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Contents

Dear authors,
Dear readers,

In the ever-evolving world we inhabit, Information and Communication Technology (ICT) has become the lifeblood of modern society.

This edition of our journal delves into the multifaceted impacts of ICT, exploring its potential to bridge divides while also critically examining the challenges it presents.

The articles featured in this issue highlight how ICT is reshaping fields like implementation of artificial intelligence (AI) in trafic safety, different human-computer interfaces and internet of things (IoT), but and also some advanced programming related articles. Other articles in this issue are covering more practical approaches in implementation of modern tehnologies in education using Wikipedia and different automatised translation tools, as well as implementation in different industries, such as metal factories and energy sector.

We invite you to immerse yourself in the insights and discussions presented in this issue. May these perspectives inspire new ideas, spark meaningful dialogue, and drive forward our collective commitment to harness the transformative power of ICT for the greater good.

Warm regards,

Dalibor P. Drljača
JITA Editor-in-Chief

Pattern Proposal for detecting object occupancy in AVs utilizing ML, Edge Cloud, AI, and CV for parking LoTs

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Original scientific paper

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Abstract: The purpose of this article is to provide an overview of current parking system management issues as well as support for effective object identification in circumstances of autonomous parking. In particular, we will look at existing solutions and patterns that have the most immediate use in automobiles and other businesses that rely on these technical approaches. The question arises as to the effectiveness and expense of existing solutions during various times of day (rain, fog, snow) and weather conditions, which can significantly alter the visibility of any systems that use cameras for object detection. This is applicable to parking lots that use cameras and a computer system's integrated capabilities to detect and classify items using a machine model that makes certain decisions or suggests certain objects for object occupancy tracking. Our parking system concept proposal can be summed up in a dozen successful implementations for autonomous vehicle (AV) control and other Internet of things (IoT) systems. Image processing could be carried out using a mix of one or more algorithms and patterns that require specific hardware and software in the background, such as CI/CD, HPC, edge, cloud computing, and cluster microservices. Key contributions and findings can be given in the form of a novel pattern method known as combined detection of parking occupancy on chip (ComDPOCh), which can be applied in a real-world setting using appropriate hardware and software.

Keywords: Machine learning and computer vision, parking lot occupancy, watershed segmentation algorithm, object detection in autonomous vehicles, image processing, autonomous vehicles, artificial intelligence, Internet of things (IoT)

Introduction

A practical analytical approach to solving the current problem related to the best possible management of the parking system requires a more precise determination of the number of vehicles in the parking lot or during vehicle movement. Cameras that constantly monitor the required terrain, combined with advanced software inside the vehicle, can detect the availability and number of parking places. Each research requires certain funds for investment into new technology, as well as its maintenance [1, 2, 3, 4]. In company which deals with innovative research and creation of new technologies it is also important to have certain knowledge, with the help of which competitiveness on the market can be achieved using SEO, SEM, CI/CD, Cloud and Edge technologies [5, 6, 7, 8]. External influences can create reduced sight, making it difficult to operate these devices in case of problems with logistics organization and product availability on the market. All this together affects the economic profitability and delays in the delivery of the final product, such as a complete vehicle that can be partially or fully automated.

Improving software technologies and security is a prerequisite for improving hardware solutions to common challenges with different power sources [8, 9, 10]. In other words, we have reached a point where a software system can surpass a hardware solution in all aspects [10, 11]. That is why algorithms are utilized for the identification and classification of movements in the continuous monitoring of parking lots and points of interest, based on which the machine model makes certain conclusions or suggests specific items.

Detection model training processes in most situations need the application of HPC, cloud computing, cluster microservices [12], edge or a development process that uses CI/CD at its core [13, 14, 15, 16], to successfully obtain an efficient and applicable detection module inside the vehicle or camera itself.

There are many methods that deal with image processing, motion detection, and object classification using cameras and IoT devices, but the challenge of accuracy and speed remains. In this case, image processing can be performed using a combination of one or more algorithms to improve visual content under low visibility conditions. These algorithms can also be applied in the field of parking management [17]. The lack of object detection support under night conditions is evident in existing systems. In general, in difficult conditions, all solutions give significantly worse results.

Computer assistance is gradually improving, and there is still space to upgrade existing surveillance camera systems and solve difficulties with limited visibility utilizing patterns and algorithms. However, all possible solutions are better or worse than others in individual scenarios and produce different results.

Existing solutions use only one method with only one approach, but no implementation is robust enough to be used for several different scenarios (parking schedule, car position, camera angle, etc.) and temporal and spatial conditions [18, 19]. The work is intended for readers who have a certain knowledge and experience in the field of machine learning (ML), artificial intelligence (AI), computer vision (CV), autonomous vehicles (AV), along with other interconnected technologies and hardware approaches [20, 21, 22]. Considering the intended use, it is important to choose the algorithm best suited for the serving the purpose.

The main contributions within this paper relate to the presentation of the idea proposal of implementing a technical solution for parking occupancy. This proposal relies on the possible application of several different algorithms for detection in mixed lighting and weather conditions. While within the conceptual proposal, the contribution is providing a better understanding of the computationally efficient approach and the complexity of the future computer system with the required number of components for successful implementation by using video surveillance systems and cameras in the vehicle.

The research is divided into the following sections: introduction, materials and methods, cost of automotive sensors and optimization processes, related work which include the important literature in this topic. This section discusses the opportunities and challenges associated with existing solutions and how some difficulties can be solved by combining multiple algorithms based on the time of day and light intensity. The results section encompasses solution ideas and collected assumptions. In this section, we described alternative methodologies and algorithms, along with a proposal for a future solution presented in the form of a visual representation of a computer system that could be deployed. Additionally, the prospects for software development and integration with CI/CD are being investigated, and conclusion summarizes the current findings and directions of future research.

METHODS AND MATERIALS

Methods and materials were gathered through research questions. The research method is based on empirical observation and the possibility of proposing future solutions. The study focuses on non-numerical data and the collecting of various ideas and perspectives on the topic of direct application, summarizing the current state of affairs in this field. The volume of literary study connected to all solutions from 2004 to 2024. The literature is studied through the lens of possible direct applicability in many applications and sectors. We looked at the financial implications of sensors and their impact on the development of appropriate detecting software.

Research Questions

The research framework is focused on finding answers to the following questions:

1. What are the sensor prices and total costs for a partially or completely automated vehicle?
2. What solutions exist for object detection and support for nighttime applications?
3. What is the optimal solution for effective parking detection and application within AV and other industries?

Related Work

The question arises as to how well existing solutions perform depending on time of day (rain, fog, snow) and weather conditions, which can have a considerable impact on the visibility of any systems that employ cameras to detect objects. In general, this has an impact on the management of self-driving vehicles as well as assistance for successful object recognition in automatic parking applications. Based on all of this, the camera is unable to acquire a sufficient amount of high-quality data, which has a substantial impact on the algorithm's outcomes.

Where the details related to the existing approaches are summarized and selected based on the possibility of obtaining certain results during the analysis of the obtained graphic display. The focus within the related literature is on looking at the possibility of connecting future implementations of algorithms, technologies, software, hardware, and the subsequent implementation of real experiments. The planned experiments should be realized inside the vehicle and on video surveillance systems, where could be obtained the possibilities of application for different purposes. Key findings and arguments on the direct use and use of small embedded computers inside a car or a laboratory environment that might be used in a public free parking lot.

Within the mentioned section, we focused on algorithms and their application possibilities. On the basis of which we made the appropriate organization in the following way: image preprocessing, Fog and haze, Darkness, Precipitation, Motion tracking, Algorithm in scene illumination, Image segmentation and Categorization.

Cost of Automotive Sensors and Optimization processes

Automotive sensors play an important function in modern automobiles, ranging from improving reliability towards enabling automated driving. The integration of the sensors in automobiles has become vital for optimizing performance and costs [22, 23]. For example, the cost implications of sensors vary depending on the level of autonomy of a vehicle. According to the data we collected, 9 sensors in a Level 1 vehicle add $300 to the total cost, but 28 sensors in a Level 5 vehicle add $1,758. There is a significant difference in adding the additional total cost of the finished product without accounting for software production costs [23, 24].

This emphasizes the significance of cost minimization measures in sensor integration. In the pursuit of cost optimization, advances in the field of sensors have been developed to improve efficiency and cut wasteful costs. For example, the use of AI in vehicle upkeep has been shown to minimize sustaining costs and resources through the provision of scheduled repairs. The new self-driving capabilities include a wide range of sensors and autonomous characteristics, and their number is projected to grow in the future which is shown in Figure. 1.

Figure 1. *Matching Sensor Cost with Automotive Disruption. Source: [22]*

Furthermore, optimizing sensor placement on vehicles is crucial to boosting performance. In the sphere of security, we must strike a balance between cost optimization for automotive cyber-physical systems and security-related hardware cost optimization. While CAN FD-based systems have highlighted

the importance of balancing security measures with financial costs in the event of a breach of security [25].

Types of existing detection solutions

There are several ways to approach the solution to this problem in the literature and related works. In general, the solutions could be classified into 2 or 3 groups, surface-oriented and object-oriented, and the third group would be a hybrid combination of methods from the first two.

Disruptive factors, such as bad weather, affect more solutions in the surface group. However, problems regardless of time can be caused by shadows or differently lit surfaces. Some of the algorithms in these situations can scan and recognize an occupied part of the parking lot that is in the shade, and in the sun as free.

In the following, Dakić et. al [11] we discuss existing solutions that have the greatest degree of direct application within vehicles and other industries that rely on these technological approaches. This applies to parking lots that rely on cameras and the integrated capabilities of a computer system that detects and classifies objects. Most solutions require the application of appropriate standards Dakić et al. [26] and their harmonization depending on the country in which the solution is used. In most cases, Todorović et al. [26] standards compliance is monitored on appropriate control panels/dashboards using analytical software in real time.

Surface-oriented solutions

Surface-oriented implementations of the relevant software and hardware use the parking lot's surface to detect whether parking spaces are free and occupied. The solution of Liu et al. [27] is presented via the use of multi-support vector machines on portions of three neighboring parking lots to find linkages between adjacent patches. The essential parking space is classified according to its qualities. According to the authors of Liu et al. [28] and their understanding reveals that there are options based on a breakdown of blocks of grayscale parking cell photos. The approach is based on dividing each parking place into four equal-sized chunks. Each of these was then evaluated using particular homogeneity criteria. If the unit in question does not match these requirements, it is broken into four subunits, which can be represented as a computational grid or programming code. Most software deployments, Kročka et. al [29] necessitate the use or the creation of machine detection models with AI and CV application capabilities that employ table detection approaches where direct application can be done within the vehicle, using static cameras in the parking lot.

Each block is split interactively until the output passes the homogeneity condition and is consistent with the trained recognition model. The consistency of the parked cell (1x1) can be found by summing all of the reinforcing blocks of one parking cell, i.e. if it contains non-homogeneous constructions, such as vehicles. Their presentation can be realized in a number of different ways within 2D and 3D space using matrices. A similar approach is offered by Funck et al. [30]. They also apply to parking areas in their grouping of parking cells, where an image of an empty parking lot is used as a reference and compared to the present status in each consecutive frame. A better approach is Huang et al. [31], who improved this group's solutions by referring to the complete object in the parking compartment as a surface. This strategy may be the most productive of the entire collection of approaches.

Best possible detection and classification

The second group's solutions are based on the most accurate identification and classification of items from photographs. Parking system solutions can be summarized in a dozen effective automobile industry deployments and highway vehicle control. An outstanding solution using a CNN classifier offered by Amato et al. [32] can work on smart cameras with limited resources. This approach uses a 5-layer CNN to identify both a vehicle and an empty parking space for categorization.

The third group includes hybrid solutions that use the background for motion detection. A very robust solution in the field of urban traffic management comes from Feris et al. [33] which shows the possibilities of achieving vehicle tracking and detection from many different angles. A straightforward rule-based vehicle classifier is used, which examines the form and movement of foreground spots at predetermined time intervals. They determine if the aspect ratio, size, and direction of movement of specific

foreground spots are within a predefined range of parameters that identify the vehicle.

The authors Bhaskar et al. [34] offer a unique algorithm for vehicle data recognition and tracking using the Gaussian mixture model and speckle detection methods, a similar solution was proposed by Foresti et al. [35]. Postigo et al. [36] propose an approach that allows background removal and vacancy map analysis, which is proposed by Postigo et al. [36]. From this map, vehicles are detected and tracked to determine their parked or abandoned status, as well as to account for frontal and neutral occlusions. Occlusions refer to changes in temperature and differences between certain objects that are detected by rendering them through a certain color. An estimate of free parking space is also given. Their algorithm is capable of estimating the dimensions of a parking lot. Mithun et al. [37] offered a similar solution to time-space images.

Application of various algorithms and detection conditions

Detecting procedures can be implemented in a variety of ways, and in this section, we have discovered relevant algorithms and circumstances that can be applied to our conceptual solution. Each phase step and the use of various algorithms are described in further detail and justified.

