators. Hence, a piezoelectric transducer can be regarded as a combination of a piezoelectric sensor and an actuator, and its specific design determines whether it performs both roles or only one of them. Piezoelectric transducers are compact, robust, and shock-resistive. These attributes, combined with their high frequency response, make them suitable for record players, accelerometers, electronic watches, microphones, seat bells, kitchen stoves, infertility treatment, printers, smartphones, automatic doors, and a wide range of applications. The small size of piezoelectric transducers allows for easy integration into almost any device, as they can provide precise measurements across a broad spectrum. This characteristic makes them highly adaptable and often requires minimal adjustments to fit into existing designs. Piezoelectric transducers boast flexible design options and requirements, as they can be shaped into various forms to meet specific needs. A notable feature of piezoelectric transducers is their high-frequency response and accuracy. A rapid response to pressure changes makes them ideal for

applications that demand precision down to fraction of a millisecond (particularly suitable for medical devices).

It is worth mentioning that piezoelectricity has also been discovered in bones, suggesting its involvement in important signaling mechanisms related to tissue function (Aherwar et al, 2016). Recently, piezoelectric sensors became promising candidates for integration into Internet of Things (IoT) technologies (Brogini et al, 2021). However, the transmission and reception of data over wireless channels can be extremely vulnerable to malicious attacks since wireless communication involves the transfer of significant amounts of personal information which individuals generally prefer to keep confidential (Li & Li, 2022).

Piezoelectric transductor: functions and structure

The piezoelectric transductor used for monitoring bone healing transforms the force associated with the size and structure of a newly formed callus. The application of mechanical deformation to a polarized crystal of the piezoelectric diaphragm induces electrical charge generation, i.e. a sensor generates an electrical signal in response to compression or tension (transduction) (Kausar, 2022). The key attributes of piezoelectric transductors include their flexibility and lightweight nature, dynamic and frequency range, high resistance to mechanical stress and impact, and availability in a variety of thicknesses and sizes. In sensor applications, the flat part of the frequency response (the relationship between the force input and the voltage output versus the frequency) is commonly used. The useful region for a sensor is usually between the high-pass cutoff and the resonant peak (Figure 1). Low frequencies are filtered out by the leakage resistance while the high frequencies resonate (Bansal, 2012).

The output voltage generated by a piezoelectric sensor can also serve as a power supply for additional functionalities like wireless communication (O'Connor & Kiourti, 2017). By using a piezoelectric material in the construction of the sensor, the resulting output voltage can be effectively measured to identify the strain. Consequently, the analysis of the output voltage enables motion detection. It is important to note that sensors with different designs have distinct characteristics such as durability, hysteresis, linearity, sensibility, and stretchability (Kim et al, 2022).

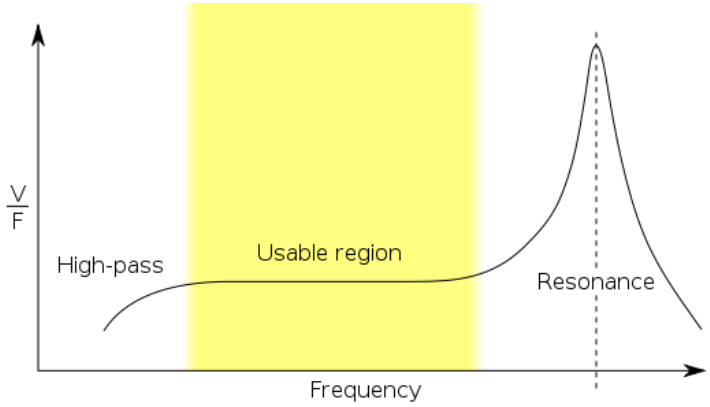

Figure 1 – Piezoelectric sensor frequency response

Data acquisition and processing

The increasing need for customized, non-hospitalized medical care has led to the growth of telemedicine, a system that uses information and communication technologies to share health data and deliver healthcare services. This innovative approach enables two-way communication between patients and doctors. When coupled with telemonitoring, telemedicine can serve a s a valuable diagnostic tool by remotely tracking patients' physiological data through sensors, microprocessors, and wireless data transmission for real-time data processing (Aguirre et al, 2016). The biomedical data related to the broken limb is a crucial element of personalized treatment, involving sensing, acquiring, processing, and interpreting bio-signals to gather essential information for doctors. The process of data acquisition (DAQ) involves the conversion of analogue signals into the digital format, ensuring both accuracy and speed to enable computer processing. This process occurs in three stages: sensing, signal processing and analysis. The sensing stage involves converting physical characteristics into electrical signals, while the signal processing stage transforms these signals into a format that can be understood by software, embedded platforms, and computer devices. Finally, the analysis stage extracts valuable features to aid in decision making (Sun, G. et al, 2018). The key components of a data acquisition system include: transducers which transform the measured quantity into an electrical signal that is proportional to the input; devices that adjust the sensor signal to the appropriate level for analogue-to-digital (AD) conversion (such as amplifiers, converters, and filters); an anti-aliasing filter that eliminates high-frequency signals that may lead to inaccurate conversions; and

various other units with different levels of complexity (Taylor, 1997). The block diagram of a DAQ system is given in Figure 2.

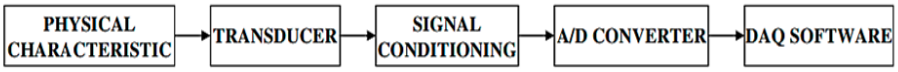

Figure 2 – Data acquisition and processing

The initial step in the data collection process involves identifying physical phenomena or characteristics that should be measured. Regardless of specific characteristic being measured, it must first be converted into the format that a DAQ system can handle. The conversion process is carried out by transducers. Piezoelectric crystal transducers convert applied force into electrical charge. The charge is then measured and converted into digital signals. The electrical signals obtained from the sensors may contain noise or other interference and need modification. The signals might also be weak to a point where the data acquisition system cannot measure them. Hence a signal conditioner is used to optimize the signals. It separates the noise from the real signal and utilizes an amplification circuit for strengthening weak signals. The A/D converter plays a crucial role in the DAQ system by transforming the data obtained from the surroundings into distinct levels that can be understood by a processor. A higher number of bits in an A/D converter results in an increased number of discrete levels available for encoding an analog signal, thereby enhancing resolution of the A/D converter. The execution of the DAQ software can be carried out by a microprocessor unit (MPU) which is capable of executing signal condition tasks specific to the process. The sensor can operate in a “report by exception” mode, where it transmits data only if there is a change in the measured variable. Additionally, the sensor may incorporate self-diagnostics, enabling the immediate detection of any developing drift in the outputs of its sensor elements. The data processing encompasses the transmission and reception of information through both wired and wireless channels. It is important to highlight that data processing, particularly when carried out wirelessly, is highly vulnerable to malicious attacks.

Telemedicine and communication protocols

The healthcare sector is currently experiencing a notable shift due to the progress in technologies, like the IoT, biosensing, non-invasive sensing, contactless sensing, artificial intelligence (AI), mobile applications, and cloud computing (Sun, G. et al, 2018). This has led to a

series of challenges in the acquisition, monitoring, processing, and sharing of patients' data highlighting the necessity for healthcare solutions that are flexible, personalized, and easy to use in order to address growing demands.

Telemedicine refers to the application of electronics information and communication technologies for the provision and enhancement of health services in cases where there is physical distance between the patient and the doctor (Atmojo et al, 2020). In contrast to telehealth that covers remote clinical and non-clinical services, telemedicine mostly focuses on remote clinical services provided by doctors (Kruse et al, 2017). It also provides convenience to both patients and doctors by eliminating the need for in-person visit to seek medical advice or treatment. Telemedicine is proved to be a cost-effective alternative when compared to the traditional approach to medical services and care. Telemedicine operations necessitate a thorough understanding of telecommunication technologies, networking and medical device technology. One of the most captivating advancements in telemedicine pertains to the capability of incorporating devices for self-monitoring or supervision by doctors (Cram, 2004). Telemedicine predominantly relies on desktop/laptop computers equipped with specialized software and corresponding devices, offering the advantage of secure data storage, processing, and transferring. Based on the mode of operation, telemedicine can be divided into an asynchronous (store-and-forward), synchronous (real-time), and remote monitoring. The patient is provided with health care through the telecommunication system (Thomas, 2023). The communication in telemedicine relay on the following standards and protocols for wired and wireless communication: Bluetooth (IEEE 802.15.1), Wi-Fi/WLAN (IEEE 802.11), WiMAX/Broadband Wireless Access (BWA) (IEEE 802.16), ZigBee (IEEE 802.15.4), Real-Time Protocol (RTP), Real-Time Transport Control Protocol (RTCP), Transmission Control Protocol/Internet Protocol (TCP/IP), and User Datagram Protocol (UDP).

Stepper motor actuator: a tool for enhancing extension mechanisms

Stepper motor actuators (SMA) are electromechanical devices that transform electrical pulses into distinct rotation movement referred to as "steps" (Harb & Zaher, 2004). They consist of a stepper motor, a mechanical transmission mechanism, and a control system. The stepper motor is a synchronous electric motor that moves in discrete steps and has a capability to achieve accurate control over position and speed without

requiring feedback systems. Stepper motors can be divided into permanent magnet stepper motors (PMSM), variable reluctance stepper motors (VRSM), and hybrid stepper motors (HSM). PMSM make use of permanent magnets on the rotor and EM stator poles. PMSM have favorable torque-to-size ratios (frequently used in cost-effective applications). VRSM have a soft iron rotor without magnets and generate torque based on the magnetic reluctance principle. They have the ability to achieve high step rates, and are frequently used in high-speed applications. HSM combine characteristics of both PMSM and VRSM. HSM have a multi-toothed rotor equipped with permanent magnets, resulting in higher torque, improved resolution, and smoother operation compared to PMSM or VRSM. The mechanical transmission mechanism in a SMA converts the motor rotary motion into linear or other motion types using lead screws, ball screws, belts, and pulleys. The control system manages the stepper motor operation by sending electrical pulses to its windings, determining its speed, direction, and step size.

The SMA used in medical devices are required to possess several characteristics, including small size, accuracy, smooth motion, quiet operation, reliability, and quality. In medical applications, limited space is often a critical factor, making smaller SMA highly desirable (Cheng & Scattareggia, 2011). To choose the most suitable SMA for a specific application, it is crucial to take into account various factors which include load, speed and acceleration requirements, resolution and precision needs, operating environment, and costs. Firstly, one needs to determine the force or torque necessary to move, lift or hold the load. This information will assist in selecting the appropriate motor size and transmission mechanism. Secondly, the desired speed and acceleration should be considered, because they will have an impact on the control system selection. Next, the required positioning resolution and accuracy should be evaluated. This will aid in choosing the motor type and the step angle.

The SMA can serve as a tool to facilitate a gradual bone lengthening procedure, enabling the bone to slowly increase in length. The fixator can be adjusted at a rate of approximately 1mm per day, until the bone has fully hardened and calcified (ICLL, 2024). The objective of the SMA is to carry out a distinct rotation of the stepper motor's movement as directed by the physician and managed remotely. It should be noted that the doctor has the ability to accelerate or decelerate the rate of distraction if necessary. The SMART orthopedic external implant system shown in Figure 3 is designed to use the SMA properties to eliminate the necessity for mechanical tools during implant extension. This system comprises a

piezoelectric sensor (PES), a stepper motor (SM), and a data acquisition and processing module (DAPM).

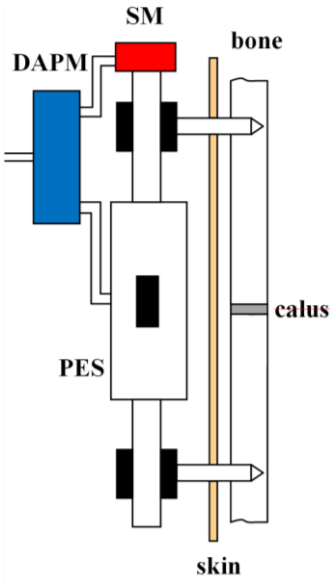

Figure 3 – SMART implant containing PES, SM, and DAPM

Effective doctor-patient communication is achieved through a hardware-software platform by providing doctors to access to bone healing data and allowing them to control the movements of broken bone parts through the stepper motor placed on the fixator. The communication process follows a two-way protocol where both parties activate processing devices and communication channels. Due to the limitations of the wired control system in controlling stepper motors over a long distance, wireless technologies are commonly used for this purpose (Sowjanya et al, 2018).

The first stage involves gathering data from the sensor, processing the data, and transmitting it wirelessly (see Figure 2). Upon reception at the doctor's location, the data is processed and encoded in the proper format. The doctor then examines the data, makes decisions, and initiates the software for processing, formatting, and wireless transmission to control SMA. Upon reaching the motor site, the data is received by the receiver unit, forwarded to the decoder, and a motor controller is used to generate the control signal for the stepper motor driver (Abas & Bakar, 2016). Various microcontroller chips with Wi-Fi interfaces can be used for the stepper motor control, including Espressif System ESP 8266, Microchip PIC16F series, Texas Instrument Stellaris, and Arduino Mega.

Conclusion

SMART orthopedic implants are devices used to measure physical stimuli during the process of fracture fixation. The implants use on-chip microelectrodes and a sensor readout unit built on an application specific integrated circuit for electrochemical monitoring. When external fixation is used, the movements of the broken bone can strain the pins and the frame of the fixator. Various factors such as extremity movements and muscle tension contribute to this issue. As the callus hardens, a load is gradually transferred from the fixator to the bone, resulting in a reduction of micromovements. SMART devices provide objective data that can assist doctors in guiding rehabilitation strategies of patients at different stages of treatment. The sensor system is an active device capable of making automatic decisions and controlling actuators based on those decisions. The SMA can be used to aid in a bone healing procedure. Effective communication between doctors and patients is achieved through a hardware-software platform, which grants that doctors asses to bone healing data and enables them to control the movements of broken bone parts through a stepper motor. The doctor reviews the sensor data, make decisions based on the information and triggers the SMA for stepper motor activation.

References

Abas, A. & Bakar, A. 2017. Design of a Microcontroller Based RF Remote Control for Stepper Motor Control. In: *Proceedings of IC-ITS 2017 3rd International Conference on Information Technology & Society,* Penang, Malaysia, pp.96-104, July 31-August 01. ISBN: 978-967-2122-04-3.

Aguirre, E., Lopez-Iturri, P., Azpilicueta, L., Rivarés, C., Astrain, J.J., Villadangos, J. & Falcone, F. 2016. Design and performance analysis of wireless body area networks in complex indoor e-Health hospital environments for patient remote monitoring. *International Journal of Distributed Sensor Networks*, 12(9). Available at: https://doi.org/10.1177/1550147716668063.

Aherwar, A., Singh, A.K. & Patnaik, A. 2016. Cobalt Based Alloy: A Better Choice Biomaterial for Hip Implants. *Trends in Biomaterials and Artificial Organs,* 30(1), pp.50-55.

Allizond, V., Comini, S., Cuffini, A.M. & Banche, G. 2022. Current Knowledge on Biomaterials for Orthopedic Applications Modified to Reduce Bacterial Adhesive Ability. *Antibiotics* 11(4), art.number:529. Available at: https://doi.org/10.3390/antibiotics11040529.

Amjadi, M., Kyung, K.-U., Park, I. & Sitti, M. 2016. Stretchable, Skin-Mountable, and Wearable Strain Sensors and Their Potential Applications: A

Review. *Advanced Functional Materials*, 26(11), pp.1678-1698. Available at: https://doi.org/10.1002/adfm.201504755.

Andrew, W. 2024. Human skeleton. *Encyclopedia Britannica,* 08 April [online]. Available at: https://www.britannica.com/science/human-skeleton [Accessed 28 March 2024].

Anene, F.A., Aiza Jaafar, C.N., Zainol, I., Azmah Hanim, M.A. & Suraya, M.T. 2021. Biomedical materials: A review of titanium based alloys. *Proceedings of the Institution of Mechanical Engingeers, Part C: Journal of Mechanical Engineering Science,* 235(19), pp.3792-3805. Available at: https://doi.org/10.1177/0954406220967694.

Antic, V., Misic, D. & Manic, M. 2023a. Strain sensor-based monitoring of smart orthopedic devices in lower limb fracture healing: a review. *Innovative Mechanical Engineering*, 2(3), pp.17-41 [online]. Available at: http://ime.masfak.ni.ac.rs/index.php/IME/article/view/60 [Accessed: 19 February 2024].

Antic, V., Misic, D. & Manic, M. 2023b. Smart orthopedic implant: conceptual solution. In: *39th International Conference on Production Engineering - Serbia*, Novi Sad, Serbia, pp.1-5, October 26-27. ISBN: 978-86-6022-610-7.

Atmojo, J.T., Sudaryanto, W.T., Widiyanto, A., Ernawati & Arradini, D. 2020. Telemedicine, Cost Effectiveness, and Patients Satisfaction: A Systematic Review. *Journal of Health Policy and Management,* 5(2), pp.103-107 [online]. Available at: https://thejhpm.com/index.php/thejhpm/article/view/172 [Accessed: 05 December 2023].

Bansal, D. 2012. Potential of Piezoelectric Sensors in Bio-signal Acquisition. *Sensors and Transducers*, 136(1), pp.147-157 [online]. Available at: https://www.sensorsportal.com/HTML/DIGEST/P_916.htm [Accessed: 05 December 2023].

Binyamin, G., Shafi, B.M. & Mery, C.M. 2006. Biomaterials: A primer for surgeons. *Seminars in Pediatric Surgery*, 15(4), pp.276-283. Available at: https://doi.org/10.1053/j.sempedsurg.2006.07.007.

Bizzoca, D., Vicenti, G., Caiaffa, V., Abate, A., Carolis, O.D., Carrozzo, M., Solarino, G. & Moretti, B. 2023. Assessment of fracture healing in orthopaedic trauma. *Injury,* 54(1), pp.S46-S52. Available at: https://doi.org/10.1016/j.injury.2020.11.014.

Borchani, W., Aono, K., Lajnef, N. & Chakrabartty, S. 2016. Monitoring of Postoperative Bone Healing Using Smart Trauma-Fixation Device with Integrated Self-Powered Piezo-Floating-Gate Sensors. *IEEE Transactions on Biomedical Engineering*, 63(7), pp.1463-1472. Available at: http://doi.org/10.1109/TBME.2015.2496237.

Brogini, S., Sartori, M., Giavaresi, G., Cremascoli, P., Alemani, F., Bellini, D., Martini, L., Maglio, M., Pagani, S. & Fini, M. 2021. Osseointegration of additive manufacturing Ti–6Al–4V and Co–Cr–Mo alloys, with and without surface functionalization with hydroxyapatite and type I collagen. *Journal of the Mechanical Behavior of Biomedical Materials,* 115, art.number:104262. Available at: https://doi.org/10.1016/j.jmbbm.2020.104262.

Button, K.S., Ioanidis, J.P.A., Mokryzs, C., Noseka, B.A., Flint, J., Robinson, E.S.J. & Munafo, M.R. 2013. Confidence and precision increase with high statistical power. *Nature Reviews Neuroscience,* 14, art.number:585. Available at: https://doi.org/10.1038/nrn3475-c4.

Cheng, M. & Scattareggia, S. 2011. How to Select the Right Stepmotor for a Medical Device. *MachineDesign.com* [online]. Available at: https://www.machinedesign.com/markets/medical/article/21832379/how-to-select-the-right-stepmotor-for-a-medical-device [Accessed: 29 February 2024].

Chiurazzi, M., Garozzo, G. G., Dario, P. & Ciuti, G. 2020. Novel Capacitive-Based Sensor Technology for Augmented Proximity Detection. *IEEE Sensors Journal*, 20(12), pp.6624-6633. Available at: https://doi.org/10.1109/JSEN.2020.2972740.

Claes, L.E. & Cunningham, J.L. 2009. Monitoring the Mechanical Properties of Healing Bone. *Clinical Orthopedic and Related Research*, 467(8), pp.1964-1971. Available at: https://doi.org/10.1007/s11999-009-0752-7.

Coneicao, C., Completo, A. & Soares dos Santos Marco P. 2023. Ultrasensitive capacitive sensing system for smart medical devices with ability to monitor fracture healing stages. *Journal of the Royal Society Interface*, 20, art.number:20220818. Available at: https://doi.org/10.1098/rsif.2022.0818.

Cram, N. 2004. 10 - Careers, Roles, and Responsibilities. In: *Clinical Engineering Handbook*. Academic Press. Available at: https://doi.org/10.1016/B978-012226570-9/50012-0.

Ernst, M., Richards, R.G. & Windolf, M. 2020. Smart implants in fracture care – only buzzword or real opportunity? *Injury,* 52(2), pp.S101-S105. Available at: https://doi.org/10.1016/j.injury.2020.09.026.

Findik, F. 2020. Recent developments of metallic implants for biomedical applications. *Periodical of Engineering and Natural Sciences,* 8(1), pp.33-57 [online]. Available at: http://pen.ius.edu.ba/index.php/pen/article/view/988/487 fAccessed: 05.12.2024].

Francis, A. 2021. Biological evaluation of preceramic organosilicon polymers for various healthcare and biomedical engineering applications: A review. *Journal of Biomedical Materials Research Part B: Applied Biomaterials,* 109(5), pp.744-764. Available at: https://doi.org/10.1002/jbm.b.34740.

Friis, E.A., DeCoster, D.A. & Thomas, J.C. 2017. 7 - Mechanical testing of fracture fixation devices. In: Friis, E.A. (Ed.) *Mechanical Testing of Orthopaedic Implants,* pp.131-141. Sawston, Cambridge, UK: Woodhead Publishing. Available at: https://doi.org/10.1016/B978-0-08-100286-5.00007-X.

Green, S.R. & Gianchandani, Y.B. 2009. Wireless Magnetoelastic Monitoring of Biliary Stents. *Journal of Microelectromechanical Systems*, 18(1), pp.64-78, Available at: http://doi.org/10.1109/JMEMS.2008.2008568.

Harb, A.M. & Zaher, A.A. 2004. Nonlinear control of permanent magnet stepper motors. *Communications in Nonlinear Science and Numerical Simulation* 9(4), pp.443-458. Available at: https://doi.org/10.1016/S1007-5704(02)00133-8.

-ICLL International Center for Limb Lengthening. 2024. Limb lengthening: The process. *Limblength.org* [online]. Available at:

https://www.limblength.org/treatments/limb-lengthening-the-process/ [Accessed: 1 March 2024].

Jacobs, J.J., Gilbert, J.L. & Urban, R.M. 1998. Current Concepts Review - Corrosion of Metal Orthopaedic Implants. *The Journal of Bone & Joint Surgery,* 80(2), pp.268-282. Available at: https://doi.org/10.2106/00004623-199802000-00015.

Jefferies, C., Al-Malaika, S. & Sheena, H.H. 2021. New and novel stabilisation approach for radiation-crosslinked Ultrahigh Molecular Weight Polyethylene (XL-UHMWPE) targeted for use in orthopaedic implants. *Polymer Degradation and Stability,* 183, art.number:109462. Available at: https://doi.org/10.1016/j.polymdegradstab.2020.109462.

Kausar, A. 2022. Sensing Materials: Nanocomposites. *Encyclopedia of Sensors and Biosensors* 2, pp.305-315. Available at: https://doi.org/10.1016/B978-0-12-822548-6.00048-0.

Kim, Y.-G., Song, J.-H., Hong, S. & Ahn, S.-H. 2022. Piezoelectric strain sensor with high sensitivity and high stretchability based on kirigami design cutting. *npj Flexible Electronics* 6, art.number:52. Available at: https://doi.org/10.1038/s41528-022-00186-4.

Kruse, C.S., Krowski, N., Rodriges, B., Tran, L., Jackeline, V. & Brooks, M. 2017. Telehealth and patient satisfaction: a systematic review and narrative analysis. *BMJ Open,* 7, e016242. Available at: https://doi.org/10.1136/bmjopen-2017-016242.

Kumar, K. 2021. Stepper Motors for Medical Applications. *Portescap.com,* 27 August [online]. Available at: https://www.portescap.com/en/newsroom/blog/2021/08/stepper-motors-for-medical-applications [Accessed: 19 February 2024].

Ledet, E.H., Liddle, B., Kradinova, K. & Harper, S. 2018. Smart implants in orthopedic surgery, improving patient outcomes: a review. *Innovative Entrepreneur in Health,* 5, pp.41-51. Available at: https://doi.org/10.2147/IEH.S133518.

Li, W. & Li, J. 2022. The Development Direction of Information Security in Wireless Communication. *Advances in Social Science, Education and Humanities Research,* 666, pp.177-180 [online]. Available at: https://www.atlantis-press.com/proceedings/stehf-22/125975590 [Accessed: 05.12.2023].

Lin, M.C., Hu, D., Marmor, M., Herfat S.T., Bahney, C.S. & Maharbiz, M.M. 2019. Smart bone plates can monitor fracture healing. *Scientific Reports,* 9, art.number:2122. Available at: https://doi.org/10.1038/s41598-018-37784-0.

Naghdi, T., Ardalan, S., Asghari Adib, Z., Shafiri, A.R. & Golmogammadi, H. 2023. Moving towards smart biomedical sensing. *Biosensors and Bioelectronics,* 223, art.number:115009. Available at: https://doi.org/10.1016/j.bios.2022.115009.

Nicholson, J.A., Yapp, L.Z., Keating, J.F. & Simpson, A.H.R.W. 2021. Monitoring of fracture healing. Update on current and future imaging modalities to predict union. *Injury,* 52(2), pp.S29-S34. Available at: https://doi.org/10.1016/j.injury.2020.08.016.

O'Connor, C. & Kiourti, A. 2017. Wireless Sensors for Smart Orthopedic Implants. *Journal of Bio- and Tribo-Corrosion,* 3, art.number:20. Available at: https://doi.org/10.1007/s40735-017-0078-z.

Pelham, H., Benza, D., Millhouse, P.W., Carrington, N., Ariffuzamann, Md., Behrend, C.J., Anker, J.N. & DesJardins, J.D. 2017. Implantable strain sensor to monitor fracture healing with standard radiography. *Scientific Reports,* 7, art.number:1489. Available at: https://doi.org/10.1038/s41598-017-01009-7.

Piconi, C. 2017. 5 - Ceramics for joint replacement: Design and application of commercial bearings*.* In: Palmero, P., Cambier, F. & De Barra, E. (Eds.) *Advances in Ceramic Biomaterials,* pp.129-179*.* Sawston, Cambridge, UK: Woodhead Publishing. Available at: https://doi.org/10.1016/B978-0-08-100881-2.00005-1.

Poinem, G.E.J., Brundavanam, S. & Fawcet, D. 2012. Biomedical Magnesium Alloys: A Review of Material Properties, Surface Modifications and Potential as a Biodegradable Orthopaedic Implant*. American Journal of Biomedical Engineering,* 2(6), pp.218-240. Available at: https://doi.org/10.5923/J.AJBE.20120206.02.

Rohani Shirvan, A., Nouri, A. & Wen, C. 2021. *12 - Structural polymer biomaterials*, In: Wen, C. (Ed.) *Woodhead Publishing Series in Biomaterials, Structural Biomaterials.* Sawston, Cambridge, UK: Woodhead Publishing, pp.395-439. Available at: https://doi.org/10.1016/B978-0-12-818831-6.00010-0.

Sellei, R.M., Kobbe, P., Dienstknecht, T., Lichte, P., Pfeifer, R., Behrens, M., Brianza, S. & Pape, H.-C. 2015. Biomechanical properties of different external fixator frame configurations. *European Journal of Trauma and Emergency Surgery,* 41, pp.313-318. Available at: https://doi.org/10.1007/s00068-014-0436-1.

Shayesteh Moghaddam, N., Taheri Andani, M., Amerinatanzi, A., Haberlend, C., Huff, S., Miller, M., Elahinia, M. & Dean, D. 2016. Metals for bone implants: safety, design, and efficacy. *Biomanufacturing Reviews,* 1, art.number:1. Available at: https://doi.org/10.1007/s40898-016-0001-2.

Sheen, J.R., Mabrouk, A. & Garla, V.V. 2023. Fracture Healing Overview. *National Library of Medicine*, 8 April [online]. Available at: https://www.ncbi.nlm.nih.gov/books/NBK551678/ [Accessed 28 March 2024].

Shekhawat, D., Singh, A., Bhardwaj, A. & Patnaik, A. 2021. A Short Review on Polymer, Metal and Ceramic Based Implant Materials. *IOP Conferences Series: Materials Science and Engineering,* 1017, art.number:012038. Available at: https://doi.org/10.1088/1757-899X/1017/1/012038.

Sirohi, J. & Chopra, I. 2000. Fundamental Understanding of Piezoelectric Strain Sensors. *Journal of Intelligent Material Systems and Structures,* 11(4), pp.246-257. Available at: https://doi.org/10.1106/8BFB-GC8P-XQ47-YCQ0.

Soares dos Santos, M.P. & Bernardo R.M.C. 2022. Bioelectronic multifunctional bone implants: recent trends. *Bioelectronic Medicine,* 8, art.number:15. Available at: https://doi.org/10.1186/s42234-022-00097-9.

Solanke, S., Gaval, V. & Sanghavi, S. 2021. In vitro tribological investigation and osseointegration assessment for metallic orthopedic bioimplant materials.

Materials Today: Proceedings, 44(6), pp.4173-4178. Available at: https://doi.org/10.1016/j.matpr.2020.10.528.

Sowjanya, V.H., Kiran, P., Ravi Kumar, V. & Chandu, B. 2018. Controlling a wireless stepper motor by rf transmitter and receiver using arduino. *International Journal of Research and Analytical Reviews,* 5(1), pp.121-125 [online]. Available at: https://www.ijrar.org/papers/IJRAR1CXP024.pdf [Accessed 28 March 2024].

Sun, R., Zhang, B., Yang, L., Zhang, W., Farrow, I., Scrapa, F. & Rossiter, J. 2018. Kirigami stretchable strain sensors with enhanced piezoelectricity induced by topological electrodes. *Applied Physics Letters,* 112(25), art.number:251904. Available at: https://doi.org/10.1063/1.5025025.

Sun, G., Matsui, T., Watai Y., Kim, S., Kirimoto, T., Suzuki, S. & Hakozaki, Y. 2018. Vital-SCOPE: Design and Evaluation of a Smart Vital Sign Monitor for Simultaneous Measurement of Pulse Rate, Respiratory Rate, and Body Temperature for Patient Monitoring. *Journal of Sensors*, art.ID:4371872. Available at: https://doi.org/10.1155/2018/4371872.

Taheri Andani, M., Moghaddam, N.S., Haberland, C., Dean, D., Miler, M.J. & Elahinia, M. 2014. Metals for bone implants. Part 1. Powder metallurgy and implant rendering. *Acta Biomaterialia* 10(10), pp.4058-4070. Available at: https://doi.org/10.1016/j.actbio.2014.06.025.

Tandon, B., Blaker, J.J. & Cartmell S.H. 2018. Piezoelectric materials as stimulatory biomedical materials and scaffolds for bone repair. *Acta Biomaterialia,* 73, pp.1-20. Available at: https://doi.org/10.1016/j.actbio.2018.04.026.

Taylor, H.R. 1997. *Data Acquisition for Sensor Systems.* Chapman & Hall. ISBN: 0-412-78560-9.

Thomas, L. 2023. What is Telemedicine? *News-Medical.net*, 18 January [online]. Available at: https://www.news-medical.net/health/What-is-Telemedicine.aspx [Accessed: 03 April 2024].

Xu, W., Lu, X., Tian, J., Huang, C., Chen, M., Yan, Y., Wang, L., Qu, X. & Wen, C. 2020. Microstructure, wear resistance, and corrosion performance of Ti35Zr28Nb alloy fabricated by powder metallurgy for orthopedic applications. *Journal of Materials Science & Technology,* 41, pp.191-198. Available at: https://doi.org/10.1016/j.jmst.2019.08.041.

SMART, Monitorización y tratamiento de la curación de fracturas: transductores piezoeléctricos y actuadores de motor paso a paso

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CAMPO: ingeniería eléctrica, ingeniería mecánica, telecomunicaciones, ingeniería biomédica
TIPO DE ARTÍCULO: artículo de revisión

Resumen:

Introducción/objetivo: Los sistemas ortopédicos SMART utilizan fijadores con capacidades de comunicación, procesamiento y monitoreo remoto para aprovechar los datos de progresión de la curación para un monitoreo personalizado en tiempo real de un proceso de curación. Los fijadores incorporan sensores piezoeléctricos pequeños y compactos que generan señales eléctricas al aplicar fuerza al diafragma piezoeléctrico. Esto permite a los médicos guiar de forma remota los dispositivos de fijación utilizando motores paso a paso controlados indirectamente y de forma remota, conocidos por su precisión y exactitud. La confiabilidad de los motores paso a paso los convierte en una alternativa viable a las herramientas mecánicas utilizadas tradicionalmente por los médicos para la extensión del fijador.

Métodos: Este estudio se centra en la evaluación de la tecnología basada en sensores en aplicaciones ortopédicas. El artículo presenta un marco teórico para la aplicación de dispositivos SMART en el proceso de curación de fracturas óseas. Profundiza en la estructura y funcionalidad de los transductores piezoeléctricos ofreciendo una visión integral de esta tecnología y diversos aspectos de ingeniería de los sistemas SMART.

Resultados: La implementación de sistemas SMART ha mejorado significativamente la comunicación médico-paciente. Esta mejora se facilita mediante un proceso de dos fases que implica recopilar, procesar y transmitir los datos de forma inalámbrica desde la interfaz (sensor) del paciente al médico, que utiliza software especializado para el análisis de datos y la transmisión inalámbrica al actuador del motor paso a paso. Posteriormente, los datos se envían al decodificador en el sitio del motor, donde un controlador del motor genera la señal de control para el controlador del motor paso a paso.

Conclusión: Los implantes SMART pueden proporcionar a los médicos datos cuantitativos que pueden utilizarse para dirigir un plan de rehabilitación. La tecnología basada en sensores ofrece información sobre el estrés inducido por la formación de callos, lo que permite la comunicación bidireccional entre el médico y el paciente. El motor paso a paso es una herramienta que ayuda al trato personalizado a distancia.

Palabras claves: implante SMART, sensor piezoeléctrico, curación de fracturas, motor paso a paso.

УМНЫЙ мониторинг и заживление переломов: пьезоэлектрические преобразователи и актуаторы шаговых двигателей

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РУБРИКА ГРНТИ: 34.57.00 Биоинженерия
ВИД СТАТЬИ: обзорная статья

Резюме:

Введение/цель: В умных ортопедических системах используются фиксаторы с возможностью дистанционного мониторинга, обработки и связи для использования данных о ходе лечения с целью персонализированного мониторинга процесса заживления в реальном времени. В состав фиксаторов входят небольшие и компактные пьезоэлектрические датчики, которые генерируют электрические сигналы при приложении усилия к пьезоэлектрической диафрагме. Это позволяет врачам дистанционно управлять фиксирующими устройствами, используя шаговые двигатели с косвенным и дистанционно управляемым приводом, отличающимися своей точностью. Надежность шаговых двигателей делает их надежной альтернативой механическим инструментам, традиционно используемым врачами для удлинения фиксаторов.

Методы: Данное исследование посвящено оценке сенсорных технологий в ортопедических приложениях. В данной статье представлены теоретические основы применения УМНЫХ устройств в процессе заживления переломов костей. Также обсуждается структура и функциональность пьезоэлектрических преобразователей и дается всестороннее представление о данной технологии и различных инженерных аспектах УМНЫХ систем.

Результаты: Внедрение УМНЫХ систем значительно улучшило коммуникацию врачей с пациентами. Такому прогрессу способствует процесс, включающий сбор, обработку и беспроводную передачу данных от интерфейса больного (датчика) врачу, который использует специальное программное

обеспечение для анализа данных и беспроводной передачи актуатору шагового двигателя. После чего данные передаются в декодер двигателя, где контроллер двигателя генерирует контрольный сигнал для драйвера двигателя.

Выводы: Умные имплантаты могут предоставить врачам количественные данные, которые можно использовать для составления плана реабилитации. Сенсорная технология дает представление о стрессе, вызванном образованием мозолей, обеспечивая двустороннюю связь между врачом и пациентом. Шаговый двигатель служит инструментом в персонализированном дистанционном лечении.

Ключевые слова: УМНЫЙ имплантат, пьезоэлектрический датчик, перелом кости, шаговый двигатель.

Смарт третман у зарастању прелома: пиезоелектрични претварачи и актуатори степ мотора

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ОБЛАСТ: електротехника, машинство, телекомуникације, биоинжењеринг
КАТЕГОРИЈА (ТИП) ЧЛАНКА: прегледни рад

Сажетак:

Увод/циљ: Смарт ортопедски системи користе фиксаторе са могућношћу даљинског праћења, обраде и комуникације како би искористили податке о напредовању лечења за персонализовано праћење процеса зарастања у реалном времену. Фиксатори садрже мале и компактне пиезоелектричне сензоре који генеришу електричне сигнале при примени силе на пиезоелектричну дијафрагму. То омогућава лекарима да даљински воде уређаје за фиксирање са удаљености користећи индиректно и даљински контролисане степ (корачне) моторе познате по прецизности и тачности. Њихова поузданост чини их одрживом алтернативом за механичке алате које лекари традиционално користе за продужавање фиксатора.

Методе: Ова студија се фокусира на евалуацију технологије засноване на сензорима у ортопедским апликацијама. У њој је

Antic, V. et al, SMART monitoring and treatment of fracture healing: Piezoelectric transducers and stepper motor actuators, pp.814-838

представљен теоријски оквир за примену смарт уређаја у процесу зарастања прелома костију. Разматра се и структура и функционалност пиезоелектричних претварача и нуди свеобухватан увид у ову технологију и различите инжењерске аспекте смарт система.

Резултати: Имплементацијом смарт система значајно је побољшана комуникација између лекара и пацијента. То је олакшано кроз процес који обухвата прикупљање, обраду и бежични пренос података од пацијентовог (сензорског) интерфејса до лекара, који користи специјализовани софтвер за анализу података и бежични пренос до актуатора степ мотора. Након тога подаци се прослеђују декодеру на локацији мотора, где контролер мотора генерише контролни сигнал за драјвер мотора.

Закључак: Смарт имплантати пружају лекарима квантитативне податке који се могу користити у усмеравању плана рехабилитације. Технологија заснована на сензорима нуди увид у стрес изазван формирањем калуса, омогућавајући двосмерну комуникацију између лекара и пацијента. Степ мотор служи као алат који помаже у персонализованом третману са удаљености.

Кључне речи: смарт имплантат, пиезоелектрични сензор, фрактура кости, степ мотор.

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Simplified formulation to evaluate forces due to shrinkage in composite steel-concrete beams with full shear connection

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Abstract:

Introduction/purpose: It has been known for a very long time that time-dependent effects such as creep and shrinkage of concrete considerably influence the behavior of composite steel-concrete beams. It is therefore

very important to take these effects into account when calculating the strength and safety of composite steel-concrete beams. To this end, many theoretical and numerical research studies have been established to control this phenomenon. Most of this research presents laborious processes and calculations requiring complex techniques.

Methods: This model consists of combining the static equilibrium equations and the two compatibility relations, in curvature and in deformation, of the composite steel-concrete cross-section with the differential equation resulting from the creep rate theory (RCM). The idea of this work was to take this model and simplify it to avoid difficult mathematical transformations.

Results: The results from this simplified approach are very satisfactory when compared to those given by the analytical model.

Conclusion: To overcome an excessive number of calculations and various difficulties associated with analytical or numerical methods to estimate additional stresses brought by the shrinkage of concrete in composite steel-concrete beams, a simplified analytical methodology has been proposed here while ensuring desired safety. This work has tried to simplify an existing analytical model based on the theory of linear viscoelasticity established in 2012.

Key words: shrinkage, concrete, steel, time, simplified approach.

Introduction

Due to the complementary performance of steel and concrete, composite steel-concrete beams have become a very suitable structural system for the construction of buildings and bridges. To obtain a monolithic section, shear connectors must be arranged along the beam to connect the concrete slab to the steel beam. This process will lead to a structural system with significantly improved strength, stiffness, ductility, and fire protection (Nguyen & Hjiaj, 2016). Under the application of service loads, the steel beam deforms elastically. On the other hand, the concrete slab will undergo strong inelastic deformations over time, particularly shrinkage, creep, and aging of the concrete (Si & Au, 2011).

Due to the effects of concrete shrinkage and creep on the one hand and the steel-concrete interaction on the other hand, the accurate prediction of the service behavior of composite steel-concrete beams becomes highly complex.

In order to evaluate the structural behavior of composite steel-concrete beams, it is very important to predict the effects of concrete shrinkage and creep (Sun et al, 2019). Until now, despite numerous

research studies carried out in this field, these two phenomena have not been mastered yet (Marí et al, 2010).

The shrinkage of concrete is, by definition, a physical phenomenon linked to various interdependent factors such as: temperature, type of cement, humidity and transverse dimensions of the element, etc. Total shrinkage includes autonomous shrinkage, drying shrinkage and plastic shrinkage (Aly et al, 2008). It affects the time-dependent behavior and reduces the volume of the concrete element. In the long term, it can cause a deformation of concrete structures or a redistribution of internal forces. When the ultimate tensile limit of concrete is reached, the durability and serviceability of concrete members will be affected (Sun et al, 2019). Shrinkage can also cause concrete cracking (Jason Weiss, 1998). If displacement is prevented or restricted, severe cracking of a concrete structure will occur (Au et al, 2007).

With the use of the theory of linear viscoelasticity, the time-dependent effects on the behavior of composite steel-concrete beams are the subject of many analytical and numerical research studies such as: Gilbert, 1989; Partov & Kantchev, 2012, 2014; Tehami & Ramdane, 2009; Rahal et al, 2012; Souici et al, 2015; Beghdad et al, 2017; Furtak, 2015; Ranzi et al, 2013; Dunwen et al 2019; Cao et al, 2018; Al-Deen et al, 2015; Ban et al, 2015; Huang et al, 2018; Huang et al 2019ab; and others.

Presentation of the idea

Based on the theory of linear viscoelasticity, Rahal et al (Rahal et al 2012) proposed an analytical model analyzing the behavior, over time, of composite steel-concrete beams subjected to concrete shrinkage. The process consists of combining the static equilibrium equations and the two compatibility relations, in curvature and in deformation, of the composite steel-concrete cross-section with the differential (constitutive) equation resulting from the creep rate theory (RCM). In this model:

1- to obtain the variation of the normal force $N_c(t)$ and that of the bending moment $M_c(t)$ brought by the shrinkage of the concrete, which solicit the concrete slab, it is compulsory to solve the system of two differential equations below:

$$\left(1+\frac{I_c}{n\,I_a}\right)\frac{dM_c(t)}{d\phi}-\frac{a.(1+n\,\rho)I_c}{n\,I_a}\frac{dN_c}{d\phi}+M_c(t)=0 \qquad (1)$$

$$\left(\frac{C_C}{I_C}-\frac{C_S}{n\,I_S}\right)\frac{dM_C(t)}{d\phi}+\left(\frac{1}{A_C}+\frac{1}{n\,A_S}+\frac{C_S}{n\,I_S}a\right)(1+n\rho)\frac{dN_C(t)}{d\phi}+ \\ +\frac{C_C}{I_C}M_C(t)+\frac{1}{A_C}N_C(t)=E_C\frac{\varepsilon_{sh\infty}}{\phi_\infty} \quad (2)$$

Its solution is as follows:

$$M_c(t)=C_1.a_{1(\lambda_1)}.e^{\lambda_1.\varphi}+C_2.a_{1(\lambda_2)}e^{\lambda_2\varphi} \quad (3)$$

$$N_c(t)=C_1.a_{2(\lambda_1)}.e^{\lambda_1.\varphi}+C_2.a_{2(\lambda_2)}e^{\lambda_2\varphi}+\frac{E_c}{A_6}\frac{\varepsilon_{sh\varphi}}{\varphi_\infty} \quad (4)$$

where C_1 and C_2 will be determined from the boundary conditions, and a_1 and a_2 will be determined from the geometric and mechanical characteristics of the composite cross-section.

The forces acting on the steel beam will be obtained by the static equilibrium of the cross-section.

A_c: the cross section area of concrete in the slab.
A_s: steel beam area.
ρ: Reinforcement percentage ($\rho = A_a/A_c$).
A_a: the area of the longitudinal reinforcement incorporated in the slab.
I_c: moment of inertia of the concrete slab.
I_s: moment of inertia of the steel beam.
a: distance between the neutral axis of the steel beam and that of the reinforced concrete slab.
b_{eff}: effective width of the reinforced concrete slab.
C_c: distance from the slab centre of gravity to the neutral fibre of the mixed section.
C_s: distance from the steel beam centre of gravity to the neutral fibre of the mixed section.
E_c: the modulus of tensile elasticity of concrete.
E_s: the modulus of tensile elasticity of steel.
n: equivalence coefficient ($n= E_s/E_c$).
$\varepsilon_{sh}(t)$: the deformation due to concrete shrinkage. It can be determined using calculation codes for concrete structures such as: EC2, ACI, fib model code, etc.
$M_c(t)$: bending moment in the concrete slab due to shrinkage.
$M_s(t)$: bending moment in the steel beam.
$N_c(t)$: normal force in the concrete slab due to shrinkage.
$N_s(t)$: normal force in the steel beam.

This work seeks to significantly simplify this formulation so that it can be easily used by engineers in design offices.

Formulation of the proposed approach

Figure 1 shows the different components of the cross-section, namely: the concrete slab, the steel beam, the reinforcement embedded in the slab, and the shear connectors. For the formulation of the present approach, Figure 1 shows various forces acting on the composite cross-section.

Static equilibrium equations

At any instant t, the static equilibrium gives the following system of equations:

$$\sum F_{/x} = 0 \Rightarrow N_s(t) + N_c(t) = N_0 \quad (5)$$

$$\sum M / Gs = 0 \Rightarrow M_s(t) - N_c(t) \times a + M_c(t) = M_0 \quad (6)$$

Under the effect of concrete shrinkage, the slab can therefore be subjected to a normal tensile force on its neutral axis. Based on Hook's law, this force can be obtained by the following relation (Eurocodes, 2006):

$$N_c(t) = \frac{1}{n_L} A_c E_c \varepsilon_{sh}(t) \quad (7)$$

The relation (Eq.7) is introduced into the static equilibrium equations (Eqs.5 and 6) of the model proposed by Rahal et al (Rahal et al 2012), therefore:

$$N_s(t) = -\frac{1}{n_L} A_c E_c \varepsilon_{sh}(t) + N_0 \quad (8)$$

$$M_s(t) = \frac{1}{n_L} A_c E_c \varepsilon_{sh}(t) \times a - M_c(t) + M_0 \quad (9)$$

Since shrinkage does not depend on external loading, N_0 and M_0 are cancelled and what is obtained is:

$$N_s(t) = -\frac{1}{n_L} A_c E_c \varepsilon_{sh}(t) \quad (10)$$

$$M_s(t) = \frac{1}{n_L} A_c E_c \varepsilon_{sh}(t) \times a - M_c(t) \quad (11)$$

n_L: modular ratio for shrinkage.

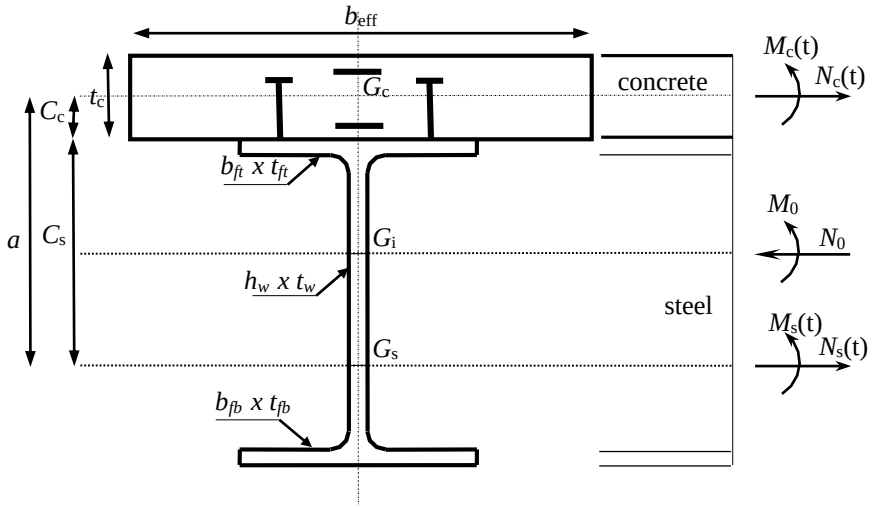

Figure 1 – Composite steel-concrete cross-section

Deformation compatibility

It is known that the curvature and the axial deformation of a beam are related to displacements by kinematic expressions (Nguyen & Hjiaj, 2016).

There are two equations (Eqs. 10 and 11) with three unknowns, $N_s(t)$, $M_c(t)$ and $M_s(t)$. From the first equation, $N_s(t)$ is obtained. It remains to find the expression of the bending moment $M_c(t)$ acting on the concrete slab and $M_s(t)$ acting on the steel beam.

To solve this problem, the compatibility of strains at the steel-concrete interface is exploited. This condition has been used by several researchers in the formulation of their models, such as: (Partov & Kantchev, 2012, 2014; Tehami & Ramdane, 2009; Rahal et al, 2012; Souici et al, 2015; Beghdad et al, 2017).

The deformation compatibility condition between steel and concrete was used by Rahal et al (Rahal et al 2012) in the model which is sought to be simplified. It translates into the following expression:

$$\varepsilon_c(t) = \frac{N_c(t)}{E_c\, A_c} + \frac{M_c(t)}{E_c\, I_c} C_c = \frac{N_s(t)}{E_s\, A_s} - \frac{M_s(t)}{E_s\, I_s} C_s \tag{12}$$

In equation (Eq.12), Ns(t) and Ms(t) are replaced by their respective expressions (Eqs. 10 and 11); the expression of Mc(t) given by equation (Eq.13) is easily found:

$$M_c(t) = \frac{\left(A_c\, E_c\, \varepsilon_{sh}(t)\right)\left[\dfrac{a\, x C_s}{E_s\, I_s} + \dfrac{1}{E_s\, A_s} + \dfrac{1}{E_c\, A_c}\right]}{n_L\left[\dfrac{C_c}{E_c\, I_c} - \dfrac{C_s}{E_s\, I_s}\right]} \quad (13)$$

Once $M_c(t)$ is known, it is very simple to calculate the expression of $M_s(t)$ by averaging the expression (Eq:11).

Validation of the proposed approach

In order to validate the presented approach, the same composite beam used by Rahal et al (2012) and Beghdad et al (2017) will be used to validate their proposed models.

This beam was also analyzed (prediction of time-dependent effects) and dimensioned in accordance with Eurocode 4 (Eurocodes, 2006). In this example, the shrinkage parameters were calculated according to Eurocode 2 (Eurocodes, 1992).

The geometric and physical characteristics of the treated example are as follows:

b_{eff} = 3100 mm, t_c = 250 mm, b_{ft} = 400 mm, t_{ft} = 20 mm, b_{fb} = 400 mm, t_{fb} = 30 mm, h_w = 1175 mm, t_w = 12.5 mm, A_c = 0.785 m^2, A_s = 0.0346875 m^2, A_a = 58.47 cm^2, ρ = 0.0074, I_c = 0.004223633272 m^4 , I_s = 0.0346875 m^2, C_c = 0.375 m,C_s = 0.451 m, a= 0.826m, E_c = 33x10^4 MPa, Es =2.1x10^5 MPa, HR = 70%, Grade of concrete = C30/37, and HR: relative humidity in %.

Results

The results obtained by this approach are compared to the existing model formulated by Rahal et al (Rahal et al 2012) and presented on the diagrams in Figures 2 to 6.

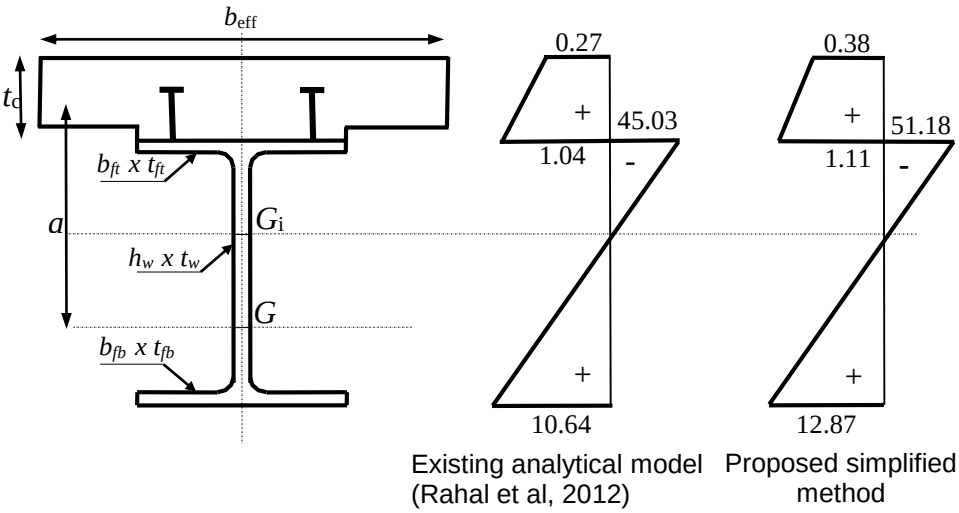

Figure 2 – Diagrams comparing the final stress (MPa) due to concrete shrinkage

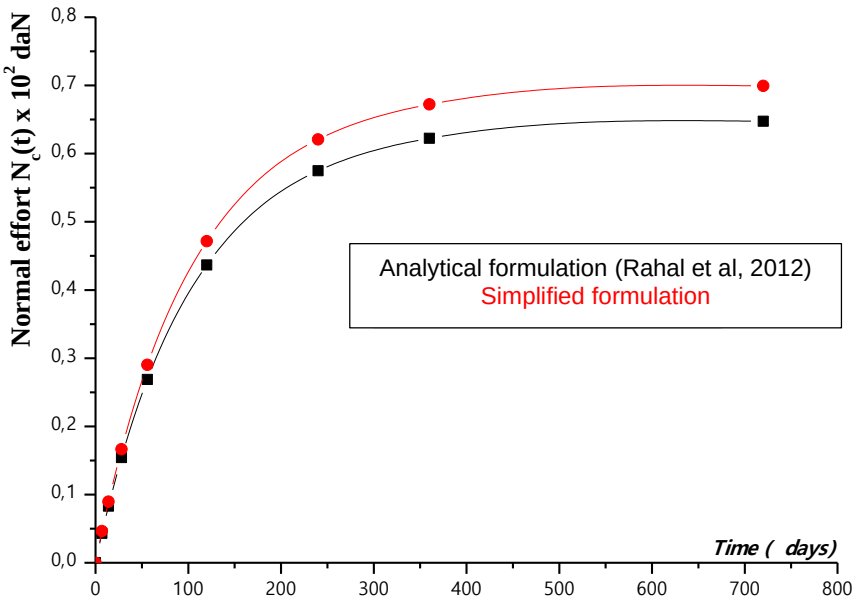

Figure 3 – Variation, in time, of the concrete slab normal effort $N_c(t)$

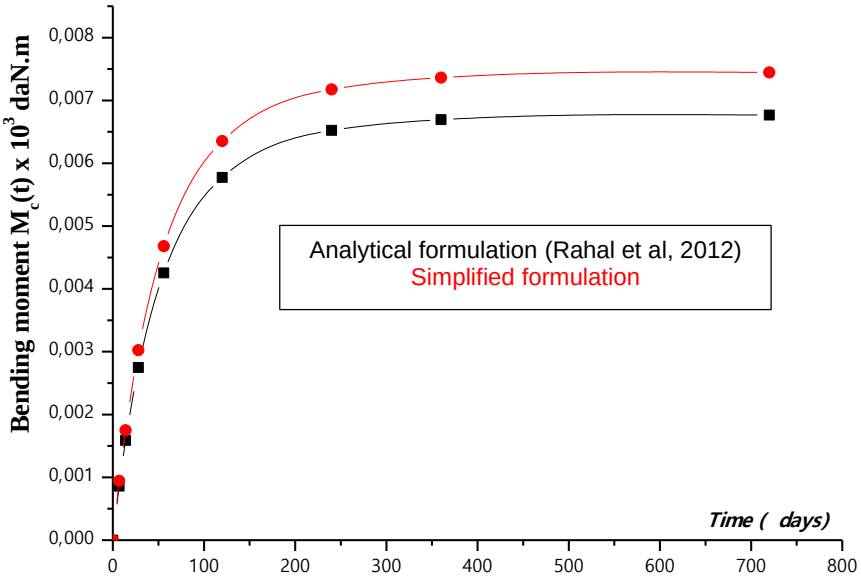

Figure 4 – Variation, in time, of the concrete slab bending moment $M_c(t)$

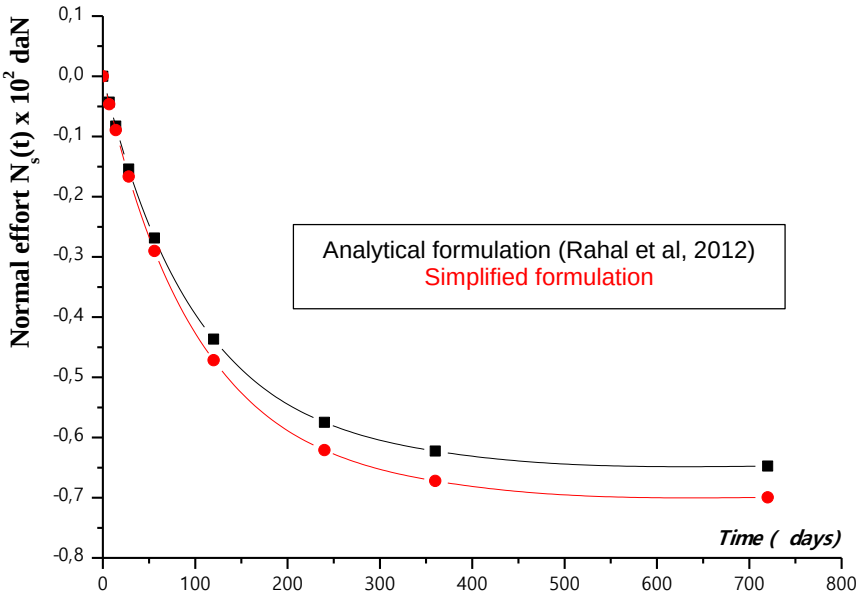

Figure 5 – Variation, in time, of the normal effort $N_s(t)$ recovered by the steel beam

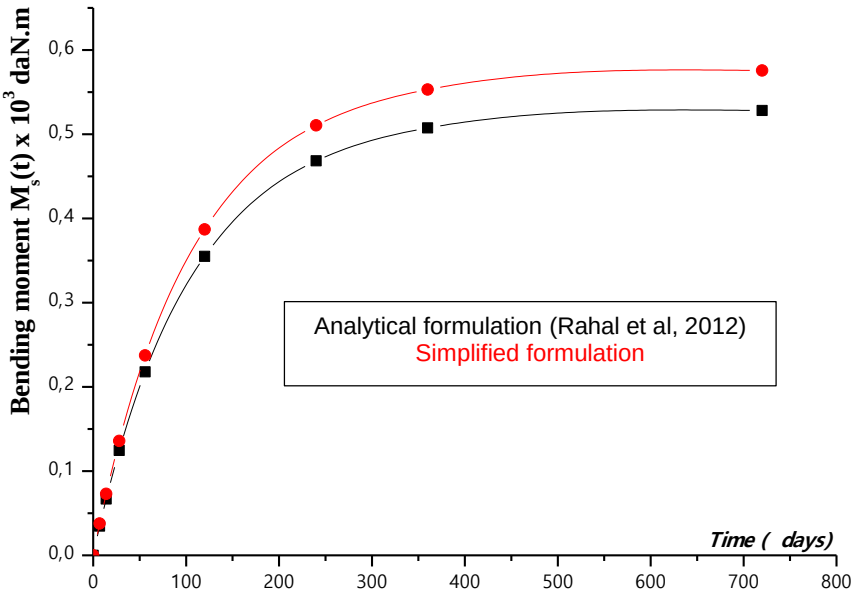

Figure 6 – Variation, in time, of the moment $M_s(t)$ recovered by the steel beam

Conclusion

The work presented in this article consists of simplifying an existing analytical model based on the aging theory of concrete. The use of the analytical model requires laborious efforts, and several constants must be calculated to determine additional stresses brought by shrinkage of concrete in composite beams. Due to these difficulties, it seemed very logical to simplify it and make it applicable with a minimum of effort while ensuring the desired security.

The approach applied here is very simple for practical use through the direct application of the developed expressions. By referring to the existing analytical model, the presented approach does not require, as the procedure shows, neither complicated mathematical calculations to be made nor constants to be determined.

The main advantage of this simplified formulation is its compatibility with any code or regulation for the calculation of composite steel-concrete structures used in the world. This possibility is clear in equation (Eq.7), in which it is enough to calculate the value of the specific deformation of the shrinkage $\varepsilon_{sh}(t)$ by the calculation regulation to be used such as: EC2, ACI, fib model code, etc.

It is clear that at any time t, the results obtained by applying the simplified approach formulated here (Figs. 2 to 6) are completely comparable to those resulting from the existing analytical model.

This idea can be further expanded to the case of composite beams in partial connection under the effect of concrete shrinkage as well as to the case of composite beams in full and partial connection under concrete creep.

References

Al-Deen, S., Ranzi, G. & Uy, B. 2015. Non-uniform shrinkage in simply-supported composite steel-concrete slabs. *Steel and Composite Structures,* 18(2), pp.375-394. Available at: https://doi.org/10.12989/scs.2015.18.2.375.

Aly, T., Sanjayan, J.G. & Collins, F. 2008. Effect of polypropylene fibers on shrinkage and cracking of concretes. *Materials and Structures,* 41(10), pp.1741-1753. Available at: https://doi.org/10.1617/s11527-008-9361-2.

Au, F.T.K., Liu, C.H. & Lee, P.K.K. 2007. Shrinkage analysis of reinforced concrete floors using shrinkage-adjusted elasticity modulus. *Computers and Concrete*, 4(6), pp.437-456. Available at: https://doi.org/10.12989/cac.2007.4.6.437.

Ban, H., Uy, B., Pathirana, S.W., Henderson, I., Mirza, O. & Zhu, X. 2015. Time-dependent behaviour of composite beams with blind bolts under sustained loads. *Journal of Constructional Steel Research,* 112, pp.196-207. Available at: https://doi.org/10.1016/j.jcsr.2015.05.004.

Beghdad, H., Tehami, M. & Rahal, N. 2017. Shrinkage Behaviour Modelling of Steel-Concrete Composite Beams with Varying Degree of Connection. *Asian Journal of Civil Engineering (BHRC)*, 18(8), pp.1271-1285 [online]. Available at : https://ajce.bhrc.ac.ir/Volumes-Issues/agentType/View/PropertyID/9500 [Accessed: 10 September 2023].

Cao, G., Han, C., Dai, Y. & Zhang, W. 2018. Long-Term Experimental Study on Prestressed Steel–Concrete Composite Continuous Box Beams. *Journal of Bridge Engineering,* 23(9). Available at: https://doi.org/10.1061/(ASCE)BE.1943-5592.0001269.

-Eurocodes. 1992. *Eurocode 2: Design of concrete structures - Part 1-1: General rules and rules for buildings* [online]. Available at: https://eurocodes.jrc.ec.europa.eu/EN-Eurocodes/eurocode-2-design-concrete-structures [Accessed: 10 September 2023].

-Eurocodes. 2006. *Designers' Guide to EN 1994-2 Eurocode 4: Design of composite steel and concrete structures Part 2, General rules and rules for bridges* [online]. Available at: https://eurocodes.jrc.ec.europa.eu/publications/designers-guide-en-1994-2-eurocode-4-design-composite-steel-and-concrete-structures [Accessed: 10 September 2023].

Furtak, K. 2015. Evaluation of the influence of shrinkage strain on the fatigue strength of the connection in steel–concrete composite beams. *Archives of Civil and Mechanical Engineering,* 15(3), pp.767-774. Available at: https://doi.org/10.1016/j.acme.2014.12.011.

Gilbert, R.I. 1989. Time-Dependent Analysis of Composite Steel-Concrete Sections. *Journal of Structural Engineering,* 115(11), pp.2687-2705. Available at: https://doi.org/10.1061/(ASCE)0733-9445(1989)115:11(2687).

Huang, D, Wei, J., Liu, X., Du, Y. & Zhang, S. 2019a. Experimental study on influence of post-pouring joint on long-term performance of steel-concrete composite beam. *Engineering Structures,* 186, pp.121-130. Available at: https://doi.org/10.1016/j.engstruct.2019.02.003.

Huang, D., Wei, J., Liu, X., Xiang, P. & Zhang, S. 2019b. Experimental study on long-term performance of steel-concrete composite bridge with an assembled concrete deck. *Construction and Building Materials,* 214, pp.606-618. Available at: https://doi.org/10.1016/j.conbuildmat.2019.04.167.

Huang, D, Wei, J., Liu, X., Zhang, S. & Chen, T. 2018. Influence of post-pouring joint on long-term performance of steel-concrete composite beam. *Steel and Composite Structures*. 28(1), pp.39-49. Available at: https://doi.org/10.12989/scs.2018.28.1.039.

Jason Weiss, W., Yang, W. & Shah, S.P. 1998. Shrinkage cracking of restrained concrete slabs. *Journal of Engineering Mechanics*, 124(7), pp.765-774. Available at: https://doi.org/10.1061/(ASCE)0733-9399(1998)124:7(765).

Marí, A.R., Bairán, J.M. & Duarte, N. 2010. Long-term deflections in cracked reinforced concrete flexural members. *Engineering Structures,* 32(3), pp.829-842. Available at: https://doi.org/10.1016/j.engstruct.2009.12.009.

Nguyen, Q.-H. & Hjiaj, M. 2016. Nonlinear Time-dependent Behavior of Composite Steel-Concrete Beams. *Journal of Structural Engineering*, 142(5), Available at: https://doi.org/10.1061/(ASCE)ST.1943-541X.0001432.

Partov, D. & Kantchev, V. 2012. Gardner&Lockman Model (2000) and its Application in Numerical Analysis of Composite Beams. *Procedia Engineering,* 40, pp.357-362. Available at: https://doi.org/10.1016/j.proeng.2012.07.108.

Partov, D. & Kantchev, V. 2014. Gardner and Lockman Model in Creep Analysis of Composite Steel-Concrete Sections. *Structural Journal*, 111(1), pp.59-70. Available at: https://doi.org/10.14359/51686430.

Rahal, N., Tehami, M., Souici, A. & Beghdad, H. 2012. Applying of Integral Equation of Volterra for Determining the Section Forces in Composite Beam, Regarding Shrinkage of Concrete. *Key Engineering Materials,* 498, pp.173-186. Available at: https://doi.org/10.4028/www.scientific.net/KEM.498.173.

Ranzi, G., Leoni, G. & Zandonini, R. 2013. State of the art on the time-dependent behaviour of composite steel-concrete structures. *Journal of Constructional Steel Research*, 80, pp.252-263. Available at: https://doi.org/10.1016/j.jcsr.2012.08.005.

Si, X.T. & Au, F.T.K. 2011. An Efficient Method for Time-Dependent Analysis of Composite Beams. *Procedia Engineering,* 14, pp.1863-1870. Available at: https://doi.org/10.1016/j.proeng.2011.07.234.

Souici, A., Tehami, M., Rahal, N., Bekkouche, M.S. & Berthet, J.F. 2015. Creep effect on composite beam with perfect steel-concrete connection. *International Journal of Steel Structures*, 15(2), pp.433-445. Available at: https://doi.org/10.1007/s13296-015-6013-6.

Sun, G., Xue, S., Qu, X. & Zhao, Y. 2019. Experimental investigation of creep and shrinkage of reinforced concrete with influence of reinforcement ratio. *Advances in concrete construction,* 7(4), pp.211-218 Available at: https://doi.org/10.12989/acc.2019.7.4.211.

Tehami, M. & Ramdane, K.-E. 2009. Creep behaviour modelling of a composite steel–concrete section. *Journal of Constructional Steel Research,* 65(5), pp.1029-1033. Available at: https://doi.org/10.1016/j.jcsr.2009.01.001.

Formulación simplificada para evaluar fuerzas por contracción en vigas compuestas de acero y hormigón con conexión total a cortante

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CAMPO: materiales, ingenieria civil
TIPO DE ARTÍCULO: artículo de revisión

Resumen:

Introducción/objetivo: Se sabe desde hace mucho tiempo que los efectos dependientes del tiempo, como la fluencia y la contracción del hormigón, influyen considerablemente en el comportamiento de las vigas mixtas de acero y hormigón. Por lo tanto, es muy importante tener en cuenta estos efectos al calcular la resistencia y seguridad de las vigas mixtas de acero y hormigón. Para ello se han establecido numerosas investigaciones teóricas y numéricas para controlar este fenómeno. La mayor parte de estas investigaciones presentan procesos y cálculos laboriosos que requieren técnicas complejas.

Métodos: Este modelo consiste en combinar las ecuaciones de equilibrio estático y las dos relaciones de compatibilidad, en curvatura y en deformación, de la sección compuesta acero-hormigón con la ecuación diferencial resultante de la teoría de la velocidad de fluencia (RCM). La idea de este trabajo era tomar este modelo y simplificarlo para evitar transformaciones matemáticas difíciles.

Resultados: Los resultados de este enfoque simplificado son muy satisfactorios en comparación con los dados por el modelo analítico.

Conclusión: Para superar un número excesivo de cálculos y diversas dificultades asociadas con los métodos analíticos o numéricos para calcular las tensiones adicionales provocadas por la contracción del hormigón en vigas compuestas de acero y hormigón, se ha propuesto aquí una metodología analítica simplificada que garantiza al mismo tiempo la seguridad deseada. Este trabajo ha intentado simplificar un modelo analítico existente basado en la teoría de la viscoelasticidad lineal establecida en 2012.

Palabras claves: retracción, hormigón, acero, tiempo, enfoque simplificado.

Упрощенная формула для оценки усилий, возникающих при усадке композитных сталебетонных балок с полным поперечным соединением

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РУБРИКА ГРНТИ: 67.09.33 Бетоны. Железобетон. Строительные растворы, смеси, составы

ВИД СТАТЬИ: обзорная статья

Резюме:

Введение/цель: Давно известно, что зависящие от времени явления, такие как ползучесть и усадка бетона, существенно влияют на поведение композитных сталебетонных балок. Поэтому весьма важно учитывать эти явления при расчете прочности и безопасности композитных сталебетонных балок. Многие теоретические и численные исследования направлены на контроль этих явлений. В большинстве исследований представлены сложнейшие процессы и расчеты, которые предполагают сложную технику.

Методы: Данная модель сочетает в себе уравнения статического равновесия и два соотношения совместимости кривизны и деформации сталебетонной композитной балки в

поперечном сечении с дифференциальным уравнением, полученным из теории скорости ползучести (CRM). Цель данной статьи заключается в упрощении данной модели во избежание сложных алгебраических преобразований.

Результаты: Результаты упрощенного подхода оказались весьма удовлетворительными, особенно по сравнению с результатами аналитической модели.

Выводы: Во избежание большого количества вычислительных операций и различных трудностей, сопровождающих аналитические или численные методы при оценке дополнительных напряжений, вызванных усадкой бетона в сталежелезобетонных композитных балках, в данной статье предлагается упрощенный аналитический метод, обеспечивающий при этом необходимую безопасность. Была предпринята попытка упростить существующую аналитическую модель, основанную на теории линейной вязкоупругости из 2012 года.

Ключевые слова: усадка, бетон, сталь, время, упрощенный подход.

Поједностављена формулација за процену сила насталих скупљањем у спрегнутим гредама од челика и бетона с потпуним смичућим спојем

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ОБЛАСТ: материјали, грађевинарство
ВРСТА ЧЛАНКА: прегледни рад

Сажетак:

Увод/циљ: Познато је да појаве зависне од времена, попут пузања и скупљања бетона, знатно утичу на понашање композитних греда од челика и бетона. Због тога је веома важно да се узму у обзир приликом израчунавања снаге и сигурности композитних греда од челика и бетона. Многа теоријска и нумеричка истраживања имају за циљ контролисање ових појава. У већини тих истраживања

заступљени су компликовани процеси и израчунавања који захтевају сложене технике.

Методе: Овај модел комбинује једначине статичке равнотеже и две релације компатибилности, по закривљености и по деформацији, попречног пресека композитне греде од челика и бетона са диференцијалном једначином насталом као резултат теорије брзине пузања (CRM). Идеја је да се овај модел поједностави како би се избегле компликоване математичке трансформације.

Резултати: Резултати поједностављеног приступа су веома задовољавајући у поређењу са резултатима аналитичког модела.

Закључак: Да би се избегао велики број рачунских операција и различите тешкоће које прате аналитичке или нумеричке методе при процени додатног напрезања услед скупљања бетона у композитним гредама од челика и бетона, овај рад предлаже поједностављену аналитичку методологију уз обезбеђивање захтеване сигурности. Покушано је поједностављивање постојећег аналитичког модела заснованог на теорији линеарне вискоеластичности из 2012. године.

Кључне речи: скупљање, бетон, челик, време, поједностављени приступ.

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Experimental study of the mechanical behavior of dam sediment renforced by geotextiles and geogrids

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FIELD: materials
ARTICLE TYPE: review paper

Abstract:

Introduction/purpose: Geosynthetic materials have been successfully used for soil reinforcement to improve bearing capacity. In this article, geotextiles are used as tension material for the reinforcement of a mixture based on dredged sediment from the Cheurfas dam (Mascara) and quarry sand.

Methods: Immediate bearing index tests were carried out in the laboratory to study the mixing behaviour, and the three-point bending flexural test was

carried out on prismatic specimens to study the traction capacity of the mixture. Mixture samples are selected and tested without reinforcement. Then, by placing one, two and three layers of geotextile at a certain depth of the sample, the effects of a number of layers and type of geotextile and geogrid on increasing the bearing capacity of the mixture are discussed.

Results: The results of these tests show that the bearing capacity of the samples reinforced by geotextile and geogrid is increased compared to that of the unreinforced samples. Based on the results obtained from Proctor-IPI, their values do not permit the movement of construction machinery during the construction of pavement layers. The Immediate Bearing Index values are found sufficient for pavement layers. Geotextile introduction increases traction strength and improves stress distribution on soil samples, with the effect being significant for woven geotextile blends.

Conclusion: All things considered, the results point to the possibility of using reinforced local soils as an affordable and practical option for building pavements. To guarantee long-term performance and optimise building methods, more research is advised.

Key words: geotextile, sediment dredged, Cheurfas dam, soil reinforcement.

Introduction

The uses of geotextiles in many engineering applications have become more apparent proving to be an effective way to improve soil. In the first applications in roads and airport runway constructions, the emphasis was placed on the separation function of geotextiles. Resl & Werner (1986) carried out laboratory tests on the soil reinforced with a non-woven needled geotextile under axisymmetric loading. The results showed that the geotextile layer placed in the middle can significantly increase the bearing capacity of loose soils of the foundation. Fannin & Sigurdsson (1996) studied the performance of an unpaved road reinforced with different geosynthetics. Many papers have examined soil reinforcement by geotextiles (Bergado et al, 2001; Raymond & Ismail, 2003; Park & Tan, 2005; Yetimoglu & Salbas, 2003; Patra et al, 2005; Varuso et al, 2005). Current research mainly emphasizes the strength, mechanism and bearing capacity of reinforced soil (Haeri et al, 2000; Michalowski, 2004; Zhang et al, 2006; Madhavi Latha & Murthy, 2007; Duncan-Williams & Attoh-Okine, 2008). Dredging sediments from the Cheurfas Dam in Algeria were studied for their potential use in road embankments. The sediments were analyzed for their physico-chemical, mineralogical, and mechanical properties, and it was found that a treatment with sand, lime, and cement was necessary for their valorization (Bourabah et al, 2010). This article presents the immediate bearing index

and the tensile strength by bending performed on a mixture of 35% sediment and 65% sand reinforced by a geotextile and a geogrid placed in one, two and three layers. It also compares the bearing capacity and the tensile strength of unreinforced soil reinforced with geotextiles.