In the first phase, Chen et al. [38] It essential to perform initial image processing from various image sources. Most sources can be found inside the car or in an external system. The procedure is receiving the image from the recording device and processing it with as much detail, high quality, and as little noise as possible before saving it. After completing the first storage operation, advanced algorithms can be used to process the data for object recognition. The approaches applied in this step shall be prioritized in low-visibility and nighttime conditions, as well as rain and fog. The selection of proper algorithms for the image processing is critical, and the degree of precision of the subsequent processes is heavily reliant on the findings.

On the basis of the knowledge gathered in this work and the literature source [39, 38, 40, 41, 42], we had the opportunity to become familiar with the most common image problems that occur in conditions of reduced visibility. All of this is represented in the image's low contrast between visible items and backdrop, poor illumination, and heavy noise. In addition, the way the image is processed is heavily influenced by the conditions in which it was captured. Simply expressed, the choice of image processing technique is determined by the challenges to be handled, which include reduced visibility, low detail, and high noise. Nevertheless, a poor image might be created by the time of day, sunlight, fog, haze, or excessive precipitation. It is required to select the option that provides the greatest score for better image quality under the specified circumstances. This necessitates the selection of appropriate image processing techniques based on the present weather and optical conditions. In the following, we discuss some of the essential methods and publications that deal with applicability under diverse weather and illumination circumstances [40].

Fog and haze

There are many great works in the field of image enhancement. One of the methods for image processing under fog and haze conditions is Efficient Image Dehazing with Boundary Constraint and Contextual Regularization by Meng et al. [43]. The advantage of this solution is that it does not depend on knowing the scene in an ideal state, i.e. only one image input is sufficient which is shown in Figure 2.

Figure 2. *Image Dehazing with Boundary Constraint and Contextual Regularization. Source: [43].*

When it comes to nighttime picture processing, the most popular methods are those that use histogram equalization to increase the brightness and contrast. These algorithms work on the principle that after finding the mean value of brightness, it begins with the lowest level and compares it to the mean value; if it is lower, the next level is added to it and compared to the mean again. The operation proceeds until the value that is closest to the mean is determined. All the levels of brightness are then grouped

together, allowing for an approximate harmonization of the histogram [42].

We can distinguish between the following equalization methods: normal histogram, adaptive, adaptive contrast histogram, adaptive contrast limited histogram, and multipeak histogram. In the work of Bhandari et al. [44] where image enhancement and object recognition for night vision surveillance are discussed, Contrast Limited AHE (CLAHE) was shown to be an algorithm with extremely good results.

The GCANet solution by Chen et al. [45] Shows excellent results in eliminating precipitation from the scene. In this network, a smoothed dilation technique is utilized to remove network artifacts generated by extensive dilated convolution with minimal additional parameters, and a closed subnet is used to integrate data from different layers.

Algorithm in scene illumination

When the illumination in the scene changes, the algorithm's functioning may get more complicated. The algorithm should account for variations caused by the day and night cycle, as well as lighting changes caused by, say, a quick change in clothing. Background noise might also hamper the algorithm's operation. For these reasons, image preparation and pre-processing are required, as shown in the example on Figure. 3 and Figure. 4. The illustration shown shows the extraction of pedestrians within 2D and 3D space.

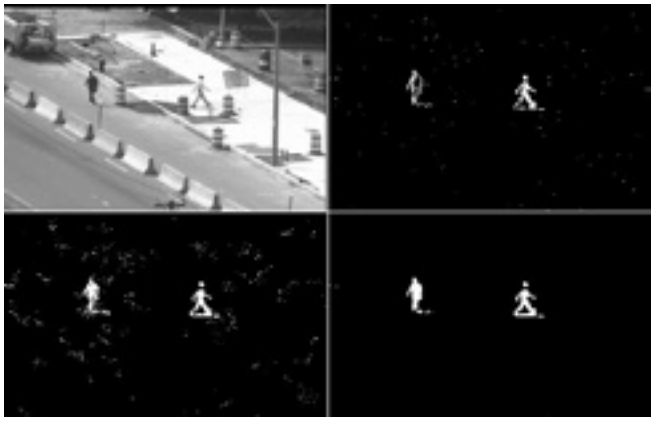

Figure 3. *Background subtraction. Source: http://vip.bu.edu/projects/vsns/background-subtraction/fa/.*

Image segmentation entails highlighting stationary elements. Due to the density of parking spaces and the usage of a limited number of cameras, vehicles are frequently obscured from the camera's view. However, this is a considerably more complicated issue because even the human eye cannot perceive what is behind the item blocking our view. This issue is particularly prevalent in computer vision. Consider the scenario in which vehicle A arrives at a full parking lot. Vehicle A passes past rows of parked cars, always concealed by the camera's eye. Watershed algorithm created by Google is later used for image segmentation [46]. For instance, the vehicle subsequently finds a free parking spot and halts for a moment and still is only partially visible to the camera lens (Figure. 4). The cameras covering vehicle begin to leave the parking lot, until the detected surface becomes fully visible. The camera lens then receives new information, but it happens that the algorithm for categorizing the received information does not take into account vehicle. The purpose of this method is to clearly and precisely distinguish the contours of objects from one another. The Watershed Algorithm views pixels as heights, with more visible pixels on higher terrain and darker pixels shown as gaps in the ground due to their low visibility. They can alternatively be represented in the table using the integers 0 and 1. Water will be injected into depressions (ground gaps) to improve pixel recognition. Also, these depressions, will be forming lakes with dams in between. The management of the dam represents the contours of the buildings and the shapes illustrated in Figure. 4.

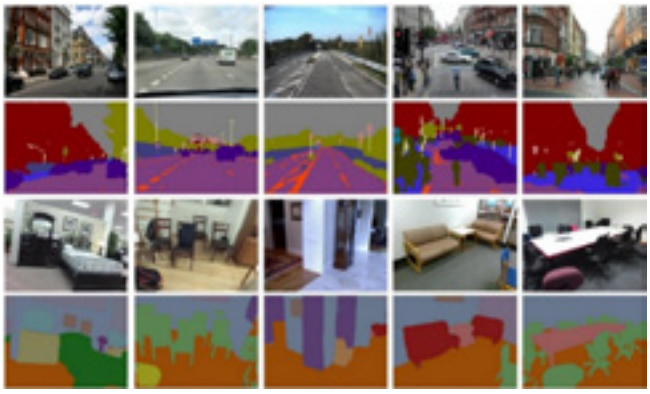

Figure 5. *Image segmentation. Source: https://mi.eng.cam.ac.uk/projects/segnet/*

Categorization operations will be accomplished by classifying things of interest, auxiliary objects, and vehicles. We need good recognizability and segmentation of the incoming input results. Since classification of objects comes at the end, it is evident that the input to this method is a processed image with de-

fined contours. Classification entails locating an object inside the group to which it belongs. As a result, object categorization requires the training and implementation of a neural network.

Results

Based on the defined questions, we managed to obtain the following results in the form of a conceptual proposal and certain initial assumptions regarding the future solution.

We developed a novel pattern method called combined detection of parking occupancy on chip (ComDPOCh). The technique described above was created as an outcome of the performed research, and based on it, we can propose a solution that would consist of four phases:

1. Image preprocessing
2. Motion tracking
3. Image segmentation
4. Categorization

The primary notion of this approach is to monitor movement in the parking lot. Motion can be defined as the difference between two (or more) pixels in the same scene. The simplest method for detecting motion is to subtract the modified frame from the original one. The outlines of the moving object can then be obtained simply by identifying the differences between the frames. To prevent detecting movements that we are not interested in, such as tree limb movement or light changes in the scene, we must first investigate and then set a suitable threshold that eliminates these events. The process would be carried out using a system that included a different scene for every OOI (object of interest). Regardless of the objects present, each new OOI would start with an empty scene (empty background). It would be required to undertake research on objects that piqued our interest. Vehicles come in a variety of shapes and sizes, and it is not uncommon for some to hide others' views to the point that just the roof, front, or back of the car is visible. Even then, it will not resemble a biker or pedestrian. This is precisely what may be used to improve the threshold for OOI.

A simpler visualization of the algorithm and patterns that are detected is shown in Figure. 5 which consists of 5 steps with two section parts A and B, that are explained below. At each step, there are two images of the scene: the color image (A - parking lot road) is the way we see it, and the black-and-white image (B - computer detection system) is the way the algorithm sees it. In the color image, the vehicle can have three colors: yellow - the vehicle is in motion, green - the vehicle is just parked, and green - the vehicle was already parked on the stage.

When the item reaches the OOI threshold, we start tracking it to the end destination Figure. 5 (steps 1-3). The scene in the computer's "eyes" appears to be a black background with a white item moving across it. When the OOI arrives at its final destination, it follows the tracks and we save its scene (steps 3 and 4). By integrating the scenes of all OOIs, we can obtain a global image and hence a clear picture of the number of vehicles parked in the parking lot (step 5). This allows us to determine the vehicle's position in relation to the parking lot as well as its proximity to other vehicles.

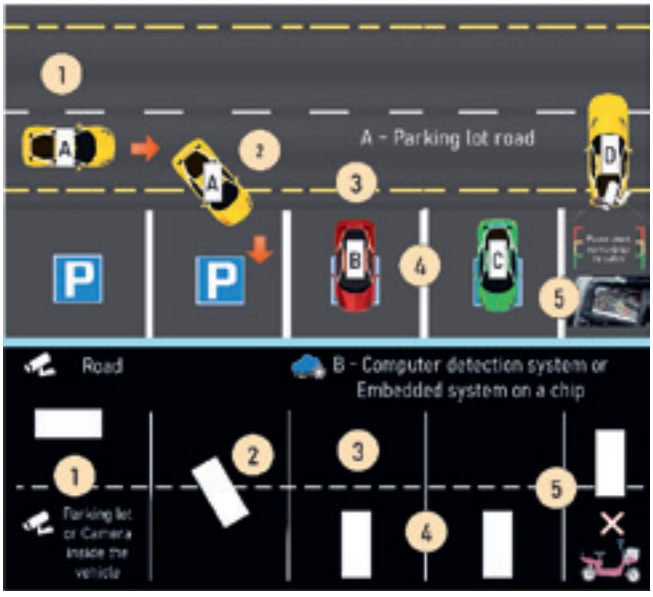

Figure 5. *Working idea proposal for the Method in detection of parking occupancy on chip (ComDPOCh). Source: author's contribution.*

It often happens that the vehicle entering the scene, vehicle A, is not visible from the camera angle because of the vehicle already on the scene, vehicle B, as vehicle B leaves, vehicle A becomes visible, and the newly discovered part of the vehicle is not always recorded at the scene when it is parked like for vehicle C. One of the ways to solve this problem is the application of the pattern for object presence detection and basin algorithm (Watershed Segmentation Algorithm) [46], which, based on the position of the ve-

hicle, can display the newly discovered part that has been detected. The application can be inside the vehicle, as well as in the parking lot with static cameras or in Internet of Things (IoT) devices. After detection, the information will be saved in a special scene that represents the detected information in the matrix coordinate system that is used to save its information for further processing.

The detection computer system shown in Figure. 5 (B - computer detection system) could be created in the form of smaller microservices that are located inside the cluster and are started depending on the load and the demandingness of the operation itself [47, 12]. The software development itself could be realized by applying a modeled business process through which the detection model is trained and tested using the CI/CD pipeline [15, 14, 48].

Based on the proposed solution, the planned studies show how to investigate the possibility of vehicle detection in complete darkness, high levels of illumination, when it is snowing or raining, and combinations of these situations. As a result, the experiments themselves further processes would be mimicked in the laboratory or in a physical setting.

Another important factor that can aid in future detection is the usage of unique colors and road markings. With the help of the aforementioned information, improved efficiency may be achieved in the identification and recognition of patterns and objects studied by the sensor during the vehicle's movement. By using marking with green glow paint – photoluminescent show on Figure. 6 we can quickly perform the detection process itself and reduce the time required for detection and the complexity of processing the data obtained from the environment itself.

Figure 6. *marking with green glow paint - photoluminescent/ glow in the dark road & line marking. Source: author's contribution.*

After the successful application of the mentioned color shown on the Figure. 6, we can see the result during the night on Figure. 7, where they are clearly seen and noticed by the driver himself and the embedded computer system inside the vehicle.

Figure 7. *highlighting the effect of photoluminescent green glow paint, which glows in the dark for road and line marking. Source: author's contribution.*

The effective use of various strategies improves the success of detection alongside additional software development techniques. So that it is easier to digest real-world information that AI cannot understand without proper visualization and display in 2D or 3D space.

DISCUSSION

All of this leads to a suitable conversation, which necessitates a more in-depth examination of the true potential and needs during software and physical vehicle testing. In accordance with the established research framework and research questions, we can summarize and report the findings, we came to the following answers:

RQ1: Referring to the studied data and available information, we found a significant difference for vehicles ranging from Level 1 to Level 5. As we can see, 9 sensors for the first level add $300 to the cost, whereas Level 5 and 28 sensors may run up to $1,758. I anticipate that in the future, the prices of the

aforementioned sensors will be much lower.