Material properties

The soil used is composed of sediments dredging of the Cheurfas dam and quarry sand; the two materials are from the region of Mascara (Algeria). The properties of these materials are shown in Table 1. In this data base, sediments can be classified according to the Road Earthworks Guide (GTR) in class A2 and sand in class B2. Three types of geosythetics are used as reinforcement, a geogrid (Geo1) made of polyester, a non-woven geotextile (Geo2) and a woven geotextile (Geo3), both made of polypropylene.

Table 1 – Geotechnical characteristics of the Cheurfas dam sediments

Characteristics	Value
Unit weight of solids, γs (KN/m3)	25.17
Organic content, % MO (à 450°C)	5.15
Methylene blue value	25.17
Liquid Limit, WL (%)	3.66
Plastic Limit, WP (%)	57
Grains size < 2µm	27
2µm < Grains size < 80µm	46%
80µm < Grains size	49%

Table 2 – Geotechnical characteristics of quarry sand (Djbel Amanfous)

Characteristics	Value
Maximum grains size, D max (mm)	2
Grains size < 2mm (%)	100
Grains size < 80µm (%)	11.01
Unit weight of solids, γs (KN/m3)	25.5
Methylene blue value	0.26
Visual sand equivalent value, ESV	53
Piston sand equivalent value, ESP	52

Study of mechanical behavior

Compaction and bearing parameters depending on the type of geotextiles

The experimental program includes three series of tests, depending on the type of geosythetics, to study the effect of three selected geosythetics (Photo 1) on the mechanical performance of lift. Each series includes three cases of reinforcement, namely the number of layers (one, two and three layers). During compaction, the geotextile material is placed in the form of a disc. A new sample of geosythetics was used for each test, to avoid any fatigue in the sample. Depending on the type of geosythetics and the number of layers, Proctor tests were carried out for five water contents between 8%; and 16%. The results of this program are presented in the following curves, which are the results of the Proctor test, as well as those of the IPI. The characteristics at the Proctor optimum are shown in Table 3.

Geo1 Geo2 Geo3

Photo 1 –Geosythetics (Geo1 is a geogrid, Geo2 is a non-woven geotextile and Geo3 is a woven geotextile

On the graphs of IPI, w, and γ_d (Figures 1-3), it can be noticed that the evolution of the compaction curve is substantially the same regardless of the type of reinforcement, which means that the compactness of the granulometrically corrected Cheurfas sediment reinforced by geosynthetics is not influenced.

In terms of immediate bearing, it is noted that the measured values decrease more rapidly with increasing water content after the optimum Proctor, which indicates a sensitivity of the bearing with the water content.

The penetration resistance values of 2.5 mm and 5 mm were obtained from the IPI curve corresponding to both unreinforced and reinforced samples. The greater of the values calculated at 2.5 mm and 5 mm penetration were taken.

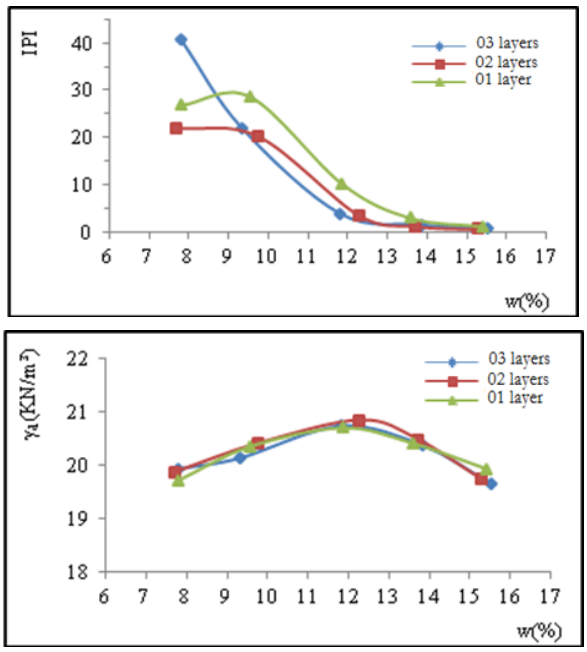

Figure 1 – Evolution of γ_d and the IPI as a function of w%, the soil reinforced by Geo1

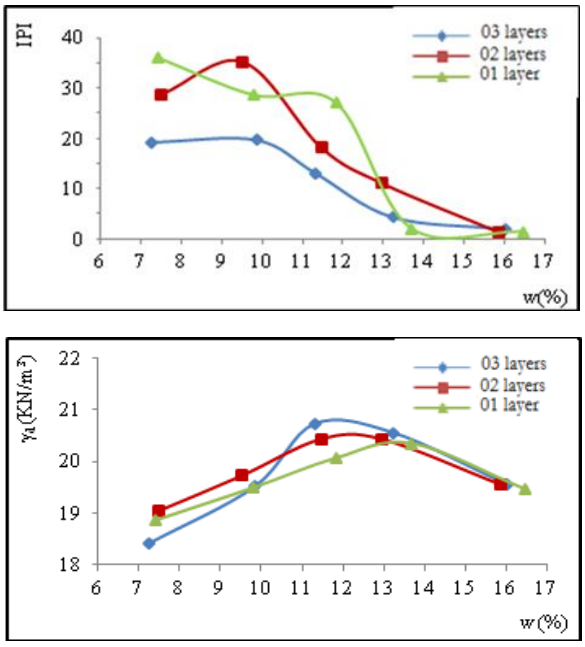

Figure 2 – Evolution of γ_d and IPI as a function of w%, the soil reinforced by Geo2

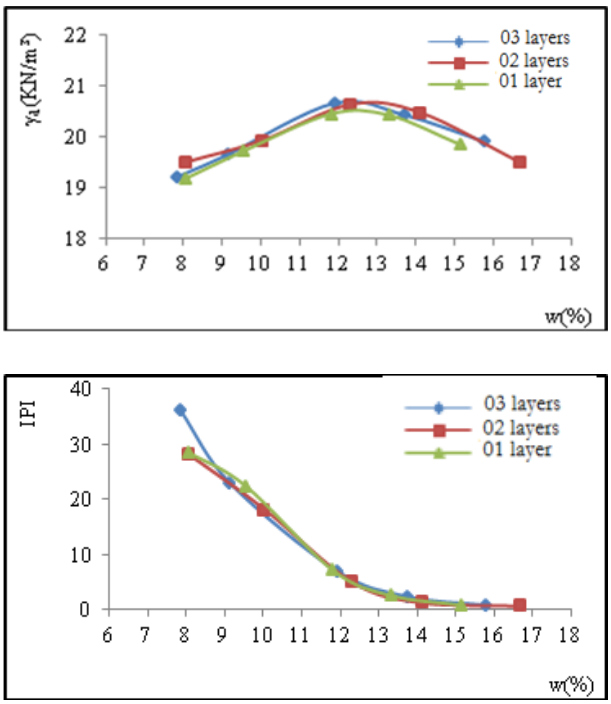

Figure 3 – Evolution of γ_d and IPI as a function of w%, the soil reinforced by Geo3

Table 3 summarizes the density of the dry material and the corresponding optimum water content, thus the desired values of IPI for unreinforced and reinforced with the three types of geosynthetics by one, two and three layers at optimum and at 98 % and 95% of the density of the dry material.

Note that the optimum of the state hydric values is practically the same. Thus the IPI values at the optimum and at 98% of $\gamma_{d\ opm}$ are below the values recommended by the GTR guide, which means difficulty in the movement of machinery on the site.

On the other hand, 95% $\gamma_{d\ opm}$ values of the immediate bearing index are much improved than those obtained at the optimum and also at 98% of $\gamma_{d\ opm}$; this increase is attributed to the decrease in water tuner.

This indicates that the integration of geosynthetics does not influence the bearing capacity of the mixture. Under these conditions, it is recommended, during the construction of pavement embankments, to take the water tuner corresponding to 95% $\gamma_{d\ opm}$ in order to guarantee the movement of machinery without difficulty.

Table 3 – Summary of the Proctor-IPI test

Type of geosythetics	Number of layers	w_{opm} (%)	γ_{dopm} (kN/m³)	IPI_{opm}	IPI 98% opm	IPI 95% opm
Without reinforcement	0	13.26	19.41	4	24	28
Geogrid (Geo1)	1	12.00	20.70	10	29	27
	2	12.28	20.84	4	20	22
	3	12.10	20.77	3	12	/
Non-woven geotextile (Geo2)	1	13.40	20.40	4	28	30
	2	12.20	20.55	14	25	34
	3	12.80	20.80	10	16	19
Woven geotextile (Geo3)	1	12.60	20.60	4	13	25
	2	12.80	20.70	3	12	/
	3	12.30	20.70	5	14	23

Influence of geotextile types and numbers on flexural tensile strength

An experimental procedure was carried out on prismatic specimens to study the influence of the geotextile type and the importance of the number of layers on the traction strength. In the presented experiment, the mixture is humidified with an optimum water tuner of Proctor and made in a wooden mold (4x100x16 cm3) to achieve a prismatic (4x4x16 cm3) form; at the same time, the geotextile is placed in one, two and three layers (Photo 2).

Photo 2 – Sample maker

The experiment consists of applying a vertical load (Photo 3a). At the end of the test, the layers of the specimen reinforced by the geotextile Geo3 are separated; on the other hand, the layers of the specimen reinforced by the geotextile Geo2 stayed stuck to each other (Photo 3b), which reflects the difference between the interfaces of a non-woven geotextile which is rough and a woven geotextile which is smooth. Consequently, it reflects the influence of the roughness of the geotextile face on cohesion with the soil.

(a) *(b)*

Photo 3 – (a) bending of a test specimen, (b)specimens after traction

The flexural tensile strength after 7 days is determined by the following formula:

$$R_{tf} = \frac{3F_r \cdot L}{a \cdot b \cdot h^2}$$

where:

F_r: the maximum load;
L: the free range;
b: the width; and
h: the thickness of the prism.

The experimental program consisted of two series, each series consisting of three cases of reinforcement depending on the number of layers.

The results of two series are shown in Figure 4 below:

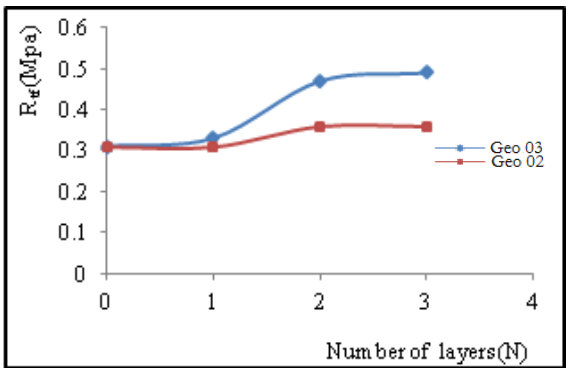

Figure 4 – Resistance t²o traction as a function of the number of layers (N)

Resistance to traction gradually increases with the number of geotextile layers, reflecting the effect of scale on the specimens. In each of the three cases of reinforcement, the tensile strength of the row reinforced woth Geo2 shows a significant increase compared to the row reinforced with Geo3. This shows the importance of the soil-geotextile interaction: the roughness of the Geo2 geotextile produces cohesion with the mixture, while no cohesion occurs due to the Geo3 geotextile. It is noted that the rigidities of the geotextile have an essential role in improving the tensile strength of the mixture.

Conclusion

The objective of this study is to contribute to the concept of safe, durable, and sustainable services and to build economic systems from reinforced indigenous soils for use in the road sector. The main findings of this study are summarized as follows:

Based on the results obtained from Proctor-IPI, their values do not permit the movement of construction machinery during the construction of pavement layers. From a geotechnical point of view, It has been shown that for 95% of the dry material density, the values of the Immediate Bearing Index are usually sufficient for all cases of reinforcement to be used in a pavement layer.

It appears from the traction test by bending, that the introduction of a geotextile in the mixture leads to an increase in traction strength and to improved stress distribution in the soil sample. This improvement is observed for both types of geotextiles. Also, the improvement in strength depends on the geotextile type. The effect is significant for the blend reinforced by the woven geotextile (Geo2).

References

Bergado, D.T., Youwai, S., Hai, C.N. & Voottipruex, P. 2001. Interaction of nonwoven needle-punched geotextiles under axisymmetric loading conditions. *Geotextiles and Geomembranes*, 19(5), pp.299-328. Available at: https://doi.org/10.1016/S0266-1144(01)00010-3.

Bourabah, M.A., Abou-Bekr, N. & Taibi, S. 2010. Geotechnical Characterization of Dredging Sediments for Valorization in Road Embankments: Case of the Cheurfas Dam (Algeria). In: *GeoFlorida 2010: Advances in Analysis, Modeling & Design,* West Palm Beach, Fl, USA, February 20-24. Available at: https://doi.org/10.1061/41095(365)224.

Duncan-Williams, E.D. & Attoh-Okine, N.O. 2008. Effect of geogrid in granular base strength – An experimental investigation. *Construction and Building Materials*, 22(11), pp.2180-2184. Available at: https://doi.org/10.1016/j.conbuildmat.2007.08.008.

Fannin, R.J. & Sigurdsson, O. 1996. Field Observations on Stabilization of Unpaved Roads with Geosynthetics. *Journal of Geotechnical Engineering*, 122(7), pp.544-553. Available at: https://doi.org/10.1061/(ASCE)0733-9410(1996)122:7(544).

Haeri, S.M., Noorzad, R. & Oskoorouchi, A.M. 2000. Effect of geotextile reinforcement on the mechanical behavior of sands. *Geotextiles and Geomembranes*, 18(6), pp.385-402. Available at: https://doi.org/10.1016/S0266-1144(00)00005-4.

Madhavi Latha, G. & Murthy, V.S. 2007. Effects of reinforcement form on the behavior of geosynthetic reinforced sand. *Geotextiles and Geomembranes*, 25(1), pp.23-32. Available at: https://doi.org/10.1016/j.geotexmem.2006.09.002.

Michalowski, R.L. 2004. Limit Loads on Reinforced Foundation Soils. *Journal of Geotechnical and Geoenvironmental Engineering*, 130(4), pp.381-390. Available at: https://doi.org/10.1061/(ASCE)1090-0241(2004)130:4(381).

Park, T. & Tan, S.A. 2005. Enhanced performance of reinforced soil walls by the inclusion of short fiber. *Geotextiles and Geomembranes*, 23(4), pp.348-361. Available at: https://doi.org/10.1016/j.geotexmem.2004.12.002

Patra, C.R., Das, B.M. & Atalar, C. 2005. Bearing capacity of embedded strip foundation on geogrid-reinforced sand. *Geotextiles and Geomembranes*, 23(5), pp.454-462. Available at: https://doi.org/10.1016/j.geotexmem.2005.02.001.

Raymond, G. & Ismail, I. 2003. The effect of geogrid reinforcement on unbound aggregates. *Geotextiles and Geomembranes*, 21(6), pp.355-380. Available at: https://doi.org/10.1016/S0266-1144(03)00044-X.

Resl, S. & Werner, G. 1986. The influence of nonwoven needle-punched geotextiles on the ultimate bearing capacity of the subgrade. In: *3rd International Conference on Geotextiles,* Vienna, Austria, pp.129-133, April 07-11 [online]. Available at: https://library.geosyntheticssociety.org/proceedings/1-c-06-the-influence-of-nonwoven-needlepunched-geotextiles-on-the-ultimate-bearing-capacity-of-the-subgrade-pdf-2/ [Accessed: 20 December 2023].

Varuso, R.J., Grieshaber, J.B. & Nataraj, M.S. 2005. Geosynthetic reinforced levee test section on soft normally consolidated clays. *Geotextiles and Geomembranes*, 23(4), pp.362-383. Available at: https://doi.org/10.1016/j.geotexmem.2004.11.001.

Yetimoglu, T. & Salbas, O. 2003. A study on shear strength of sands reinforced with randomly distributed discrete fibers. *Geotextiles and Geomembranes*, 21(2), pp.103-110. Available at: https://doi.org/10.1016/S0266-1144(03)00003-7.

Zhang, M.X., Javadi, A.A. & Min, X. 2006. Triaxial tests of sand reinforced with 3D inclusions. *Geotextiles and Geomembranes,* 24(4), pp.201-209. Available at: https://doi.org/10.1016/j.geotexmem.2006.03.004.

Estudio experimental del comportamiento mecánico de sedimentos de presa reforzados con geotextiles y geomallas

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CAMPO: materiales
TIPO DE ARTÍCULO: artículo de revisión

Resumen:

Introducción/objetivo: Los materiales geosintéticos se han utilizado con éxito para reforzar el suelo y mejorar la capacidad de carga. En este artículo se utilizan geotextiles como material tensor para el refuerzo de una mezcla a base de sedimentos dragados de la presa de Cheurfas (Mascara) y arena de cantera.

Métodos: Se realizaron ensayos de índice de carga inmediata en laboratorio para estudiar el comportamiento de la mezcla y el ensayo de flexión por flexión de tres puntos sobre probetas prismáticas para estudiar la capacidad de tracción de la mezcla. Las muestras de mezcla se seleccionan y prueban sin refuerzo. Luego, al colocar una, dos y tres capas de geotextil a una cierta profundidad de la muestra, se discuten los efectos de un número de capas y tipo de geotextil y geomalla en el aumento de la capacidad de carga de la mezcla.

Resultados: Los resultados de estas pruebas muestran que la capacidad de carga de las muestras reforzadas con geotextil y geomalla aumenta en comparación con la de las muestras no reforzadas. Según los resultados obtenidos de Proctor-IPI, sus valores no permiten el movimiento de maquinaria de construcción durante la construcción de las capas de

pavimento. Los valores del Índice de Rodamiento Inmediato se consideran suficientes para las capas de pavimento. La introducción de geotextiles aumenta la resistencia a la tracción y mejora la distribución de la tensión en las muestras de suelo, siendo el efecto significativo para las mezclas de geotextiles tejidos.

Conclusión: Considerando todo esto, los resultados apuntan a la posibilidad de utilizar suelos locales reforzados como una opción asequible y práctica para la construcción de pavimentos. Para garantizar el rendimiento a largo plazo y optimizar los métodos de construcción, se recomienda realizar más investigaciones.

Palabras claves: geotextil, dragado de sedimentos, presa de Cheurfas, refuerzo de suelos.

Экспериментальное исследование механического поведения донных отложений плотины, укрепленных геотекстилем и георешетками

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РУБРИКА ГРНТИ: 67.09.00 Строительные материалы и изделия
ВИД СТАТЬИ: обзорная статья

Резюме:

Введение/цель: Геосинтетические материалы успешно используются для укрепления грунта за счет повышения его несущей способности. В данном исследовании геотекстиль используется в качестве натяжного материала для укрепления смеси на основе донных отложений плотины Чеурфа (Маскара) и карьерного песка.

Методы: Прямые испытания индекса несущей способности проводились в лабораторных условиях в рамках испытаний поведения смеси. Испытание прочности на трехточечный изгиб проводилось в цилиндрических пробирках для проверки тяговой способности данной смеси. Образцы смеси были отобраны и испытаны без укрепления. Затем на определенной глубине в пробирку были добавлены один, два и три слоя геотекстиля с целью исследования влияния количества слоев и типа геотекстиля на несущую способность смеси.

Результаты: Результаты испытаний показали, что несущая способность образцов, укрепленных геотекстилем и георешеткой, увеличивается по сравнению с неукрепленными образцами. Результаты испытаний Proctor-IPI показали, что их значения не допускают движения строительной техники при укладке слоев дорожной одежды. Установлено, что значения показателя несущей способности достаточны для слоев дорожной одежды. Использование геотекстиля повышает прочность сцепления и улучшает распределение нагрузки на образцы грунта, причем эффект лучше выражен у тканых видов геотекстиля.

Выводы: Учитывая все обстоятельства, результаты указывают на возможность использования укрепленных местных видов грунта в качестве практичного и экономически выгодного решения для строительства дорожного полотна. Рекомендуется провести дальнейшие исследования с целью оптимизации методов строительства и гарантирования длительного срока эксплуатации.

Ключевые слова: геотекстиль, донные отложения, плотина Чеурфа, армирование грунта.

Експериментално испитивање механичког понашања седимента добијеног ископавањем бране и ојачаног геотекстилом и геомрежом

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ОБЛАСТ: материјали
КАТЕГОРИЈА (ТИП) ЧЛАНКА: прегледни рад

Сажетак:

Увод/циљ: Геосинтетички материјали се успешно користе за ојачавање тла јер побољшавају његов капацитет носивости. У овом раду геотекстили се користе као тензиони материјал за ојачавање мешавине седимента добијеног при ископавању бране Черфас (Маскара) и песка из каменолома.

Методе: Тестови непосредног индекса носивости изведени су у лабораторијским условима у оквиру испитивања понашања

Meksi, A. et al, Experimental study of the mechanical behavior of dam sediment renforced by geotextiles and geogrids, pp.855-868

мешавине. Тест на чврстоћу при савијању у три тачке изведен је на призматичним епруветама како би се испитао капацитет тракције дате мешавине. Епрувете мешавине су изабране и испитане без ојачања. Затим су на одређеној дубини епрувете додати један, два и три слоја геотекстила и испитани утицаји броја слојева и типа геотекстила на капацитет носивости мешавине.

Резултати: Показано је да је капацитет носивости епрувета ојачаних геотекстилом и геомрежом повећан у поређењу са неојачаним епруветама. Резултати тестова Проктор-ИПИ показују да њихове вредности не дозвољавају кретање грађевинске машинерије током конструкције коловозних слојева. Утврђено је да су вредности непосредног индекса носивости довољне за коловозне слојеве. Увођење геотекстила повећава затезну чврстоћу и побољшава распоређивање напона на узорцима тла, при чему је код тканих врста геотекстила ефекат израженији.

Закључак: Резултати указују на могућност коришћења ојачаних локалних типова земљишта као на практично и исплативо решење за грађење коловоза. Препоручује се даље истраживање ради оптимизације метода грађења и гарантовања перформанси у дужем периоду.

Кључне речи: геотекстил, ископани седимент, брана Черфас, ојачање тла.

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Exploring cutting-edge research trends in safety knowledge within military environments

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FIELD: military sciences
ARTICLE TYPE: review paper

Abstract:

Introduction/purpose: The military environment is characterised by high-risk operations and activities that require a comprehensive understanding of safety knowledge to ensure personnel's well-being and effectiveness. Indirectly, this scenario illustrates the military's need to prioritise adequate safety and health management within their environment, just like other organisations. The current scientometric review aims to analyse research trends related to safety knowledge within military environments.

Methods: This review utilised ScientoPy and VOSviewer to comprehend the nature of collected datasets from Scopus and Web of Science (WoS) databases.

Results: The scholarly publication "Proceedings - IEEE Military Communications Conference MILCOM" is renowned for its extensive coverage of safety knowledge research for military environments. The keyword "emergency preparedness" has significantly impacted the thematic content of scholarly safety knowledge for the past three decades, from 1990 to 2023, as previous researchers used it most frequently. Based

on overlay visualisation mapping, the current review demonstrates that the terms "emergency," "COVID-19," and "risk management" have been accorded greater significance since 2020.

Conclusion: This study provides a thorough and worldwide perspective on the crucial subjects of safety knowledge in military settings. It is aimed at potential readers and researchers interested in better understanding these concepts and conducting more rigorous research on military safety.

Key words: safety knowledge, military, scientometric.

Introduction

Navigating safety knowledge to military environments presents various obstacles and possibilities, contradicting the common belief that military settings prioritise physical safety, security, and defence activities rather than encompassing comprehensive safety and health management like other organisations. A significant challenge is developing simulations that accurately reproduce complex urban scenarios and human behaviour, enabling training to manage unexpected situations effectively (Blake & Nemergut, 2014). Also, developing adaptive virtual environments that can dynamically alter scenario difficulty levels in response to neurocognitive and psychophysiological states is an additional challenge (De Jong et al, 2016). Nevertheless, amidst these challenges lie opportunities for progress. For example, implementing risk-averse domain adaptation (RADA) techniques can facilitate cautious adaptation in safety-critical driving environments, streamlining domain adaptation processes and bolstering safety (Parsons & Reinebold, 2012). Embracing systematic learning from incidents (LFI) is another concern supporting organisational growth by drawing lessons from technical challenges within military supply chains and ensuring operational sustainability (Dyson, 2021).

Safety knowledge plays a crucial role within the military system, as it not only ensures the successful completion of missions, but also safeguards the personnel involved during the execution of combat tasks (Wei & Kuo, 2023). This aspect is also evident in the general concept of safety knowledge, which involves understanding the importance of equipping individuals with the necessary information to operate safely and adhere to established safety rules (Abdullah, 2022a). In this nexus, militaries must clearly understand risks to safeguard the nation and its people (Pettersson, 2009; Wei & Kuo, 2023).

Learning from past accidents and incidents is crucial in supporting this facet, as this knowledge is instrumental in enhancing safety measures and mitigating their consequences (Przybysz, 2020). Furthermore, the

reliability of military vehicles is paramount for mission success and crew members' safety (Ertle et al, 2012). In order to ensure safe operation, autonomous service robots operating in complex environments must be capable of assessing operational risks and integrating safety knowledge (Ertle, 2016). Given the inherent risks associated with military training, effective risk management is imperative to guarantee the safety of troops during high-intensity and high-difficulty training exercises.

Safety knowledge can enhance military operations by improving risk perception and performance (Wei & Kuo, 2023). Military organisations must have a comprehensive understanding of the risks associated with their duties in order to effectively fulfill their responsibilities (Nosary & Adiati, 2021). Through training programs that instil safety knowledge, militaries can develop a heightened sense of risk perception, thereby contributing to improved safety performance (De Florio & Blondia, 2015). Safety performance and behaviour are intricately intertwined due to the significant influence that individual behaviours have on forming safety practices, awareness, and perceptions in a given environment (Abdullah & Aziz, 2020). More specifically, this study focuses on the reciprocal enhancement of safety knowledge and safety behaviors. It also should be emphasised that a positive safety culture plays a mediating role in the association between safety leadership and safety performance (De Florio & Blondia, 2015). By promoting safety leadership and fostering a supportive safety culture, military organisations can establish an environment that values and applies safety knowledge, enhancing operational outcomes (Danielsson, 2020).

This study aims to perform a scientometric analysis to evaluate publishing trends and research progress concerning safety knowledge in military contexts. There is a critical need to undertake a scientometric analysis of safety knowledge within military contexts to ensure a thorough grasp of this field of study. Additionally, this analysis facilitates the identification of essential works, enhances our comprehension, promotes synergy, and offers guidance for future research endeavours in advancing safety knowledge in military settings and cultivating environmental awareness.

The subsequent research inquiries are indispensable in furthering the present study's comprehension of previous research regarding safety knowledge in military environments:

1. What trends and patterns have been identified in terms of the quantity and characteristics of publications related to the investigation of safety knowledge within military settings?

2. Which sources have been the most prolific in publishing research on safety knowledge in military environments?

3. What are the dominant research themes or subjects that have emerged in the investigation of safety knowledge in military settings?

4. Which academic publications have had the most significant impact on safety knowledge in military environments?

5. Which research institutions have made significant contributions to the study of safety knowledge in military contexts?

Materials and methods

This study aims to review and analyse existing research on the applications, capabilities, roles, and effects of safety knowledge in military environments. To attain this goal, various techniques were utilised, including implementing mapping analysis with VOSviewer and measuring research trends with ScientoPy. This review retrieved Scopus and Web of Science (WoS) datasets relevant to safety knowledge within military environments. The resilient keywords illustrated in Table 1 were utilised when populating the retrieved datasets. The datasets were searched without any temporal restrictions until February 2, 2024. The Scopus and WoS databases were used for this study due to their widespread use in academia and research institutes for scientometric analysis (Abdullah & Sofyan, 2023). These datasets are known for their comprehensive coverage, high-quality data, detailed metadata, advanced analytical tools, and global accessibility (Hafiar et al, 2024).

The current investigation employed ScientoPy and VOSviewer for analysis and visualisation. ScientoPy is a scholarly-scientometric analysis software platform that measures the rank of a study's essential subjects, authors, countries, and associated publications (Abdullah & Sofyan, 2023). ScientoPy is also recognised as a Python-based programme for scientometric analysis that is both publicly available and open-source. Notably, an exceptional characteristic of the system is its pre-processing component, which effectively removes any partiality present in individual articles (Ruiz-Rosero et al, 2019). This pre-processing phase improves the

legibility, precision, organisation, comprehensiveness, and representativeness of the findings derived from a substantial volume of Scopus and Web of Science (WoS) data. In this study, VOSviewer was employed to create a co-occurrence map of the authors' terms on safety knowledge. It is crucial to provide accurate information on various themes or issues previously studied and has influenced the research on safety knowledge in military contexts worldwide (Abdullah, 2022b).

Table 1 – Search strategy for extracting data from the Web of Science and Scopus databases

Database	Search Strategy	Records
Web of Science	Topic: ("Safety knowledge" OR "Safety expertise" OR "Security awareness" OR "Risk management knowledge" OR "Safety proficiency" OR "Protective know-how" OR "Hazard awareness" OR "Safety understanding" OR "Security competence" OR "Accident prevention knowledge" OR "Health and safety awareness" OR "Safety protocol knowledge" OR "Emergency preparedness" OR "Preventive measures awareness" OR "Safety education" OR "defensive awareness") AND ("Military" OR "Army" OR "Soldiers" OR "Armed Forces" OR "Defence Forces")	123
Scopus	Article Title, Abstract, Keywords: ("Safety knowledge" OR "Safety expertise" OR "Security awareness" OR "Risk management knowledge" OR "Safety proficiency" OR "Protective know-how" OR "Hazard awareness" OR "Safety understanding" OR "Security competence" OR "Accident prevention knowledge" OR "Health and safety awareness" OR "Safety protocol knowledge" OR "Emergency preparedness" OR "Preventive measures awareness" OR "Safety education" OR "defensive awareness") AND ("Military" OR "Army" OR "Soldiers" OR "Armed Forces" OR "Defence Forces")	230

Pre-processing of retrieved datasets

The currently used datasets were pre-processed to eliminate duplicate entries and consolidate significant data using ScientoPy. Diagram 1 shows the initial data collection findings, indicating a total of 353 unprocessed data items obtained from publications in Scopus and WoS. Based on the findings, 31 articles, accounting for 8.80% of the datasets, were excluded due to the use of the automatic document-type filtering technique. Initially, 322 papers were detected, but duplicate datasets were subsequently removed. The analysis discovered 101 cases of duplication, which accounts for 31.40% of the dataset, within the Scopus database.

A total of 221 papers were considered suitable for inclusion in the current study. Among them, 118 papers (53.40%) were sourced from the WoS, while the rest of 103 publications (46.60%) were sourced from Scopus. Datasets containing over 100 components facilitated the execution of scientometric analysis.

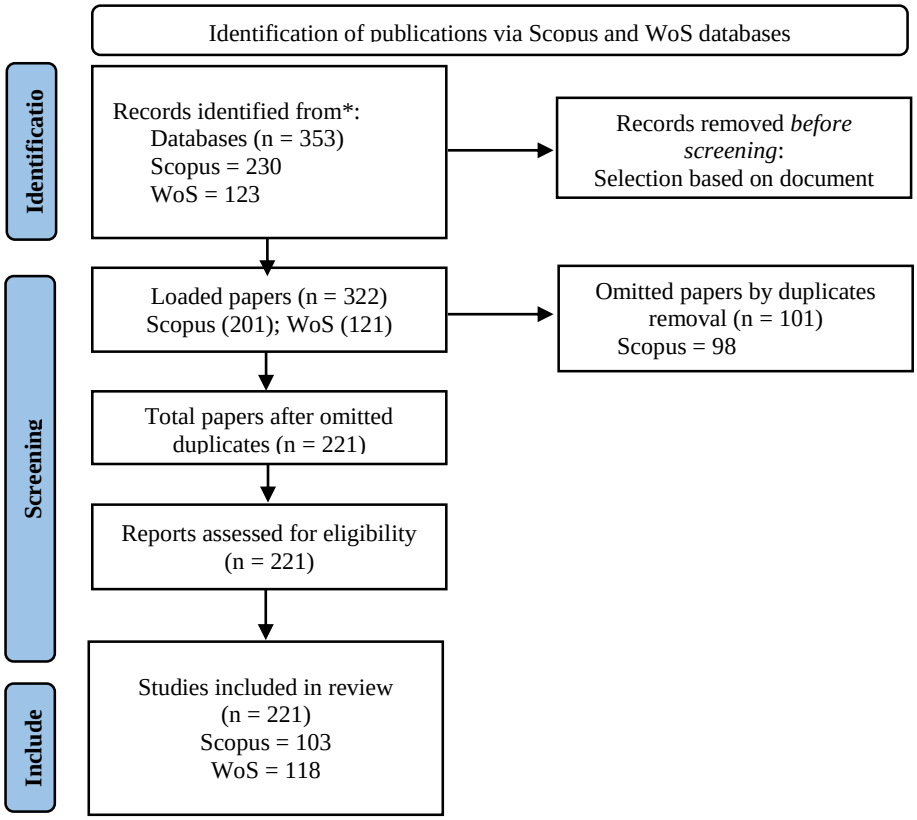

Diagram 1 – Flow diagram of the research of databases and registers

Results

The results of the present investigation sufficiently answer each of the research inquiries delineated in the methodology segment.

The results are also presented using graphical visualisations generated by ScientoPy and VOSviewer.

Trends and patterns in publishing

This investigation examines the tendencies and configurations in the dissemination of scholarly works pertaining to the intersection of safety knowledge and military environments. More precisely, this section examines the number of publications and the specific categories of papers released within this particular sector. The data shown in Figure 1 portrays the trends in developing safety knowledge in military situations as documented in recent publications. The topic being discussed is relatively new, as shown by the oldest article discovered in the Scopus database, which dates back to 1991. No publications were documented in the WoS database prior to 1992. Nevertheless, this number saw a significant surge to 11 publications by 2023. Based on the statistics from the Scopus database, the number of articles in 1991 was 3, but it significantly rose to 5 by 2023.

Figure 1 depicts the graphical representation of the timeline, which demonstrates that the number of published works in both databases during the period of 1996 to 2006 was fewer than four. Nevertheless, the data from 2008 onwards reveals an upward trend in the WoS databases, surpassing the Scopus database. The culmination of the number of publications in both databases transpired in 2019. The noted phenomenon could potentially be ascribed to the increased attention given to ecological issues in the midst of the COVID-19 outbreak. Additionally, there has been a discernible upsurge in the utilization of safety expertise within military circles, with the aim of fostering awareness of environmental matters and fostering camaraderie among individuals who encounter challenging situations.

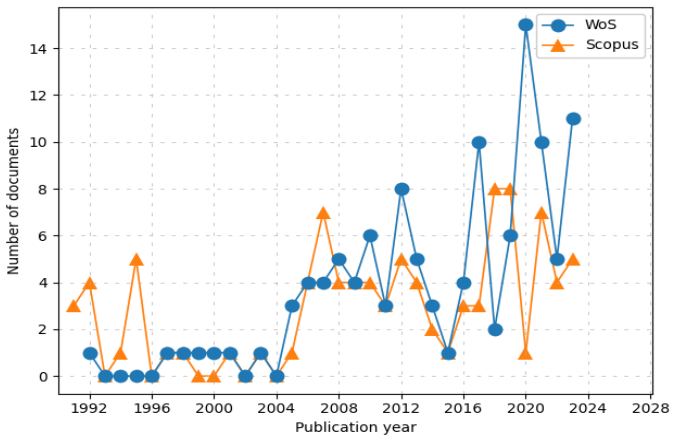

Figure 1 – The evolution of publication growth (Source: Authors, using ScientoPy 2.1.3)

Figure 2 shows a comprehensive overview of the extensively analysed document types, by the objective of identifying the most pertinent research on safety knowledge in military contexts, as examined in both databases Referring to the information depicted in Figure 2, the types of articles displayed a significantly increased count of documents, amounting to 134. This constitutes 14% of the total number of the documents published between 2022 and 2023. In contrast, conference papers accounted for 39 documents. Both document categories encompass more than 30 sources, surpassing the combined number of sources from proceeding papers, reviews, and book chapters. The existing proof suggests convincingly that a substantial amount of original investigation has been conducted in this particular area, as evidenced by the increasing number of scholarly publications dedicated to it. Additionally, it is crucial to recognise that conference papers frequently function as condensed iterations of extensive research publications presented at academic conferences or gatherings. The literary conference circuit is characterised by considerable attention and discussion surrounding safety knowledge in military research.

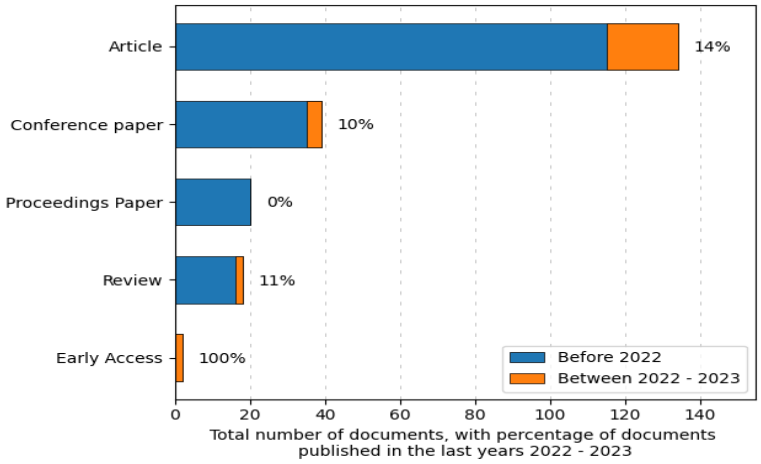

Figure 2 – Bar-trend graph of the document types (Source: Authors, using ScientoPy 2.1.3)

Prominent publishing titles

This investigation comprised the titles of sources that were acknowledged for their remarkable effectiveness in terms of disseminating scholarly articles on the topic of safety knowledge in military settings. These titles were identified as the most productive among multiple sources

of publications in this particular field. Figure 3 presents the top ten source titles that were discovered in this investigation. The data presented in Figure 3 indicates that a considerable portion of academic publications centered on the amalgamation of safety knowledge and the military are disseminated through esteemed scholarly journals and conference proceedings. The source titles with a document count exceeding four include “Proceedings - IEEE Military Communications Conference MILCOM,” “BMJ MILITARY HEALTH,” “Disaster Medicine and Public Health Preparedness,” and “TRANSFUSSION.” The publication “Proceedings - IEEE Military Communications Conference MILCOM” primarily focuses on disseminating safety knowledge within military contexts. The journals “BMJ MILITARY HEALTH” and “Disaster Medicine and Public Health Preparedness” are the second and third most prominent sources of research on safety knowledge in military contexts, respectively. Notably, the publication titled “Disaster Medicine and Public Health Preparedness” has achieved a 40% dissemination rate, establishing it as one of the most widely published works in the field from 2022 to 2023. These three academic publications and conference proceedings are highly esteemed and possess significant impact factors, indicating the presence of research of exceptional quality. These publications and conference proceedings disseminate the most comprehensive research on safety knowledge in military contexts,"thus showing an increasing attraction for both researchers and practitioners’.

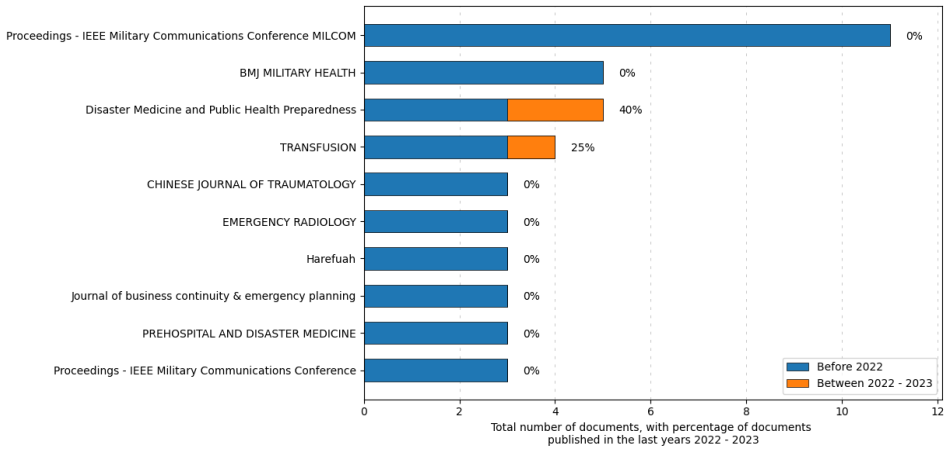

Figure 3 – The prolific source titles (Source: Authors, using ScientoPy 2.1.3).

Emerging topics or themes in research

This study utilises ScientoPy and VOSviewer to evaluate the authors' keywords and investigate the prevailing research trends and noteworthy topics in the domain of safety knowledge in military contexts. Figure 4 showcases the top 10 keywords associated with safety knowledge in military environments. The selection of words in the list is based on their frequency of appearance in the papers, depicted by the blue bars. Furthermore, the orange shade represents the proportion of articles published in the past two years (PDLY - personnel-driven learning activities), specifically in 2022 and 2023.

Based on the data presented in Figure 4, the phrase “emergency preparedness” has the highest frequency, appearing in 21 papers with a PDLY of only 9%. This finding emphasises the importance of understanding and promoting heightened awareness of safety issues and challenges in military settings. Recent studies have underscored the need to enhance environmental consciousness through various means, such as safety education, between 2022 and 2023.

The words "preparedness" is the second most commonly utilised expression, appearing in 9 papers. This observation underscores the acknowledgment of safety information as potent instruments for advancing safety and well-being among military personnel and organisations. The PDLY of 11% signifies a considerable volume of research undertaken within the last two years, centering on the evolving importance of safety knowledge in fostering environmental awareness and education within military contexts.

The word “COVID-19” appears in 6 papers, indicates the crucial aspect of integrating practices and fundamental principles of sustainability into efforts to enhance safety awareness in the military context. The 50% PDLY signifies the growing importance attributed to incorporating safety knowledge principles specific to military environments during the pandemic era. This is directly relevant to enforcement entities currently facing new challenges in enforcing government-imposed movement control orders (MCO).

The inclusion of terms such as “disaster,” “education,” “security,” “emergency management,” and “terrorism” contributes to a more comprehensive understanding of the subject area. However, there is currently no research that combines these words with safety awareness in military contexts, as indicated by the existing PDLY. The differing quantities of papers and PDLY that have been identified in this particular

study indicate distinct areas of research interest and the continual development of safety knowledge within the context of military studies.

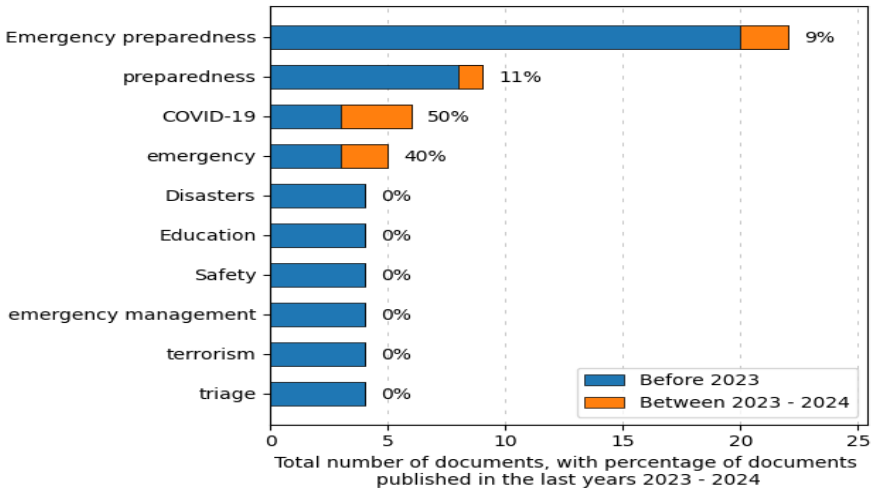

Figure 4 – The bar-trend graph of the research themes and topics emerging (Source: Authors, using ScientoPy 2.1.3).

The current research utilised the VOSviewer platform to understand the interconnections among the keywords used in previous studies. Analysing the different various correlations among the main keywords studied since 2010 is crucial. As depicted in Figure 5, the examination of authors' keyword co-occurrence was conducted with a minimum threshold of 3 instances for each term. Out of the 431 terms, only 17 met this threshold. The examination of author-selected terms holds significant value for researchers seeking to ascertain patterns in research. Furthermore, it is essential to recognize the importance of author keyword analysis when assessing the progress of research subjects. The study utilized VOSviewer to conduct mapping analysis within the context of keyword analysis. The VOSviewer software visually depicts the concurrent occurrence of these terms, as depicted in Figure 5. The configuration of nodes within this visual network denotes the degree of interconnection among words or concepts. Every node represents a unique phrase or idea. The overlaid visualization, exemplified in Figure 5, underscores the dominance of the terms "covid-19," "risk management," "safety," and "emergency" throughout the year 2020. These keywords mirror the prevailing focus on safety knowledge within military domains.

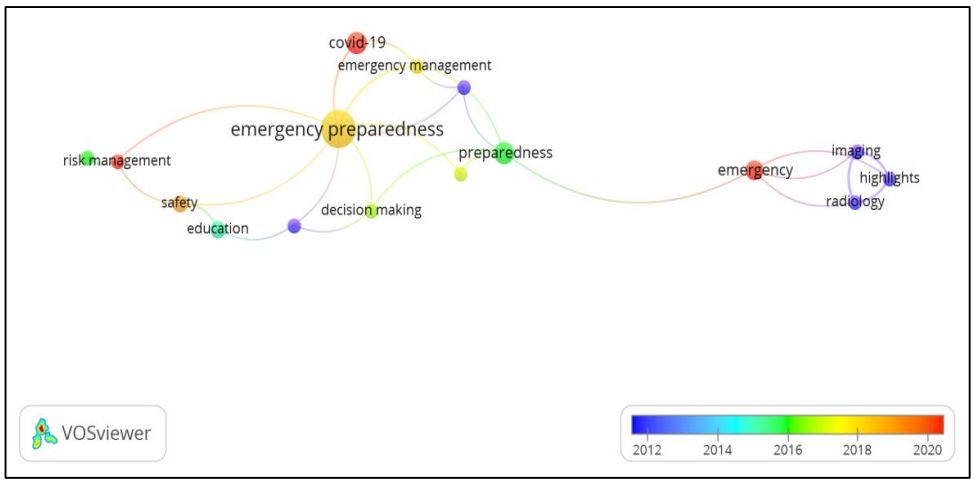

Figure 5 – The visualization of the overlapping keywords co-used by authors (Source: Author, using VOSviewer 1.6.19)

The Most influential academic works

Traditionally, the impact of a publication on a discipline was evaluated based on its citations per publication. Citations indicate how many times an article is referenced in all the documents within a database. During the pre-processing stage, ScientoPy was employed to gather the number of citations originating from the Scopus and WoS databases. The top ten papers concerning safety knowledge in military environments, which have garnered a minimum of 48 citations, are displayed in Table 2. The paper titled “Experiences in Hardware Trojan Design and Implementation” by Jin et al. (2009) received the highest citations, reaching a total of 164.

The second highest number of citations was obtained by Stevelink et al, (2018), the authors of the paper “Mental health outcomes at the end of the British involvement in the Iraq and Afghanistan conflicts: A cohort study,” which amassed 150 citations. Close behind, the article “Weapons of mass destruction events with contaminated casualties - Effective planning for health care facilities” by Macintyre et al, (2000) accumulated 138 citations, ranking it as the third most frequently referenced publication.

Table 2 – The top ten most cited papers

No	Source	Title	Citation count	Document type
1.	(Jin et al, 2009)	"Experiences in Hardware Trojan Design and Implementation"	164	Conference
2.	(Stevelink et al, 2018)	"Mental health outcomes at the end of the British involvement in the Iraq and Afghanistan conflicts: A cohort study"	150	Articles
3.	(Macintyre et al, 2000)	"Weapons of mass destruction events with contaminated casualties - Effective planning for health care facilities"	138	Articles
4.	(Ghafir et al, 2018)	"Security threats to critical infrastructure: the human factor"	97	Articles
5.	(Boukerche et al, 2008)	"Secure localisation algorithms for wireless sensor networks"	94	Articles
6.	(Schmaljohn, 2009)	"Vaccines for hantaviruses"	68	Articles
7.	(Sharp et al, 1998)	"Medical preparedness for a terrorist incident involving chemical or biological agents during the 1996 Atlanta Olympic games"	58	Articles
8.	(Garbutt et al, 2008)	"Evaluation of an Instrument to Measure Nurses' Familiarity with Emergency Preparedness"	51	Articles
9.	(Phillips et al, 2011)	"Disaster threat: Preparedness and potential response of the lowest income quartile"	48	Articles
10.	(Howell, 2011)	"The Demise of PTSD: From Governing through Trauma to Governing Resilience"	48	Articles

Productive institutions

The data analysis presented in Figure 6 sheds light on the inclusion of a considerable number of top-ranked colleges. Notably, the Royal Centre for Defence Medicine in the United Kingdom stands out as the leading institution, having published the highest number of articles, totaling five, surpassing its counterparts. Two universities, namely the Uniformed Services University of Health Sciences in the United States and the University of Ottawa in Canada, have collaborated to produce a combined total of four scholarly articles. In contrast, the remaining institutes have published fewer than three publications. Such achievements serve as a testament to the exceptional quality and effectiveness of these institutions within their respective academic domains. Furthermore, this occurrence highlights the worldwide aspect of scholarly cooperation, as educational institutions from different nations have equally contributed to the progress of research and dissemination of information.

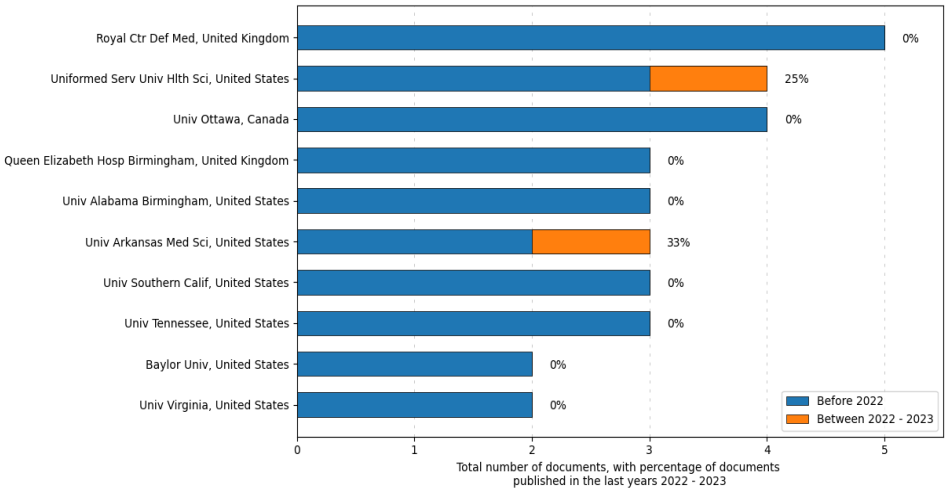

Figure 6 – The ten leading institutions in terms of productivity (Source: Authors, using ScientoPy 2.1.3)

Discussion

Given the limited existing research on evaluating safety knowledge articles in military situations using scientometric methods, conducting a comprehensive analysis of current studies utilising analytical techniques would be a valuable addition to the field. This study aims to investigate the present condition of investigations regarding safety knowledge in military situations worldwide while offering essential insights into academic collaboration through a visualisation approach that illustrates the relationships between significant studies and researchers in the field. This is achieved by examining the most frequently cited papers.

Scientometric investigations, which employ analytical methods, are crucial for a comprehensive understanding of specific areas of study. Scientists are able to analyse patterns in scientific research pertaining to a particular subject or discipline. This involves evaluating the growth of published literature, identifying prevalent topics, scrutinising the sources of these works, and categorising different types of papers. Furthermore, they have the capability to provide valuable advice to fellow researchers in the same field by pinpointing research organizations and individuals who have showcased their proficiency in their research pursuits. The use of knowledge components pertaining to safety is vital in enhancing military safety environments and enhancing the distribution of pertinent details about environmental consciousness and its connected fields issues, which

are currently widespread. These phenomena can be identified by analysing the dominant research subjects and themes in this study. Consequently, researchers can examine the present state of the subject to identify potential contributions and novel approaches for future research.

The study findings regarding the concentration of security knowledge within the military domain yield valuable insights into the publishing patterns and observed trends within this specific sector. Figure 1 demonstrates that an examination of the increase in publications indicates a steady rise in research activities concerning this subject, starting from 2005. Publications have experienced a substantial increase since 2018, a rise that can be attributed to the heightened attention on ecological concerns, specifically during the COVID-19 outbreak. It is actively utilised in the implementation of the Movement Control Order (MCO) as a safety precaution, adapting safety protocols to the existing safety policy.

According to Chirindza & Mangona (2022), the primary factor influencing the adoption of safety knowledge in military environments during the COVID-19 pandemic crisis is the environmental context. The discovery of this information possesses significant consequences for individuals responsible for making decisions and professionals who aim to comprehend the factors that impact the execution of safety knowledge. Thus, in military environments, it is crucial to provide accurate and comprehensive information about COVID-19, highlight the severity of the disease, and address cognitive and socio-structural factors in order to raise awareness and promote behavioral changes among military personnel to protect against COVID-19 (Hein et al, 2021). Therefore, the increase in publications since 2018 suggests a significant impact of the COVID-19 pandemic on safety knowledge in military environments. This phenomenon has also received considerable attention in the field of safety knowledge over the past two years.

Figure 2 depicts the prevalence of journal articles as the primary type of documents generated within this sector. This observation suggests that the advancement of safety knowledge in military contexts heavily relies on original research and academic discourse. The profusion of papers indicates the considerable focus and discourse encompassing this topic in educational and conference settings. According to Garousi and Fernandes (2017), as cited by Abdullah (2023), journal publications receive an average of 12.6 citations, whereas conference papers receive an average of 3.6 citations. This finding supports the conventional belief that, overall, scholarly journal publications have a greater impact than conference papers. Journal papers offer several advantages as sources of study findings. They confer recognition and status upon the authors and their

work (Vadhera et al, 2022). Furthermore, journal papers undergo a rigorous evaluation process to ensure the high quality of the research (Gustafsson, 2022).

Figure 3 illustrates that esteemed scholarly publications and conference proceedings play a crucial role in effectively disseminating safety knowledge in studies related to the military. Noteworthy sources include reputable journals such as “BMJ MILITARY HEALTH” and conference papers like “Proceedings - IEEE Military Communications Conference MILCOM”. The substantial impact factor and publication volume of these sources attest to the growing significance and relevance of safety knowledge in military research, piquing the interest of researchers and practitioners alike. This can be attributed, in part, to the fact that articles published in prestigious and influential journals tend to garner more citations. It is therefore advisable for researchers to submit their scientifically rigorous work to these journals, in order to enhance the impact and visibility of their studies (Achugbue & Tella, 2023; Bahadoran et al, 2020). The utilisation of policy tools within national research assessment systems, academic promotion processes, and competitive funding schemes may also impact the number of published articles. Policy tools, such as interest registries, can play a role in identifying and resolving conflicts of interest that may influence publication practices (Kianersi et al, 2023). It is worth noting that the increase in publication numbers has not been accompanied by a decline in publishing quality, as assessed by scientometric indicators.

Figure 4 portrays the primary domains of investigation and emerging apprehensions pertaining to safety comprehension within military settings. The phrase "Emergency preparedness" is notably prominent as the most frequently employed keyword, emphasizing the significance of promoting consciousness regarding environmental dangers and difficulties. The extensive utilization of the term "Emergency preparedness" in contemporary studies on safety knowledge within military contexts suggests that academics and experts acknowledge the importance of employing safety knowledge to augment individuals' awareness of matters within a military framework. According to Kao et al, (2019), improving safety knowledge in a military setting can effectively enhance individual awareness of specific concerns. This can be achieved through targeted education and training initiatives, which provide knowledge and teach individuals the essential skills needed to demonstrate appropriate behavior in dangerous situations (Szykula-Piec et al, 2020). Furthermore, fostering a culture of psychological safety can facilitate the exchange of information and enhance coworkers understanding (Barbara et al, 2020). Therefore,

the purpose of implementing safety knowledge in military settings is to minimise preventable injuries and illnesses, increase the success of missions, and improve combat efficiency. Gaining an understanding of safety is essential for maintaining secure functioning in complex and hazardous environments.

Additionally, the analysis of the co-occurrence of keywords by means of VOSviewer, as illustrated in Figure 5, provides clarification regarding the interconnection between different research topics and concepts. The growing importance of terms such as "emergency," "Covid-19," and "risk management" in recent times highlights the changing research focus and the significance of safety-related knowledge in promoting environmental consciousness and education. The frequent utilisation of the term “emergency” in scholarly discussions implies a recognition of the necessity to disentangle safety from its survival-centric rationale and to challenge the exceptionalist model in the study of emergencies (Kurylo, 2022). The concept of emergency has been presented and anticipated in a multitude of contexts, exerting influence on societal priorities and reshaping measures for mitigating risks (Seebach & Beriain Bañares, 2021). An examination of safety knowledge in emergency scenarios can be achieved by investigating the dynamics of leadership development within military contexts (Vallikannu et al, 2023). Researchers in the military field, including psychologists, sociologists, and economists, have conducted studies on organisations that may offer valuable insights to the safety and engineering communities (Vallikannu et al, 2023). The safety and engineering communities can enhance their understanding of safety knowledge in emergency scenarios by leveraging the insights gained from research on military organisations (Li & Chen, 2018). This research subject exemplifies a burgeoning scholarly interest in comprehending the emergency dimension of environmental concerns and employing approaches from emergency studies to gain significant insights into the attitudes and perspectives of military personnel.

The prevalence of the term "Covid-19" in the examination of keyword co-occurrence suggests that it is widely acknowledged as a significant determinant throughout the worldwide Covid-19 pandemic spanning from 2020 to 2022. This recognition holds importance in terms of adapting safety knowledge in the military environment and promoting environmental awareness and education. The impact of the COVID-19 pandemic on the understanding of safety knowledge in military settings is evident, as it presents new challenges and obstacles for healthcare professionals and workers. The working conditions at military hospitals have undergone changes, including increased infection risks, inadequate staffing, and

excessive workloads, all of which can influence safety knowledge and practices (Midboe et al, 2023). External influences on safety knowledge and decision making have a significant impact on the military's decision to deploy during the pandemic (Dietrich et al, 2023). Customised measures were implemented in military basic training to prevent epidemics, emphasising the importance of tailored strategies in military environments to ensure safety (España et al, 2022). Understanding the knowledge, attitudes, and behaviours of military personnel regarding COVID-19 prevention is crucial in identifying areas that require improvement and addressing any vaccine hesitancy (Woolley et al, 2023). Therefore, by cultivating a thorough comprehension of the environmental awareness within military personnel, the acquisition of safety knowledge can serve as a potent means of conveying information and viewpoints on both current and emerging environmental issues.

The results presented in Figures 4 and 5 are supported by the significant occurrence of terms related to emergency preparedness, emergency, and COVID-19. These findings demonstrate the evolving focus of research and emphasise the importance of safety knowledge in improving situational awareness and education in military contexts. An examination of keyword co-occurrence provides useful insights into the interrelationships among different study subjects and ideas, eventually augmenting the comprehension of the level of safety consciousness among military personnel with respect to environmental concerns.

Table 2 illustrates an aggregation of significant academic articles, ordered based on the number of citations acquired per article. These highly cited works provide valuable insights into the current state of safety knowledge in military environments. The publication titled "Experiences in Hardware Trojan Design and Implementation" by Jin et al. (2009) has received the highest number of citations, indicating its significant impact in the field. Publications that receive a substantial number of citations indicate widespread use and recognition within the academic community. Hence, these notable publications serve as significant assets for scholars aiming to comprehend the present condition of safety comprehension in dialogues connected to military situations. They aid in moulding the course of research and progressing the established knowledge pool.

The examination of efficacious establishments, as illustrated in Figure 6, elucidates the noteworthy contributions rendered by diverse establishments throughout various nations. "The Royal Centre for Defence Medicine, Uniformed Services University of Health Sciences", and "University of Ottawa" have consistently demonstrated their dedication to researching safety knowledge in military contexts, as evidenced by the

publication of four or more articles. This consistent output serves as a testament to their unwavering commitment and outstanding performance in these domains.

Based on the aforementioned findings and discussion, it is evident that safety knowledge plays a critical role as a mediator in the relationship between safety management practice and safety performance, particularly in military situations (refer to Figure 7). The link between safety management practice and safety performance is influenced by safety knowledge (Jo et al, 2023; Sandora et al, 2023). The research suggests that safety management techniques have a positive and significant impact on safety performance, and this impact is mediated by safety knowledge (Saleem & Malik, 2022). Safety management methods encompass the implementation of safety training, installation of safety signage, updating of standard operating procedures, and conducting safety discussions and briefings (Kalteh et al, 2022). The research proposes that safety regulations should prioritise tangible measures instead of solely focusing on risk awareness in order to enhance safety performance (Kalteh et al, 2022). Furthermore, responsible leadership has the potential to improve safety performance in situations where the safety climate is lacking or there is a low level of safety awareness. Safety knowledge is essential for effectively implementing safety management techniques and enhancing safety performance, particularly in military settings.

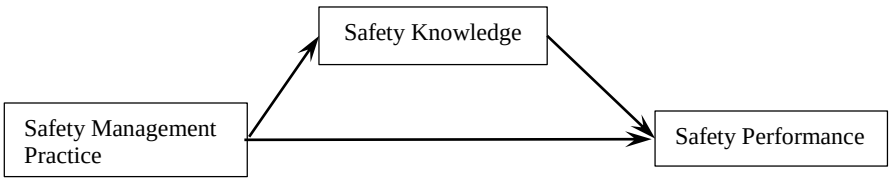

Figure 7 – Role of safety knowledge as a mediator in the research framework

Conclusion

This investigation has significantly bolstered the comprehension and practices connected to safety knowledge in military circumstances via the utilization of scientometric analysis. By examining publication patterns, research subjects, influential publications, and productive institutions, this examination has supplied valuable observations into the current state of research in this domain. The discoveries of this examination emphasize the expanding emphasis on safety knowledge in military settings, as demonstrated by the steady rise in research endeavors over time. The identification of the key research subjects, for example, "emergency

preparedness," and the acknowledgement of the importance of safety information, for example, emergency response, as practical means of promoting environmental awareness, underscores the critical significance of safety knowledge in addressing issues in military scenarios. Moreover, the evaluation of notable scholarly publications, considering their citation count, has unveiled a collection of seminal articles that have significantly influenced the discipline. These publications function as indispensable resources for scholars and practitioners striving to grasp and contribute to the comprehension of safety in military situations.

While this study has the potential to make a significant scholarly contribution to the understanding and implementation of safety measures in military environments, it is important to acknowledge the inherent limitations of this research endeavor. The use of the WoS and Scopus databases may inadvertently result in the exclusion of relevant literature on the subject matter. Additionally, the scientometric approach used in this study primarily focuses on quantitative data, specifically the quantitative assessment of publications and citations. However, it is of paramount importance to acknowledge that the qualitative elements of the articles, such as the overall excellence of the investigation or the importance of the discoveries, are not fully encompassed within this theoretical structure.

Future investigation should strive to rectify these constraints by integrating a more extensive array of datasets and undertaking a more exhaustive assessment of the caliber and influence of the articles. Additionally, it is recommended that future studies focus on exploring specific subcategories of safety knowledge within military contexts. For example, research could center on assessing the effectiveness of various strategies for promoting environmental awareness through safety knowledge or analysing the influence of enforcement entities on the adoption of environmentally-friendly practices. The use of scientometric analysis in the field of safety information in military settings offers a valuable approach to understanding publication patterns, research trends, and significant works in this area. This information can be used to inform future research endeavors, provide guidance to practitioners in implementing effective solutions, and contribute to the development of safety awareness and environmental sustainability within military culture.

References

Abdullah, K.H. 2022a. Mapping of literature on safety knowledge research using ScientoPy and VOSviewer. *Journal of Metrics Studies and Social Science*, 1(1), pp.36-49. Available at: https://doi.org/10.56916/jmsss.v1i1.75.

Abdullah, K.H. 2022b. Publication Trends in Biology Education: A Bibliometric Review of 63 Years. *Journal of Turkish Science Education*, 19(2), pp.465-480 [online]. Available at: https://www.tused.org/index.php/tused/article/view/1190 [Accessed: 25 February 2024].

Abdullah, K.H. 2023. Eco-literacy and Social Media: A Bibliometric Review. *Journal of Scientometric Research*, 12(3), pp.631-640. Available at: https://doi.org/10.5530/jscires.12.3.061.

Abdullah, K.H. & Abd Aziz, F.S. 2020. Safety Behaviour in the Laboratory among University Students. *The Journal of Behavioral Science*, 15(3), pp.51-65 [online]. Available at: https://so06.tci-thaijo.org/index.php/IJBS/article/view/241208 [Accessed: 25 February 2024].

Abdullah, K.H. & Sofyan, D. 2023. Machine Learning in Safety and Health Research: A Scientometric Analysis. *International Journal of Information Science and Management*, 21(1), pp.17-37. Available at: https://doi.org/10.22034/ijism.2022.1977763.0.

Achugbue, E.I. & Tella, A. 2023. Publication in High Impact Journals and Implications for University Rankings of African Universities. In: Onyancha, O. & Tella, A. (Eds.) *Impact of Global University Ranking Systems on Developing Countries*, pp. 309-334. IGI Global. Available at: https://doi.org/10.4018/978-1-6684-8266-7.ch017.

Bahadoran, Z., Mirmiran, P., Kashfi, K. & Ghasemi, A. 2020. Scientific Publishing in Biomedicine: How to Choose a Journal? *International Journal Of Endocrinology And Metabolism*, 19(1), e108417. Available at: https://doi.org/10.5812/IJEM.108417.

Blake, J. & Nemergut, E.C. 2014. Hope for the Best, but Prepare for the Worst. *Anesthesia & Analgesia*, 118(2), pp.249-250. Available at: https://doi.org/10.1213/ANE.0000000000000057.

Chirindza, N.A.T. & Mangona, L.B.M. 2022. Military Knowledge and Practices in Relation to Preventing and Combating COVID-19 (PREPRINT, Version 1). *Research Square,* 06 October. Available at: https://doi.org/10.21203/rs.3.rs-2073597/v1.

Danielsson, A. 2020. Knowledge in and of military operations: enriching the reflexive gaze in critical research on the military. *Critical Military Studies*, 88(3), pp.313-333. Available at: https://doi.org/10.1080/23337486.2020.1835341.

De Florio, V. & Blondia, C. 2015. Safety enhancement through situation-aware user interfaces. *arXiv:1504.03731*. Available at: https://doi.org/10.48550/arXiv.1504.03731.

De Jong, S., Klein, A., Smelik, R. & van Wermeskerken, F. 2016. Integrating Run-Time Incidents in a Large-Scale Simulated Urban Environment. In: Thangarajah, K., Tuyls, S.M. & Jonker, C. (Eds.) *Proceedings of the 15th International Conference on Autonomous Agents and Multiagent Systems (AAMAS 2016)*, Singapore, pp.1401-1402, May 9-13 [online]. Available at: https://www.ifaamas.org/Proceedings/aamas2016/pdfs/p1401.pdf [Accessed: 25 February 2024]. ISBN: 978-1-4503-4239-1.

Dietrich, N., Eck, K. & Ruffa, C. 2023. How governance shaped military responses to the COVID-19 pandemic. *European Political Science Review*, 15(4), pp.628-640. Available at: https://doi.org/10.1017/s1755773923000024.

Dyson, T. 2021. The Challenge of Creating an Adaptive Bundeswehr. *German Politics*, 30(1), pp.122-139. Available at: https://doi.org/10.1080/09644008.2019.1612369.

Ertle, P. 2016. Safety of Autonomous Cognitive-oriented Robots. *KI - Künstliche Intelligenz*, 30, pp.89-90. Available at: https://doi.org/10.1007/s13218-015-0408-6.

Ertle, P., Tokic, M., Cubek, R., Voos, H. & Söffker, D. 2012. Towards learning of safety knowledge from human demonstrations. In: *2012 IEE/RSJ International Conference on Intelligent Robots and Systems*, Vilamoura-Algarve, Portugal, pp.5394-5399, October 07-12. Available at: https://doi.org/10.1109/IROS.2012.6385714.

España, G., Perkins, T.A., Pollett, S.D., Smith, M.E., Moore, S.M., Kwon, P.O., Hall, T.L., Beagle Jr, M.H., Murray, C.K., Hakre, S., Peel, S.A., Modjarrad, K. & Scott, P.T. 2022. Prioritizing interventions for preventing COVID-19 outbreaks in military basic training. *PLOS Computational Biology*, 18(10), e1010489-e1010489. Available at: https://doi.org/10.1371/journal.pcbi.1010489.

Garousi, V. & Fernandes, J.M. 2017. Quantity versus impact of software engineering papers: a quantitative study. *Scientometrics*, 112, pp.963-1006. Available at: https://doi.org/10.1007/s11192-017-2419-6.

Gustafsson, L. 2022. Journal-based or article-based metrics: What should be applied to assess a researcher's performance? *Australian Occupational Therapy Journal*, 69(1), pp.1-2. Available at: https://doi.org/10.1111/1440-1630.12789.

Hafiar, H., Budiana, H.R., Abdullah, K.H., Sofyan, D. & Amin, K. 2024. Scoring big: a bibliometric analysis of the intersection between sports and public relations. *Cogent Social Sciences*, 10(1), art.number:2297706. Available at: https://doi.org/10.1080/23311886.2023.2297706.

Hein, G., Gamer, M., Gall, D., Gründahl, M., Domschke, K., Andreatta, M, Wieser, M.J. & Pauli, P. 2021. Social cognitive factors outweigh negative emotionality in predicting COVID-19 related safety behaviors. Preventive Medicine Reports, 24, art.number:101559. Available at: https://doi.org/10.1016/J.PMEDR.2021.101559.

Jo, Y.K., Lee, J.W., So, H.S., Jung, T.H. & Kim, B.J. 2023. Multiple Parallel Mediation Effects of Perceived Risk and Safety Practice Behavior in the Relationship between Indoor Swimming Pool Safety regulation and Safety Performance. *Korean Journal of Safety Culture*, 28(22), pp.193-206. Available at: https://doi.org/10.52902/kjsc.2023.22.193.

Kalteh, H.O., Salesi, M. & Mokarami, H. 2022. The mediator role of safety motivation and knowledge between safety culture and safety performance: The results of a sociotechnical and macroergonomics approach. *Work*, 72(2), pp.707-717. Available at: https://doi.org/10.3233/WOR-205085.

Kao, K.-Y., Spitzmueller, C., Cigularov, K. & Thomas, C.L. 2019. Linking safety knowledge to safety behaviours: A moderated mediation of supervisor and worker safety attitudes. *European Journal of Work and Organizational Psychology*, 28(2), pp.206-220. Available at: https://doi.org/10.1080/1359432X.2019.1567492.

Kianersi, S., Grant, S.P., Naaman, K., Henschel, B., Mellor, D., Apte, S., Deyoe, J.E., Eze, P., Huo, C., Lavender, B.L., Taschanchai, N., Zhang, X. & Mayo-Wilson, E. 2023. Evaluating Implementation of the Transparency and Openness Promotion Guidelines: Reliability of Instruments to Assess Journal Policies, Procedures, and Practices. *Advances in Methods and Practices in Psychological Science*, 6(1). Available at: https://doi.org/10.1177/25152459221149735.

Kurylo, B. 2022. Emergency: A Vernacular Contextual Approach. *International Studies Review*, 24(3), art.number:viac036. Available at: https://doi.org/10.1093/isr/viac036.

Midboe, A.M., Javier, S.J., Salsbury, S.A., Katsovich, L., Burgess, D.J., King, H.A., Taylor, S.L., Martino, S., Wallace, R.B., Der-Martirosian, C. & Kerns, R.D. 2023. Impact of COVID-19 pandemic on nonpharmacological pain management trials in military and veteran healthcare settings: an evaluation informed by implementation science. *Translational Behavioral Medicine*, 13(8), pp.601-611. Available at: https://doi.org/10.1093/tbm/ibad015.

Nosary, I.P. & Adiati, R.P. 2021. Pengaruh Kepemimpinan Tranformational Dan Safety Climate Terhadap Safety Behavior di Mediasi Oleh Safety Knowledge. *Buletin Riset Psikologi Dan Kesehatan Mental (BRPKM)*, 1(1), pp.756-767. Available at: https://doi.org/10.20473/BRPKM.V1I1.26930.

Parsons, T.D. & Reinebold, J.L. 2012. Adaptive virtual environments for neuropsychological assessment in serious games. *IEEE Transactions on Consumer Electronics*, 58(2), pp.197-204. Available at: https://doi.org/10.1109/TCE.2012.6227413.

Pettersson, U. 2009. Sharing Knowledge: How to Highlight Proven Experience in the Swedish Armed Forces. In: Landgren, J. & Jul, S. (Eds.) *Proceedings of the 6th International ISCRAM Conference*, Gothenburg, Sweden, May 10-13 [online]. Available at: https://idl.iscram.org/files/pettersson/2009/842_Pettersson2009.pdf [Accessed: 25 February 2024].

Przybysz, K. 2020. Dependability for the military vehicles in the safety aspects. *Inżynieria Bezpieczeństwa Obiektów Antropogenicznych*, 1, pp.35-42. Available at: https://doi.org/10.37105/IBOA.47.

Saleem, F. & Malik, M.I. 2022. Safety Management and Safety Performance Nexus: Role of Safety Consciousness, Safety Climate, and Responsible Leadership. *International Journal of Environmental Research and Public Health*, 19(20), art.number:13686. Available at: https://doi.org/10.3390/ijerph192013686.

Sandora, R., Kurniasih, D. & Putri, G.A. 2023. Influence of Safety Management Practices on Safety Performance with Safety Knowledge as Intervening Variable in Safety Representative. *Tibuana*, 6(1), pp.38-43. Available at: https://doi.org/10.36456/tibuana.6.1.6496.38-43.

Seebach, S. & Beriain Bañares, A. 2021. Towards a sociology of emergency. Epidemics, biorisks, and the society of the Coronavirus. *Digithum*, 28(July), pp.1-7. Available at: https://doi.org/10.7238/d.v0i28.400351.

Szykula-Piec, B., Grabowska-Lepczak, I. & Wojakowska, M. 2020. From Social Research to Education and Training - Campaigns to Raising Public Awareness of Hazards. *Journal of Education and Training*, 7(2), pp.14-35. Available at: https://doi.org/10.5296/JET.V7I2.16323.

Vadhera, A.S., Lee, J.S., Veloso, I.L., Singh, H., Trasolini, N.A., Kunze, K.N., Gursoy, S., Geeslin, A.G., Verma, N.N. & Chahla, J. 2022. Technique Articles Are More Effective at Increasing Social Media Attention in Comparison With Original Research Articles: An Altmetrics-Based Analysis. *Arthroscopy, Sports Medicine, and Rehabilitation*, 4(3), pp.e989-e995. Available at: https://doi.org/10.1016/j.asmr.2022.02.002.