RQ2: We have learned about different algorithms and the impact in detection conditions that must be met before starting the detection process itself. We have seen that there is a high level of complexity within this area and the necessity of knowing different solutions.

RQ3: Based on the research, we came to the knowledge that the best detection method is the collection of graphic information reflected in the reaction during the fulfillment of certain weather conditions, lighting, and object detection. Which can minimize the impact of false detection can be represented by combining the positive aspects of each of the solutions and applying them under certain favorable conditions.

Conclusion

In low-light settings, simpler visibility enhancement strategies can improve motion detection, complementing efficient classification methods and other object detection systems. These improvements allow for more reliable performance of the proposed solution under low-visibility conditions. Motion tracking can alert the system to activity in the parking lot and around vehicles, while accurate image segmentation will further enhance vehicle detection.

We developed a novel pattern recognition method called Combined Detection of Parking Occupancy on Chip (ComDPOCh), which offers a promising solution for efficient parking space monitoring. This method, the outcome of rigorous research, forms the basis of a comprehensive four-phase solution addressing critical challenges in real-time parking management.

The implications of this research extend to both practical applications and future studies. Practically, the proposed method can significantly enhance the reliability and efficiency of smart parking systems, particularly in urban areas where such solutions are in high demand. Integration into CI/CD pipelines will facilitate seamless implementation and thorough testing under diverse environmental conditions. However, legal and ethical issues, such as the suppression of personal data throughout picture processing, remain significant obstacles that must be solved to maintain compliance and create user confidence.

To increase system robustness, future research should focus on enhancing the reliability of occupancy detection in tough settings such as low visibility or weather-related issues. Furthermore, a more thorough examination of security and privacy of data standards would assure regulatory compliance while also enabling new applications. Addressing these issues will refine the proposed solution and contribute significantly to advancements in intelligent transportation systems.

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Informed consent

Not applicable

Conflict of interest

The author(s) declare(s) that they have no conflict(s) of interest.

Ethical approval

Not applicable.

Data Availability Statement

Not applicable.

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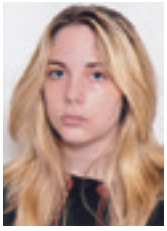

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TRANSFORMING TRAFFIC SAFETY: DETECTION OF CAR-PEDESTRIAN CONTACT USING COMPUTER VISION TECHNOLOGIES

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Abstract: This paper explores the integration of computer vision technologies to enhance traffic safety through the effective detection of car-pedestrian interactions. As urban environments become more congested, pedestrian safety remains a critical concern. The system's performance was evaluated using real-life footage from vehicle-mounted cameras, as well as images and videos sourced from online platforms. These real-world scenarios enabled a detailed assessment of the system's accuracy and efficiency in practical conditions. The study highlights the potential for significant improvements in traffic safety, particularly in Bosnia and Herzegovina, where over 38% of registered vehicles are older than 23 years, and nearly 62% exceed 14 years. The aging vehicle fleet heightens the risk of accidents, underscoring the need for advanced detection methods. The proposed system automates the identification of hazardous situations on roads, allowing timely responses from relevant authorities.

Keywords: Traffic safety, YOLOv8, Computer vision, OpenCV, Object detection

INTRODUCTION

Computer vision technologies have demonstrated considerable potential in improving traffic safety, especially in detecting and analyzing interactions between pedestrians and vehicles. These systems facilitate automated identification of traffic conflicts and violations, delivering crucial data for safety assessments and the development of preventive measures [1]. Within cities, traffic congestion has emerged as the primary challenge. [2]. Monitoring pedestrian movements and their interactions with vehicles, commonly referred to as object tracking [3], can significantly enhance pedestrian safety. By analyzing pedestrian behavior, recognizing traffic patterns, and predicting potential conflicts, authorities can implement various measures, such as pedestrian crossing signals, improved signage, and traffic calming techniques, to boost overall pedestrian safety. According to the latest statistics on traffic accidents, their causes, and consequences in Bosnia and Herzegovina, 31,321 traffic accidents were reported on Bosnian-Herzegovinian roads in 2022. Of these, 7,230 resulted in casualties and injuries, while 24,091 cases involved material damage. The total number of accidents marked an increase of 1,083 compared to 2021, highlighting a persistent upward trend in traffic incidents each year. [4]. Given these alarming statistics regarding traffic incidents in Bosnia and Herzegovina, this research aims to provide practical solutions for enhancing traffic safety.

LITERATURE REVIEW

Recent advancements in computer vision technologies have significantly improved traffic safety and surveillance systems. These systems utilize object detection and recognition techniques to identify vehicles, pedestrians, and traffic signs. [5]. Despite challenges like varying weather conditions and lighting changes, these technologies continue to evolve, contributing to the development of intelligent transportation systems and autonomous vehicles.

Patil et al. [6] propose a real-time traffic sign detection system utilizing deep learning models, which

improves road safety by recognizing traffic signs and aiding traffic management. Similarly, S. S et al. [7] introduce an IoT-based system that employs YOLO for real-time traffic monitoring and accident detection, optimizing traffic signal timings to alleviate congestion. Chadha et al. [8] focus on driver safety by developing a fatigue detection system using MediaPipe and OpenCV, which monitors driver attention and alerts them to prevent accidents. Kushwaha et al. [9] address lane detection challenges, proposing a system that identifies lane boundaries under varying conditions, thereby enhancing driver awareness and reducing accidents.

Rocky et al. [10] have tackled the necessity for a dependable system to detect high-risk incidents. They highlight the significance of enabling self-driving vehicles to function autonomously for prolonged durations without human oversight. Their review centers on utilizing dashboard cameras (dashcams) as a cost-effective means to improve the safety of autonomous vehicles during accident scenarios. The authors provide a thorough overview of the evolution of concepts in this field, classifying methods into supervised, self-supervised, and unsupervised learning. They meticulously analyze evaluation criteria and available datasets, shedding light on the advantages and drawbacks of various approaches.

These studies illustrate the transformative potential of computer vision in improving road safety and traffic management.

Methods and materials

The preparation for this experimental study involved collecting various video materials and photographs obtained from real-life situations as well as online sources, ensuring an authentic representation of traffic scenarios (Figure 1). The dataset used in the research includes 150 images and 50 video clips, as well as additional data from the NYC Motor Vehicle Collisions to Person dataset available on Kaggle [11]. This additional dataset enhanced the analysis, providing a broader spectrum of traffic scenarios and increasing the validity of the findings. The goal was to provide deeper insights into the system's detection efficiency and assess its applicability in real-world conditions.

Image Processing

Image processing encompasses the manipulation of digital data in the form of images and videos, allowing for the extraction of information regarding shape, position, orientation, size, dimensions, and color [12]. When individuals view images or videos, they can easily identify objects, gauge distances between them, and discern colors and positions. The main goal of digital image processing is to extract and interpret this information. Our image processing workflow consists of several steps, including loading, resizing, edge detection, object detection, converting to grayscale, and removing noise.

Loading an image

When loading an image, the initial step is to import the necessary library. Following this, the cv2.imread() function is invoked to load the image, and the resulting data is stored in the variable img. This function's parameters include the file path of the image and an integer that specifies whether the image should be loaded in color or grayscale (stored in the variable img_1). To display the loaded image in a new window, the cv2.imshow() function is called, which takes as parameters the name of the window and the variable containing the image data. Next, the waitKey() function is executed, which temporarily halts program execution until a key is pressed. Once a key is detected, the destroyAllWindows() function is called to close all open windows.

Figure 1. *Image loaded in its original format*

Resizing the image

To resize an image by its width and height in pixels, the resize() function from the OpenCV library (cv2) is

employed. The image dimensions can be adjusted according to specific requirements. In this example, the image size is reduced by 50%, and the new dimensions are calculated accordingly. If only one dimension is known, the other can be determined based on the aspect ratio of the original image.

Here's a breakdown of the process [13]: The cv2.imread() function reads the specified file in cv2.IMREAD_UNCHANGED mode, returning a NumPy array containing the pixel values. The variable scaling_percentage is set to 50, indicating that the image will be reduced to 50% of its original dimensions (both width and height). img.shape[1] retrieves the width of the original image. int(img.shape[1] * scaling_percentage / 100) computes the new width, which represents 50% of the original width (Figure 2). The new size of the image is established with these calculated dimensions. The cv2.resize() function resizes the image img to the new dimensions stored in the variable new_image, returning a NumPy array. Finally, the resized image is saved to disk with the name "traffic_resize.jpg".

Figure 2. *Size comparison: 50% reduction (right) compared to the original size (left)*

Converting an RGB image to grayscale

To create a grayscale image, you can either read the file directly in grayscale mode or if an RGB image is already loaded, convert it to grayscale using the cvtColor method from the OpenCV library (Figure 3).

Figure 3. *Original RGB image (left) converted to grayscale (right)*

Noise removal

One of the key challenges in image processing and computer vision is the removal of noise from images. The "denoising" process entails estimating the original image by minimizing the noise that may be present (Figure 4). Noise can originate from various sources, including sensors and environmental factors, making it often unavoidable in real-world applications.

Figure 4. *Result of noise removal from the image*

Edge detection

Edge detection is a critical and essential function in computer vision and image processing, with numerous applications [14]. Its primary objective is to identify significant variations in grayscale images and to understand the physical phenomena that cause these changes.

This process involves locating the boundaries or edges of objects by detecting sudden shifts in shading within the image [15]. This technique is instru-

Figure 5. *Result of edge detection on the image*

mental in extracting structural information about the objects represented in the image. Various algorithms are available for edge detection, given their broad applicability, with one notable example being the Canny Edge Detection algorithm (Figure 5).

Characteristics of vehicle-pedestrian collisions

Vehicle-pedestrian collision contacts occur at various points depending on factors such as the speed of the vehicle, the height of the pedestrian, and the type of vehicle involved. These contact points typically include the front bumper, hood, and windshield of the vehicle, which often result in injuries to the lower limbs, torso, and head of the pedestrian. The dynamics of such collisions are crucial for understanding injury mechanisms and improving vehicle safety design. Figure 6 illustrates the typical contact positions during these types of collisions.

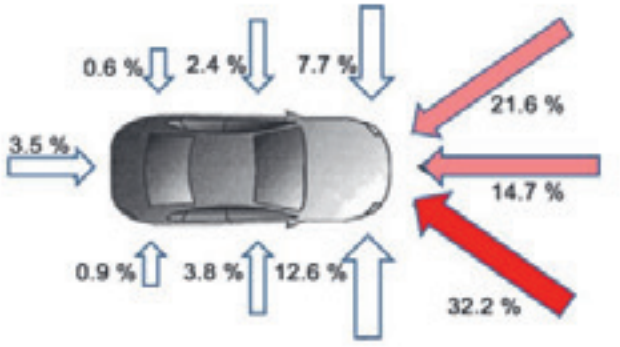

Figure 6. *Positions of vehicle-pedestrian collision contacts [16]*

Results

Global Workflow Architecture for Object Detection and Collision Analysis

A systematic workflow was designed to implement object detection and collision analysis using advanced computer vision techniques (Figure 7). The workflow consists of four main stages:

Preprocessing, Object Detection, Collision Detection, and Postprocessing and Validation. Each stage plays a crucial role in ensuring the robustness and accuracy of the system.

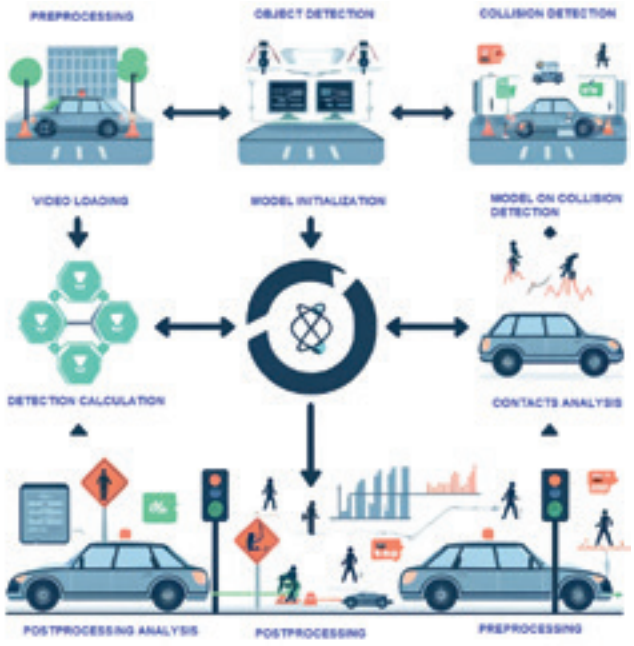

Figure 7. *Global Workflow Architecture for Object Detection and Collision Analysis*

Object detection

Object detection, a crucial task in computer vision, has undergone significant advancements with the emergence of deep learning techniques. This technology enables machines to analyze and identify thousands of individual objects in real-time as they move past a sensor. [17].