Vallikannu, R., Kanpur Rani, V., Kavitha, B.C. & Sankar, P. 2023. An Analysis of Situational Intelligence for First Responders in Military. In: *2023 International Conference on Artificial Intelligence and Applications (ICAIA) Alliance Technology Conference (ATCON-1)*, Bangalore, India, pp.1-4, April 21-22. Available at: https://doi.org/10.1109/ICAIA57370.2023.10169306.

Wei, S-Y. & Kuo, Y.-K. 2023. The relationship among safety leadership, risk perception, safety culture, and safety performance: Military volunteer soldiers as a case study. *Frontiers in Psychology*, 14. Available at: https://doi.org/10.3389/fpsyg.2023.1000331.

Woolley, S.D., Chambers, R., Bishop, J.R.B., Logan, A., McMillan, P., Fletcher, T.E., Taegtmeyer, M. & O'Shea, M.K. 2023. COVID-19 risk, attitudes and behaviour study (CRAB study): A knowledge, attitudes, and practise qualitative study of COVID-19 in the Royal Navy. *Frontiers in Public Health*, 10. Available at: https://doi.org/10.3389/fpubh.2022.1101817.

Explorando las tendencias de investigación de vanguardia en conocimientos de seguridad en entornos militares

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CAMPO: ciencias militares
TIPO DE ARTÍCULO: artículo de revisión

Resumen:

Introducción/objetivo: El entorno militar se caracteriza por operaciones y actividades de alto riesgo que requieren una comprensión integral de los conocimientos de seguridad para garantizar el bienestar y la eficacia del

personal. Indirectamente, este escenario ilustra la necesidad de los militares de priorizar una gestión adecuada de la seguridad y la salud dentro de su entorno, al igual que otras organizaciones. La actual revisión cienciométrica tiene como objetivo analizar las tendencias de investigación relacionadas con el conocimiento de la seguridad en entornos militares.

Métodos: Esta revisión utilizó ScientPy y VOSviewer para comprender la naturaleza de los conjuntos de datos recopilados de las bases de datos Scopus y Web of Science (WoS).

Resultados: La publicación académica "Proceedings - IEEIEEE Military Communications Conference MILCOM" es reconocida por su amplia cobertura de la investigación del conocimiento de seguridad para entornos militares. La palabra clave "preparación para emergencias" ha tenido un impacto significativo en el contenido temático del conocimiento académico sobre seguridad durante las últimas tres décadas, de 1990 a 2023, debido a que los investigadores anteriores la habían utilizado con mayor frecuencia. Basado en un mapeo de visualización superpuesto, la revisión actual demuestra que a los términos "emergencia", "COVID-19" y "gestión de riesgos" se les ha otorgado una mayor importancia desde 2020.

Conclusión: Este estudio proporciona una perspectiva exhaustiva y mundial sobre los temas cruciales del conocimiento de seguridad en entornos militares. Está dirigido a lectores e investigadores potenciales interesados en comprender mejor estos conceptos y realizar investigaciones más rigurosas sobre seguridad militar.

Palabras claves: conocimientos de seguridad, militar, cienciométrico.

Анализ современных научных тенденций в исследованиях в области безопасности в военной среде

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РУБРИКА ГРНТИ: 78.19.01 Общие вопросы военной науки
ВИД СТАТЬИ: обзорная статья

Резюме:

Введение/цель: Военная среда характерна по операциям с высоким уровнем риска и по видам деятельности, требующих всестороннего понимания техники безопасности ради обеспечения благополучия и эффективности персонала. Такой сценарий косвенно иллюстрирует необходимость посвящения особого внимания надлежащему управлению безопасностью

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труда и охране здоровья в военном секторе, также, как это делается в других организациях. Целью данного научного обзора является анализ тенденций в исследованиях области безопасности в военной среде.

Методы: В данной обзорной статье использовались ScientoPy и VOSviewer для понимания характера наборов данных, собранных из баз данных Scopus и Web of Science (WoS).

Результаты: Научное издание "Proceedings - IEEE Military Communications Conference MILCOM" известно своим обширным освещением исследований в области безопасности в военной среде. Ключевой термин "готовность к чрезвычайным ситуациям" оказало значительное влияние на тематическое содержание научных публикаций по безопасности за последние три десятилетия с 1990 по 2023 год, поскольку исследователи его использовали весьма часто. Благодаря применению метода визуального наложения карт данный обзор недвусмысленно показывает, что с 2020 года термины «чрезвычайная ситуация», «covid-19» и «управление рисками» стали более значимыми.

Выводы: Данное исследование представляет собой всесторонний детальный обзор важнейших аспектов знаний о безопасности в военной среде. Оно предназначено для потенциальных читателей и исследователей, заинтересованных в лучшем понимании этих концепций и проведении более тщательных исследований в области военной безопасности.

Ключевые слова: знания о безопасности, вооруженные силы, наукометрические данные.

Анализа најсавременијих трендова у истраживању знања о безбедности у војним окружењима

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КАТЕГОРИЈА (ВРСТА) ЧЛАНКА: прегледни рад

Сажетак:

Увод/циљ: Војно окружење карактеришу операције и активности високог ризика које захтевају свеобухватно разумевање знања о

безбедности ради обезбеђивања сигурности и ефикасности особља. Индиректно, овај сценарио илуструје потребу војног сектора да да приоритет адекватном управљању у области безбедности и здравља у свом окружењу, као што то чине и друге организације. Овај сциентометријски преглед има за циљ да анализира трендове у истраживању знања о безбедности у војним окружењима.

Методе: У раду се користе ScientoPy и VOSviewer како би се разумела природа сакупљених скупова података из база података Scopus и Web of Science (WoS).

*Резултати: Научна публикација „*Зборник радова са конференције ИЕЕЕ о војним саопштењима MILCOM*" позната је по свом опсежном истраживању у области безбедносног знања у војним окружењима. Кључни термин* припремљеност за ванредне ситуације *имао је значајан утицај у тематским садржајима научних публикација о знању о безбедности у последње три деценије, од 1990. до 2023. године, јер су га истраживачи веома често користили. Визуелном техником преклапања мапирања јасно је показано да су термини* ванредна ситуација, ковид-19 *и* управљање ризиком *добили већи значај од 2020. године.*

Закључак: Студија пружа детаљан и свеобухватан преглед најважнијих предмета истраживања знања о безбедности у војним окружењима. Намењена је потенцијалним читаоцима и истраживачима заинтересованим за боље разумевање ових концепата како би приступили темељнијим истраживањима у области војне безбедности.

Кључне речи: знање о безбедности, војска, сциентометријски преглед.

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International security regimes in preventing the spread of nuclear armaments and their global significance

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FIELD: nuclear engineering
ARTICLE TYPE: review paper

Abstract:

Introduction/purpose: The paper provides an overview of international regimes and agreements that aimed to halt the spread of nuclear weapons. For each regime, its impact on nuclear weapons proliferation is presented, as well as its significance in stopping nuclear tests that posed a threat of a global ecological catastrophe. Many of these regimes are no longer in effect today, but throughout history, they played their role in fulfilling specific needs to halt the global spread of nuclear weapons or characteristic nuclear weapons of a certain range.

Methods: The paper analyses the international agreements in this field, as well as the papers in the field of nuclear safety from journals of international importance.

Results: The analysis of nuclear security regimes gave results that speak of their strengths and weaknesses. The importance and weaknesses of the regimes are given through the analysis and several diagrams that show the trend of increasing the amount of nuclear weapons over time.

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Conclusions: The work points to the historical importance of nuclear security regimes, but also to their weaknesses, both in earlier times and today. It is clear that these regimes halted nuclear weapons, but this halt did not lead to the complete abolition of nuclear weapons, which is the ultimate goal of the agreements.

Key words: security regimes, nuclear weapons, proliferation, nuclear tests, international agreements.

Introduction

The moment World War II ended, the threat to humanity did not diminish; on the contrary, it became even greater and continued to escalate day by day. Those dark clouds looming over humanity stem from the potential escalation of conflicts among nuclear powers, which would inevitably lead to a nuclear war, effectively marking the beginning of a nuclear winter (Coupe et al, 2019; Vilhelmsson & Baum, 2023).

Even when people survive a nuclear catastrophe or exposure to radioactive radiation, they endure lasting health consequences (Boice et al, 2022; Šefl et al, 2021).

The fear of Armageddon and nuclear winter did not always exist. In fact, at the very beginning of the development of nuclear weapons, American authorities did not take intelligence reports about the Nazi nuclear program seriously. Albert Einstein played a crucial role in this regard; he was already a prominent figure at the time and managed to persuade the US authorities to initiate a nuclear program. The Manhattan Project, after several years, ultimately provided the world with nuclear weapons (Reed, 2015; Chadwick, 2021; Andrews et al, 2021).

The race in nuclear armament was initiated by the authorities of Nazi Germany. Subsequently, the United States of America took the lead, but had to continue the race with the Soviet Union in 1949. Soon, other countries also joined the race (Sood et al, 2021).

The first atomic, or fission, bomb was detonated in 1945 (Beck et al, 2020), while the first thermonuclear bomb was tested in 1952 (Hain et al, 2020; Krass et al, 2022). Today, a total of nine countries possess nuclear weapons. These include the five permanent members of the UN Security Council (the USA, Russia, China, the UK, and France), as well as India, Pakistan, Israel, and North Korea. There are various criteria for classifying nuclear weapons. Apart from the basic division based on the nuclear reaction they rely on, weapons can also be classified by warhead strength, delivery method to the target, missile range, and more. Perhaps the most fundamental classification would be based on the weapon's purpose. In

this case, weaponry could be categorized into strategic nuclear weapons and tactical nuclear weapons.

Due to all the aforementioned reasons, it is evident that there is a substantial need for educating the general population and implementing nuclear security regimes. All protocols and standards related to nuclear safety are of utmost importance (Nikač et al, 2022), and there are a significant number of articles discussing this (Mianji et al, 2013; D'auria & Galassi, 2019; Tsai, 2017). Agreements to halt the spread of nuclear weapons are particularly crucial due to the serious challenges currently faced by the international community.

The need for this research arises from the inherent significance of the topic, its complexity, and its essential importance to human civilization as a whole. The existence of nuclear weapons constantly casts a shadow of a potential catastrophe over mankind. Preventing the spread of nuclear weapons and their reduction, even complete elimination, are highly intricate issues, especially considering that throughout history, the world has been polarized and continues to be, perhaps more than ever. We have always had two sides engaged in power-demonstrating games. In World War II, it was Germany and its allies against America and its allies. This competition persisted through the Cold War and continues to this day, albeit with participants arranged slightly differently. During the Cold War, the USSR and the Warsaw Pact were on one side and the USA and NATO on the other, while today the world is largely divided into the East and the West.

A new threat of nuclear terrorism has emerged in recent times. Terrorist organizations may not have the capability to possess nuclear arsenals, but they do have the potential to use various other methods to spread fear through nuclear terrorism. Firstly, there are radiological "dirty" bombs, then contamination through stolen radioactive sources, as well as attacks on nuclear power plants (Gale & Armitage, 2018; Leikin et al, 2003).

The aim of this study is a systematic compilation of knowledge about nuclear security regimes (from the first initiative in 1953 to the present day), as well as in examining their abuses, compliance, and the double standards in their implementation. Additionally, the study aims to highlight the historical development and significance of the IAEA, while addressing the gravity of the global situation due to the existence of nuclear weapons. Furthermore, it seeks to contribute to the acquisition of knowledge crucial for the prohibition of the proliferation of these armaments.

The significance of this research is underscored by the question: How much have international security regimes truly contributed to the reduction of nuclear weapons?

International security regimes in preventing the proliferation of nuclear weapons

International nuclear security regimes encompass a range of multilateral and bilateral agreements and arrangements between states aimed at avoiding conflicts, particularly those of a nuclear nature.

The enforcer in implementing these agreements is the International Atomic Energy Agency (IAEA) (Krass et al, 2022).

The first substantial initiative to halt the spread of nuclear weapons emerged in 1953 when U.S. President Eisenhower delivered the "Atoms for Peace" speech before the UN (Krass et al, 2022). Subsequently, the establishment of the IAEA followed, along with the creation of numerous international agreements and a significant number of bilateral nuclear agreements between the USA and the USSR (Russia).

Non-proliferation treaty (NPT)

The Treaty on the Non-Proliferation of Nuclear Weapons (NPT) (IAEA, 1970) is not the first agreement within the realm of international security regimes aimed at halting the spread of nuclear weapons. However, it is the first one that defined which states are recognized as declared nuclear powers and introduced practical measures to prevent further nuclear weapon proliferation. This treaty serves as one of the cornerstones upon which international nuclear security regimes are built and it could arguably be considered the most important or central nuclear security agreement (Cooper, 2023).

The adoption of this international agreement was preceded by multi-year, or perhaps even better to say, multi-decade initiatives for the abolition of all forms of nuclear weapons. One of the most important initiatives is the previously mentioned "Atoms for Peace" initiative. It was of fundamental importance for the establishment of the IAEA, and the existence of the Agency contributed to the eventual achievement of the Treaty. Nevertheless, it took time for this to happen, as more than ten years passed from the establishment of the IAEA to the adoption of the NPT. The Treaty was adopted in 1968 and came into force two years later, in 1970, when it was signed by over 90 countries and ratified by 47. Currently, it has 191 valid signatories (IAEA, 2022), with the exception of North Korea, which withdrew from the Treaty in 2003 (IAEA, 2024).

Representatives of India, Pakistan, South Sudan, and Israel never signed the NPT (United Nations, 1968).

In 1968, when this act was adopted, the first countries to sign it were the USA, the USSR (today's Russian Federation), and the UK. These states were designated as Depositary Governments in 1970 when the Agreement came into effect (Cooper, 2023).

According to Article III, paragraph IX of the Agreement, all signing states are divided into two groups: Nuclear Weapon States (NWS) and Non-Nuclear Weapon States (NNWS). NWS includes all states that possessed nuclear weapons before 1967, namely: the USA, Russia (USSR), China, Great Britain, and France. This created a significant divide between states categorized as NWS and those in the NNWS group. Some NNWS were on the brink of testing their nuclear weapons at that time but could not do so if they signed the Agreement. This is why India, Israel, and Pakistan have never accepted being part of the Agreement in any way. Apart from these states, which are considered de facto nuclear-armed states today, other countries accepted the NNWS status and signed the NPT with firm assurances that NWS would aid them in the development of peaceful nuclear programs (Bunn, 2003).

The Treaty sets forth three fundamental goals to which all signatory states should strive: the cessation of nuclear weapons proliferation, the complete disarmament of these weapons, and comprehensive cooperation in the peaceful use of nuclear energy. The agreement defines the fundamental obligations of NWS. The obligations of these five states are not to transfer their weaponry to other states in any manner and not to assist or encourage the development of nuclear programs that could be used for armament purposes. The states in the NNWS group are obliged not to accept offers from other states to participate in the development of programs intended for armament purposes of this kind, nor to accept the transfer of such weaponry from any other state. The Treaty defines the role of the IAEA within the monitoring system. NNWS states undertake to allow a system of control during the production of fissile materials used for peaceful purposes and during their exchange with other states. The Agency commits not to impede the technological and economic prosperity of these states in any way, nor their cooperation in peaceful activities. Each of the signatory parties has the right to withdraw from the NPT if it deems there are extraordinary events that jeopardize the fulfillment of the Agreement.

Comprehensive nuclear-test-ban treaty

Nuclear tests can be categorized into four groups: underwater - in oceans and seas, atmospheric - in the atmosphere, exoatmospheric - above the atmosphere, and underground - beneath the Earth's surface (Wiesner & York, 1964). The Comprehensive Nuclear-Test-Ban Treaty (CTBT) has prohibited all four types of tests.

The agreement is the result of decades-long efforts to establish a ban on testing in order to preserve the environment. Prior to this Agreement, there were other initiatives, but this is the first comprehensive treaty, which is why it is a crucial factor in nuclear security regimes.

The draft of the Agreement was presented on September 10, 1996, by the United Nations General Assembly, and signing followed four days later. All five declared nuclear-armed states signed this document, but despite that, it has not yet come into force. Namely, in addition to signatures, it needs to be ratified, and for it to take effect, it must be signed and ratified by all states that possess any form of nuclear technology within their territories. The total number of states possessing nuclear reactors and using nuclear energy is 44. These are the states listed in Annex 2 of this Agreement. Therefore, it is necessary for all these states to ratify the Agreement for it to come into force. Out of the 44 states listed in Annex 2 of the Agreement, 5 have not ratified the treaty - the USA, China, Iran, Israel, and Egypt. Three states from this annex have not even signed it - North Korea, Pakistan, and India (NTI, 1996). It is precisely these three states that conducted nuclear tests even after the CTBT was open for signing and ratification, which clarifies why these specific states have not even engaged in signing this Agreement.

With this Agreement, all countries are called to stop nuclear testing to prevent nuclear weapon proliferation, which further leads to "the cessation of the arms race and disarmament under strict and effective international control". Through this Agreement document, the member states established the Comprehensive Nuclear-Test-Ban Treaty Organization. The primary purpose of the Organization lies in ensuring the implementation of the agreed upon terms. The headquarters are located in Vienna, and the bodies of the Organization include the Conference of States Parties, the Executive Council, and the Provisional Technical Secretariat, which also encompasses the International Data Centre. The Agreement also defines the conditions for data confidentiality and the exchange of information between the Organization and individual states, as well as the financing of the Organization. The member states fund this body, and any member failing to meet its obligations loses its voting rights.

Furthermore, the Treaty specifies the organizational structure and thoroughly defines various bodies constituting it - the Conference of States Parties, the Executive Council, and the Technical Secretariat, along with their functions, privileges, and immunities. The verification system consists of the International Monitoring System, the Consultation and Clarification Process, on-site inspection, and confidence-building measures. An International Data Centre is introduced, defined as the central hub within the Provisional Technical Secretariat, receiving data from the International Monitoring System or on-site inspections and managing them. The Center supports the System, comprising seismic monitoring stations, radionuclide monitoring, hydroacoustic monitoring, infrasound monitoring, and data transmission capabilities. Furthermore, the Agreement also regulates the rights and obligations of the member states, the modes of withdrawal, the circumstances leading to the denial of rights, and define the depository of the Agreement - the UN Secretary-General.

The Protocol to the Comprehensive Nuclear-Test-Ban Treaty elaborates further on the functions of the International Monitoring System and the International Data Centre (NTI, 1996; Ahn et al, 2021).

Bilateral agreements between the USA and the USSR (today's Russia)

Bilateral agreements, as a type of a nuclear security regime, have been primarily signed between the United States of America and the USSR (today's Russia), the two states that engaged most intensely in the race for nuclear power. These states possess the largest number of nuclear warheads (Akiyama, 2020), making them the two most powerful nuclear nations in the world. Any agreement between them would result in changes to the international landscape. In this context, the agreements reached between the United States of America and the USSR (Russia) represents significant security outcomes, even though they do not encompass the entire international community; rather, their adherence is conditioned by the bilateral relationship between the two sides.

To this day, these two states have signed a series of bilateral agreements concerning the cessation of the nuclear arms race and the reduction of the number of nuclear missiles. Some agreements never came into force. The first agreement, named SALT I, was signed in 1972. This was followed by the ABM Treaty, signed on the same date as SALT I, and then the TTBT, signed in 1974, which came into force in 1990, and SALT II, signed in 1979, but never came into force as the USA side never ratified it in protest of the Soviet war in Afghanistan. The INF Treaty was agreed upon in 1987, came into force the following year, and was fully

implemented by 1991. In 1991, when a new climate in the relations between the two countries emerged, START I was signed, replacing the SALT agreements. It came into force in 1994. After the dissolution of the USSR in 1991, it was necessary to define which state succeeded the former state's nuclear program. This was agreed upon through the Lisbon Protocol, signed in 1992 (Kurosawa, 2021), which allowed the implementation of the new situation in the East within the framework of START I. Belarus, Kazakhstan, and Ukraine renounced nuclear weapons through the Protocol and committed to joining the NPT. Russia was declared the successor to the former state's nuclear program. In 1993, START II was signed, but it never came into force. The deadline for fulfilling the agreed conditions was the end of 2003. Due to the dynamics of meeting these conditions, it was agreed in 1997 to extend the deadline until the end of 2007. At that time, the parties envisaged the signing of the START III agreement in 2007. Meanwhile, in 2002, the SORT or Moscow Treaty, as it is alternatively known, was signed, along with the Declaration on Strategic Partnership between the United States and the Russian Federation. This agreement marked the end of the "START" agreements, so START III remained in the plan and was never realized. The "New START" is the latest agreement in this series, signed in 2010 and coming into force in 2011 (Akiyama, 2020; Kurosawa, 2021; Puentes et al, 2020).

SALT I – Strategic Arms Limitation Talks "freezes" the current state in terms of the number of strategic nuclear missiles until an agreement is reached for the complete elimination of nuclear weapons (Kurosawa, 2021).

ABM or ABMT – Anti-Ballistic Missile Treaty limits the development of anti-ballistic missile systems of the two countries. The agreement restricts the number of anti-ballistic missiles to a maximum of 100. It was valid for 30 years and is believed to have prevented the placement of anti-ballistic missile systems in space. The United States withdrew from the agreement in 2002 and established the Missile Defense Agency, ending the validity of the agreement. Along with the agreement, the idea called MAD – Mutually Assured Destruction came into effect. This idea predicted that if one country launched a nuclear attack on another, the other country had the right to respond in kind, without any attempts by the first country to defend itself. Thus, this idea guaranteed equal damage in the event of a nuclear conflict.

TTBT – Threshold Test Ban Treaty restricts the yield of underground nuclear tests to 150 kt considering that there was already a Partial Test Ban Treaty in place at that time, which will be discussed in the next chapter. It can be concluded that this treaty slowly led to the CTBT.

INF – Intermediate-range Nuclear Forces Treaty is an agreement to eliminate all missiles with ranges between 500 and 5500 km. This includes all ballistic and land-launched cruise missiles. Submarine-launched missiles are not covered by this agreement. Since 2014, both sides have made mutual accusations of violating the INF Treaty. The USA finally withdrew from the treaty in 2019, blaming Russia as the main culprit for this course of events (Akiyama, 2020; Kurosawa, 2021; Puentes et al, 2020).

Since the dissolution of the USSR, four more agreements have been signed: START I, START II, SORT, and New START. START stands for Strategic Arms Reduction Treaty and, as already mentioned, aimed to replace the SALT agreements, which did not meet expectations. Each of the START agreements had the same significance and similar goals: primarily reducing and then limiting the number of strategic nuclear missiles of both parties to prevent further growth. It was envisaged that the parties would agree on deadlines for achieving specific tasks regarding the reduction of warheads, and then after a certain period, agree on new tasks, continuing until the last nuclear missile was eliminated. However, it is evident that there is no serious political will for this, so we must wait and see what the last agreed-upon treaty, called New START, will bring. It was expected to fulfill its obligations by February 2021 or be extended until 2026. During those years, the USA sought to include China in the Treaty from 2021, considering China a threat due to its close cooperation with Russia and the development of more advanced ICBMs by China (Akiyama, 2020). However, this did not happen. The treaty was extended for another 5 years in 2021, but in the meantime (2023) President Putin suspended it due to the USA involvement in the war in Ukraine (Bugos, 2023).

International Convention for the Suppression of Acts of Nuclear Terrorism

The International Convention for the Suppression of Acts of Nuclear Terrorism (CNT) (United Nations, 2005) was opened for signature in September 2005 at the United Nations and entered into force in July 2007. Its purpose is to criminalize acts of nuclear terrorism, define measures for sanctioning involved parties in case of such acts, and enhance cooperation between investigative and enforcement authorities to prevent and combat nuclear terrorism, one of the most undesirable forms of terrorism. Currently, the Convention has been signed by 115 parties and has 120 state participants (NTI, 2005).

The agreement covers a wide range of potential attacks and targets, including nuclear facilities such as nuclear reactors. Threats and attempts to commit crimes are defined, as well as the concept of complicity in case of nuclear terrorism acts, and the methods of sanctioning each of these offenses are outlined. States parties are encouraged to collaborate, as well as to conclude bilateral or multilateral regional agreements aimed at countering all forms of nuclear terrorism. The Convention calls for information sharing, police assistance, peaceful conflict resolution, and crisis management support.

The IAEA is guaranteed to provide assistance under the Convention in dealing with crises related to nuclear terrorism and the removal of undesirable radioactive materials from the territory of an affected state. The Secretary-General of the United Nations is appointed as the depositary.

The Convention is a result of states efforts to enhance international cooperation to prevent acts of nuclear terrorism and was enacted for this purpose. Moreover, the Convention aims to curb cooperation between states and terrorist organizations in terms of the use of any nuclear isotopes or weapons employing such isotopes. This approach prevents secret state actions through terrorist organizations and thus helps to prevent the escalation of conflicts between nuclear powers.

Remaining agreements that can be classified within nuclear security regimes

There is a whole range of agreements that cannot be directly classified as nuclear security regimes due to their nature, primarily because they were established to regulate other contentious issues in the field of international law. Issues related to nuclear weapons are only mentioned in certain articles of these documents and pertain to resolving nuclear weapon matters within the framework of another larger international dispute, the resolution of which involves the enactment of agreements. On the other hand, there are agreements that address specific nuclear security issues, but their uniqueness, which prevents us from describing them as part of the current security regimes, lies in the fact that they have been supplemented over time and accepted by the international community in the form of new comprehensive agreements.

The Antarctic Treaty, along with other agreements related to Antarctica, is part of the Antarctic Treaty System (ATS). This document defines Antarctica as an uninhabited continent encompassing the entire landmass and all ice-covered areas south of 60° south latitude. The Antarctic Treaty was opened for signature in 1959, and to this day, a total

of 53 states have signed it (NTI, 1959). In a way, this document represents the first nuclear security regime. Specifically, it prohibits military activity on the continent's territory, particularly nuclear explosions and the storage of nuclear waste on the Antarctic land. Therefore, this is the first agreement that prohibits the use of nuclear weapons in a specific region, making it partly a security regime.

The Partial Nuclear Test Ban Treaty (PTBT) was adopted in 1963. The full title of this document is the Treaty Banning Nuclear Tests in the Atmosphere, in Outer Space, and Under Water. As the full title of the Treaty suggests, it essentially serves as a document that prohibits three out of the four mentioned types of nuclear tests: atmospheric, exoatmospheric, and underwater. However, the Treaty did not ban underground tests, so nuclear testing not only did not cease but continued even more intensively, with the exception that tests were conducted only below the Earth's surface. The Treaty defines two groups of tests that are prohibited: a) atmospheric, and b) all tests conducted in any other environment if there is a possibility of nuclear waste dispersal beyond the borders of the testing state. Of course, it is clear that exoatmospheric and underwater nuclear tests fall into this second category. Furthermore, the Treaty states that this prohibition does not prejudge the ban on underground tests, aiming for a comprehensive prohibition of nuclear tests.

The Outer Space Treaty, formally known as the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies, was presented in late 1966 and adopted on October 10, 1967. The adoption of this treaty was preceded by significant diplomatic efforts, primarily between the United States of America and the Soviet Union (Johnson-Freese, 2017), as well as among all nuclear powers and other states worldwide. From the beginning of the Cold War, politicians from both sides recognized the potential of space and the possibilities that placing nuclear weapons in Earth's orbit, on the Moon, and other celestial bodies could bring. When the Soviet Union successfully launched the first artificial satellite into Earth's orbit in 1957, certain factions in the United States, influenced by this event and fearing that the Soviet Union could pose a threat given its achievement in conquering part of space, urged then-President Eisenhower to initiate a program that would lead to the deployment of nuclear missiles in space. Eisenhower rejected this idea and began advocating for the use of space exclusively for peaceful and scientific purposes before the international community (Vlajnić, 2015). Following that, several resolutions and declarations were adopted over the next

decade that eventually led to the formulation of the Outer Space Treaty. The specificity of this document is that it does not strictly pertain to nuclear weapons, but rather to all forms of military technology. However, it is evident that it was primarily adopted due to nuclear weapons, as emphasized in Article IV, which prohibits nuclear weapons.

The Treaty on the Prohibition of the Emplacement of Nuclear Weapons and Other Weapons of Mass Destruction on the Sea-Bed and the Ocean Floor and in the Subsoil thereof, commonly referred to as the Seabed Treaty, adopted in 1971, is also one of the security regimes introduced to prevent the spread of nuclear weapons to undesirable areas and to avoid further environmental contamination. It pertains to a specific area and is introduced to protect a part of the living world. In the preamble of the Treaty, the contracting parties are encouraged to engage in peaceful research of marine and oceanic areas. On the other hand, they are called upon to halt the arms race in nuclear weapon development, which is the context of this document. The Treaty is considered a step forward toward ultimate disarmament. All signatory states are prohibited from storing nuclear weapons or any weapons of mass destruction on the seabed or beneath its surface. Therefore, this treaty also does not explicitly focus on nuclear weapons, but it is more than clear that it was introduced primarily due to this type of weaponry, which can be inferred by analogy with the Space Treaty.

The Agreement Governing the Activities of States on the Moon and Other Celestial Bodies, commonly referred to as the Moon Agreement, from 1979, could be seen as a supplement to the Outer Space Treaty, providing more precise definitions of obligations regarding the use of the Moon. The Moon Agreement, in a way, "fills in legal gaps" that existed within the Outer Space Treaty.

The Fissile Material Cutoff Treaty (FMCT) is one of the agreements that remained only in proposal. The first proposal for such a treaty was put forward in 1993 by then-President of the United States, Bill Clinton. Several ideas were suggested regarding this agreement, either by the United States of America or Russia, but none was accepted. Such a treaty would ban the production of certain fissile materials known to be used as fuel in nuclear bombs. The challenges mainly arise in defining nuclear fuels used for military purposes. Even today, a clear proposal for this treaty does not exist, despite several attempts to reach an agreement.

This is one of the main topics of the Conference on Disarmament (CD), established in 1995 following the adoption of UN Resolution 48/75L. The resolution calls for the elimination of fissile materials used for nuclear weapons. The CD deals with the elimination of all types of weapons of

mass destruction and has made multiple attempts to present the FMCT. In 2006, the International Panel on Fission Materials (IPFM) was even established with the purpose of promoting nuclear disarmament and the cessation of production of fissile materials used for military purposes. In 2009, this body presented its version of the FMCT, which somewhat represents the organization's statute. The organization consists of numerous experts in the field of nuclear physics from a total of 18 countries, including the United States of America and Russia (NTI, 2024).

It is unfortunate that the treaty has not come into force within the framework of the UN. However, many conditions of the Nuclear Non-Proliferation Treaty (NPT) and other security regimes call on states to refrain from producing highly enriched uranium and plutonium used for the construction of atomic and thermonuclear bombs. In a way, this makes the treaty somewhat redundant. It is also important to note that the International Atomic Energy Agency (IAEA) has mechanisms through which it can detect the production of prohibited fuels through its inspectors, as will be discussed in the following chapter.

The Nuclear-Weapons-Free Zones (NWFZ) is also part of the group of security regimes. This group includes The Antarctic Treaty, the Outer Space Treaty, and the Seabed Treaty, among others. However, due to the fact that these zones are uninhabited, they can also be regarded as distinct agreements. In a narrower sense, the NWFZ includes: the Treaty for the Prohibition of Nuclear Weapons in Latin America, commonly known as the Treaty of Tlatelolco from 1967, the South Pacific Nuclear-Free-Zone Treaty, also known as the Treaty of Rarotonga from 1985, the Southeast Asian Nuclear-Weapon-Free Zone Treat or Treaty of Bangkok from 1995, the African Nuclear-Free-Zone Treaty, known as the Treaty of Pelindaba from 1996, and the Central Asian Nuclear-Weapon-Free Zone Treaty, also known as the Treaty of Semipalatinsk from 2006. As the names of these agreements suggest, they establish certain regions, in consultation with the nations in those regions, as zones free of any form of nuclear energy-related military application (United Nations, 2006; IAEA, 2015).

The Treaty on the Prohibition of Nuclear Weapons (TPNW) is the latest addition to the series of international nuclear security regimes. The treaty was opened for signing in 2017 and came into effect in 2021. In comparison to previous agreements, this treaty takes an extremely radical approach towards the complete elimination of nuclear weaponry (Ruff, 2022). It appears that this regime lacks significant influence, as none of the nuclear-armed states, whether recognized (NWS) or unrecognized (India, Pakistan, North Korea, and Israel), participate in it.

IAEA as the guarantor of the regime implementation

"The IAEA (International Atomic Energy Agency) is an international organization that serves as the leading global intergovernmental forum for coordinating scientific and technical cooperation in the peaceful use of nuclear energy and nuclear technologies. It also operates as an international inspectorate for the implementation of nuclear inspection measures, verifying activities related to civil nuclear programs. Established in 1957 as an independent organization under the umbrella of the United Nations, it now encompasses a wide range of services, programs, and activities based on the needs of its 176 member states. The Agency, headquartered in Vienna, has offices at the UN in New York, Rome, and Geneva, inspection offices in Toronto and Tokyo, and laboratories in Austria and Monaco. It also supports a research center in Trieste under the auspices of UNESCO. The strategy and policies of the Agency are determined based on the recommendations from the Board of Governors at the General Conference. The Secretariat, led by a Director-General and six Deputy Directors-General responsible for specific areas, manages the implementation of programs and activities" (IAEA, 2023).

IAEA inspection oversight

The inspection system, in a way, represents the executive body within nuclear security regimes. The establishment of the inspection system was awaited for two years after the founding of the Agency. It was agreed upon in Canada in 1959; however, the document regulating the functioning of this body was awaited for just as long. In 1961, the first document was signed, regulating the procedures for the application and instructions for the work of IAEA inspectors. This document is known as INFCIRC/26, and after an amendment in 1965, it was introduced as INFCIRC/66 (IAEA, 2015; Alger, 2008).

When the Treaty on the Non-Proliferation of Nuclear Weapons came into force in 1970, conditions were created for the Agency to take "decisive" actions, which in 1971 led to the introduction of a new INFCIRC/153 inspection document, primarily introducing Comprehensive Safeguards Agreements (CSA). It defined the manner of cooperation between the Agency and the signatory states, especially non-nuclear-weapon states that have nuclear energy facilities for peaceful purposes. By signing the document, these states committed to Comprehensive Inspection Oversight by the IAEA on their territory and to provide inspectors with all information related to nuclear facilities and the use of radioactive materials in any area (IAEA, 2015; Alger, 2008).

Due to the Agency's inability, along with its inspectors, to respond to the challenges posed before it, there arose a need to introduce the Additional Protocol (INFCIRC/540) within the mechanisms implemented in order to respect the NPT. This Protocol expands the authorities of the Agency and its inspectors, granting greater rights to significant information and facilitating the detection of prohibited nuclear activities. The Additional Protocol was adopted in 1997 (IAEA, 2015).

Methods for detecting unauthorized activities

The inspection oversight system involves the application of various methods to detect and verify events that imply the occurrence of separation or any misuse of nuclear materials listed as prohibited and potentially usable for nuclear weapon production.

Materials of interest to inspectors are commonly referred to as special fissile materials. These usually include uranium isotopes 233 and 235, and plutonium-239. Some of these are naturally occurring, while others are artificially produced. For example, uranium-235 is found in small amounts in spent nuclear fuel. The process known as separation is used to obtain these isotopes of interest in a form necessary for the creation of the nuclear bomb core (IAEA, 2015). Separation is a complex and expensive method and has been a stumbling block for anyone attempting nuclear weapon production.

Each radioactive element leaves its unique signature on the environment when present. These are the traces used by nuclear forensics (Mayer et al, 2013; Ilić et al, 2022), to determine whether there has been production of a radioactive isotope, its use (López-Lora et al, 2023), or a nuclear test (Child & Hotchkis, 2013) in a particular space.

To detect the existence of these prohibited isotopes within a country's territory, inspectors utilize a range of methods, specifically detector tools that have significantly improved with technological advancements in recent years. Methods for detecting "special" fissile materials include: Environmental sampling for safeguards (ESS), Multi-channel analyzers (MCA), Alloy detectors (ALEX), Environmental monitoring instruments, Digital video surveillance systems, Satellite imagery, and Inspection Database (Donohue, 2002).

For uncovering unauthorized radioactive materials, the methods using environmental samples (ESS) include: High-resolution gamma spectrometry (HRGS), X-ray fluorescence spectrometry (XRF), Scanning electron microscopy electron/X-ray fluorescence spectrometry (SEM/XRF), Thermal ionization mass spectrometry (TIMS), and

Secondary ion mass spectrometry (SIMS). All these methods use dust samples collected from areas near the tested facility (Donohue, 2002).

Essentially, as almost all countries have agreed to the conditions of the Treaty on the Non-Proliferation of Nuclear Weapons, it is expected that the reports submitted by states are in line with the agreed-upon terms, and that no one would report nuclear activities prohibited by the Treaty, as they are committed otherwise. Thus, the inspector's role is to determine whether any signatory state is secretly pursuing nuclear program development. Inspectors effectively engage in accounting tasks, as they monitor the field's status and compare it with the reports from states and the records maintained by authorities overseeing nuclear facilities. In the past, numerous unauthorized activities were detected, but with the introduction of the Additional Protocol and reinforcement of other measures, they have significantly diminished. It is worth noting that participation in the Treaty and the Agency is voluntary, meaning the Agency lacks jurisdiction over territories of non-signatory or suspended states. A clear example is North Korea.

In addition to all these methods for monitoring the implementation of the Comprehensive Nuclear-Test-Ban Treaty, seismic methods are used to monitor ground tremors to identify those caused by nuclear tests (Sykes & Evernden, 1982). Various methods are also employed to avoid data manipulation and potential deception, which could undermine the regime and its effectiveness (He et al, 2021).

Discusions and conclusions

Since there are no absolute parameters determining the success of regimes, conclusions have to be drawn about their effectiveness from the available data, compared to projections related to the spread of nuclear weapons. Here, this part will deal with the number of nuclear warheads in the world, as well as with the conducted tests up to now. These two pieces of information are currently the only relevant parameters for evaluating the success of security regimes.