This technology finds broad application in areas such as surveillance, autonomous vehicles, medical imaging, and beyond. By continuously scanning and analyzing multiple objects in real-time, machines can accurately detect and classify them, unlocking vast opportunities for automation and intelligent decision-making. Object detection leverages computer vision and image analysis to identify specific elements within images and video content. Using the YOLOv8 algorithm for object detection, various objects in the image were successfully identified (Figure 8). The detected objects included individuals, cars, and traffic lights, all of which were identified with high precision and speed.

For this detection, the command yolo predict source=viber_image_traffic.jpg model=yolov8n.pt was used.

Figure 8. *Object Detection using YOLOv8 Algorithm*

Pedestrian-Vehicle Contact Detection

The development of the "Pedestrian-Vehicle Contact Detection" application in Python significantly improves pedestrian safety in traffic. The application aims to assist in accident prevention by using advanced computer vision techniques, specifically YOLO (You Only Look Once) version 8, to detect potential collisions between vehicles and pedestrians in real-time.

In the initial phase of the code, the necessary libraries for video processing are imported. These libraries include OpenCV for handling video files, Torch for deep learning model operations, and NumPy for numerical data manipulation. A function called load_yolov8_model() is defined to load the YOLOv8 model for object detection. This function utilizes the torch.hub.load method to download the model from the popular Ultralytics/YOLOv8 repository. If the model fails to load, an appropriate error message is displayed.

The path to the video file, defined as video_file_path, specifies the input for processing. The main video processing function is responsible for detecting objects and potential collisions. It starts by loading the YOLOv8 model, followed by opening the specified video file for processing and initializing variables to track object and collision data. In the main loop, each frame of the video is read and preprocessed before being passed to the detection model. Detected objects are classified into categories (vehicles and pedestrians), and the average size of vehicle bounding boxes is calculated. Bounding boxes are then drawn on the frame to visualize detected objects.

Afterward, collisions between objects are detected, and collision data is overlaid on the frame for enhanced visualization. The processed video is displayed, and the loop continues until the user decides to exit, typically by pressing 'q' on the keyboard.

$$Detection\ Ratio = \frac{Detected\ accident\ cases}{Total\ accident\ cases\ in\ the\ dataset} \times 100 \quad (1)$$

$$False\ Alarm\ Rate = \frac{Patterns\ where\ false\ alarm\ occurs}{Total\ number\ of\ patterns} \times 100 \quad (2)$$

Equations (1) and (2) represent the detection rate and false alarm rate, respectively [18]. This application framework achieved a detection rate of 79%, calculated using Equation (1), and a false alarm rate of 10.3%, based on Equation (2). These results demonstrate the system's solid performance, considering multiple factors contributing to collision detection.

DISCUSSION

Although the system has achieved a high detection rate, certain challenges have been identified. In conditions of heavy traffic, the system occasionally fails to detect certain vehicles, resulting in a higher number of false positives. In situations where detected objects in the image partially overlap in daylight, the objects are identified, and their relative positions indicate contact. However, during the processing of footage recorded at night, when street lighting is minimal, various issues may arise.

In such conditions, the following can occur:

- Non-detection of objects (vehicles or pedestrians).
- Inaccurate detection of objects.
- Misclassification of objects.

For example, if a vehicle and a pedestrian are in an initial position of mutual contact, the system may assign the wrong class to the vehicle, recognizing it as a pedestrian, which leads to a lack of contact detection.

To improve detection accuracy in these challenging conditions, spatial depth compensation could be implemented [19], which, by comparing the relative positions of vehicles and pedestrians, may help reduce classification and detection errors. This strategy could potentially optimize the system's performance in various weather and lighting conditions, ensuring more reliable collision detection.

Conclusion

By exploring the application of computer vision and utilizing OpenCV and YOLOv8 for detecting traffic accidents, we have opened the door to innovative solutions that can significantly improve traffic safety. Early detection of hazardous situations and enabling quick responses from relevant authorities can drastically reduce traffic accidents and save lives. The combination of real-world scenarios and online video materials allowed for extensive testing of the system in realistic conditions, providing valuable insights into the effectiveness of various detection methods.

However, certain limitations of the research must be acknowledged. The dataset used for testing was relatively small. The system's performance in low-light conditions or heavy traffic remains an area for improvement.

Further research should focus on expanding the dataset to include a wider range of traffic and weather conditions. This initiative not only enhances road safety in Bosnia and Herzegovina but also lays the foundation for further technological advancements in the field of traffic safety.

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Development of an Open-Source Voice-Controlled Smart Home System

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Abstract: This paper explores the design and implementation of a voice-controlled smart home system utilizing the Raspberry Pi platform and Node.js framework. The system aims to provide users with an intuitive method for managing household devices through voice commands while enhancing functionality with integrated sensors. Leveraging the Hidden Markov Model Toolkit (HTK) for speech recognition, the system accurately interprets user commands, facilitating control over lighting, temperature, and various IoT devices. In addition to voice activation, the system incorporates multiple sensors: a temperature sensor for monitoring ambient conditions, a motion sensor (PIR) for detecting occupancy, and a light sensor for assessing natural light levels. These sensors work in harmony with the voice control features, enabling automated responses such as adjusting the heating or cooling based on temperature readings, activating lights upon detecting movement, and regulating artificial lighting according to available daylight. Comprehensive testing demonstrated the system's high accuracy in command recognition and its responsiveness to user inputs, as well as its robust integration with additional smart devices. User feedback was instrumental in refining the system, leading to improvements in command clarity and operational efficiency. This research highlights the potential of combining voice control and sensor technology to create a more responsive and user-friendly smart home environment.

Keywords: IoT, Smart home systems, voice recognitions, sensors, open-source

Introduction

In recent years, smart home systems have gained significant popularity, driven by advancements in Internet of Things (IoT) technology [1] and artificial intelligence (AI) [2]. Voice-controlled systems, in particular, have revolutionized the way users interact with devices, providing hands-free, intuitive control over various household functions [3]. Proprietary solutions like Amazon Echo and Apple HomeKit have dominated the market, offering integrated services that facilitate voice control over smart home environments [4] [5]. However, these solutions are limited by their commercial nature, which restricts customization, scalability, and user control over data privacy.

To address these limitations, we propose a fully open-source, affordable voice-controlled smart home system that provides flexibility, transparency, and ease of customization. Our system is designed to operate on widely available, cost-effective hardware, enabling users to create personalized smart home environments without the constraints of proprietary platforms. By combining open-source tools such as the HTK Tool for speech and speaker recognition with Node.js as the software framework, this system not only provides core functionalities but also offers modular extensibility for further community-driven development. The HTK (Hidden Markov Model Toolkit) was selected for its robust capabilities in speech and speaker recognition, offering a proven, adaptable framework well-suited to accurately interpreting voice commands in diverse home environments [6]. Node.js was chosen for its efficient, event-driven architecture,

making it ideal for managing real-time data from multiple sensors and processing voice commands seamlessly, which are essential for responsive smart home control [7].

Our choice of the Raspberry Pi as a hardware platform ensures that the system remains affordable [8], accessible [9], and easy to expand, while integrated text-to-speech (TTS) [10] capabilities facilitate natural user interaction. With voice control predicted to play a crucial role in the future of IoT, this project contributes to the field by providing a foundation for open-source smart home systems that encourage innovation and user involvement [11].

This paper presents the design, implementation, and potential applications of our voice-controlled smart home system, aiming to establish a scalable framework that can be utilized and extended by a broad user base.

METHODS AND MATERIALS

Our open-source voice-controlled smart home system was developed using affordable hardware and readily available software tools, ensuring ease of configuration, expandability, and cost-effectiveness. Below is a table (table 1) of the core components and methods applied in the system's development:

Table 1. *Core Components and Methods for the Development of an Open-Source Voice-Controlled Smart Home System*

	Component	Description
Hardware components	*Raspberry Pi*	Model 3, chosen for affordability, versatility, and support for IoT applications; serves as the primary processing unit, handling audio processing and integration with sensors/actuators.
	Microphone and Speakers	USB microphone and speakers connected to the Raspberry Pi for capturing voice commands and providing audio feedback to the user.
	Additional Sensors & Actuators	Integrated with various sensors (temperature, motion, light) and actuators (smart lights, plugs) for expanded smart home control.
Software Components	*HTK (Hidden Markov Model Toolkit)*	Used for speech and speaker recognition; robust algorithm for interpreting voice commands accurately. Commands are pre-defined and trained in HTK to optimize accuracy.
	Node.js Framework	Serves as the primary software platform, processing commands, handling sensor data, and managing device states; includes custom modules to interpret HTK output and process commands.
	Text-to-Speech (TTS) Module	Integrated within Node.js to enable verbal responses for user interaction, status updates, and answering questions.
System Architecture	*Input Processing*	Microphone captures user commands, which are processed by HTK to identify command content and speaker identity (when multiple users are set up).
	Command Interpretation	Node.js matches interpreted commands with pre-defined functions, triggering appropriate responses like turning on lights or adjusting temperature.
	User Feedback	TTS module synthesizes responses for playback through speakers, confirming command execution or providing additional info.
Evaluation and Testing	*Testing Approach*	Tested for command accuracy, response time, and ease of integration with additional devices. Repeated commands in varied conditions (e.g., background noise, different voices) to assess HTK recognition accuracy and robustness.
	User Feedback	Collected from user trials to refine the command set and enhance response clarity.

For this research, we implemented a voice-controlled smart home system in five selected households, utilizing Raspberry Pi as the central processing unit. The process involved developing custom modules in Node.js, configuring affordable hardware, and integrating low-cost sensors and actuators. Below are the key steps:

1. Selection of Households

Five households were chosen based on diverse family structures and varying levels of familiarity with technology. This ensured a representative sample for evaluating user experiences.

2. Deployment of Raspberry Pi

The Raspberry Pi Model 3 was installed in each household due to its affordability, versatility, and compatibility with IoT applications. It served as the

central unit for processing voice commands, integrating sensors, and controlling actuators.

Setup Procedure: The Raspberry Pi was pre-configured with the latest Raspbian OS to ensure compatibility with the software. Each device was connected to the household Wi-Fi network to enable seamless communication with sensors and actuators.

3. Software Components Installation

To enable system functionality, the following software components were installed:

Node.js Framework was installed using Node Version Manager (nvm) to manage software versions and host the custom application for processing commands and managing device states. HTK (Hidden Markov Model Toolkit) was configured for accurate speech recognition and optimized for predefined command sets.

4. Sensor and Actuator Integration

Sensors and actuators were installed to extend the system's functionality:

- Temperature Sensors: For monitoring ambient conditions and enabling automatic climate control.
- Motion Sensors: Positioned near entry points to trigger actions like turning on lights or sending alerts.
- Light Sensors: To detect natural light levels and adjust artificial lighting accordingly.
- Voice Control: USB microphones and speakers were installed for voice command input and audio feedback.

5. Testing and Calibration

After installation, the system was tested and calibrated for: Sensor accuracy and reliability under different environmental conditions;

Command recognition accuracy using HTK in scenarios with varying background noise;

Integration and response times between the Raspberry Pi, sensors, and actuators.

6. User Training and Feedback Collection

Households received training on system usage, followed by a feedback collection phase to identify usability issues and inform system refinements.

Proposed System Architecture

The proposed architecture for the voice-controlled smart home system is designed to offer a modular, flexible, and scalable solution for smart home automation (Figure 1). The system integrates various components that work together to provide seamless user interaction and control over home devices. The main elements of the system include the Raspberry Pi as the central unit, voice processing through the HTK (Hidden Markov Model Toolkit), and real-time control of smart devices using Node.js.

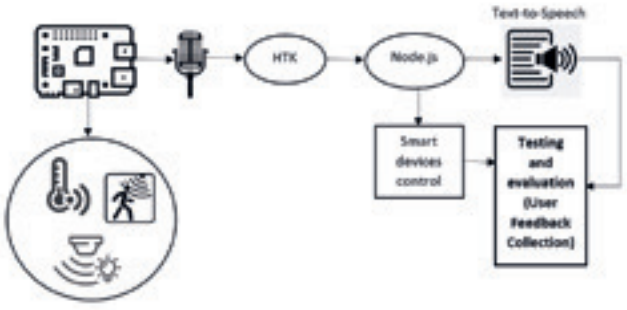

Figure 1. *System Architecture for Voice-Controlled Smart Home*

At the core of the system, the Raspberry Pi serves as the processing hub. It connects to a microphone to capture voice commands from the user. These audio signals are first processed through the HTK module, which performs speech recognition and speaker identification. The HTK system is responsible for converting the user's voice into text commands, allowing the system to interpret and act upon the user's requests. Once the voice command is processed, it is passed to Node.js, which serves as the platform for interpreting these commands and controlling smart devices. Node.js executes the necessary logic to map voice commands to corresponding actions, such as turning on lights, adjusting temperature, or activating other connected devices. The system integrates various smart devices, such as temperature sensors, motion detectors, and smart lights, which can be controlled based on voice inputs or environmental triggers.

To ensure interactive communication with the user, the system also includes a Text-to-Speech (TTS) module. After the system performs the requested actions, the TTS component provides feedback to the user, confirming the actions or providing additional information, such as the status of a device or an error message.

Additionally, the system includes a feedback loop for testing and evaluation. User feedback is gathered through interactions with the system, allowing for continuous improvement. This feedback helps refine the voice recognition and response accuracy, ensur-

ing that the system evolves to meet user needs and preferences effectively.

This architecture provides a robust and user-friendly platform for controlling and automating smart home devices, allowing for easy customization and expansion. The use of open-source components and affordable hardware makes the system accessible while maintaining high scalability and performance. The integration of speech recognition, real-time control, and user feedback creates a system that is not only functional but also adaptable to a wide range of applications in smart home environments.

RESULTS

The implementation and testing of the smart home system across five households yielded valuable insights into the system's functionality, user satisfaction, and overall performance. The results are presented across several key areas: sensor performance, system responsiveness, voice command accuracy, and user feedback.

Table 2. *Summary of Smart Home System Performance and User Feedback*

Category	Result	Observations
Temperature Sensors	Accuracy rate of ~95% in maintaining set temperature levels.	Users reported improved comfort due to automatic temperature adjustments.
Motion Sensors	High detection accuracy with occasional false triggers in households with pets.	Calibration adjustments helped reduce false triggers in households with frequent pet movement.
Light Sensors	Effective in gauging ambient light, enabling automatic lighting adjustments.	Users noticed energy savings, particularly in daylight hours.
System Responsiveness	Average response time of 1-2 seconds from command input to action execution.	Smooth and timely interaction for users; met expected responsiveness benchmark.
Node.js Processing	Efficient handling of multiple sensor data inputs and voice commands with no noticeable latency.	Node.js provided reliable real-time processing, enhancing the user experience.
HTK Voice Processing	Achieved ~92% accuracy in recognizing voice commands, with slightly lower accuracy in noisy environments.	Microphone sensitivity adjustments and HTK fine-tuning helped mitigate noise interference.
Multiple User Recognition	Successful in differentiating between multiple users' voices, enabling personalized responses.	Personalization allowed for tailored interactions based on individual users within each household.
User Satisfaction with Automation	High satisfaction with temperature and lighting automation features.	Users cited convenience and energy savings as major advantages of the system's automation.
Voice Interaction	Users found voice commands intuitive and enjoyed hands-free control.	Suggested expansion of recognized command set to improve flexibility.
Suggestions for Improvement	Users recommended better noise filtering and support for additional devices (e.g., smart locks, cameras).	Future updates could include enhanced noise filtering and expanded device integration for more comprehensive home automation.

The table 2 summarizes the effectiveness and user experience of the implemented smart home system. Overall, the system demonstrated reliable sensor accuracy, prompt responsiveness, and a high level of user satisfaction, particularly in automation features like temperature and lighting control. Minor challenges, such as occasional false triggers and voice recognition sensitivity in noisy environments, were addressed with system adjustments and calibrations. Users expressed an interest in further expanding the system's capabilities to include additional smart devices, indicating both the system's value in enhancing household convenience and opportunities for future improvements.

During the testing phase, two key types of evaluations were carried out: technical system testing and user feedback collection.

The system testing covered the accuracy of voice commands, response time, and integration with additional devices. Commands were tested under various conditions, such as background noise and different user voices, to assess the accuracy and robustness of speech recognition using HTK (Hidden Markov Model Toolkit). The response time of the system and its ability to interface with other smart home devices were also evaluated. Commands were repeated under varying conditions to ensure stable and accurate system performance in real-world usage scenarios.

User feedback was collected through trial runs of the system, allowing for refinement of the command set and improvement of response clarity. Users tested the system in everyday settings, using voice com-

mands to control devices and interact with sensors. Based on their feedback, adjustments were made to the system's settings, and further optimizations were applied to improve accuracy and ease of use.

Testing showed that the system correctly recognizes voice commands in various conditions and efficiently controls smart devices. The user interface was rated as intuitive, and users expressed satisfaction with the system's response speed and recognition accuracy.

Discussion

The implementation of a smart home system across five households has offered significant insights into the capabilities and limitations of low-cost home automation solutions. Overall, the system proved reliable in managing basic tasks through components like the Raspberry Pi and sensors for temperature, motion, and light. The high accuracy rates of these sensors highlight the effectiveness of low-cost technology in providing comfort and energy efficiency in everyday household operations. However, minor challenges, such as false triggers in homes with pets, indicate that further adjustments and calibrations would improve sensor reliability, especially in households with unique environmental factors.

Voice recognition, facilitated by HTK and managed through Node.js, was a well-received feature, achieving high accuracy in quieter settings. Yet, background noise presented occasional difficulties in command recognition, particularly in homes near busy streets. Users appreciated the ease of hands-free control, but the need for further noise filtering became apparent, suggesting that enhanced audio processing could strengthen the system's usability across diverse household environments. Additionally, participants expressed a desire for a broader set of recognized commands, indicating that an expanded command repertoire would increase interaction flexibility and overall user satisfaction.

Feedback from users also revealed a high level of satisfaction with automated features, such as lighting and temperature adjustments. These functions not only added convenience but also contributed to energy savings, fulfilling one of the project's primary objectives. However, several users suggested integrating additional smart devices, such as security cameras and smart locks, to extend the system's functionality beyond home automation to include security and monitoring. This interest in added features points to a growing user expectation for more comprehensive smart home ecosystems.

This study's findings resonate with the global trend toward accessible, modular smart home technology. Using affordable components like the Raspberry Pi and basic sensors, the system demonstrated that effective home automation can be achieved on a budget, aligning with industry efforts to make smart home solutions more widely available without high costs.

Feedback on voice control limitations also reflects a broader industry focus on refining accuracy in diverse home environments. Major companies are enhancing noise filtering and multi-user recognition, addressing similar challenges faced in this study [12] [13].

Conclusion

This study demonstrates the feasibility and impact of implementing a low-cost smart home system in enhancing household comfort, energy efficiency, and convenience. The system, based on the Raspberry Pi and supported by various sensors, performed reliably in automating essential functions, such as temperature and lighting adjustments. Additionally, the integration of voice command functionality provided an intuitive, hands-free experience that was well-received by users, though some minor challenges with background noise highlighted areas for refinement in audio processing.

User feedback indicated high satisfaction with the automation features, especially regarding energy savings and ease of use. Suggestions for expanding the system's functionality to include additional devices, such as smart locks and security cameras, reflect the growing interest in comprehensive smart home ecosystems that go beyond basic automation.

In summary, this smart home system offers a promising solution for accessible and efficient home automation. Future enhancements, including improved noise filtering, broader command recognition, and compatibility with a wider range of smart devices, could further elevate its usability and appeal. With these refinements, the system has the potential to bring smart home technology into everyday use for a diverse range of households, promoting a more integrated, energy-conscious living environment.

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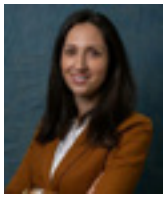

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Exploring the Impact of Technology on Human Interaction and Engaging Business Needs Through Software Design Patterns

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Original scientific paper

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Abstract: This paper explores the impact of technology on human interactions by integrating software engineering patterns to address business needs. A specialized development environment is proposed to enhance collaboration, focusing on bridging the technical and business perspectives through adaptable patterns. By leveraging classic and emergent software patterns, the approach supports real-time feedback and iterative improvements, enabling agile development practices that align with evolving user and business requirements. Key contributions include a modular framework for improved team communication and a Conceptual Framework on Human Interaction (CFI), along with an Embedded Business and Safety Human-AI Interaction Pattern (EBSH-AI). These tools aim to enhance interaction across technical and business domains while addressing ethical considerations in AI, such as privacy and authenticity in lifelike avatars. The findings indicate that structured software patterns improve cross-functional communication, fostering productivity and trust in AI-driven environments. This research provides a pathway to more meaningful interactions and user-centered outcomes in software engineering, with particular emphasis on the emerging role of AI avatars in the Metaverse and their impact on business and social engagements.

Keywords: AI avatar and Metaverse applications, business engineering, and technology, human interaction, patterns, software development, team collaboration

Introduction

Aligning software development with strategic business objectives is a challenging and ongoing task as digital demands increase in healthcare, banking, and transportation. As a result, sectors important to human existence must constantly improve operations [1]. What implies the possession of corporate strategies to shorten time to market, and improve user experiences by using knowledge management and continuous integration and continuous delivery/continuous deployment (CI/CD) [2, 3, 4]. However, ongoing communication gaps between technical teams and business units can jeopardize these objectives, and various standards and legal norms may be violated [5, 6]. Divergent terminologies, priorities, and methodologies inhibit efficient collaboration, often resulting in misalignment of projects and costly delays [6, 7, 8].

Traditional development approaches cannot respond quickly to changing global needs, which has a limiting influence on agile solutions in high-impact businesses. This research proposes a more efficient development environment and communication structure based on certain software engineering principles [7, 8]. This strategy involves linking technological and business sectors. They must foster efficient cross-functional collaboration, leading to faster, more reliable implementations that meet the strategic and operational needs of industries crucial to modern life [9, 10, 11].

Every notion in today's business, based on new technologies, necessitates a strategic initiative that

integrates various types of digital technology and human connection across all divisions of the corporation. Identify solutions to improve operational efficiency and accelerate the commercialization of products or services [12]. In this scenario, we are primarily would be employing the Model-View-Controller (MVC) software architectural pattern, which is commonly utilized in the design and development of user interfaces. MVC separates a program into three interconnected components, each with a specific task, to promote modularity and scalability. One of the current trends and ''problems'' that will soon emerge is the creation of AI avatars, which will surely influence how humans interact with computers and machines in general. This leads to the fact that it will be difficult to distinguish between a human and an AI model that is being communicated with [13]. Artificial intelligence (AI) supports the operation of most corporate and educational technologies and systems, transforming everything we use and generate daily into the new post-digital society [14].

AI avatars and adaptive AI systems are increasingly being integrated into everyday interactions, from customer service to personal wellness. This is modifying human behavior patterns in unexpected ways [15]. Because these AI-powered interfaces resemble human expressions and conversational patterns, people commonly respond to them with familiar social cues, viewing robots as quasi-human alternatives. The issues of AI in the Metaverse include ensuring realistic interactions, maintaining user privacy, and addressing ethical concerns about immersive AI avatars. AI avatars represent users or virtual entities that impact social dynamics and behavior. The achievement of lifelike avatars that respect user limitations and promote engagement requires powerful AI and explicit ethical norms [16].

The proposed research is organized in the following sections and contains certain logical units: introduction, literature review, contributions and novelty, materials and methods, software design patterns costs, results, limitations of the study, discussion, and conclusion.

Literature Review

There is numerous research demonstrate the effectiveness and importance of technology as a significant impact on human interaction in business and software development. The study carried out by Walliser et al. [17] explores how AI improves human-computer interaction, enhancing team involvement and creating efficiency in team collaboration. Silva et al. [18]describe the importance of technology to understanding user needs and challenges in designing effective mobile interactions [19].

To give a more comprehensive overview of the available literature, we have created appropriate subsections that contain information pertinent to our research topic, the interaction of people, machines (computers), and their influences. Based on the above, we implemented the following organization:

1. Technology and important effects on human interaction
2. Specific engagement designs impact
3. Topic of interest in various industries
4. Evolving digital landscape

Technology and important effects on human interaction

Kong et al. [19] describe that technology has important effects on human interaction, whereas Walliser et al. [17] and Mohapatra et al. [20]show that technology including AI and chatbots improve decision-making in business.

Alshuridehet et al. [21] describe the effectiveness of technology in improving marketing performance and customer confidence in the business, also human interaction minimizes bias in AI systems and is critical for encouraging user trust and effective involvement in business enhancement [22].

Ahsan and Junaid [23] study the dynamics of human interactions and propose the use of communication, and quality work to improve collaborative processes in organizations [24].

Specific engagement designs impact

Fasano et al. [25], Jung et al. [26], and Pennathur et al. [27] found that while digital tools improve information collecting in bank-firm partnerships and bank crisis, human contact is still required to minimize data differences and assure effective financial settlements are considered.

Studies by Wu et al. [28], Branzoli et al. [29], and Dou et al. [30] highlight that technology's impact on human contact in corporate contexts is frequently dependent on specific engagement designs, and Sima et

al. [31] and Dell'Acqua et al. [32] support the role of structured digital tools, AI and adopting technologies in building communication, decision-making, and organizational connection as an important part for business growth.

Topic of interest in various industries

The impact of technology on human interaction has been a topic of interest in various industries. As such, Malik et al. [33], conducted a case study on Amazon to analyze the impact of Virtual Reality (VR) on product sales in the customer relationship management sector.

Pfnür et. al. [34] explored the transformation of the real estate and construction industry, highlighting the pressure to adapt existing business models and the opportunities for further development. Also, Sykes et. al. [35] emphasized the importance of digital spaces in interlanguage pragmatics, stressing the need for language learners to engage in digital communities for success in a technology-saturated world.