Estimating the number and trend of growth of nuclear warheads as a parameter of the effectiveness of the NPT

The current estimate of the number of warheads worldwide, through an overview of the status in individual states possessing this type of weaponry, is presented in the graph shown in Figure 1 (SIPRI, 2023). The total number of warheads has been decreasing for several years. This is primarily happening due to the United States of America and Russia, the

countries that are reducing their arsenals in accordance with bilateral agreements, as well as with their efforts to modernize their arsenals. Other nuclear powers are slightly increasing the number of nuclear warheads. Out of all, China stands out the most in this trend. In 2014, China had 250 nuclear warheads, but today, it possesses 410 warheads.

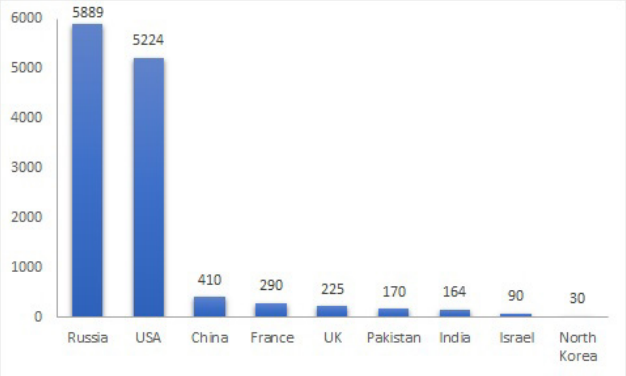

Figure 1 – Number of nuclear warheads per country today

The decreasing trend in the last 5 years is shown in the graph in Figure 2 (SIPRI, 2023).

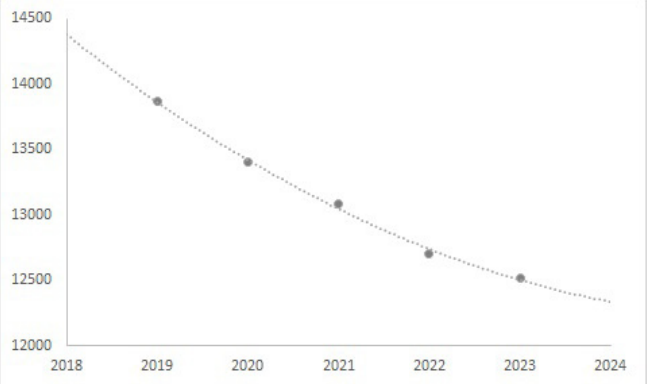

Figure 2 –Trend of decreasing the total number of nuclear warheads in the last 5 years (SIPRI, 2023)

The reduction trend for Russia and the USA was much more significant 10-15 years ago. Now, the decrease is occurring at a much

slower pace. This is likely influenced by the lack of trust and tensions that have persisted in the last few years (SIPRI, 2023).

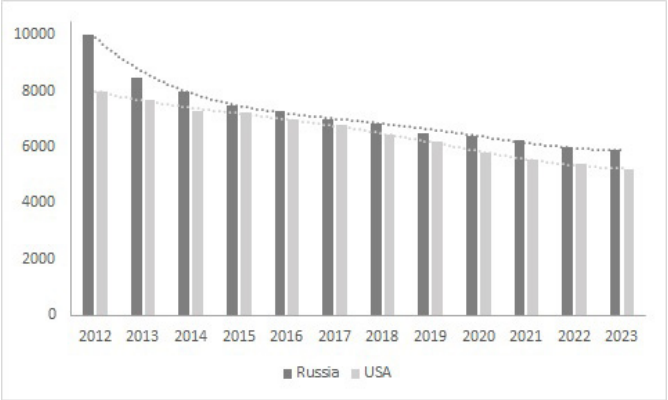

Figure 3 – Trend of reducing the number of warheads for Russia and the USA for period 2012-2023 (SIPRI, 2023)

Taking into consideration everything that has been mentioned, the impression arises that the regimes led by the NPT have not been particularly efficient in reducing nuclear armaments. However, considering that, at the time of the NPT's introduction, it was projected that by the year 1990, a total of 25-30 states would possess nuclear weapons (Carlson, 2005), today, over 20 years after that projected date, there are only 5 NWS along with an additional 4 states possessing nuclear warheads, most of which were on the brink of discovery. It is clear that the NPT, along with other regimes, has played a significant role in curbing the spread of nuclear weaponry.

Nuclear tests as an indicator of regime respect, foremost the CTBT

After World War II and throughout the Cold War era, nuclear weapons testing was a common practice to determine the effectiveness of specific weaponry and, likely even more so, to showcase power to other players participating in the race. There is indeed a vast number of studies, both older (Carter & Moghissi, 1977) and more recent ones (Gillies & Haylock, 2022), that address the impact of radionuclides resulting from nuclear tests on the natural world (Johansen et al, 2020; Prăvălie, 2014), as well as on humans specifically (Drozdovitch et al, 2021; Simon et al, 2006), not only

in terms of health but also concerning other essential factors that again influence human health deterioration (Riad et al, 2023) and the well-being of other living beings (Bouville, 2020).

To this day, over 2000 nuclear tests have been conducted, with the majority carried out by the United States of America (1032) and Russia (715). Most of these tests took place in the northern hemisphere of the Earth, while the number of nuclear tests in the southern hemisphere is almost negligible. This is somewhat expected, given that a significant portion of the southern hemisphere belongs to nuclear-free zones. In addition to the United States of America and Russia, nuclear tests were conducted by France (210), the United Kingdom (45), China (45), India (3), Pakistan (2), and North Korea (7). Other countries had some attempts at nuclear tests, but the only successful one was conducted in 1979. It took place in the Indian Ocean under the auspices of the governments of South Africa and Israel. After this event, South Africa abandoned its nuclear program. Although Israel has never been proven to possess nuclear weapons, it has unofficially been confirmed that the country holds a "serious" nuclear arsenal. The highest number of tests, a total of 178, was conducted in 1962 (Bergkvist & Ferm, 2000; United Nations, 2024).

Therefore, since the entry into force of the CTBT, 10 nuclear tests have been carried out. Of these 10, India and Pakistan each conducted two, while North Korea conducted 6 (United Nations, 2024). The tests by India and Pakistan are a result of their long-standing animosity. Specifically, these were the first two successful tests for Pakistan, and as India is in constant conflict with Pakistan, it also conducted two more tests (in addition to the one in 1974) to demonstrate its power. After these events, international pressure was exerted, and both India and Pakistan ceased testing, pledging to refrain from any form of nuclear weapon rattling. After 1998, only North Korea conducted tests in 2003, 2006, 2009, 2013, 2016, and 2017. The frequency of these tests diminished after 2017. A year earlier, North Korea successfully tested a thermonuclear bomb for the first time (Kristensen & Korda, 2022) . North Korea likely halted testing due to a combination of two factors: continuous UN pressure accompanied by sanctions and a relatively limited number of nuclear warheads (30) compared to other states possessing this type of weaponry.

Considering all of the above, it can be concluded that the CTBT is the most successful international security regime. However, the Agreement did not come about due to states' efforts to reduce the number of nuclear warheads worldwide but exclusively due to significant pressure from the scientific community, which recognized the harmfulness of tests and their impact on the environment (Carter & Moghissi, 1977).

References

Ahn, J., Park, J., Sim, H., An, G. & Seo, H. 2021. Design requirements of safeguards sealing system for real-time verification. *Nuclear Technology & Radiation Protection,* 36(4), pp.376-383. Available at: https://doi.org/10.2298/NTRP2104376A.

Akiyama, N. 2020. Nuclear weapons: arms-control efforts need China. *Nature,* 584, pp.40-42. Available at: https://doi.org/10.1038/d41586-020-02282-9.

Alger, J. 2008. A Guide to Global Nuclear Governance: Safety, Security and Nonproliferation. *Cigionline.org.* Available at: h https://www.cigionline.org/static/documents/a_guide_to_nuclear_power.pdf [Accessed: 15. January 2024].

Andrews, S.A., Andrews, M.T. & Mason, T.E. 2021. Canadian Contributions to the Manhattan Project and Early Nuclear Research. *arXiv:2103.08582*, 15 March. Available at: https://doi.org/10.48550/arXiv.2103.08582.

Beck, H.L., Simon, S.L., Bouville, A. & Romanyukha, A. 2020. Accounting for Unfissioned Plutonium from the Trinity Atomic Bomb Test. *Health Physics,* 119(4), pp.504-516. Available at: https://doi.org/10.1097/HP.0000000000001146.

Bergkvist, N.-O. & Ferm, R. 2000. *Nuclear Explosions 1945 - 1998.* Stockholm, Sweden: Defence Research Establishment, Div. of Systems and Underwater Technology [online]. Available at: https://inis.iaea.org/search/search.aspx?orig_q=RN:31060372 [Accessed: 15. January 2024].

Boice, J.D., Cohen, S.S., Mumma, M.T., Chen, H., Golden, A.P., Beck, H.L. & Till, J.E. 2022. Mortality among U.S. military participants at eight aboveground nuclear weapons test series. *International Journal of Radiation Biology,* 98(4), pp.679-700. Available at: https://doi.org/10.1080/09553002.2020.1787543.

Bouville, A. 2020. Fallout from Nuclear Weapons Tests: Environmental, Health, Political, and Sociological Considerations. *Health Physics,* 118(4), pp.360-381. Available at: https://doi.org/10.1097/HP.0000000000001237.

Bugos, S. 2023. Russia Suspends New START. *Arms Control Association,* March [online]. Available at: https://www.armscontrol.org/act/2023-03/news/russia-suspends-new-start [Accessed: 15. January 2024].

Bunn, G. 2003. The Nuclear Nonproliferation Treaty: History and Current Problems. *Arms Control Association* [online]. Available at: https://www.armscontrol.org/act/2003_12/Bunn [Accessed: 15. January 2024].

Carlson, J. 2005. Safeguards and Non-Proliferation: Current Challenges and the Implications for Australia. In: *Conference of the Australian Nuclear Association,* Sydney, Australia, pp.1-9, November 10 [online]. Available at: https://www.dfat.gov.au/sites/default/files/2005_060201_safeguards_presentation.pdf [Accessed: 15. January 2024].

Carter, M.W. & Moghissi, A.A. 1977. Three Decades of Nuclear Testing. *Health Physics,* 33(1), pp.55-71. Available at: https://doi.org/10.1097/00004032-197707000-00006.

Chadwick, M.B. 2021. Nuclear Science for the Manhattan Project and Comparison to Today's ENDF Data. *Nuclear Technology,* 207(1), pp.24-61. Available at: https://doi.org/10.1080/00295450.2021.1901002.

Child, D.P. & Hotchkis, M.A.C. 2013. Plutonium and uranium contamination in soils from former nuclear weapon test sites in Australia. *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms,* 294, pp.642-646. Available at: https://doi.org/10.1016/j.nimb.2012.05.018.

Cooper, A.R. 2023. Inspectors for Peace: A History of the International Atomic Energy Agency by Elisabeth Roehrlich (review). *Technology and Culture,* 64(1), pp.254-256. Available at: https://doi.org/10.1353/tech.2023.0046.

Coupe, J., Bardeen, C.G., Robock, A. & Toon, O.B. 2019. Nuclear Winter Responses to Nuclear War Between the United States and Russia in the Whole Atmosphere Community Climate Model Version 4 and the Goddard Institute for Space Studies ModelE. *JGR Atmospheres,* 124(15), pp.8522-8543. Available at: https://doi.org/10.1029/2019JD030509.

D'auria, F.S. & Galassi, G.M. 2019. The Best Estimate Plus Uncertainty approach in nuclear reactor safety and licensing: Brief history and the elements after licensing. *Nuclear Technology & Radiation Protection,* 34(3), pp.299-312. Available at: https://doi.org/10.2298/NTRP190413022D.

Donohue, D.L. 2002. Key Tools for Nuclear Inspections. *IAEA Bulletin*, 44-2, June, pp.17-23 [online]. Available at: https://www.iaea.org/publications/magazines/bulletin/44-2/key-tools-nuclear-inspections [Accessed: 15. January 2024].

Drozdovitch, V., Bouville, A., Taquet, M., Gardon, J., Tetuanui, T., Xhaard, C., Ren, Y., Doyon, F. & de Vathaire, F. 2021. Thyroid Doses to French Plynesians Resulting from Atmospheric Nuclear Weapons Tests: Estimates Based on Radiation Measurements and Populatin Lifestyle Data. *Health Physics,* 120(1), pp.34-55. Available at: https://doi.org/10.1097/HP.0000000000001262.

Gale, R.P. & Armitage, J.O. 2018. Are We Prepared for Nuclear Terrorism? *The New England Journal of Medicine,* 378(13), pp.1246-1254. Available at: https://doi.org/10.1056/NEJMsr1714289.

Gillies, M. & Haylock, R.G.E. 2022. Mortality and cancer incidence 1952–2017 in United Kingdom participants in the United Kingdom's atmospheric nuclear weapon tests and experimental programmes. *Journal of Radiological Protection,* 42(2), art.number:021507. Available at: https://doi.org/10.1088/1361-6498/ac52b4.

Hain, K., Steier, P., Froehlich, M.B., Golser, R., Hou, X., Lachner, J., Nomura, T., Qiao, J., Quinto, F. & Sakaguchi, A. 2020. $^{233}U/^{236}U$ signature allows to distinguish environmental emissions of civil nuclear industry from weapons fallout. *Nature Communications,* 11, art.number:1275. Available at: https://doi.org/10.1038/s41467-020-15008-2.

He, Q.-H., Li, T., He, X.-S., Lu, K.-K. & Wang, S.-K. 2021. A physically cryptographic hoteling observer for nuclear warhead verification. *Nuclear*

Technology & Radiation Protection, 36(4), pp.358-363. Available at: https://doi.org/10.2298/NTRP2104358H.

-IAEA International Atomic Energy Agency. 1970. Treaty on the Non-Proliferation of Nuclear Weapons*. IAEA.org (Information Circular)* [online]. Available at: https://www.iaea.org/sites/default/files/publications/documents/infcircs/1970/infcirc140.pdf [Accessed: 15. January 2024].

-IAEA International Atomic Energy Agency. 2015. IAEA Safeguards: Serving Nuclear Non-Proliferation. *IAEA.org* [online]. Available at: https://www.iaea.org/sites/default/files/safeguards_web_june_2015_1.pdf [Accessed: 15. January 2024].

-IAEA International Atomic Energy Agency. 2022. IAEA and the Non-Proliferation Treaty. *IAEA.org* [online]. Available at: https://www.iaea.org/topics/non-proliferation-treaty [Accessed: 15. January 2024].

-IAEA International Atomic Energy Agency. 2023. IAEA International Atomic Energy Agency: About us. *IAEA.org* [online]. Available at: https://www.iaea.org/about [Accessed: 10. July 2023].

-IAEA International Atomic Energy Agency. 2024. Fact Sheet on DPRK Nuclear Safeguards. *IAEA.org* [online]. Available at: https://www.iaea.org/newscenter/focus/dprk/fact-sheet-on-dprk-nuclear-safeguards [Accessed: 15. January 2024].

Ilić, S., Radovanović, R., Milić, S., Aleksić, A. & Ivković, A. 2022. Nuklearna forenzika - metode za otkrivanje procesa proizvodnje, prometovanje i krijumčarenje nedozvoljenih fisionih materijala. In: *Proceedings of LXVI Conference ETRAN 2022*, Novi Pazar, Serbia, June 6-9 [online]. Available at: https://www.etran.rs/2022/zbornik/ETRAN-22_radovi/SSFO1.4.pdf (in Serbian) [Accessed: 15. January 2024]. ISBN: 978-86-7466-930-3.

Johansen, M.P., Child, D.P., Hotchkis, M.A.C., Johansen, A., Thiruvoth, S. & Whiting, S.D. 2020. Radionuclides in sea turtles at the Montebello Islands former nuclear test sites: Current and historical dose rates for adults and embryos. *Marine Pollution Bulletin,* 158, art.number:111390. Available at: https://doi.org/10.1016/j.marpolbul.2020.111390.

Johnson-Freese, J. 2017. Build on the outer space treaty. *Nature,* 550, pp.182-184. Available at: https://doi.org/10.1038/550182a.

Krass, A.S., Boskma, P., Elzen, B. & Smit, W.A. 2002. *Uranium Enrichment and Nuclear Weapon Proliferation (Routledge Library Editions: Nuclear Security), 1st Edition.* London, UK: Routledge. ISBN: 978-0367523374.

Kristensen, H. & Korda, M. 2022. North Korean nuclear weapons, 2022. *Bulletin of the Atomic Scientists,* 78(5), pp.273-294. Available at: https://doi.org/10.1080/00963402.2022.2109341.

Kurosawa, M. 2021. Progress in Nuclear Disarmament during the 50 Years of the NPT. *Osaka University Law Review,* 68, pp.1-24 [online]. Available at: https://ir.library.osaka-u.ac.jp/repo/ouka/all/78529/oulr068-001.pdf [Accessed: 15. January 2024].

Leikin, J.B., McFee, R.B., Walter, F.G. & Edsall, K. 2003. A primer for nuclear terrorism. *Disease-a-Month,* 49(8), pp.485-516. Available at: https://doi.org/10.1016/S0011-5029(03)00100-7.

López-Lora, M., Olszewski, G., Chamizo, E., Törnquist, P., Pettersson, H. & Eriksson, M. 2023. Plutonium Signatures in a Dated Sediment Core as a Tool to Reveal Nuclear Sources in the Baltic Sea. *Environmental Science & Technology,* 57(5), pp.1959-1969. Available at: https://doi.org/10.1021/acs.est.2c07437.

Mayer, K., Wallenius, M. & Varga, Z. 2013. Nuclear Forensic Science: Correlating Measurable Material Parameters to the History of Nuclear Material. *Chemical Review,* 113(2), pp.884-900. Available at: https://doi.org/10.1021/cr300273f.

Mianji, F.A., Karimi, D.J. & Kardan, M.R. 2013. Internal dose assessment for environmental monitoring in nuclear power plant accidents. *Nuclear Technology & Radiation Protection,* 28(3), pp.325-331. Available at: https://doi.org/10.2298/NTRP1303325M.

Nikač, Ž.V., Stanković, S.J. & Radović, N.D. 2022. Legislative framework of nuclear security in the Republic of Serbia. *Nuclear Technology & Radiation Protection,* 37(3), pp.241-252. Available at: https://doi.org/10.2298/NTRP2203241N.

-NTI Nuclear Threat Initiative. 1959. Antarctic Treaty. *NTI.org*, 1 December [online]. Available at: https://www.nti.org/education-center/treaties-and-regimes/antarctic-treaty/ [Accessed: 15. January 2024].

-NTI Nuclear Threat Initiative. 1996. Comprehensive Nuclear Test Ban Treaty (CTBT). *NTI.org*, 24 September [online]. Available at: https://www.nti.org/education-center/treaties-and-regimes/comprehensive-nuclear-test-ban-treaty-ctbt/ [Accessed: 15. January 2024].

-NTI Nuclear Threat Initiative. 2005. International Convention on the Suppression of Acts of Nuclear Terrorism. *NTI.org*, 13 April [online]. Available at: https://www.nti.org/education-center/treaties-and-regimes/international-convention-suppression-acts-nuclear-terrorism/ [Accessed: 15. January 2024].

-NTI Nuclear Threat Initiative. 2024. FMCT: Proposed Fissile Material (Cut-off) Treaty (FMCT). *NTI.org* [online]. Available at: https://www.nti.org/education-center/treaties-and-regimes/proposed-fissile-material-cut-off-treaty/ [Accessed: 15. January 2024].

Prăvălie, R. 2014. Nuclear Weapons Tests and Environmental Consequences: A Global Perspective. *AMBIO,* 43(6), pp.729-744. Available at: https://doi.org/10.1007/s13280-014-0491-1.

Puentes, D., Kuhn, M.J., Boodoo, C., Smith, K.R. & Young, N.T. 2020. White Paper: The Possible Expiration of the New START, the Last Nuclear Bilateral Treaty Between the United States and the Russian Federation. *Journal of Science Policy & Governance,* 16(1), 13 April [online]. Available at: https://www.sciencepolicyjournal.org/article_1038126_jspg_16_01_09.html [Accessed: 15. January 2024].

Reed, B.C. 2015. Nuclear weapons at 70: reflections on the context and legacy of the Manhattan Project. *Physica Scripta,* 90(8), art.number:088001. Available at: https://doi.org/10.1088/0031-8949/90/8/088001.

Riad, A., Drobov, A., Alkasaby, M.A., Peřina, A. & Koščik, M. 2023. Nuclear Anxiety Amid the Russian-Ukrainian War 2022 (RUW-22), Descriptive Cross-Sectional Study. *International Journal of Environmental Research Public Health,* 20(4), art.number:3551. Available at: https://doi.org/10.3390/ijerph20043551.

Ruff, T.A. 2022. Ending nuclear weapons before they end us: current challenges and paths to avoiding a public health catastrophe. *Journal of Public Health Policy,* 43, pp.5-17. Available at: https://doi.org/10.1057/s41271-021-00331-9.

Simon, S., Bouville, A. & Land, C. 2006. Fallout from Nuclear Weapons Tests and Cancer Risks: Exposures 50 years ago still have health implications today that will continue into the future. *American Scientist,* 94(1), pp.48-57. Available at: https://doi.org/10.1511/2006.57.48.

-SIPRI Stockholm International Peace Research Institute. 2023. SIPRI Yearbook: Armaments, Disarmament and International Security*. Sipri.org* [online] Available at: https://www.sipri.org/yearbook/archive [Accessed: 15. January 2024].

Sood, A., Forster, R.A, Archer, B.J. & Little, R.C. 2021. Neutronics Calculation Advances at Los Alamos: Manhattan Project to Monte Carlo. *arXiv:2103.06260*, 10 March. Available at: https://doi.org/10.48550/arXiv.2103.06260.

Šefl, M., Zhou, J.Y., Avtandilashvili, M., McComish, S.L. & Tolmachev, S.Y. 2021. Plutonium in Manhattan Project workers: Using autopsy data to evaluate organ content and dose estimates based on urine bioassay with implications for radiation epidemiology. *PLOS ONE,* 16(10), e0259057. Available at: https://doi.org/10.1371/journal.pone.0259057.

Sykes, L.R. & Evernden, J.F. 1982. The Verification of a Comprehensive Nuclear Test Ban. *Scientific American,* 247(4), pp.47-55 [online]. Available at: http://www.jstor.org/stable/24966702 [Accessed: 15. January 2024].

Tsai, M.-K. 2017. Enhancing Nucler Power Plant Safety Via on-site Mental Fatigue Management. *Nuclear Technology & Radiation Protection,* 32(1), pp.109-114. Available at: https://doi.org/10.2298/NTRP1701109T.

-United Nations. 1968. Treaty on the Non-Proliferation of Nuclear Weapons. *Treaties.unoda.org* [online]. Available at: https://treaties.unoda.org/t/npt?_gl=1*14pc4k8*_ga*MTAyMjE4MzQxLjE2NDU4ODM2MjI.*_ga_TK9BQL5X7Z*MTY4ODczOTc2NS4xLjEuMTY4ODc0MDM2OS4wLjAuMA [Accessed: 15. January 2024].

-United Nations. 2005. 15. International Convention for the Suppression of Acts of Nuclear Terrorism. *Treaties.un.org*, 13 April [online]. Available at: https://treaties.un.org/pages/ViewDetailsIII.aspx?src=TREATY&mtdsg_no=XVIII-15&chapter=18&Temp=mtdsg3&clang=_en [Accessed: 15. January 2024].

-United Nations. 2006. Overview of Nuclear-Weapon-Free Zones. *Un.org* [online]. Available at: https://www.un.org/nwfz/content/overview-nuclear-weapon-free-zones [Accessed: 15. January 2024].

-United Nations. 2024. International Day against Nuclear Tests 29 August. *Un.org* [online]. Available at: https://www.un.org/en/observances/end-nuclear-tests-day/history [Accessed: 15. January 2024].

Vilhelmsson A. & Baum, S.D. 2023. Public health and nuclear winter: addressing a catastrophic threat. *Journal of Public Health Policy,* 44, pp.360-369. Available at: https://doi.org/10.1057/s41271-023-00416-7.

Vlajnić, J.M. 2015. Principle of the peaceful use of outer space. *Zbornik radova Pravnog fakulteta, Novi Sad,* 49(3), pp.1419-1439 (in Serbian). Available at: https://doi.org/10.5937/zrpfns49-9647.

Wiesner, J.B. & York, H.F. 1964. National Security and the Nuclear-Test Ban. *Scientific American,* 211(4), pp.27-35 [online]. Available at: http://www.jstor.org/stable/24931658 [Accessed: 15. January 2024].

Regímenes de seguridad internacionales para prevenir la propagación de armamentos nucleares y su importancia global

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CAMPO: Ingeniería Nuclear
TIPO DE ARTÍCULO: artículo de revisión

Resumen:

Introducción/objetivo: El documento proporciona una visión general de los regímenes y acuerdos internacionales que tenían como objetivo detener la proliferación de armas nucleares. Para cada régimen, se presenta su impacto en la proliferación de armas nucleares, así como su importancia para detener las pruebas nucleares que representaban una amenaza de catástrofe ecológica global. Muchos de estos regímenes ya no están vigentes hoy, pero a lo largo de la historia desempeñaron su papel en el cumplimiento de necesidades específicas para detener la proliferación global de armas nucleares o de armas nucleares características de cierto alcance.

Métodos: El artículo analiza los acuerdos internacionales en este campo, así como los artículos en el campo de la seguridad nuclear procedentes de revistas de importancia internacional.

Resultados: El análisis de los regímenes de seguridad nuclear arrojó resultados que hablan de sus fortalezas y debilidades. La importancia y debilidades de los regímenes se dan a través del análisis y varios diagramas que muestran la tendencia al aumento de la cantidad de armas nucleares a lo largo del tiempo.

Conclusión: El trabajo señala la importancia histórica de los regímenes de seguridad nuclear, pero también sus debilidades, tanto en el pasado como en la actualidad. Está claro que estos regímenes suspendieron las armas nucleares, pero esta suspensión no condujo a la abolición completa de las armas nucleares, que es el objetivo final de los acuerdos.

Palabras claves: regímenes de seguridad, armas nucleares, proliferación, ensayos nucleares, acuerdos internacionales.

Режимы международной безопасности в предотвращении распространения ядерного оружия и их глобальное значение

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РУБРИКА ГРНТИ: 78.25.19 Ядерное оружие
ВИД СТАТЬИ: обзорная статья

Резюме:

Введение/цель: В данной статье представлен обзор международных режимов и соглашений, цель которых заключается в прекращении распространения ядерного оружия. В статье представлено влияние каждого режима на распространение ядерного оружия, а также его значение в прекращении ядерных испытаний, которые представляли угрозу в виде глобальной экологической катастрофы. Многие из этих режимов сегодня уже не действуют, но на протяжении своей истории они играли важную роль в удовлетворении конкретных потребностей в прекращении глобального распространения ядерного оружия различного назначения.

Методы: Анализ международных соглашений в этой области, а также анализ статей в области ядерной безопасности из журналов международного значения.

Результаты: Анализ режимов ядерной безопасности дал результаты, выявляющие их сильные и слабые стороны. Значимость и недостатки режимов представлены путем анализа и нескольких диаграмм, которые показывают тенденцию роста и снижения общего количества ядерного оружия с течением времени.

Выводы: Данная статья освещает историческую важность режимов ядерной безопасности, а также показывает их недостатки как с исторической, так и с современной точки зрения. Более чем очевидно, что эти режимы остановили ядерное

вооружение. Однако это не привело к полной отмене ядерного оружия, что является конечной целью вышеуказанных соглашений.

Ключевые слова: режимы безопасности, ядерное оружие, распространение, ядерные испытания, международные соглашения.

Међународни безбедносни режими у спречавању ширења нуклеарног наоружања и њихов глобални значај

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ОБЛАСТ: нуклеарни инжењеринг
КАТЕГОРИЈА (ТИП) ЧЛАНКА: прегледни рад

Сажетак:

Увод/циљ: У раду је представљен преглед међународних режима и споразума који имају за циљ да зауставе ширење нуклеарног оружја. Приказан је утицај сваког режима на ширење нуклеарног оружја, као и његов значај у заустављању нуклеарних проба које су представљале претњу у смислу изазивања глобалне еколошке катастрофе. Многи од ових режима данас више нису на снази, али су током историје имали своју улогу у испуњавању специфичних потреба у заустављању глобалног ширења нуклеарног оружја или карактеристичног нуклеарног оружја одређеног домета. Методе: Анализирани су међународни уговори из ове области, као и текстови из области нуклеарне безбедности из часописа од међународног значаја.

Резултати: Анализа нуклеарних безбедносних режима дала је резултате који говоре о њиховој снази, односно слабостима. Значај и слабости режима приказани су кроз анализу и неколико дијаграма који показују тренд раста, односно пада укупног броја нуклеарних бојевих глава током времена.

Закључак: Рад указује на историјски значај нуклеарних безбедносних режима, али и на њихове слабости, како у ранијим временима, тако и данас. Јасно је да су ови режими зауставили нуклеарно наоружавање, али то није водило ка његовом потпуном укидању, што је крајњи циљ споразума.

Кључне речи: безбедносни режими, нуклеарно наоружање, ширење, нуклеарни тестови, међународни споразуми.

EDITORIAL NOTE: The second author of this article, Radovan V. Radovanović, is a current member of the Editorial Board of the *Military Technical Courier*. Therefore, the Editorial Team has ensured that the double blind reviewing process was even more transparent and more rigorous. The Team made additional effort to maintain the integrity of the review and to minimize any bias by having another associate editor handle the review procedure independently of the editor – author in a completely transparent process. The Editorial Team has taken special care that the referee did not recognize the author's identity, thus avoiding the conflict of interest.

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Methodology of training members of river units on a ship simulator

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FIELD: computer science (education), mechanical engineering
ARTICLE TYPE: review paper

Abstract:

Introduction/aim: This paper aims to present the methodology for creating educational content/scenarios on a ship simulator (bridge simulator) that will serve officers of river units in developing the ability to react when performing regular and military tactical tasks on the ships of the River Flotilla. Also, training on the simulator aims to train officers of river units using modern information technologies.

Methods: The paper uses simulation methods, experimental methods, case studies, and operational research.

Results: Specific educational content/scenarios were created, also specific methodology was developed and the principles were clearly defined according to which content/scenarios are created on the ship simulator.

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Conclusion: By using the ship simulator, in different teaching scenarios, cadets of river units as well as members of river units are trained and acquire the ability to react adequately in real situations in the shortest possible time.

Keywords: ship simulator (bridge simulator), training methodology, river units, emergency response, ship maneuvering.

Introduction

Simulation is one of the most realistic methods in training ship personnel (crew). While training during ship navigation provides a realistic situation of the environment and movement of the ship, there are also several disadvantages such as costs, required time, and difficulty to ensure different situations and specific hydrometeorological conditions during navigation. This can be overcome by using a ship simulator as a training platform since it is cheaper, provides opportunities for rapid scenario changes, and can provide situations with different levels of risk without the risk of damage to a real ship (European Commission, 2018). Simulations as a substitute for reality are very useful. Namely, experimental methods, to which simulations belong, are evaluated as the most realistic. The use of simulators for the acquisition of navigational skills has been present for several decades. The use of the simulator made it possible to see specific and complex navigational conditions in a new way. Namely, the simulators enable the training of various maneuvers and navigation in very specific hydrometeorological conditions. Simulators are very successfully used in the education of future officers of river units, members of the River Flotilla, as well as all other watchkeeping officers. Also, the simulator can be used for training experienced navigation officers who do not have experience with certain ship types which exist as mathematical ship models in the ship simulator.

The research was conducted on the *Wärtsilä Navigation Simulator NTPRO 5000* (Figure 1) which includes:

- two instructor workplaces with a control and supervision station,
- ship control station,
- radar station – Automatic Radar Plotting Aid (ARPA),
- station with electronic charts – Electronic Chart Display and Information System (ECDIS),
- station for ship satellite and radio communication – Global Maritime Distress and Safety System (GMDSS), and
- panels and monitors for visualization.

Figure 1 – NTPRO 5000 Wärtsilä Navigation Simulator

The instructor station on the *NTPRO 5000 simulator* is intended for:

- creation and refinement of training scenarios,
- starting and conducting exercises on the simulator, and
- exercise debriefing.

Simulators also enable the analysis of the ship's maneuvering characteristics by performing various maneuvers such as the ship's stopping distance, turning circle, zig-zag maneuver, etc. By comparing the results of the mentioned maneuvers obtained in real environmental conditions with those obtained on the simulator, it is possible to evaluate the quality of the ship simulator itself. Although practical experience on certain types of ships is of great importance, prior training on a ship simulator can make it easier to get to know their maneuvering characteristics. Also, in this way, the expected ship maneuverability can be tested on the simulator, i.e., in real environmental conditions.

Creation of training scenarios

To create training scenarios, it is necessary to define a clear aim (goal), and the starting point of the exercise. Since the goals are the improvement of special skills in subjects related to ship maneuvering and navigation, it is necessary to respect international Maritime and River

conventions and regulations (International Maritime Organization, 2010, 2014; Službeni glasnik Republike Srbije, 111/2020) which represent the normative basis for the development of training. In particular, it is necessary to respect the regulations that define training based on simulations and apply the required standards, primarily to improve the safety and security of navigation. The International Convention on Standards for Training, Certification and Watchkeeping of Seafarers (International Convention on Standards of Training, Certification and Watchkeeping for Seafarers - STCW) adopted in 1978 with the amendments from Manila in 2010, defines the requirements and standards of seafarers' training (Šoškić et al, 2011).

By using ship simulators, during simulations of extraordinary and specific navigation conditions, participants gain the ability to predict and evaluate critical moments and situations when performing tasks. Thus, the risk of possible accidents is reduced and it helps the members of river units to anticipate and correctly respond to emergencies that may arise in navigation, i.e., to acquire knowledge so that they can perform tasks independently (Radojević, 2013). Training is the process that new cadets of river units go through when they are onboard to learn how to carry out their ordinary tasks, and above all to understand how the ship functions to perform a specific task. In essence, training has a goal that cadets are educated and trained to perform proper actions and procedures onboard and to perform tasks independently. Today, simulations are an inevitable part of almost every learning or training process, and they are especially important in ship management training as well as in basic aircraft management training (Vlačić et al, 2022).

Some of specific situations onboard that can be simulated are search and rescue (Radojević & Kresojević, 2020; Kresojevic & Ristic Vakanjac, 2023), navigation in difficult conditions, navigation in ice and the passage through a lock, but also many others.

The principles of good practice on a ship simulator are:

- risk reduction;
- efficient bridge team management;
- building teamwork in achieving goals;
- an inexhaustible source of the possibility of repeating actions in the created situations; and
- a tool that enables qualitative and quantitative analysis of the created scenarios.

The ship simulator enables teamwork and communication on the bridge as well as building leadership and commanding skills. The following resources are available on the ship simulator to provide the highest possible quality training to the members of river units:

- electronic navigation equipment;
- maps and publications, including electronic resources;
- panels and monitors that simulate the hydrometeorological environment;
- ECDIS;
- GMDSS; and
- ARPA radar.

The ship simulator makes it possible to observe the work of a person in training and if necessary the instructor can run the same scenario and practice all phases of the decision-making process onboard.

The ship simulator is used in river and sea navigation to solve problems of maneuvering, primarily in conditions of restricted waterways, navigation in a limited water area, conditions of shallow water, occurrence of icebergs, overtaking and passing other ships, etc. (Ari et al, 2013).

Considering that the members of river units realized their tasks in navigation on inland waterways, teaching scenarios were created so that they precisely simulate specific situations of navigation on inland waterways. Namely, navigation through inland waterways, canals, or straits is very complex and requires experience and alertness, primarily due to limited water areas, ie., narrow and shallow waterways. The methodology training on the ship simulator (Diagram 1) begins with defining the aims of the training through the creation of a scenario that represents the way and path from the idea to the realization of the exercise itself and later analysis (Sharma et al, 2018). In this research, the defined parameters of environmental conditions, river speed, wind speed and direction, and visibility were used as the parameters of the greatest importance when performing the maneuver of passing through the lock. After defining the ship model, the parameters of the environment, the design and definition of the tasks that trainees should fulfill, as well as the definition of the parameters that are monitored to make the work itself measurable, i.e., to define the success of the exercise itself, are approached. The above data is entered into the software of the ship simulator which creates the training scenarios. In this way, the instructor creates the most faithful navigation simulation.

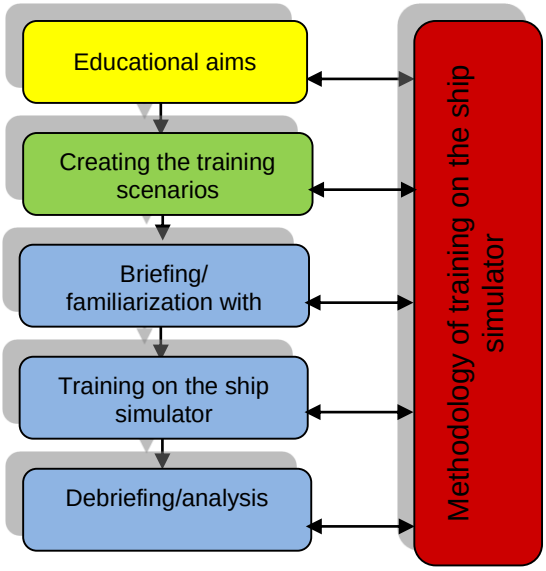

Diagram 1 – Methodology of training on the ship simulator

In the briefing, the instructor presents the simulation to the entire group of trainees. The briefing is "commonly focused on practical information regarding the upcoming scenario and the learning objectives". (Sellberg, 2018).

The instructor also points out the need to know the meteorological and hydrological factors that affect river navigation in order to create the most realistic simulation possible. The instructor, from the instructor's station, constantly monitors the exercise, monitors the reactions of the trainees during the training and records the parts of the exercise interesting for re-examination and analysis (Figure 2).

Figure 2 – Members of the River Units working on the ship bridge simulator

The instructor can stop or pause the exercise, if necessary. This allows the instructor to observe and analyze the characteristic phases of the exercise with the trainees and determine positive actions as well as possible mistakes they made. At the end of the exercise, the analysis starts. In the analysis, the instructor discusses individual procedures on the bridge with the trainees. In this way, critical thinking and reasoning are developed and correct procedures on the ship bridge are learned.

Solving specific navigational tasks

One of specific tasks in navigation on inland waterways is overcoming unevenness, which is achieved by ship locks (Bugarski et. al, 2020). Such a scenario of a passage through a lock is shown in Figure 3.

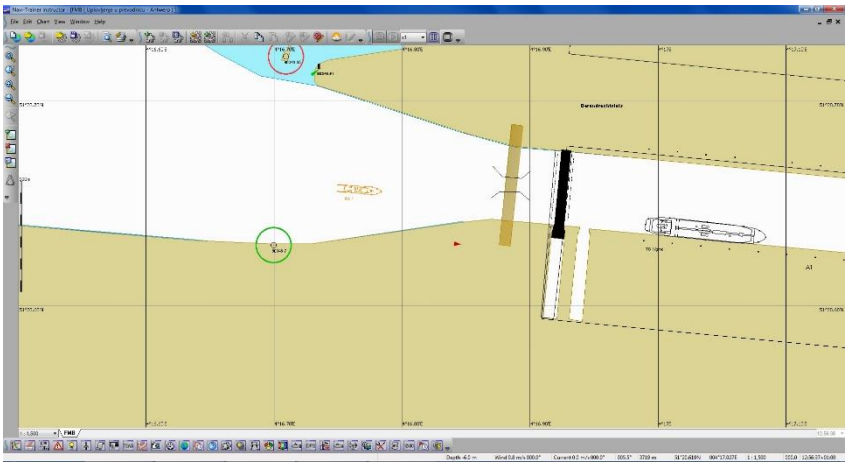

Figure 3 – Instructor's station – ship passing through the lock

The lock itself has its parameters of height and speed transition. In the presented simulation, the lock near Antwerp was used. The mathematical model of the ship used is a patrol ship, which in terms of dimensions is most similar to the ships in the River Flotilla. Ship locks are important elements of waterway systems. To improve the efficiency of transport on inland waterways, it is important to ensure that ships pass through locks without having to spend unnecessary time waiting at lock entrances, which is especially important on frequent waterways (Figure 4). The use of the simulator is particularly effective when practicing entering a lock, where hydrometeorological conditions (wind, visibility, river current) are simulated. The lock specificity requires navigation officers to be very well trained regarding the choice of maneuvers when entering the lock,

mooring the ship, going through the lock, changing the water level and choosing maneuvers when leaving the lock, i.e., exiting it.

The technical characteristics of the lock (length and width of the lock, capacity in terms of the number of ships in the lock depending on their characteristics) determine the actions of navigation officers during the maneuver of entering, going through the lock and leaving it.

By simulating these conditions, cadets and members of river units get an almost realistic picture of the conditions prevailing in the lock and the actions during maneuvering.

All ship maneuvers in locks are complex and complicated tasks for all ships of the River Flotilla, so training in the lock itself without prior preparation would pose a certain risk to crews and ships. Also, in the lock itself, due to the dynamics of activities and the specifics of passage conditions, members of river units are not able to see all the necessary parameters as they can do it on the ship simulator.

At a time when waterways are being digitized and becoming "smart", it is important to work on the availability of information that could contribute to the optimization of the operation of locks and the passage of ships through locks. Certain authors suggest the use of fuzzy logic and smart signalization for better traffic organization in the lock area (Bugarski et. al, 2020).

In this way, trainees understand the importance of efficiency in addition to the safety and security of navigation.

Figure 4 – Visualization of a ship waiting to enter the lock

From the point of view of navigation and execution of a task, ie., in the cases when an entire riverine unit (fleet/flotilla) needs to pass through the lock because there is no alternative waterway, it is necessary for a trainee to calculate the time for that operation. In such situations, the lock throughput is calculated and expressed by the number of vessels that can pass through the lock in a certain period. The throughput capacity of a lock depends, first of all, on the size of the chamber, the duration of the lifting, the method (one-way or two-way lock), the degree of occupancy of the chamber, and the like.

The daily throughput, expressed in the number of ships that pass through the lock, is equal to the ratio of the daily throughput and the time of one lifting (one-way or two-way), which is calculated according to formula (1). So, for example, the daily throughput during one-way transiting the lock of the Danube-Tisa-Danube hydro system (dimensions L=85m, W=12m, T=3m) amounts to 34 ships (if one ship is accommodated in the lock), and it is calculated according to the form:

$$N_1 = \frac{24 \times 60}{T_{pr}} = \frac{1440}{41{,}5} \approx 34 \qquad (1)$$

where: T_{pr} – one-way lifting time.

Large locks, such as the Djerdap lock, which have much larger dimensions (L=310m, W=34m, T=4.5m) and a passage time of 90 minutes, have a much higher throughput.

Throughput power for two-way lifting is calculated according to the same principle as the throughput power for one-way lifting (Rosić, 2010). We can use operational research for the problem of lifting a riverine unit and placing several ships in the lock chamber. In this way, it contributes to the optimization of the process and the efficiency of the task execution.

Comparative analysis of the use of the ship simulator and the training in real conditions on board

After the completion of the training of cadets and the training of members of river units, a comparative analysis of the training on the ship simulator and the training in real environmental conditions on the ship was carried out; among others, the following conclusions were reached:

- The simulator provides opportunities to carry out training under more difficult hydrological and meteorological conditions, which later, especially for navigation officers, gives better results when working onboard.

- The use of simulators for the analysis of certain events (reconstruction) - real situations - accidents, exercises, and similar is particularly important. The simulator enables a detailed analysis of a large number of parameters that cannot be observed in a real situation and subsequently analyzed. Also, this feature of the simulator can be used when planning exercises or real, especially specific military tactical tasks, where, by using the simulator, certain problems can be predicted and overcome, which otherwise could not be timely detected and preemptively warned against. This characteristic of the simulator represents a great step forward in preparing for the implementation of tasks, where a certain number of difficulties can be prevented by preventive organizational measures, which favors the preparation of trainees for the implementation of tasks. The use of simulators with previously performed reconnaissance of the area where the task will be carried out is particularly noteworthy. This feature is basic, and usable for a larger range of tasks, and depending on the character of the specific task, it depends on the effectiveness - the usability of the simulator. In this domain, in addition to better preparation and possible supplementary training for a specific task, it also has a psychological effect, because better-prepared personnel are more confident in themselves and in their technique, and will perform tasks better.
- On the inland waterways of the Republic of Serbia, numerous navigationally difficult areas require great caution because there are dangerous obstacles that threaten safe navigation and therefore the simulator can significantly contribute to preventing accidents and incidents in such areas.

Such assessments were also the subject of analysis in European Union projects or research within academic and scientific institutions. The results reached are similar, and among other things, the conclusions are:

- that training onboard and on the simulator needs to be understood as complementary.
- that it is certain that the degree of realism is always somewhat lacking in the simulator. On the other hand, the training possibilities and the degree of freedom regarding the content of the simulator training are much greater (European Commission, 2018).
- that the last meter during the berthing operation, i.e., as the ship approaches the dock, the behavior of the ship in the simulator becomes less realistic. This also applies to approaching any coastal structure or other ship (Zghyer & Ostnes, 2019).

All researchers agree that the simulator puts the candidates in real situations on the river, enabling navigation in various navigation areas with the same or similar hydrometeorological conditions, without spending material and technical resources, enabling a greater frequency than would be the practice without a ship simulator, while also shortening the time necessary to prepare the exercise.

The training can be carried out on various subsystems (radar, electronic charts, etc.) that are on the ships in particular, which is important for river units cadets because for them the simulator would represent the first contact with those subsystems so that, after boarding the River Flotilla ships, the time required to familiarize with, train on and master these subsystems would be significantly reduced. The simulator is used throughout the education, so that cadets, by gradually mastering the skills necessary for ship management and navigation, reach the maximum level of training that will enable them to use the simulator as an integrated system (Nikolić, 2016).

As the simulator enables navigation with various types of ships, officers who prepare for naval missions have the opportunity to gain insight into the maneuverability of the ships on which they would perform tasks during the mission.

Since practice is important in the training of members of river units, working on the simulator will significantly increase the level of skills and practical knowledge necessary to perform various jobs on the ships of the River Flotilla (Nikolić, 2016).

Conclusion

With the development of modern technologies, the current education system encounters inevitable changes to which the Military Academy, as a higher education institution, continuously adapts. To this end, the NT PRO 5000 ship simulator was introduced into the system of education and training of cadets in preparing for river unit officers as well as of river unit officers' undergoing training. The introduction of the simulator significantly improves the education and training system, which results in better training of river unit cadets for initial duties, in improved levels of training of officers at training courses, as well as in better preparedness of officers for participation in naval missions (multinational operations).

The ship simulator is a system that realistically represents the ship bridge. Training based on simulations contributes to the development of the safety and security of navigation. The goals of the research are the creation of education content/scenarios on the simulator as well as

operational research that is applied to specific situations such as navigation on inland waterways and the ship passing through locks.

Navigation scenarios on the ship simulator are created based on defined and calculated environmental conditions, as well as specific types of ships and locks. Instructors, in this way, create the most faithful navigation simulation. In solving the tasks of optimizing the passage of vessels, ie., operational research is applied to navigation through locks. Seafarers and shipowners around the world use simulators and operational research to solve specific problems in navigation. In addition, simulations provide a platform for professional seafarers, shipowners, and engineers to work together in virtual "real world" conditions to solve specific navigational tasks. This synergy creates the potential for significant savings in the costs of building ships and facilities, their exploitation, and increases the efficiency of safety and security of navigation. The lessons learned using these methods are extremely important in the education of nautical personnel and represent a contribution to the introduction of modern training methods. Training on the ship simulator at the Military Academy provides excellent results, which, in addition to better preparation and possible additional training for a specific task, also has a psychological effect, because better-prepared personnel are more confident in themselves and in their technique, and will better realize assigned tasks.

References

Ari, I., Aksakalli, V., Aydogdu, V. & Kum, S. 2013. Optimal ship navigation with safety distance and realistic turn constraints. *European Journal of Operational Research*, 229(3), pp.707-717. Available at: https://doi.org/10.1016/j.ejor.2013.03.022.

Bugarski, V., Kulić, F., Kanović, Ž. & Bačkalić, T. 2020. Fuzzy logic applications in inland waterway transportation. *Journal on Processing and Energy in Agriculture*, 24(3-4), pp.115-118. Available at: https://doi.org/10.5937/jpea24-30238.

-European Commission. 2018. *HORIZON 2020: Promoting Innovation in the Inland Waterways Transport Sector*. Brussels, Belgium: European Commission CORDIS EU research results. Available at: https://doi.org/10.3030/633929.

-International Maritime Organization (IMO). 2010. *International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW), 1978 (the 2010 Manila amendments)*. London, UK: IMO-International Maritime Organization [online]. Available at: https://www.imo.org/en/OurWork/HumanElement/Pages/STCW-Convention.aspx [Accessed: 10 October 2023].

-International Maritime Organization (IMO). 2014. SOLAS, consolidated edition 2014: consolidated text of the International Convention for the Safety of Life at Sea, 1974, and its Protocol of 1988: articles, annexes and certificates. *ATS Library* [online]. Available at: https://atslib.omeka.net/items/show/9157 [Accessed: 10 October 2023].

Kresojevic, M. & Ristic Vakanjac, V. 2023. Ship Maneuvering Using a Ship Simulator in Search and Rescue Operation. In: Li, Y., Hu, Y., Rigo, P., Lefler, F.E. & Zhao, G. (Eds.) *Proceedings of PIANC Smart Rivers 2022. PIANC 2022. Lecture Notes in Civil Engineering*, 264, pp.969-977, Singapore: Springer. Available at: https://doi.org/10.1007/978-981-19-6138-0_86.

Nikolić, L. 2016. *Upotreba brodskog simulatora u osposobljavanju pripadnika roda rečnih jedinica.* BA thesis. Belgrade: University of Defence, Military Academy (in Serbian).

Radojević, S. 2013. *Sigurnost i bezbednost plovidbe*. Belgrade: Media Center „Odbrana“ (in Serbian). ISBN: 978-86-335-0361-7.

Radojević, S. & Kresojević, M. 2020. Saving Migrants From The Sea: Improving Training For Search And Rescue Operations. *TransNav International Journal on Marine Navigation and Safety of Sea Transportation*, 14(1), pp.129-133. Available at: https://doi.org/10.12716/1001.14.01.15.

Rosić, S. 2010. *Plovidba unutrašnjim plovnim putevima*. Belgrade: Media Center „Odbrana“ (in Serbian). ISBN: 978-86-335-0303-7.

Sellberg, C. 2018. From briefing, through scenario, to debriefing: the maritime instructor's work during simulator-based training. *Cognition, Technology & Work*, 20, pp.49-62. Available at: https://doi.org/10.1007/s10111-017-0446-y.

Sharma, A., Nazir, S., Wiig, A.C., Sellberg, C., Imset, M. & Mallam, S. 2018. Computer supported collaborative learning as an intervention for maritime education and training. In: Nazir, S., Teperi, A.M. & Polak-Sopińska, A. (Eds.) *Advances in Human Factors in Training, Education, and Learning Sciences. AHFE 2018. Advances in Intelligent Systems and Computing, vol 785,* Orlando, FL, USA, pp.3-12, July 21-25. Cham: Springer. Available at: https://doi.org/10.1007/978-3-319-93882-0_1.

-Službeni glasnik Republike Srbije. 111/2020. *Uredba o dopuni uredbe o uslovima za plovidbu i pravilima plovidbe na unutrašnjim vodama*. Belgrade: JP „Službeni glasnik“ (in Serbian) [online]. Available at: https://www.paragraf.rs/glasila/rs/sluzbeni-glasnik-republike-srbije-111-2020.html [Accessed: 10 October 2023].

Šoškić, S., Ćurčić, J. & Radojević, S. 2011. Implementation of the STCW Convention at the Serbian Military Academy. In: Weintrit, A. & Neumann, T. (Eds) *Human Resources and Crew Resource Management: Marine Navigation and Safety of Sea Transportation, 1st Edition*. London: CRC Press. Available at: https://doi.org/10.4324/9781315266299.

Vlačić, S.I., Knežević, A.Z., Grbović, V.M., Vitsas, P.A. & Mihajlović, M.M.S. 2022. Implementation of the digital training concept in the basic flight training at the Serbian Military Academy. *Vojnotehnički glasnik/Military Technical Courier,* 70(1), pp.87-108. Available at: https://doi.org/10.5937/vojtehg70-34610.

Zghyer, R. & Ostnes, R. 2019. Opportunities and Challenges in Using Ship-Bridge Simulators in Maritime Research. In: *Proceedings of Ergoship 2019,* Haugesund, Western Norway University of Applied Sciences (HVL), pp.119-129, September 24-25 [online]. Available at. https://www.hvl.no/contentassets/9d0c2d7885534c1fb21d17d7c474a828/ergoship_2019_proceedings.pdf [Accessed: 10 October 2023].

Metodología de formación de integrantes de unidades fluviales en un simulador de barco

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CAMPO: informática (educación), ingeniería mecánica
TIPO DE ARTÍCULO: artículo de revisión

Resumen:

Introducción/objetivo: Este artículo tiene como objetivo presentar la metodología para la creación de contenidos/escenarios educativos en un simulador de barco (simulador de puente) que sirva a los oficiales de unidades fluviales en el desarrollo de la capacidad de reacción al realizar tareas tácticas regulares y militares en los barcos de la Flotilla fluvial. Además, el entrenamiento en el simulador tiene como objetivo capacitar a los oficiales de las pequeñas unidades fluviales utilizando las tecnologías modernas de la información.

Métodos: El artículo utiliza métodos de simulación, métodos experimentales, estudios de casos e investigación operativa.

Resultados: Se crearon contenidos/escenarios educativos específicos, también se desarrolló una metodología específica y se definieron claramente los principios según los cuales se crean contenidos/escenarios en el simulador de barco.

Conclusión: Mediante el uso del simulador de barco, en diferentes escenarios de enseñanza, tanto cadetes de unidades fluviales como miembros de unidades fluviales se entrenan y adquieren la capacidad de reaccionar adecuadamente en situaciones reales en el menor tiempo posible.

Palabras claves: simulador de barco (simulador de puente), metodología de entrenamiento, unidades fluviales, respuesta a emergencias, maniobras de barcos.

Методология обучения военнослужащих речной флотилии на судовом симуляторе

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РУБРИКА ГРНТИ: 28.17.31 Моделирование процессов управления,
30.15.35 Теория механизмов и машин,
27.47.00 Математическая кибернетика
ВИД СТАТЬИ: обзорная статья

Резюме:

Введение/цель: Цель данной статьи заключается в представлении методологии создания образовательного контента/сценариев на судовом симуляторе (bridge simulator), который поможет военнослужащим речного флота развить способность быстрого реагирования при выполнении штатных, а также боевых и тактических задач на судах Речной флотилии. При подготовке военнослужащих речного флота на судовом симуляторе используются современные информационные технологии.

Методы: В статье используются методы моделирования, экспериментальные методы, исследование случая и операционные исследования.

Результаты: Были разработаны конкретные образовательные контенты/сценарии, а также конкретная методология при четко определенных принципах, в соответствии с которыми контенты/сценарии создаются на судовом симуляторе.

Выводы: Используя судовой симулятор в различных учебных сценариях, курсанты, а также военнослужащие речной флотилии проходят учения и развивают навыки быстрого реагирования в реальных ситуациях.

Ключевые слова: судовой симулятор, методология обучения, речная флотилия, реагирование на чрезвычайные ситуации, маневрирование судном.

Методика обуке припадника рода речних јединица на бродском симулатору

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ОБЛАСТ: рачунарске науке, машинство
КАТЕГОРИЈА (ТИП) ЧЛАНКА: прегледни рад

Сажетак:

Увод/циљ: Циљ овог рада је да се прикаже методика креирања наставних садржаја/сцена на бродском симулатору који ће служити официрима рода речних јединица у развијању способности реаговања приликом извршавања редовних и борбених задатака на бродовима Речне флотиле. Такође, циљ обуке на симулатору је едукација официра рода речних јединица применом савремених информационих технологија.

Методе: У раду се користи метода симулације, метода експеримента, студије случаја и операциона истраживања.

Резултати: Креиране су специфичне наставне сцене/садржаји, при чему је развијена и методика креирања, и јасно су дефинисани принципи по којима се дизајнирају садржаји/сцене на бродском симулатору.

Закључак: Употребом бродског симулатора, у различитим наставним сценама, кадети рода речних јединица, као и припадници овог рода, обучавају се и стичу способности да у стварној ситуацији реагују адекватно за што краће време.

Кључне речи: бродски симулатор, методика обуке, речне јединице, реаговање у критичним ситуацијама, маневрисање бродом.

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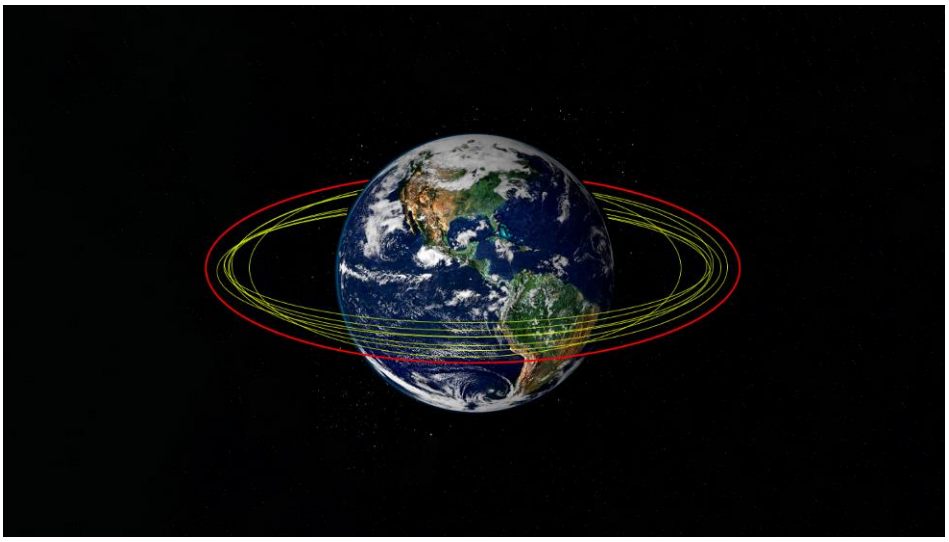
Да ли је руски сателит Cosmos 2553 тест за будуће орбитално нуклеарно оружје?[1]

Вебсајт Breaking Defense добио је ексклузивне информације које показују јединствену путању руског система, за који, како стручњаци кажу, америчка влада сматра да се ради о свемирском нуклеарном оружју. У САД се сумња да представља тестни сателит за будућност свемирског ратовања, односно да се ради о нуклеарном противсателитском оружју које лети у несвакидашњој орбити. Један аналитичар каже да се ради о сателиту са радаром са синтетичким отвором (synthetic aperture radar (SAR)) за посматрање Земље — али вероватно и за тестирање будућег распореда орбиталног нуклеарног оружја.

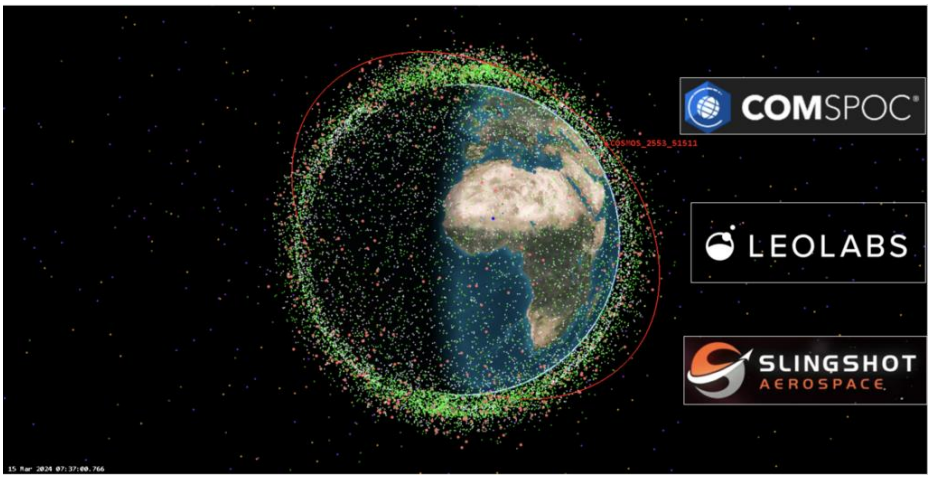


Сателитске орбите око Земље

Cosmos 2553, према независним стручњацима, налази се у кружној орбити од око 2.000 километара на најдаљој ивици појаса ниске Земљине орбите (low Earth orbit (LEO). Покренут у фебруару 2022, ради у области у којој нема других система; једини познати пратиоци су му један мртав руски сателит и 10 мртвих америчких комерцијалних сателита из касних деведесетих година.

[1] https://www.wsj.com, 17. мај 2024.

Та орбита могла је бити изабрана како би омогућила експериментисање које не би утицало на друге сателите, и зато што отежава праћење. Такође, претпоставља се да би таква орбита могла бити безбеднија за дуготрајно стационирање сателита који носи опасан нуклеарни терет, јер би била мања могућност удара од крхотина или неког другог сателита. Ниједан амерички званичник не тврди, нити сугерише, да Cosmos 2553 носи нуклеарно оружје. Али, постоји одређен редослед између навода из САД о намери Русије да постави нуклеарно оружје у свемир, што почиње од фебруара, и сателита Cosmos 2553.



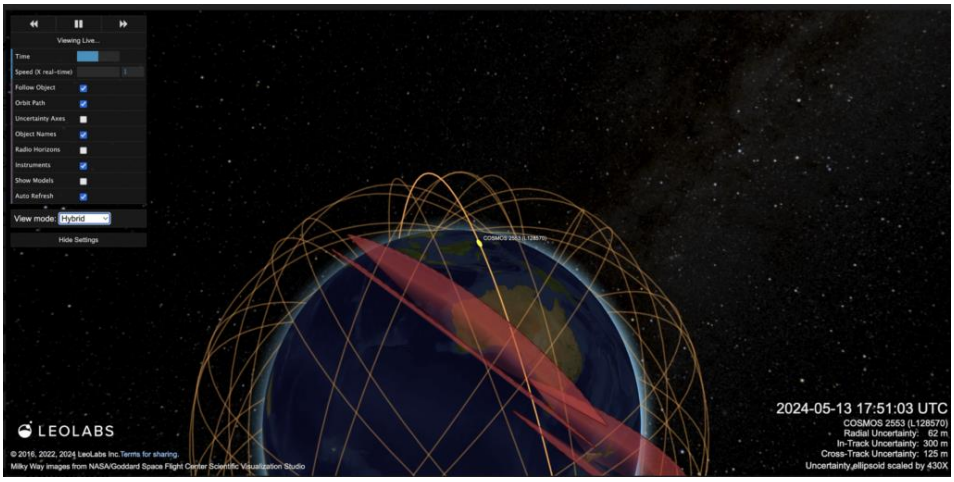
Орбитални план сателита Cosmos 2553

Амерички Стејт департмент је, 3. маја, изнео загонетне опаске о неименованом сателиту у „необичној" орбити који је део новог руског програма. Наводи се да орбита сателита „није била довољно висока у односу на радијацијско окружење да би омогућила убрзано тестирање електронике, као што је Русија описала сврху".

Вебсајт Breaking Defense је потврдио извештај часописа Wall Street Journal, од 16. маја, у којем се каже да је сателит Cosmos 2553 систем на који је Стејт департмент мислио. Међутим, до сада ниједан званичник САД није јавно означио Cosmos 2553 као сателит о коме је реч, упркос чињеници да Пентагон има приступ прецизнијим подацима за праћење свемира од других цивилних истраживача који су били заузети проучавањем руског система.

Бројни независни стручњаци означили су Cosmos 2553 као, највероватније, првенствено дизајниран као САР сателит за шпијунирање земаљских циљева. Али, неколико њих спекулише да би сателит могао да спроводи експерименте са другим корисним теретом, фокусираним на тестирање заштите подсистема било ког будућег нуклеарног антисателитског оружја од дуготрајног излагања амбијенталном зрачењу и

наелектрисаним честицама у свемирском окружењу, што би могло да доведе до квара инсталација на сателиту. На скоро 2.000 километара висине, сателит Cosmos 2553 био би изложен вишим нивоима радијације него у нижој орбити. Велики је проблем што нуклеарно оружје које је распоређено у свемиру мора да проведе дуг период без надзора. „Претпоставља се да би једно од могућих објашњења било прикупљање података о дугорочним ефектима боравка у орбити", речено је у Центру за студије непролиферације „Џејмс Мартин" Института Мидлбери у Монтереју, Калифорнија.



Радарско праћење путање сателита Cosmos 2553

На Институту Уједињених нација за истраживање разоружања у Женеви слажу се са оваквом констатацијом и сматрају да се ради о експерименту који проучава заштиту различите електронске опреме. Чини се да америчка обавештајна заједница верује да ова опрема има везе са нуклеарним оружјем. Али, то је скоро немогуће доказати или оповргнути.

Званичници САД страхују да Русија развија нуклеарно противсателитско оружје чији је циљ уништавање свих сателита у ниској Земљиној орбити.

Фокус на ниску Земљину орбиту

Једна необичност орбите сателита Cosmos 2553 јесте одлука да се сателит постави у горњи ток ниске Земљине орбите, знатно изнад већине других сателита у том орбиталном региону.

Ниска Земљина орбита је место на којем се налази већина светских сателита за даљинско детектовање, али је тај слој све интересантнији америчком Министарству одбране, које настоји да омогући безбеднији положај за мноштво малих сателита за мисије које је у прошлости покривало неколико великих сателита. Поред тога, ту се налазе и мега-

сазвежђа од неколико хиљада брзих комуникационих сателита велике комуникационе пропусности које тренутно користе украјинске снаге у рату те земље са Русијом.

И Сједињене Државе и Русија су све више заинтересоване за постављање сателита за надгледање других сателита у ниској Земљиној орбити како би, у најмању руку, пратили активности једни других. Иако су амерички сателити који надгледају свемир били стационирани у нижој орбити од руског сателита Cosmos 2553's, то није тако далеко да би се избегло њихово испитивање.

Свемирске снаге су лансирале сателите опремљене системом ситуационе свесности у ниској Земљиној орбити, као део експерименталне кампање службе за убрзавање циклуса лансирања, како би убрзано реаговале на орбиталне претње, али и омогућиле брзу замену свих свемирских система изгубљених у борби.

У јуну 2021. године, Команда свемирских система лансирала је свој први мали сателит SDA под називом Odyssey у оквиру свог програма Лансирање тактичког одговора (Tactically Responsive Launch-2 (TacRL-2), мисије која је почела да ради у ваздухопловним снагама у мају 2019. под називом Rapid Space Launch Initiative (RSLI). Тај сателит је 18. децембра 2022. године изашао из орбите, поново ушао у Земљину атмосферу и изгорео.

Друга мисија под називом Tactically Responsive Space-3 (TacRS-3) познатија је по кодном имену сателита који се лансира – Victus Nox. У Компанија Boeing Millennium Space Systems је, у септембру 2022. године, изабрана за изградњу тог сателита, а компанија Firefly Aerospace обезбедила је лансирно возило. Мисија је успешно испунила свој циљ и лансирала сателит 14. септембра 2023. године.

Victus Nox. назван је „оперативним" експериментом, дизајнираним да пружи подршку америчком сателиту SpaceCom.

Сателит тренутно остаје у својој орбити на око 435 километара висине. Команда свемирских система је, 22. маја, обавестила да Victus Nox не „води мисију нити емитује". Сателит је „стављен у орбиту коначног одлагања и пасивизиран, пратећи стандардне праксе за ублажавање орбиталног отпада".

Међутим, јасно је да су и Victus Nox и Odyssey пре њега имали прилику, док су били оперативни, да процене руски Cosmos 2553.

Истина је да је незамисливо да би неки амерички сензори у нижој Земљиној орбити игнорисали било који оперативни руски сателит у близини. То се не односи само на Cosmos 2553 већ и на сателит који је Русија лансирала 16. маја, за који је амерички амбасадор Роберт Вуд рекао у Савету безбедности УН да је вероватно антисателитско оружје које сада прати сателит америчке владе.

Space News је прва агенција која је известила да се нови руски сателит Cosmos 2576 попео и ушао у заједничку орбиту на око 440

километара висине са америчким извиђачким/шпијунским сателитом USA 314.

Чини се да је Cosmos 2576 још један од сателита који је Русија назвала „надзорним" јер служи за праћење објеката у нижој Земљиној орбити. На интернет блоговима круже информације да су руски надзорни сателити заправо коорбитална противсателитска оружја, али да нису наоружани нуклеарним оружјем.

Американци већ планирају следећу итерацију TacRS-3, названу Victus Haze. У априлу је Команда свемирских система објавила уговоре у оквиру новог напора за националну безбедност за Rocket Lab National Security и True Anomaly. Сателити које ће развити ове две фирме треба да буду оптимизовани за блиске приступе другим сателитима.

Генерал-потпуковник Philip Garrant, који руководи Командом свемирских система, изјавио је да ће сателити-птице Victus Haze бити лансирани „негде 2025. године".

Русија је лансирала антисателитско оружје[2]

Америчка влада оптужила је Русију за лансирање новог антисателитског оружја. Чини се да се објекат који је Русија одбила да идентификује, налази у свемиру у близини важног америчког сателита. Независни посматрачи неба могу потврдити да је нови руски сателит врло близу тајанственом америчком сателиту, али нико осим руског Министарства одбране не може рећи шта је његов задатак.

[2] thewarzone.com, 3. мај 2024. г.

Мистериозни сателит лансиран је у ниску Земљину орбиту 16. маја 2024. године, а на недавном брифингу Пентагонапотврђено је да влада надгледа тај објекат и верује да представља оружје против сателита.

Такође је речено да је Русија лансирала сателит у ниску Земљину орбиту за који Пентагон процењује да је вероватно противсвемирско оружје за које се претпоставља да може да нападне друге сателите у ниској Земљиној орбити. Нису прецизирани разлози због којих је руски сателит идентификован као оружје, а не као још једна операција надзора.

На друштвеној мрежи Икс (бивши Твитер), астроном Џонатан Мекдауел је потврдио да руски сателит, познат као К-2576, заиста виси око америчког сателита US 314, такође мистериозног сателита лансираног 2021. године. Сателитом US 314 управља Национална извиђачка канцеларија, што сугерише да се ради о шпијунском сателиту. Мекдауел напомиње да је К-2576 у истој орбиталној равни као и US 314, али је најближи приступ тренутно неколико стотина километара. Он сматра да ће се К-2576 вероватно ускоро потпуно приближити сателиту US 314.

У накнадном посту, Мекдауел изражава скептицизам да је К-2576 оружје против сателита. Он исправно истиче да је Русија лансирала бројне сателите који само посматрају америчку имовину у свемиру, али је не нападају. С друге стране, не би било неуобичајено да Русија лансира свемирско оружје. Наиме, руско Министарство одбране је у прошлости тестирало антисателитско оружје, и хвали се својом способношћу да омета орбитална средства која припадају противницима. Русија још није спровела те претње у дело.

Рајдер је на брифингу навео неколико примера руског антисателитског оружја. Наводни тест руског сателитског убице 2021. године произвео је облак крхотина који је претио међународној свемирској станици ИСС. Следеће године НАСА је успела да помери станицу ван опасности. Ипак, постоји озбиљна забринутост око тога шта би се могло догодити са америчком орбиталном имовином ако више сателита буде уништено у координираном нападу. Таква ескалација би, такође, могла да угрози констелацију Starlink компаније SpaceX, којој је Русија директно претила због њене доступности оружаним снагама украјинске војске.

У овом случају није јасно о каквој врсти антисателитског оружја се ради. Прва антисателитска оружја произведена су крајем седамдесетих и почетком осамдесетих година; то су биле ракете које су се лансирале са америчког ловца F-15. Ракете ASAT су развијене за време америчког програма „рата звезда”, америчког председника Регана. У међувремену су се откривале понеке, некада строго поверљиве информације, па је речено да је Совјетски Савез развио посебне топове (калибра 23 мм) који су могли да бране свој сателит (или да нападају туђ). Појављивале су се и спекулације о разним начинима дејства по противничким сателитима који су укључивали муницију кинетичког дејства, усмерене нуклеарне експлозије, али и усмерена нуклеарна зрачења. Уз такве више-мање фантастичне идеје (које су можда и реализоване) развијана су и

Vučković, D., SAVREMENO NAORUŽANJE I VOJNA OPREMA / MODERN WEAPONS AND MILITARY EQUIPMENT, pp.940-946

усавршавана ракетна оружја са кинетичким или фрагментационим дејством са америчке, руске, а у последње време и са кинеске стране.

Још увек се не зна много о стотинама и хиљадама сателита који круже Земљином орбитом, од којих само мрежа Илона Маска броји неколико хиљада. Комплетна америчка војна доктрина се ослања на употребу података и комуникационе мреже из свемира. Свака претња усмерена ка слабљењу америчког свемирског система за надзор, комуникација, а можда и офанзивних дејстава умногоме би урушило моћ америчке војне силе. У овом случају, евентуално губљење украјинског комуникационог система у рату са Русијом је потпуно неважно.

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ПОЗИВ И УПУТСТВО АУТОРИМА
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ПОЗИВ И УПУТСТВО АУТОРИМА О НАЧИНУ ПРИПРЕМЕ ЧЛАНКА

Упутство ауторима о начину припреме чланка за објављивање у *Војнотехничком гласнику* урађено је на основу Правилника о категоризацији и рангирању научних часописа Министарства просвете, науке и технолошког развоја Републике Србије ("Службени гласник РС", број 159/20). Примена овог Правилника првенствено служи унапређењу квалитета домаћих часописа и њиховог потпунијег укључивања у међународни систем размене научних информација.

Војнотехнички гласник / Vojnotehnički glasnik / Military Technical Courier (втг.мо.упр.срб, www.vtg.mod.gov.rs, ISSN 0042-8469 – штампано издање, e-ISSN 2217-4753 – online, UDC 623+355/359, DOI: 10.5937/VojnotehnickiGlasnik; https://doi.org/10.5937/VojnotehnickiGlasnik), јесте рецензирани научни часопис.

Власници часописа су Министарство одбране Републике Србије и Војска Србије. Издавач и финансијер часописа је Универзитет одбране у Београду (Војна академија).

Програмска оријентација часописа заснива се на годишњој категоризацији часописа, коју врши надлежно државно министарство у одређеним областима, као и на његовом индексирању у међународним индексним базама.

Часопис обухвата научне, односно стручне области у оквиру образовно-научног поља **природно-математичких наука**, као и у оквиру образовно-научног поља **техничко-технолошких наука**, а нарочито области **одбрамбених наука и технологија**. Објављује теоријска и практична достигнућа која доприносе усавршавању свих припадника српске, регионалне и међународне академске заједнице, а посебно припадника војски и министарстава одбране. Публикује радове са уравнотеженим извештавањем о аналитичким, експерименталним и примењеним истраживањима, као и нумеричким симулацијама, обухватајући различите дисциплине. Објављени материјали су високог квалитета и релевантности, написани на начин који их чини доступним широкој читалачкој публици. Сви радови који извештавају о оригиналним теоријским и/или практично оријентисаним истраживањима или проширеним верзијама већ објављених радова са конференција су добродошли. Радови за објављивање одабиру се двоструко слепим поступком рецензије како би се осигурала оригиналност, релевантност и читљивост. Притом циљ није само да се квалитет објављених радова одржи високим већ и да се обезбеди правовремени, темељни и уравнотежени поступак рецензије.