Furthermore, Bandaragoda et. al. [36] proposed an Artificial Intelligence-based commuter behavior profiling framework using the Internet of Things for real-time decision-making, aiming to optimize operations through the analysis of commuter behavioral patterns.

Visconti et. al. [37] delved into healthcare digitalization and pay-for-performance incentives in smart hospital project financing, investigating the impact of digital health on project financing and supply chain bottlenecks. Shoesmith et. al., [38] investigated the impact of interactions between humans and animals on mental and physical health during the COVID-19 lockdown period in the United Kingdom, emphasizing the value of such partnerships during difficult times.

Evolving digital landscape

Chandra et. al. [39] theorized the role of human-like competencies in conversational AI agents, focusing on user engagement and the mediating role of user trust in these relationships. Touriano et. al., [40] investigated the effects of technological advances on talent management operations, particularly the installation of a human resource management system to improve efficiency and effectiveness. Lastly, Gao et. al., [41] investigated the visual impact of character components in digital human guides for tourism, using eye-tracking technology to see how different elements influence user focus and interaction. The findings of this research highlight the relevance of technology in altering human relationships and corporate demands, underlining the necessity to leverage patterns and innovative techniques to adapt to the changing digital landscape.

Contributions and Novelty

We investigate how technology influences business needs and human interaction by analyzing domain-specific organizational patterns as potential solutions for both industries and academia. To address the challenges identified in our study regarding technology's effects on human interactions, we developed a new framework. This framework highlights the similarities among various patterns and their implications for effective communication and collaboration. Our research not only uncovers existing gaps in current technological processes but also offers actionable recommendations for organizations to better identify their business needs and adapt to evolving demands. The main contributions include:

1. Developed a framework to identify the impact of technology on human interaction
2. Composing patterns as pattern language for solving recurring problems
3. Provide solutions to mapping technology to business via organizational patterns
4. Adopted design patterns and connected them with organizational patterns to identify business needs
5. Analyzed the association between design and organizational patterns
6. Identify business needs through technology and human interaction.

Materials and Methods

The proposed research method offers a structured framework for examining the intersection of software engineering patterns, human interaction, and the metaverse. A mixed-methods approach will be used to analyze the impact of software patterns and AI avatars on communication between technical and business teams.

The study will conduct a comprehensive literature review to identify key themes, challenges, and solu-

tions in communication frameworks, particularly in the context of the metaverse. Sources will include peer-reviewed articles, industry reports, and case studies. By analyzing the literature and offering actionable insights, the study aims to improve communication, enhance project outcomes, and better align technical solutions with business objectives in software engineering, artificial intelligence, and metaverse environments.

Selection Criteria

The selected literature focuses on communication approaches, software engineering patterns, and human-computer interaction. Industries such as automotive, telecommunications, psychology, development technology, and healthcare significantly impact our daily lives. We prioritized peer-reviewed studies and ongoing research that explore the psychological challenges of balancing human needs with technology. These studies often reveal that people's relationships with computers are complex and sometimes unclear. Additionally, there are negative effects on concentration and attention during interactions.

Foundational papers are based on software patterns that provide a basis for present and future design concepts. The collected case studies provided us with some practical, human-centered applications. By providing information on emerging technologies such as virtual interfaces, artificial intelligence (AI), and holograms. We investigate the evolving interplay between humans and robots, providing new insights into how to improve team alignment and communication in technologically advanced situations.

Keywords

To properly construct the search procedure, we used the following keywords and terms:

1. Applying organizational patterns in human interaction to identify business needs
2. Human-computer interaction and innovative AI avatars
3. Communication Frameworks and Human Psychological Effects
4. Health and communication issues in software engineering patterns.
5. Cross-functional alignment in sustaining attention throughout communication
6. Emerging collaborative technologies and current trends in the automotive, healthcare, and IT sectors

Questions

1. How can software patterns improve communication between technical and business teams?
2. What development features support agile alignment with business goals?
3. How do communication frameworks affect efficiency and customer satisfaction?

SOFTWARE DESIGN PATTERNS COSTS

Software design patterns affect the architecture of many software systems. This underscores the importance of design patterns in developing software for electric vehicle charging management platforms and many industries in general [42, 43]. Similarly, immersive visual scripting based on VR software design patterns is offered for experiential instruction, emphasizing the use of novel software design patterns to replicate behavioral tasks in VR experiences [43]. However, on the other side, we must address the concept of resilience design patterns in extreme-scale high-performance computing systems, emphasizing the importance of established methodologies for detection, mitigation, and recovery. Focus on architecture anti-patterns that create considerable maintenance costs in large-scale software systems, emphasizing the importance of adhering to key design principles to avoid them [44].

Furthermore, investigating the energy cost of AI design patterns, illustrating the difference in energy consumption that may be achieved by selecting the appropriate design pattern for IoT applications and energy systems [45]. We should also examine how the Decorator pattern affects energy consumption, emphasizing the need to adjust software designs for greater efficiency. Software design patterns are essential across various fields, such as electric vehicle charging management and VR software for high-performance computing. These findings underscore the importance of choosing the right design patterns to optimize software systems and cut costs.

In this section, we'll explore the factors that influence custom software development expenses. Precise cost assessment is challenging, as one decision can either drive up costs or reduce them when approached thoughtfully. Careful cost monitoring is essential to

prevent budget overruns and ensure resources are allocated effectively shown on Figure 1. Our goal is to provide short guidance for making well-informed, strategic decisions.

We'll also discuss significant unavoidable expenditures (Figure 1), such as those associated with the technology stack, emphasizing the significance of recognizing and managing these expenses. Certain expenditures are unavoidable, regardless of the size or type of the software product. These include charges for your tech stack, third-party services, and more, all of which have an impact on your total budget. We can look at these key cost issues more closely [46]:

1. Tech Stack Costs: certain expenditures cannot be avoided, regardless of the size or type of your software product. These include expenses associated with your chosen tech stack, third-party services, and more, all of which can have a substantial impact on your entire budget
2. Back-end Development: Back-end development can cost a lot of money, depending on how complicated your service or product is. Python coders in Eastern Europe typically charge around $40-$55 per hour. If we hunt for a more sophisticated language, like Java, the cost may increase to roughly $50-$65 per hour.
3. Front-end Development: JavaScript is still a popular front-end programming language in Eastern Europe, with hourly rates ranging from $35 to $50
4. Mobile app development: can be done using Swift for iOS (about $45-$55 per hour) or Kotlin for Android (around $40-$50 per hour).

Figure 1. *Unavoidable Costs Accounting for the Price of Technology Stack. Source: [46].*

Outsourcing a project to an Eastern European company can result in a total labor cost of approximately $80,000 (or less, depending on the type of development) [48]. Outsourcing custom software development appears to provide a significant cost advantage, even after accounting for project administration and other potential costs [46]. A junior Java programmer from a particular country will earn a different hourly rate than a senior programmer from another. For example, a senior Java programmer in the UK earns an average of €35.06 per hour [46].

Results

The proposed framework combines design patterns, such as Observer, Adapter, and Model-View-Controller (MVC), with organizational patterns to enhance human interaction through technology and address business needs across software companies and industries [47, 48] . We also use patterns such as Community of Trust, Developer Control Process, and Engage Customers. This method allows us to identify and meet business requirements by mapping human interactions with technology. This methodical usage of patterns allows us to more effectively identify and handle company demands.

This shift has a subtle impact on users' views of real-life interactions, occasionally heightening expectations of speed and precision in human exchanges. However, as these technologies progress, they raise questions about privacy, ethical boundaries, and possible dependency. Finding a balance between innovation and ethical controls will be critical to AI's position in human-centered situations.

The Conceptual Framework for Human Interaction (CFI), illustrated in Figure 2 outlines the arrangement of teams, businesses, and clients, providing solutions to various challenges. The figure demonstrates how Agile teams, Human-Computer Interaction (HCI), design principles, and organizational patterns influence human interaction and fulfill business needs. The flow from steps 1 to 12 clarifies how these components facilitate meaningful human engagement and achieve corporate objectives through technologies like Virtual Reality (VR) and the metaverse.

Figure 2. *Conceptual framework for human interaction (CFI). Source: author's contribution.*

The framework demonstrates how technology impacts business through improved human interaction. The Observer design pattern enhances responsiveness to user inputs in real-time. The Adapter pattern allows for seamless integration of business components, while the MVC pattern increases transparency by separating user interactions from backend code. By incorporating organizational patterns that strengthen relationships between Agile teams, customers, and software companies, the framework effectively identifies business needs and fosters collaboration. This integration of design patterns establishes a technological environment that supports human interaction. It enables users to engage with technology and emphasizes the importance of user involvement in software development, ultimately building trust and ensuring quality outcomes.

In response to recent technological advancements, including AI avatars, the proposed Embedded Business and Safety Human-AI Interaction Pattern (EBSH-AI) as illustrated in the Figure 3 serves as a framework for software production. It combines design and organizational patterns to outline a process for identifying business needs while mapping the impact of technology on human interaction. Businesses are increasingly challenged by growing technology demands, the need for skilled employees, and potential risks in software production.

The EBSH-AI framework integrates design patterns such as the Observer, Adapter, and MVC. Where we connect the organizational patterns such as Developer Control Process, Community of Trust, and Engage Customer [47, 48]. This combination provides flexible, adaptable guidelines that can anticipate requirements, analyze data in real-time, and enhance the efficiency of interactions with business demands and technological support. These patterns empower EBSH-AI to tackle recurring challenges and deliver long-term strategic solutions. The proposed EBSH-AI patterns, shown in Figure 2 and Figure 3, help identify business needs through human interaction and AI avatars while enhancing safety measures. This approach assembles organizational and design patterns to create a cohesive framework.

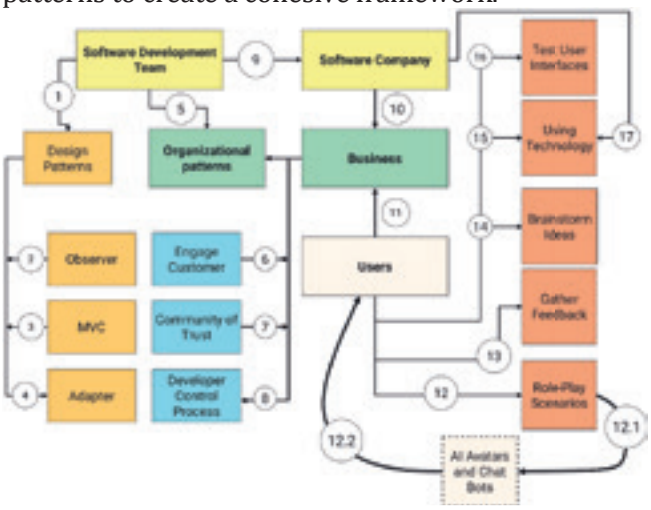

Figure 3. *Embedded Business and Safety Human-AI Interaction Pattern (EBSH-AI) as Framework for software development, as well as organizational and design patterns. Source: author's contribution.*

Connecting the presented approach and the implementations themselves, we can present them in the following way [51, 52]:

1. **Software Company:** A software company aims to develop products based on customer requirements and preferences. It connects the software development team with customers, users, and stakeholders to identify business needs in response to rapid technological growth.
2. **Software Development Team:** The software development team is crucial in defining business requirements and bridging the gap between business and technical domains. They utilize design and organizational patterns to make the most of company resources and improve business connections.
3. **Design Patterns:** Our approach incorporates design patterns that serve as reusable solu-

tions for common software design challenges. These patterns simplify technical processes, making the code more flexible and maintainable for long-term support and enhancement.

4. **Observer Pattern:** In our context, the Observer pattern is used when a subject needs to notify multiple observers about changes in its state. When users interact with the system and perform actions, any change triggers updates to the observers, keeping them informed of the new state.
5. **MVC Pattern:** The Model-View-Controller (MVC) design pattern simplifies business and application logic. It manages data and user views effectively, providing an organized interface for user interactions. This allows businesses to receive feedback from user engagement while supporting developers in maintaining logical flow within the software product.
6. **Adapter Pattern:** The adapter pattern in our framework demonstrates how technology influences human contact and addresses business demands more comprehensively.
7. **Software Organizational Patterns:** Utilizing organizational patterns helps align the software company with the business and connect customers with the Agile team. These patterns facilitate efficient and safe collaboration, bridging the gap between business and software companies to easily identify and address challenges.
8. **Engage Customer:** We employed this organizational pattern to enhance customer participation and involvement. This fosters a collaborative working environment between the software development team and customers. Effective communication between the agile team and customers is essential to achieving the project's common goals. Both parties are encouraged to work together, allowing customers to design, select features, test the product, and actively participate in the development process.
9. **Community of Trust:** Building a strong relationship between the software company and the business requires trust, respect, and mutual understanding. A Community of Trust is vital for sharing knowledge between partners. This pattern creates an environment of mutual respect and transparency, empowering team members to collaborate openly and share responsibility for project outcomes.
10. **Developer Control Process:** It is important to give technical staff, particularly the agile team, the freedom to use resources effectively. The Developer Control Process pattern allows developers to understand their roles and take ownership of their work. This freedom fosters accountability and innovation within the team, improving product quality and streamlining processes for better results.
11. **Business:** Effective communication between the software company and the business is essential to identifying business needs. It helps meet customer expectations and supports human interaction with technology, contributing to global business growth.
12. **Users:** Users are key stakeholders in the software product. They help improve system performance, provide feedback for further enhancements, and share business requirements.

    12.1. AI Avatars and Chat Bots: AI avatars and chatbots enhance user engagement by providing personalized interactions and instant responses. These technologies simulate human-like conversations, improving customer support and user experience.

    12.2. Enhanced Human Interaction Devices: Immersive devices like virtual reality (VR) and the metaverse create enriched environments for social interaction. They enable users to connect and collaborate in innovative ways.
13. **Test User Interface:** Evaluate the user interface design and services. Ensure it works based on user preferences, is responsive, and meets both user expectations and company standards.
14. **Using Technology:** Recent technological advancements have transformed business operations. They have significantly enhanced industries and academia while providing users with better support to work efficiently. Users, businesses, and software companies need to

stay updated with technology to prevent security breaches.

15. **Brainstorming Ideas:** We focus on creating a collaborative environment among teams, industries, and customers. This encourages knowledge sharing, idea generation, and open discussions with all stakeholders.
16. **Gather Feedback:** Gathering feedback is crucial for improving processes and software products. It enhances collaboration between teams and customers and helps identify gaps between businesses and software companies.
17. **Role Play Scenarios:** Role play allows individuals to engage with different roles and characters. This opportunity helps them learn and explore interactions effectively in the workplace.

Listing 1: *The MVC design pattern describes user interaction by notifying several classes about customer service, user engagement, and other events. Source: author's contribution.*

```
1    Interface IObserverCreater
2    Method Update(detail)
3
4  Class UserInteractionToSystem
5    List<IObserverCreater> observers
6
7    Method AddObserver(observer)
8      observers.Add(observer)
9
10   Method NotifyObservers(detail)
11     For observer in observers
12       observer.Update(detail)
13
14   Method TriggerInteraction(detail)
15     Print detail
16     NotifyObservers(detail)
17
18 Class Analytics, CustomerService,
19 Marketing implements IObserverCreater
20   Method Update(detail)
21     Print "[Type] " + detail
22
23 Main
24   ui = UserInteractionToSystem()
25   ui.AddObserver(Analytics())
26   ui.AddObserver(CustomerService())
27   ui.AddObserver(Marketing())
28   ui.TriggerInteraction("User
       purchased an item.")
```

The Observer design pattern used in our approach defines a user interaction class that notifies multiple observer classes. These observers include analytics, customer service, user interaction, query response, and marketing. This architecture enables them to effectively react to user interactions with the system.

Listing 2: *the Adapter pattern shows the analytic and processing data, the algorithm shows the legacy and analytic system data process. Source: author's contribution.*

```
1    Interface IAnalyticsProcess
2    Method Process(data)
3
4  Class ModernAnalytics implements
     IAnalyticsProcess
5    Method Process(data) Print
       "Processing: " + data
6
7  Class AdoptingLegacyData
8    Method Get() Return "Legacy Data"
9
10 Class AdoptingLegacyData implements
     IAnalyticsProcess
11   LegacyData legacy
12   Constructor(AdoptingLegacyData
       legacy)
13   this.legacy = legacy
14   Method Process(data)
15   Print "Adapting: " + legacy.Get()
16
17 Main
18   ModernAnalytics().Process("Modern
       Data")
19   LegacyAdapter(
20   AdoptingLegacyData()).Process("")
```

The following code presents the algorithm for the Adapter design pattern in Listing 2. This listing demonstrates how modern analytics for data processing can adapt legacy system data through compatibility with the adapter class, as illustrated in the Figure 3. To provide more clarity, we can use the following definition of the pattern groups: the Design Patterns section (view), which includes Observer, MVC, and Adapter. The pseudocode shows that implementing the adapter pattern allows the current interface to be used alongside an existing interface. It explains how the modern analytics system processes data while

the legacy system's data is made compatible through the adapter class.

Listing 3: *Implementing MVC design pattern, Source: author's contribution.*

```
1
2     Class UserInteractionToSystem
3     Property Id
4     Property InteractionDetail
5     Property Timestamp
6
7     Method GetUser Interactions()
8     Return List of sample
          UserInteraction
9
10  Class AnalyticsViewProvider
11    Method
          DisplayInteractions(interactions)
12    Print "User Interactions Report:"
13    For each interaction in
          interactions
14    Print "ID: " + interaction.Id +
          ", Detail: " +
          interaction.InteractionDetail
          + ", Time: " +
          interaction.Timestamp
15
16  Class AccessUserInteractionController
17    Constructor(model, view)
18    this.model = model
19    this.view = view
20
21    Method UpdateView()
22    interactions =
          UserInteractionToSystem.GetUser
          Interactions()
23    view.DisplayInteractions(
24    interactions
25    )
26
27  Main
28    controller =
          AccessUserInteractionController(
29    UserInteractionToSystem(),
30    AnalyticsViewProvider()
31    )
32    controller.UpdateView()
```

The following pseudo-code explains the MVC design pattern. In this pattern, the user interaction class acts as the model, managing the user data for processing. The AnalyticsView class is responsible for displaying the gathered data. Meanwhile, the User Interaction Controller facilitates the interaction between the model and the view, ensuring the relevant data is displayed correctly.

Limitations of the Study

Using organizational patterns to address general business problems can limit the effectiveness of our proposed framework. Therefore, we identified different working environments tailored to business needs while engaging customers in the development process. We provided agile teams with access to resources and developed solutions for specific recognition problems through our framework, which combines design and organizational patterns.

Our research indicates that the specific organizational approach we investigated may limit the generalization of findings across various business settings. Additionally, the rapid pace of technological change can render some patterns irrelevant or require them to be adapted as businesses grow and evolve. This variability can affect the study's applicability in different technological environments. Nevertheless, our approach connects business with technology and enhances human interaction through the application of patterns. However, the effectiveness of this approach may vary based on individual business culture and levels of engagement.

Patterns are established solutions to the recurring challenges in managing people, code, and business processes. Without knowledge of these patterns, individuals unfamiliar with them may struggle to implement solutions effectively. This study faces limitations due to a lack of sufficient research on the impact of software patterns, design patterns, organizational patterns, and AI avatars on communication between technical and business personnel. There is also limited research on how to combine design and organizational patterns to create effective solutions.

Additionally, the rapid advancement of technology means that much previous research may be outdated. Differences between industry and academic contexts can limit the generalizability of our results. Challenges in participant recruitment may also restrict the di-

versity of perspectives. Relying on self-reported data, exploring unknown domains, and the lack of knowledge may introduce bias. Furthermore, the limited number of case studies may not fully represent the core ideas of software products, their implementation, and outcomes, which can differ significantly.

DISCUSSION

Organizational success is strongly reliant on efficient communication frameworks and the integration of quickly changing technologies. The value of software in these industries cannot be emphasized, as it allows for more efficient operations, improves data management, and aids decision-making processes. Teams can increase interactions and collaboration across technical and business groups by using software engineering patterns, design patterns, and organizational patterns. This method helps projects meet deadlines and fosters a collaborative agile culture focused on attaining common goals.

Despite these attempts, misconceptions can result from the usage of specialist technical jargon. This issue emphasizes the need for a more accessible common language to bridge the communication barriers between people, technology, and business. Visual aids, virtual technology, and creative tools such as holograms can all be incredibly useful for simplifying complex concepts and encouraging real-time engagement. To successfully employ these strategies, firms must embrace a mindset that values ongoing feedback and iterative procedures. Moving forward, research should look into how communication mechanisms evolve and the long-term effects of these frameworks on team dynamics and adaptability in different contexts.

According to the research conducted, we were able to obtain the following information regarding the previously asked questions:

RQ 1:

The findings indicate that applying software patterns enhances communication between technical and business teams. These patterns provide structured frameworks that clarify roles, responsibilities, and processes. For example, patterns like Community of Trust and Engage Customer to improve information flow and reduce misunderstandings, ensuring all stakeholders stay updated in real-time. They bridge the gap between technical jargon and business objectives by promoting a shared vocabulary.

Additionally, visual representation tools linked to these patterns help clarify complex ideas and foster collaboration. Overall, using software patterns leads to better alignment, increased efficiency, and a more collaborative work environment.

RQ 2:

Our investigation revealed that agile alignment with business goals relies on iterative development cycles and collaboration tools for real-time communication. We found that incorporating AI and virtual reality (VR) enhances user engagement and provides deeper insight into user behavior. Prioritizing user stories and performance metrics helps teams deliver value and adapt to changing needs.

RQ 3:

Our investigation revealed that effective communication frameworks boost efficiency and customer satisfaction. Through our approach(s) and work on the code, we gained interesting insights into the interaction between human-computer interfaces and users. These insights highlighted clear reasons for change, enabling quick responses to customer needs and fostering stronger engagement.

We believe that future research in this area will focus on improving human-computer interaction through sophisticated AI and immersive technologies, resulting in more intuitive and seamless communication frameworks that bridge the gap between users and devices.

Open Questions

As a guiding idea for future research, we can provide three straightforward open questions for future research, which we believe have not yet been adequately investigated:

1. How will AI avatars affect communication skills and human-computer interaction among young users?
2. What ethical frameworks ensure privacy in AI interactions?
3. How software design patterns and organizational patterns compositions can improve quality in human interaction with business needs?
4. How can we design future AI avatars to enhance user experience without dependency?

We discovered that software patterns promote collaboration among technical and business teams. AI avatars can help to bridge communication barriers and improve user experiences. However, we must create ethical frameworks to protect privacy and authenticity in AI interactions, while also conserving real-life social skills and avoiding over-reliance on technology. The future working hypothesis and discussion box serve as a conceptual framework or forum for ongoing dialogue. As a study on the impact of AI avatars on communication and social behavior, particularly among younger users. This entails a proactive approach to hypothesize possible outcomes and sparking discussions.

Conclusion

This study emphasizes the importance of software engineering patterns in improving communication between technical and business teams, especially in high-impact areas. Organizations may improve cooperation, streamline interactions, and better match their goals with business demands by merging design and organizational patterns. The presented frameworks address common difficulties in the literature, resulting in better project outcomes and higher customer satisfaction.

As AI avatars become more prevalent in digital interactions, particularly in immersive environments such as the Metaverse, an emphasis on safety and ethical norms is critical. This study integrates technology, ethics, and human psychology, implying that well-designed AI interfaces can improve user experiences while preserving real-world social skills. Furthermore, our research shows that software patterns can bridge communication gaps, although the ethical implications of AI interactions remain a major concern.

Future research should look into the psychological and social effects of AI technologies on younger generations, including empathy and social conduct, as well as the ethical frameworks required to maintain privacy and authenticity in these interactions. Addressing these issues will pave the path for more inclusive, human-centered AI development across multiple industries. Future research may look into the changing impact of AI avatars on user experiences, social dynamics, and the effects of technology on human behavior in everyday interactions. Furthermore, research might examine how these tools affect ethical decision-making and personal interactions in increasingly digital worlds.

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Informed consent
Not applicable

Conflict of interest
The author(s) declare(s) that they have no conflict(s) of interest.

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LINEAR PROGRAMMING ROUTING FOR WIRELESS BODY AREA NETWORKS – LOBAN ALGORITHM

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Abstract: IoMT systems are one of the most important segments of the future global IoT concept, which includes complete networking and data exchange related to all aspects of human life and activity. As a physical layer of these systems, WBAN is used as a network of wireless sensor nodes placed on certain parts of the human body with the aim of collecting data that is relevant for monitoring the health status of the monitored patient. Data transmission in networks of this type is specific in many respects compared to classic WSN networks, so even when solving problems typical for wireless sensor networks, such as data routing, it is necessary to apply specific solutions. Energy consumption of sensor nodes is one of the basic goals that are set by designers of wireless sensor networks. Short-range technologies implemented on networks that cover smaller areas of the terrain have additional specificities that require special attention. In this paper, the influence of different criteria on problem analysis is observed, as well as the application of several methods characteristic for optimization through linear programming. We propose an original algorithm for routing data through the network called LOBAN, which takes into account two criteria when choosing a relay node, the importance of which is emphasized through different combinations of coefficients in linear programming. The goal of the algorithm is to optimize energy consumption in the network and extend its lifetime.