Уређивачка политика *Војнотехничког гласника* заснива се на препорукама Одбора за етичност у издаваштву (COPE Core Practices) и заједничким принципима транспарентности и најбоље праксе у издаваштву COPE, DOAJ, OASPA и WAME, као и на најбољим прихваћеним праксама у научном издаваштву. *Војнотехнички гласник* је члан COPE (Committee on Publication Ethics) од 2. маја 2018. године и члан OASPA (Open Access Scholarly Publishers Association) од од 27. новембра 2015. године.

Министарство просвете, науке и технолошког развоја Републике Србије утврдило је дана 27. 12. 2023. године категоризацију *Војнотехничког гласника*, за 2023. годину:

– **на листи часописа за рачунарске науке:**
категорија врхунски часопис националног значаја **(M51)**,

– **на листи часописа за електронику, телекомуникације и информационе технологије:**
категорија врхунски часопис националног значаја **(M51)**,

– **на листи часописа за машинство:**
категорија национални часопис међународног значаја **(M24)**,

– **на листи часописа за материјале и хемијске технологије:**
категорија национални часопис међународног значаја **(M24)**.

Усвојене листе домаћих часописа за 2023. годину могу се видети на сајту *Војнотехничког гласника*, страница *Категоризација часописа*.

Детаљније информације могу се пронаћи и на сајту Министарства просвете, науке и технолошког развоја Републике Србије.

Подаци о категоризацији могу се пратити и на сајту КОБСОН-а (Конзорцијум библиотека Србије за обједињену набавку).

Категоризација часописа извршена је према Правилнику о категоризацији и рангирању научних часописа Министарства просвете, науке и технолошког развоја Републике Србије ("Службени гласник РС", број 159/20).

Часопис се прати у контексту Српског цитатног индекса – СЦиндекс (база података домаћих научних часописа), Научно-информационог система Redalyc и Руског индекса научног цитирања (РИНЦ). Подвргнут је сталном вредновању (мониторингу) у зависности од утицајности (импакта) у самим базама. Детаљи о индексирању могу се видети на сајту *Војнотехничког гласника*, страница *Индексирање часописа*.

Војнотехнички гласник, у погледу свог садржаја, пружа могућност отвореног приступа (DIAMOND OPEN ACCESS) и примењује Creative Commons (CC BY) одредбе о ауторским правима. Детаљи о ауторским правима могу се видети на сајту часописа, страница *Ауторска права и политика самоархивирања*.

Радови се предају путем онлајн система за електронско уређивање АСИСТЕНТ, који је развио Центар за евалуацију у образовању и науци (ЦЕОН).

Приступ и регистрација за сервис врше се на сајту www.vtg.mod.gov.rs, преко странице *АСИСТЕНТ* или *СЦИНДЕКС*, односно директно на линку aseestant.ceon.rs/index.php/vtg.

Детаљно упутство о регистрацији и пријави за сервис налази се на сајту www.vtg.mod.gov.rs, страница *Упутство за АСИСТЕНТ*.

Потребно је да се сви аутори који подносе рукопис за објављивање у *Војнотехничком гласнику* региструју у регистар ORCID (Open Researcher and Contributor ID), према упутству на страници сајта *Регистрација за добијање ORCID идентификационе шифре*.

Војнотехнички гласник објављује чланке на енглеском језику (arial, величина слова 11 pt, проред Single).

Поступак припреме, писања и уређивања чланка треба да буде у сагласности са *Изјавом о етичком поступању* (http://www.vtg.mod.gov.rs/izjava-o-etickom-postupanju.html).

Чланак треба да садржи сажетак са кључним речима, увод (мотивацију за рад), разраду (адекватан преглед репрезентативности рада у његовој области, јасну изјаву о новини у представљеном истраживању, одговарајућу теоријску

позадину, један или више примера за демонстрирање и дискусију о представљеним идејама), закључак и литературу (без нумерације наслова и поднаслова). Обим чланка треба да буде до једног ауторског табака (16 страница формата А4 са проредом Single), а највише 24 странице.

Чланак треба да буде написан на обрасцу за писање чланка, који се у електронској форми може преузети са сајта на страници *Образац за писање чланка*.

Наслов

Наслов треба да одражава тему чланка. У интересу је часописа и аутора да се користе речи прикладне за индексирање и претраживање. Ако таквих речи нема у наслову, пожељно је да се придода и поднаслов.

Текући наслов

Текући наслов се исписује са стране сваке странице чланка ради лакше идентификације, посебно копија чланака у електронском облику. Садржи презиме и иницијал имена аутора (ако аутора има више, преостали се означавају са „et al.“ или „и др.“), наслове рада и часописа и колацију (година, волумен, свеска, почетна и завршна страница). Наслови часописа и чланка могу се дати у скраћеном облику.

Име аутора

Наводи се пуно име и презиме (свих) аутора. Веома је пожељно да се наведу и средња слова аутора. Имена и презимена домаћих аутора увек се исписују у оригиналном облику (са српским дијакритичким знаковима), независно од језика на којем је написан рад.

Назив установе аутора (афилијација)

Наводи се пун (званични) назив и седиште установе у којој је аутор запослен, а евентуално и назив установе у којој је аутор обавио истраживање. У сложеним организацијама наводи се укупна хијерархија (нпр. Универзитет одбране у Београду, Војна академија, Катедра природно-математичких наука). Бар једна организација у хијерархији мора бити правно лице. Ако аутора има више, а неки потичу из исте установе, мора се, посебним ознакама или на други начин, назначити из које од наведених установа потиче сваки од наведених аутора. Афилијација се исписује непосредно након имена аутора. Функција и звање аутора се не наводе.

Контакт подаци

Адреса или е-адреса свих аутора даје се поред имена и презимена аутора.

Категорија (тип) чланка

Категоризација чланака обавеза је уредништва и од посебне је важности. Категорију чланка могу предлагати рецензенти и чланови уредништва, односно уредници рубрика, али одговорност за категоризацију сноси искључиво главни уредник.

Војнотехнички гласник објављује научне чланке.

Научни чланак је:

– оригиналан научни рад (рад у којем се износе претходно необјављени резултати сопствених истраживања научним методом);

– прегледни рад (рад који садржи оригиналан, детаљан и критички приказ истраживачког проблема или подручја у којем је аутор остварио одређени допринос, видљив на основу аутоцитата);

– кратко или претходно саопштење (оригинални научни рад пуног формата, али мањег обима или прелиминарног карактера);

– научна критика, односно полемика (расправа на одређену научну тему, заснована искључиво на научној аргументацији) и осврти.

Изузетно, у неким областима, научни рад у часопису може имати облик монографске студије, као и критичког издања научне грађе (историјско-архивске, лексикографске, библиографске, прегледа података и сл.), дотад непознате или недовољно приступачне за научна истраживања.

Радови класификовани као научни морају имати бар две позитивне рецензије.

Ако се у часопису објављују и прилози ваннаучног карактера, научни чланци треба да буду груписани и јасно издвојени у првом делу свеске.

Пожељно је да обим кратких саопштења буде 4 до 7 страница, научних чланака и студија случаја 10 до 14 страница, док прегледни радови могу бити и дужи. Број страница није строго ограничен и, уз одговарајуће образложење, пријављени чланци такође могу бити дужи или краћи.

Ако су радови који су претходно објављени на конференцији проширени, уредници ће проверити да ли је додато довољно новог материјала који испуњава стандарде часописа и квалификује поднесак за поступак рецензије. Додати материјал не сме бити претходно објављен. Нови резултати нису нужно потребни, али су пожељни. Међутим, поднесак треба да садржи проширене кључне идеје, примере, разраде, итд., који су претходно били садржани у поднеску са конференције.

Језик рада

Језик рада треба да буде енглески.

Текст мора бити језички и стилски дотеран, систематизован, без скраћеница (осим стандардних). Све физичке величине морају бити изражене у Међународном систему мерних јединица – SI. Редослед образаца (формула) означава се редним бројевима, са десне стране у округлим заградама.

Сажетак

Сажетак јесте кратак информативан приказ садржаја чланка који читаоцу омогућава да брзо и тачно оцени његову релевантност. У интересу је уредништава и аутора да сажетак садржи термине који се често користе за индексирање и претрагу чланака. Саставни делови сажетка су увод/циљ истраживања, методи, резултати и закључак. Сажетак треба да има од 100 до 250 речи и треба да се налази између заглавља (наслов, имена аутора и др.) и кључних речи, након којих следи текст чланка.

Кључне речи

Кључне речи су термини или фразе које адекватно представљају садржај чланка за потребе индексирања и претраживања. Треба их додељивати ослањајући се на неки међународни извор (попис, речник или тезаурус) који је најшире прихваћен или унутар дате научне области. За нпр. науку уопште, то је листа кључних речи Web of Science. Број кључних речи не може бити већи од 10, а у интересу је уредништва и аутора да учесталост њихове употребе буде што већа. У чланку се пишу непосредно након сажетка.

Систем АСИСТЕНТ у ту сврху користи специјалну алатку KWASS: аутоматско екстраховање кључних речи из дисциплинарних тезауруса/речника по избору и рутине за њихов одабир, тј. прихватање односно одбацивање од стране аутора и/или уредника.

Датум прихватања чланка

Датум када је уредништво примило чланак, датум када је уредништво коначно прихватило чланак за објављивање, као и датуми када су у међувремену достављене евентуалне исправке рукописа наводе се хронолошким редоследом, на сталном месту, по правилу на крају чланка.

Захвалница

Назив и број пројекта, односно назив програма у оквиру којег је чланак настао, као и назив институције која је финансирала пројекат или програм, наводи се у посебној напомени на сталном месту, по правилу при дну прве стране чланка.

Претходне верзије рада

Ако је чланак у претходној верзији био изложен на скупу у виду усменог саопштења (под истим или сличним насловом), податак о томе треба да буде наведен у посебној напомени, по правилу при дну прве стране чланка. Рад који је већ објављен у неком часопису не може се објавити у *Војнотехничком гласнику* (прештампати), ни под сличним насловом и измењеном облику.

Табеларни и графички прикази

Пожељно је да наслови свих приказа, а по могућству и текстуални садржај, буду дати двојезично, на језику рада и на енглеском језику.

Табеле се пишу на исти начин као и текст, а означавају се редним бројевима са горње стране. Фотографије и цртежи треба да буду јасни, прегледни и погодни за репродукцију. Цртеже треба радити у програму word или corel. Фотографије и цртеже треба поставити на жељено место у тексту.

За слике и графиконе не сме се користити снимак са екрана рачунара програма за прикупљање података. У самом тексту чланка препоручује се употреба слика и графикона непосредно из програма за анализу података (као што су Excel, Matlab, Origin, SigmaPlot и други).

Навођење (цитирање) у тексту

Начин позивања на изворе у оквиру чланка мора бити једнообразан.

Војнотехнички гласник за референцирање (цитирање и навођење литературе) примењује Харвардски систем референци, односно Харвардски приручник за стил (Harvard Referencing System, Harvard Style Manual). У самом тексту, у обичним заградама, на месту на којем се врши позивање, односно цитирање литературе набројане на крају чланка, обавезно у обичној загради написати презиме цитираног аутора, годину издања публикације из које цитирате и, евентуално, број страница. Нпр. (Petrović, 2012, pp.10–12).

Детаљно упутство о начину цитирања, са примерима, дато је на страници сајта *Упутство за Харвардски приручник за стил*. Потребно је да се позивање на литературу у тексту уради у складу са поменутим упутством.

Систем АСИСТЕНТ у сврху контроле навођења (цитирања) у тексту користи специјалну алатку CiteMatcher: откривање изостављених цитата у тексту рада и у попису референци.

Напомене (фусноте)

Напомене се дају при дну стране на којој се налази текст на који се односе. Могу садржати мање важне детаље, допунска објашњења, назнаке о коришћеним

изворима (на пример, научној грађи, приручницима), али не могу бити замена за цитирану литературу.

Листа референци (литература)

Цитирана литература обухвата, по правилу, библиографске изворе (чланке, монографије и сл.) и даје се искључиво у засебном одељку чланка, у виду листе референци. Референце се не преводе на језик рада и набрајају се у посебном одељку на крају чланка.

Војнотехнички гласник, као начин исписа литературе, примењује Харвардски систем референци, односно Харвардски приручник за стил (Harvard Referencing System, Harvard Style Manual).

Литература се обавезно пише на латиничном писму и набраја по абецедном редоследу, наводећи најпре презимена аутора, без нумерације.

Детаљно упутство о начину пописа референци, са примерима, дато је на страници сајта *Упутство за Харвардски приручник за стил*. Потребно је да се попис литературе на крају чланка уради у складу са поменутим упутством.

Нестандардно, непотпуно или недоследно навођење литературе у системима вредновања часописа сматра се довољним разлогом за оспоравање научног статуса часописа.

Систем АСИСТЕНТ у сврху контроле правилног исписа листе референци користи специјалну алатку RefFormatter: контрола обликовања референци у складу са Харвардским приручником за стил.

Изјава о ауторству

Поред чланка доставља се *Изјава о ауторству* у којој аутори наводе свој појединачни допринос у изради чланка. Такође, у тој изјави потврђују да су чланак урадили у складу са *Позивом и упутством ауторима* и *Изјавом о етичком поступању часописа*.

Сви радови подлежу стручној рецензији.

Списак рецензената *Војнотехничког гласника* може се видети на страници сајта *Списак рецензената*. Процес рецензирања објашњен је на страници сајта *Рецензентски поступак*.

Уредништво

Адреса редакције:
Војнотехнички гласник
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e-mail: vojnotehnicki.glasnik@mod.gov.rs.
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ПРИГЛАШЕНИЕ И ИНСТРУКЦИЯ ДЛЯ АВТОРОВ О ПОРЯДКЕ ПОДГОТОВКИ СТАТЬИ

Инструкция для авторов о порядке подготовки статьи к опубликованию в журнале *«Военно-технический вестник»* разработана согласно Регламенту о категоризации и ранжировании научных журналов Министерства образования, науки и технологического развития Республики Сербия («Службени гласник РС», № 159/20). Применение этого Регламента способствует повышению качества отечественных журналов и их более полному вовлечению в международную систему обмена научной информацией.

Военно-технический вестник (**Vojnotehnički glasnik / Military Technical Courier**), втг.мо.упр.срб, www.vtg.mod.gov.rs/index-ru.html, ISSN 0042-8469 – печатное издание, e-ISSN 2217-4753 – online, UDK 623+355/359, DOI: 10.5937/VojnotehnickiGlasnik; https://doi.org/10.5937/VojnotehnickiGlasnik, является рецензируемым научным журналом.

Собственники журнала: Министерство обороны и Вооруженые силы Республики Србия.

Издатель журнала: Университет обороны в г. Белград (Военная академия).

Программная ориентация журнала основана на ежегодной категоризации журнала, которая производится соответствующим отраслевым министерством, в зависимости от области исследований, а также на его индексировании в международных наукометрических базах данных.

Журнал охватывает научные и профессиональные сферы в рамках учебно-научной области **естественно-математических наук**, а также в рамках учебно-научной области **технико-технологических наук**, особенно в области **оборонных наук и технологии**. В журнале публикуются теоретические и практические достижения, которые способствуют повышению квалификации представителей сербского, регионального и международного академического сообщества, особенно служащих Министерств Обороны и Вооружённых сил. В журнале публикуются статьи со соответствующими обзорами об аналитических, экспериментальных и прикладных исследованиях, а также о численном моделировании, охватывая различные дисциплины. Публикуемые материалы отличаются высоким качеством и актуальностью. Они написаны научным, но понятным и доступным для широкого круга читателей языком. Приветствуются все статьи, сообщающие об оригинальных теоретических и/или практических исследованиях и/или расширенные версии ранее опубликованных статей, представленных на конференциях. Статьи для публикации отбираются путем двойного слепого рецензирования, которое гарантирует оригинальность, актуальность и удобочитаемость. Цель состоит не только в поддержании высокого качества публикуемых статей, но и в обеспечении своевременного, тщательного и соответствующего процесса рецензирования.

Редакционная политика журнала *«Военно-технический вестник»* основана на рекомендациях Комитета по этике научных публикаций (COPE Core Practices), общих принципах прозрачности и лучшей практике издательской деятельности COPE, DOAJ, OASPA и WAME, а также на лучшей практике научно-издательской деятельности. Журнал *«Военно-технический вестник»* является членом COPE (Комитет по этике научных публикаций) со 2 мая 2018 года и членом OASPA (Ассоциация научных издателей открытого доступа) с 27 ноября 2015 года.

Министерством образования, науки и технологического развития Республики Сербия утверждена 27 декабря 2023 г. категоризация журнала *«Военно-технический вестник»* за 2023 год:

- **Область компьютерные науки:**
  ведущий журнал государственного значения **(M51)**,
- **Область электроники, телекоммуникаций и информационных технологий:**
  ведущий журнал государственного значения **(M51)**,
- **Область машиностроения:**
  национальный журнал международного значения **(M24)**,
- **Область материалов и химической технологии:**
  национальный журнал международного значения **(M24)**.

С информацией относительно категоризации за 2023 год можно ознакомиться на странице сайта *«Военно-технического вестника» Категоризация Вестника*.

Более подробную информацию можно найти на сайте Министерства образования, науки и технологического развития Республики Сербия.

С информацией о категоризации можно ознакомиться и на сайте КОБСОН (Консорциум библиотек Республики Сербия по вопросам объединения закупок).

Категоризация Вестника проведена согласно Регламенту о категоризации и ранжировании научных журналов Министерства образования, науки и технологического развития Республики Сербия («Службени гласник РС», № 159/20)

Журнал соответствует стандартам Сербского индекса научного цитирования (СЦИндекс/SCIndeks) - наукометрической базы данных научных журналов Республики Сербия, Научно-информационного система Redalyc, а также Российского индекса научного цитирования (РИНЦ). Журнал постоянно подвергается мониторингу и оценивается количественными наукометрическими показателями отражающими его научную ценность.

С информацией об индексировании можно ознакомиться на странице сайта журнала *Индексирование Вестника*.

«Военно-технический вестник» относительно своего содержания предоставляет пользователям возможность открытого доступа (DIAMOND OPEN ACCESS) и положениями об авторских правах, утвержденными Creative Commons (CC BY). С инструкцией об авторских правах можно ознакомиться на странице сайта журнала *Авторские права и политика самоархивирования*.

Рукописи статей направляются в редакцию журнала с использованием online системы ASSISTANT, запущенной Центром поддержи развития образования и науки (ЦПРОН). Регистрация в системе и оформление прав доступа выполняется по адресу http://www.vtg.mod.gov.rs/index-ru.html, через страницу *ASSISTANT* или *СЦИНДЕКС* (aseestant.ceon.rs/index.php/vtg). С инструкцией по регистрации и правам доступа можно ознакомиться по адресу http://www.vtg.mod.gov.rs/index-ru.html, на странице *Инструкция по ASSISTANT*.

Все авторы, предоставляющие свои рукописи для публикации в редакцию журнала *«Военно-технический вестник»* должны пройти предварительную регистрацию в реестре ORCID (Open Researcher and Contributor ID). Эта процедура осуществляется в соответствии с инструкцией, размещенной на странице сайта *Регистрация в реестре ORCID для присвоения идентификационного кода*.

«Военно-технический вестник» публикует статьи на английском языке (Arial, шрифт 11 pt, пробел Single). Процесс подготовки, написания и редактирования статьи

должен осуществляться в соответствии с принципами *Этического кодекса* (http://www.vtg.mod.gov.rs/etichyeskiy-kodyeks.html). Статья должна содержать резюме с ключевыми словами, введение (цель исследования), основную часть (соответствующий обзор представительного исследования в данной области, четкое изложение научной новизны в представленном исследовании, соответствующую теоретическую основу, один или несколько примеров для демонстрирования и обсуждения представленных тезисов), заключение и список литературы (без нумерации заголовков и подзаголовков). Объем статьи не должен превышать один авторский лист (16 страниц формата А4 с одинарным интервалом, максимум до 24 страниц, включая ссылки и приложения). Статья должна быть набрана на компьютере с использованием специально подготовленного редакцией макета, который можно скачать на странице сайта *Правила и образец составления статьи*.

Заголовок

Заголовок должен отражать тему статьи. В интересах журнала и автора необходимо использовать слова и словосочетания, удобные для индексации и поиска. Если такие слова не содержатся в заголовке, то желательно их добавить в подзаголовок.

Текущий заголовок

Текущий заголовок пишется в титуле каждой страницы статьи с целью упрощения процесса идентификации, в первую очередь копий статьей в электронном виде. Заголовок содержит в себе фамилию и инициал имени автора (в случае если авторов несколько, остальные обозначаются с «et al.» или «и др.»), название работы и журнала (год, том, выпуск, начальная и заключительная страница). Заголовок статьи и название журнала могут быть приведены в сокращенном виде.

ФИО автора

Приводятся полная фамилия и полное имя (всех) авторов. Желательно, чтобы были указаны инициалы отчеств авторов. Фамилия и имя авторов из Республики Сербия всегда пишутся в оригинальном виде (с сербскими диакритическими знаками), независимо от языка, на котором написана работа.

Наименование учреждения автора (аффилиация)

Приводится полное (официальное) наименование и местонахождение учреждения, в котором работает автор, а также наименование учреждения, в котором автор провёл исследование. В случае организаций со сложной структурой приводится их иерархическая соподчинённость (напр. Военная академия, кафедра военных электронных систем, г. Белград). По крайней мере, одна из организаций в иерархии должна иметь статус юридического лица. В случае если указано несколько авторов, и если некоторые из них работают в одном учреждении, нужно отдельными обозначениями или каким-либо другим способом указать в каком из приведённых учреждений работает каждый из авторов. Аффилиация пишется непосредственно после ФИО автора. Должность и специальность по диплому не указываются.

Контактные данные

Электронный адрес автора указываются рядом с его именем на первой страницы статьи.

Категория (тип) статьи

Категоризация статьей является обязанностью редакции и имеет особое значение. Категорию статьи могут предлагать рецензенты и члены редакции, т.е.

редакторы рубрик, но ответственность за категоризацию несет исключительно главный редактор.

Журнал *«Военно-технический вестник»* публикует научные статьи.

Научные статьи:

– оригинальная научная статья (работа, в которой приводятся ранее неопубликованные результаты собственных исследований, полученных научным методом);

– обзорная статья (работа, содержащая оригинальный, детальный и критический обзор исследуемой проблемы или области, в который автор внёс определённый вклад, видимый на основе автоцитат);

– краткое сообщение (оригинальная научная работа полного формата, но меньшего объёма или имеющая предварительный характер);

– научная критическая статья (дискуссия-полемика на определённую научную тему, основанная исключительно на научной аргументации) и научный комментарий.

Однако, в некоторых областях знаний научная работа в журнале может иметь форму монографического исследования, а также критического обсуждения научного материала (историко-архивного, лексикографического, библиографического, обзора данных и т.п.) – до сих пор неизвестного или недостаточно доступного для научных исследований. Работы, классифицированные в качестве научных, должны иметь, по меньшей мере, две положительные рецензии. В случае если в журнале объявляются и приложения, не имеющие научный характер, научные статьи должны быть сгруппированы и четко выделены в первой части номера.

Объем кратких сообщений составляет 4-7 страниц, исследовательские статьи и тематические исследования с проблемно-ситуационным анализом − 10-14 страниц, однако объем обзорных статей может быть больше. Ограничения по количеству страниц не являются строгими, следовательно при соответствующем обосновании предоставленные работы могут быть длиннее или короче. В случае подачи расширенных версий ранее опубликованных докладов, представленных на конференции, редакция проверит было ли добавлено достаточно новых материалов для того, чтобы статья соответствовала стандартам журнала и условиям рецензирования. Добавленный материал должен быть новым, неопубликованным ранее. Новые результаты приветствуются, но не являются обязательным условием; однако ключевые тезисы, примеры, разработки и пр. должны быть более подробно представлены в статье по сравнению с первичным докладом на конфереции.

Язык работы

Статья должна быть написана на английском языке. Текст должен быть в лингвистическом и стилистическом смысле упорядочен, систематизирован, без сокращений (за исключением стандартных). Все физические величины должны соответствовать Международной системе единиц измерения – СИ. Очередность формул обозначается порядковыми номерами, проставляемыми с правой стороны в круглых скобках.

Резюме

Резюме является кратким информативным обзором содержания статьи, обеспечивающим читателю быстроту и точность оценки её релевантности. В интересах редакции и авторов, чтобы резюме содержало термины, часто используемые для индексирования и поиска статьей. Составными частями резюме

являются введение/цель исследования, методы, результаты и выводы. В резюме должно быть от 100 до 250 слов, и оно должно находится между титулами (заголовок, ФИО авторов и др.) и ключевыми словами, за которыми следует текст статьи.

Ключевые слова

Ключевыми словами являются термины или фразы, адекватно представляющие содержание статьи, необходимые для индексирования и поиска. Ключевые слова необходимо выбирать, опираясь при этом на какой-либо международный источник (регистр, словарь, тезаурус), наиболее используемый внутри данной научной области. Число ключевых слов не может превышать 10. В интересах редакции и авторов, чтобы частота их встречи в статье была как можно большей. В статье они пишутся непосредственно после резюме.

Программа ASSISTANT предоставляет возможность использования сервиса KWASS, автоматически фиксирующего ключевые слова из источников/словарей по выбору автора/редактора.

Дата получения статьи

Дата, когда редакция получила статью; дата, когда редакция окончательно приняла статью к публикации; а также дата, когда были предоставлены необходимые исправления рукописи, приводятся в хронологическом порядке, как правило, в конце статьи.

Выражение благодарности

Наименование и номер проекта, т.е. название программы благодаря которой статья возникла, совместно с наименованием учреждения, которое финансировало проект или программу, приводятся в отдельном примечании, как правило, внизу первой страницы статьи.

Предыдущие версии работы

В случае если статья в предыдущей версии была изложена устно (под одинаковым или похожим названием, например, в виде доклада на научной конференции), сведения об этом должны быть указаны в отдельном примечании, как правило, внизу первой страницы статьи. Работа, которая уже была опубликована в каком-либо из журналов, не может быть напечатана в *«Военно-техническом вестнике»* ни под похожим названием, ни в изменённом виде.

Нумерация и название таблиц и графиков

Желательно, чтобы нумерация и название таблиц и графиков были исполнены на двух языках (на языке оригинала и на английском). Таблицы подписываются таким же способом как и текст и обозначаются порядковым номером с верхней стороны. Фотографии и рисунки должны быть понятны, наглядны и удобны для репродукции. Рисунки необходимо делать в программах Word или Corel. Фотографии и рисунки надо поставить на желаемое место в тексте. Для создания изображений и графиков использование функции снимка с экрана (скриншота) не допускается. В самом тексте статьи рекомендуется применение изображений и графиков, обработанных такими компьютерными программами, как: Excel, Matlab, Origin, SigmaPlot и др.

Ссылки (цитирование) в тексте

Оформление ссылок на источники в рамках статьи должно быть однообразным. *«Военно-технический вестник»* для оформления ссылок, цитат и списка использованной литературы применяет Гарвардскую систему (Harvard Referencing System, Harvard Style Manual). В тексте в скобках приводится фамилия цитируемого автора (или фамилия первого автора, если авторов несколько), год издания и по

необходимости номер страницы. Например: (Petrović, 2010, pp.10-20). Рекомендации о способе цитирования размещены на странице сайта *Инструкция по использованию Гарвардского стиля*. При оформлении ссылок, цитат и списка использованной литературы необходимо придерживаться установленных норм. Программа ASSISTANT предоставляет при цитировании возможность использования сервиса CiteMatcher, фиксирующего пропущенные цитаты в работе и в списке литературы.

Примечания (сноски)

Примечания (сноски) к тексту указываются внизу страницы, к которой они относятся. Примечания могут содержать менее важные детали, дополнительные объяснения, указания об использованных источниках (напр. научном материале, справочниках), но не могут быть заменой процедуры цитирования литературы.

Литература (референции)

Цитированной литературой охватываются, как правило, такие библиографические источники как статьи, монографии и т.п. Вся используемая литература в виде референций размещается в отдельном разделе статьи. Названия литературных источников не переводятся на язык работы. *«Военно-технический вестник»* для оформления списка использованной литературы применяет Гарвардскую систему (Harvard Style Manual). В списке литературы источники указываются в алфавитном порядке фамилий авторов или редакторов. Рекомендации о способе цитирования размещены на странице сайта *Инструкция по использованию Гарвардского стиля*. При оформлении списка использованной литературы необходимо придерживаться установленных норм. При оформлении списка литературы программа ASSISTANT предоставляет возможность использования сервиса RefFormatter, осуществляющего контроль оформления списка литературы в соответствии со стандартами Гарвардского стиля. Нестандартное, неполное и непоследовательное приведение литературы в системах оценки журнала считается достаточной причиной для оспаривания научного статуса журнала.

Авторское заявление

Авторское заявление предоставляется вместе со статьей, в нем авторы заявляют о своем личном вкладе в написание статьи. В заявлении авторы подтверждают, что статья написана в соответствии с *Приглашением и инструкциями для авторов*, а также с *Кодексом профессиональной этики журнала*.

Все рукописи статей подлежат профессиональному рецензированию.

Список рецензентов журнала *«Военно-технический вестник»* размещён на странице сайта *Список рецензентов*. Процесс рецензирования описан в разделе *Правила рецензирования*.

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CALL FOR PAPERS AND ARTICLE FORMATTING INSTRUCTIONS

The instructions to authors about the article preparation for publication in the *Military Technical Courier* are based on the Regulations on categorization and ranking of scientific journals of the Ministry of Education, Science and Technological Development of the Republic of Serbia (Official Gazette of the Republic of Serbia, No 159/20). This Regulations aims at improving the quality of national journals and raising the level of their compliance with the international system of scientific information exchange.

The Military Technical Courier / Vojnotehnički glasnik (www.vtg.mod.gov.rs/index-e.html, втг.мо.упр.срб, ISSN 0042-8469 – print issue, e-ISSN 2217-4753 – online, UDC 623+355/359, DOI: 10.5937/VojnotehnickiGlasnik; https://doi.org/10.5937/VojnotehnickiGlasnik), is an peer-reviewed scientific journal.

The owners of the journal are the Ministry of Defence of the Republic of Serbia and the Serbian Armed Forces. The publisher and financier of the *Military Technical Courier* is the University of Defence in Belgrade (Military Academy).

The program of the journal is based on the annual classification of journals performed by a relevant Ministry as well as on its indexing in international indexing databases.

The journal covers scientific and professional fields within the educational-scientific field of **Natural-Mathematical Sciences**, as well as within the educational-scientific field of **Technical-Technological Sciences**, and especially the field of **defense sciences and technologies**. It publishes theoretical and practical achievements leading to professional development of all members of Serbian, regional and international academic communities as well as members of the military and ministries of defence in particular. It publishes papers with balanced coverage of analytical, experimental, and applied research as well as numerical simulations from various disciplines. The material published is of high quality and relevance, written in a manner that makes it accessible to a wider readership. The journal welcomes papers reporting original theoretical and/or practice-oriented research as well as extended versions of already published conference papers. Manuscripts for publication are selected through a double-blind peer-review process to validate their originality, relevance, and readability. This being so, the objective is not only to keep the quality of published papers high but also to provide a timely, thorough, and balanced review process.

The editorial policy of the *Military Technical Courier* is based on the COPE Core Practices, common COPE, DOAJ, OASPA and WAME Principles of Transparency and Best Practice in Scholarly Publishing as well as on the best accepted practices in scientific publishing. The Military Technical Courier has been a COPE (Committee on Publication Ethics) member since 2nd May 2018 and a member of OASPA (Open Access Scholarly Publishers Association) since 27th November 2015.

The Ministry of Education, Science and Technological Development of the Republic of Serbia classified the *Military Technical Courier* for the year 2023, on December 27, 2023

- **on the list of periodicals for computer sciences,**
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  category: reputed national journal **(M51)**,
- **on the list of periodicals for mechanical engineering,**
  category: national journal of international importance **(M24)**,
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  category: national journal of international importance **(M24)**.

The approved lists of national periodicals for the year 2023 can be viewed on the website of the *Military Technical Courier*, page *Journal categorization*.

More detailed information can be found on the website of the Ministry of Education, Science and Technological Development of the Republic of Serbia.

The information on the categorization can be also found on the website of KOBSON (Consortium of Libraries of Serbia for Unified Acquisition).

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All authors submitting a manuscript for publishing in the *Military Technical Courier* should register for an ORCID ID following the instructions on the web page *Registration for an ORCID identifier*.

The *Military Technical Courier* publishes articles in English, using Arial and a font size of 11pt with Single Spacing.

The procedures of article preparation, writing and editing should be in accordance with the *Publication ethics statement* (http://www.vtg.mod.gov.rs/publication-ethics-statement.html).

The article should contain an abstract with keywords, introduction (motivation for the work), body (adequate overview of the representative work in the field, a clear statement of the novelty in the presented research, suitable theoretical background, one or more examples to demonstrate and discuss the presented ideas), conclusion, and references (without heading and subheading enumeration). The article length should not normally exceed 16 pages of the A4 paper format with single spacing, up to a maximum of 24 pages with references and supplementary material included.

The article should be formatted following the instructions in the Article Form which can be downloaded from website page *Article form*.

Title

The title should be informative. It is in both Journal's and author's best interest to use terms suitable for indexing and word search. If there are no such terms in the title, the author is strongly advised to add a subtitle.

Letterhead title

The letterhead title is given at a top of each page for easier identification of article copies in an electronic form in particular. It contains the author's surname and first name initial (for multiple authors add "et al"), article title, journal title and collation (year, volume, issue, first and last page). The journal and article titles can be given in a shortened form.

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Full name(s) of author(s) should be used. It is advisable to give the middle initial. Names are given in their original form (with diacritic signs if in Serbian).

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The full official name and seat of the author's affiliation is given, possibly with the name of the institution where the research was carried out. For organizations with complex structures, give the whole hierarchy (for example, University of Defence in Belgrade, Military Academy, Department for Military Electronic Systems). At least one organization in the hierarchy must be a legal entity. When some of multiple authors have the same affiliation, it must be clearly stated, by special signs or in other way, which department exactly they are affiliated with. The affiliation follows the author's name. The function and title are not given.

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The postal addresses or the e-mail addresses of the authors are given in the first page.

Type of articles

Classification of articles is a duty of the editorial staff and is of special importance. Referees and the members of the editorial staff, or section editors, can propose a category, but the editor-in-chief has the sole responsibility for their classification.

The *Military Technical Courier* publishes scientific articles.

Scientific articles:

– Original scientific papers (giving the previously unpublished results of the author's own research based on scientific methods);

– Review papers (giving an original, detailed and critical view of a research problem or an area to which the author has made a contribution demonstrated by self-citation);

– Short communications or Preliminary communications (original scientific full papers but shorter or of a preliminary character);

– Scientific commentaries or discussions (discussions on a particular scientific topic, based exclusively on scientific argumentation) and opinion pieces.

Exceptionally, in particular areas, a scientific paper in the Journal can be in a form of a monograph or a critical edition of scientific data (historical, archival, lexicographic, bibliographic, data survey, etc.) which were unknown or hardly accessible for scientific research.

Papers classified as scientific must have at least two positive reviews.

If the journal contains non-scientific contributions as well, the section with scientific papers should be clearly denoted in the first part of the Journal.

Short communications are usually 4-7 pages long, research articles and case studies 10-14 pages, while reviews can be longer. Page number limits are not strict and, with

appropriate reasoning, submitted manuscripts can also be longer or shorter. If extended versions of previously published conference papers are submitted, Editors will check if sufficient new material has been added to meet the journal standards and to qualify such manuscripts for the review process. The added material must not have been previously published. New results are desired but not necessarily required; however, submissions should contain expansions of key ideas, examples, elaborations, etc. of conference papers.

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The date of the reception of the article, the dates of submitted corrections in the manuscript (optional) and the date when the Editorial Board accepted the article for publication are all given in a chronological order at the end of the article.

Acknowledgements

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If an article preliminary version has appeared previously at a meeting in a form of an oral presentation (under the same or similar title), this should be stated in a separate note at the bottom of the first page. An article published previously cannot be published in the *Military Technical Courier* even under a similar title or in a changed form.

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All the captions should be in the original language as well as in English, together with the texts in illustrations if possible. Tables are typed in the same style as the text and are denoted by Arabic numerals at the top. Photographs and drawings, placed appropriately in the text, should be clear, precise and suitable for reproduction. Drawings should be created in Word or Corel.

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Citation in the text must be uniform. The *Military Technical Courier* applies the Harvard Referencing System given in the Harvard Style Manual. When citing sources within your paper, i.e. for in-text references of the works listed at the end of the paper, place the year of publication of the work in parentheses and optionally the number of the page(s) after the author's name, e.g. (Petrovic, 2012, pp.10-12). A detailed guide on citing, with examples, can be found on *Military Technical Courier* website on the page *Instructions for Harvard Style Manual*. In-text citations should follow its guidelines. For checking in-text citations, the ASSISTANT system uses a special tool CiteMatcher to find out quotes left out within papers and in reference lists.

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Authorship Statement

The Authorship statement, submitted together with the paper, states authors' individual contributions to the creation of the paper. In this statement, the authors also confirm that they followed the guidelines given in *the Call for papers* and the *Publication ethics and malpractice statement of the journal*.

All articles are peer reviewed.

The list of referees of the *Military Technical Courier* can be viewed at website page *List of referees*. The article review process is described on the *Peer Review Process* page of the website.

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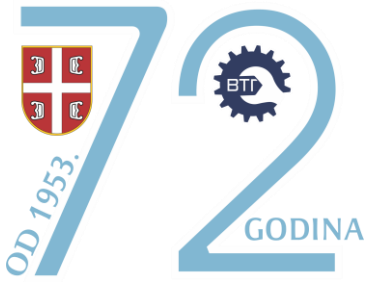
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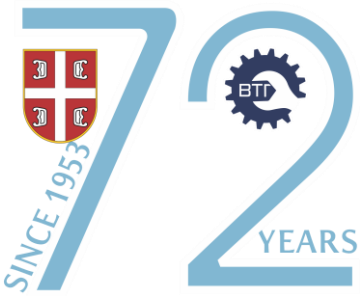
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