Keywords: Data Routing, Linear Programming, LOBAN, WBAN

INTRODUCTION

Wireless sensor networks WSN (Wireless Sensor Networks) represent one of the technologies that dominantly influence the further development of the information society. The integration of sensor devices with computer systems and their interconnection enable unrestricted access to all data in real time and timely delivery of the necessary information to the place where it is processed. A special type of wireless sensor networks is represented by WBAN (Wireless Body Area Network). WBAN represents wirelessly networked sensors that are installed in certain positions of the patient's body. These sensors measure specific data that are of interest for health monitoring, such as blood pressure, pulse, body temperature, glucose, pH value, body weight, etc. The network consists of relatively cheap, very small and lightweight wireless sensors. Sensors can be worn (in the patient's clothing or appropriate pouches) or implanted inside the body [1]. Their role is to deliver the specific readings they perform in real time or periodically to the patient himself, his doctor or other persons who monitor the patient's state of health.

Connecting sensors on the human body, especially sensors that are embedded inside the body, via wires is not a reasonable option. Therefore, wireless connectivity has no alternative [2].

As with other types of wireless sensor networks, the critical parameter here is the lifetime of the network. Failure of individual sensors in the network rarely occurs due to failure, as these are very reliable devices, especially when specialized sensors are used to measure certain parameters of the patient's health condition. Compared to classic WSN, the time until the failure of the first sensor node in the network is the most important, since each of the sensors reads a different health parameter.

Communication between sensors consumes the largest part of energy, far more than the actual reading performed by the sensor [3]. Therefore, it is necessary to save energy primarily in the phases of data exchange between sensors. The conventional model

of data transmission in a sensor network implies a direct connection of each sensor to a base station. The energy consumed by each sensor, when sending data to the base station, increases with the square of the distance from the base station. Relay data transmission in order to save sensor energy is one of the possibilities that can contribute to saving energy in the network. The role of a relay is played by sensor nodes that transmit messages from other nodes to their destination. Using a relay reduces the distance between the transmitter and the receiver in the network, thus saving energy. Relay transmission is carried out on an ad-hoc basis, so at each step in the transmission of the message to the destination, it is necessary to select the next node in the sequence.

Various approaches to reducing energy consumption in the network have been proposed in the literature. Some of them are based on linear programming. In this paper, we propose a variant of the problem solution that takes into account two criteria, giving them different importance depending on the situation [4].

Related works

A large number of algorithms for data routing in WBAN networks have been proposed in the literature. The solutions are based on different principles: direct transmission, ad-hoc networks, clustering, etc [5-8]. In this paper, we will propose an original solution based on relay transmission and compare it with two older algorithms:

The M-ATTEMPT algorithm belongs to the group of routing algorithms that are determined based on the temperature of nodes as a result of heating caused by sensor activity [9]. It works in parallel in single-hop (for urgent messages) and multi-hop (for normal messages) mode. This routing protocol supports mobility of the human body with energy management. The protocol is thermal-aware which senses the link Hot-spot and routes the data away from these links. After selection of routes sink node creates TDMA schedule for communication between sink node and root nodes for normal data delivery using multihop communication.

The SIMPLE algorithm is a multi-hop relay algorithm [10]. Messages are forwarded to the sink via a single relay node. The main part of the algorithm is the selection of the relay node, where a new selection is made in each round. The sink has knowledge of the residual energy, distance, and ID of each node in the network. A cost function is calculated for each node, and the obtained result is forwarded to all nodes so that they can make a decision on whether to accept the role of a relay node or not. The cost function is calculated by the expression:

$$C.F(i) = {}^{d(i)}\!/_{R.E(i)} \quad (1)$$

Where d(i) is the distance from node i to the sink and R.E(i) is the remaining energy in node i after the energy consumed by the node in that round is subtracted from the energy of the node at the beginning of the round. The node with the lowest cost function is chosen as the relay (forwarder) node in a given round. This node aggregates data from all other nodes and forwards them to the sink. The two nodes that are closest to the sink do not participate in forwarding data from other nodes and send their data directly to the sink.

Data routing in WBAN is specific in relation to other WSNs in several important points [11]:

- The dimension of the network is very small related to the size of the body on which it is located
- The number of sensor nodes in the network is not too large
- The distance between sensors in the network is relatively small
- Sensors are required to be extremely precise and reliable
- The size of the sensors should be as small as possible so that their dimensions do not represent an additional burden for the patient.
- The entire network moves through the space together with the patient's body
- The mutual position of the sensors in the network changes according to the position of the patient's body
- It is necessary to detect all events that may affect the state of individual sensors and the network as a whole
- A high level of data protection is required due to the confidentiality of information about the patient's health status
- Accuracy of transmitted information is extremely important. Loss of data or wrongly

provided information can be fatal to the life of the patient
- Sensors on the human body have different purposes, ie. they do not read the same sizes, so the failure of one of the sensors cannot be replaced by the others

WBAN network

WBAN is a system of wirelessly connected sensor nodes that are placed on specific, characteristic points of the human body with the task of reading various physiological attributes of the patient in real time [11]. The given data must be wirelessly transmitted in some way to the processing center located at a location far from the local WBAN network. WBAN communicates with a remote location usually through one node that has the role of a base station (sink) and acquires data from all other nodes of the associated network. The sink is a node that has no a problem with energy consumption, since it is an easily accessible device that, as such, can easily replace the power source or top it up. This is very important since it is the node that suffers the highest energy consumption as it communicates with the environment by transferring all the data from the network. However, other nodes are powered autonomously and are often implanted under the surface of the body, so replacing the batteries or topping them up requires surgery, which significantly complicates the whole process. Therefore, it is necessary to find a way to somehow minimize the energy consumed by these devices during their work, especially when communicating (since the consumption is much higher there compared to the reading of phenomena and data processing) with the environment. The only way to do this is to apply appropriate protocols for routing data in the network, which aim to optimize energy consumption and increase the lifetime of the network.

Figure 1. *WBAN network, arrangement of nodes on the body used for simulation*

Sensors are placed on the patient's clothing, on the surface of the body or implanted inside the body. The arrangement of the nodes depends on the parameters to be read. An example of a network with 8 nodes is shown in Figure 1.

Sensor types and their coordinates are shown in Table 1:

Table 1. *The positions of nodes from the figure 1.*

The node number	Sensor type	X(m)	Y(m)
1	EEG	0.35	1.65
2	T	0.15	0.95
3	SM	0.6	0.95
4	MD	0.2	0.2
5	IMU	0.5	0.2
6	EMG	0.22	0.47
7	LS	0.3	1.17
8	GS	0.2	0.85
SINK	SINK	0.35	1.1

Where sensors are as follows:
- EEG: Electroencephalography
- T: Temperature
- SM: Sweat Monitor
- MD: Motion Detector
- IMU: Inertial measurement unit
- EMG: Electromyography
- LS: Lung Sounds
- GS: Glucose Sensor

Linear programming optimization in WBAN

Linear Programming is a technique used for optimizing a particular scenario in order to get optimal results. It deals with finding efficient solutions with linear equalities and inequalities.

The objective function in linear programming is generally given in the following form:

$$\min f(x_1, x_2, \ldots x_n) = c_1 x_1 + c_2 x_2 + \cdots + c_n x_n \quad (2)$$

In practice, a linear combination of normalized objective functions is often used in order to avoid inconsistencies caused by different quantities taken as optimization criteria, i.e. problem solved:

$$minf(x) = \sum_{k=1}^{p} w_k f_k^0(x) \quad (3)$$

Where: , the weight coefficient of the kth criterion, is the normalized kth objective function . In this way, linear objective functions whose sum of coefficients with variables is equal to 1 are obtained.

According to the given energy models and its possibilities, but also the limitations of linear programming and the specificities of WBAN networks, it is shown that there are a large number of scenarios where linear programming gives good results in optimizing energy consumption when routing data to the destination.

By transmitting the collected data about the patient's state of health through the WBAN network, i.e. sensors placed on the patient's body at each step, when selecting the relay node at which a specific hop ends, a normalized cost function is calculated according to the previous expression.

LOBAN (Linear Optimization Body Area Network)

The WBAN network we propose in this paper is specific because each of the sensors has a different task. By switching off any of the sensors, its function is interrupted, since the neighboring sensors cannot take over its role. Therefore, network lifetime can be defined as the time that has passed from network starting to shutdown of the first sensor, although the network may remain partially functional thereafter. In order to achieve the best possible result, we propose a data routing algorithm that aims at balanced energy consumption in the network. Some other algorithms achieve better results with a differently defined lifespan, e.g. in case the network is considered functional while a certain percentage of the sensor is active.

Therefore, in this paper we propose an algorithm that finds the optimal routing path for WBAN. Each of the sensors should deliver the collected data to the sink periodically. The path along which the data is transmitted is selected in each round, in accordance with the set optimization criteria. The path selection is reduced to the selection of the next node through which the data will be forwarded to the sink, ie. the paths consist of only two hops. Candidates for the next node in the path are all active nodes in the network. In order to achieve the desired goal, it is necessary to take into account two parameters:

The remaining energy of the candidate for the next node. It is advisable to choose a sensor that is in good energy condition for the next node. If the path were established through a node whose energy is already quite depleted, it could be switched off and thus interrupt the life of the network.

Distance of the candidate for the next node from the sink. The energy consumption of the transmitter increases with the square of the distance to the destination. This means that a candidate who has more remaining energy and is farther from the sink could consume his energy faster by forwarding the message in another hop.

However, unlike the SIMPLE algorithm in the proposed algorithm, we use linear programming so that we adjust the influence of the proposed parameters with weight coefficients.

The following expression is used as a normalized cost function:

$$C.F(i) = w_1 \frac{d(i)}{d_{sr}} + w_2 \frac{R.E_{sr}}{R.E(i)} \quad (4)$$

With a constraints:

Where the normalization parameters are:

$$d_{sr} = \frac{1}{n}\sum_{i=1}^{n} d(i) \quad (5)$$

$$R.E_{sr} = \frac{1}{n}\sum_{i=1}^{n} R.E(i) \quad (6)$$

For the relay node, the one with the smallest cost function is chosen.

Simulation results

The authors tested the proposed algorithm in the MATLAB environment, using the coordinates listed in Table 1, and made a comparison with the results obtained for the M-ATTEMPT and SIMPLE algorithms.

Two cases with different combinations of parameters and measured values were tested:

- Number of dead nodes
- Remaining energy in the network.

I Scenario: w1=0.8, w2=0.2

Based on the performed simulation, we obtained graphics:

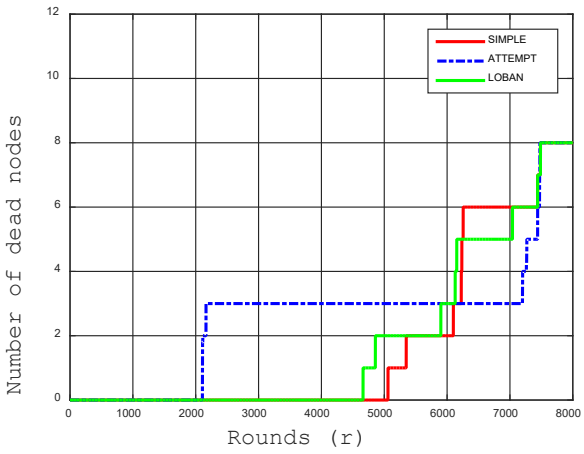

Figure 2: Number of dead nodes w1=0.8, w2=0.2

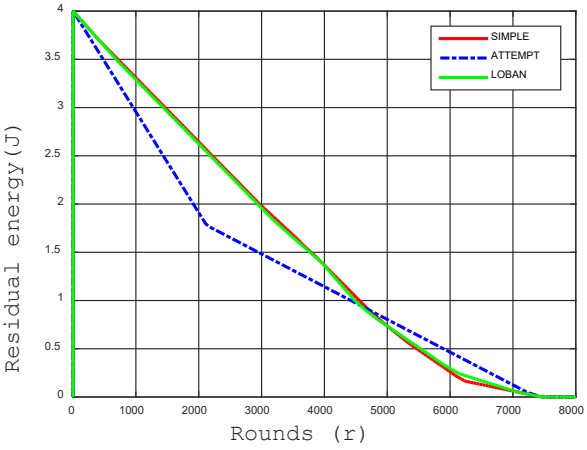

Figure 3: Residual energy w1=0.8, w2=0.2

II Scenario: w1=0.8, w2=0.2

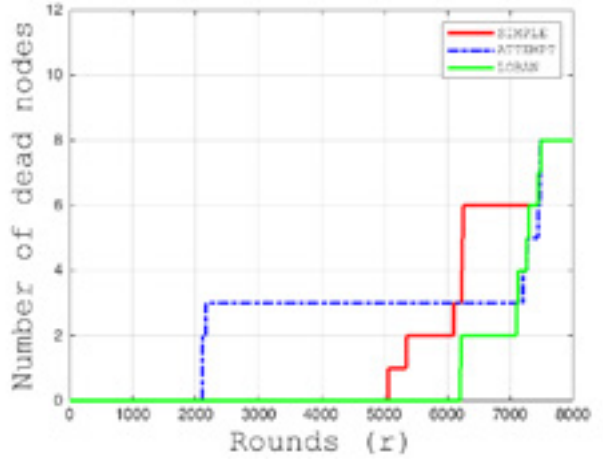

Figure 4: *Number of dead nodes w1=0.2, w2=0.8*

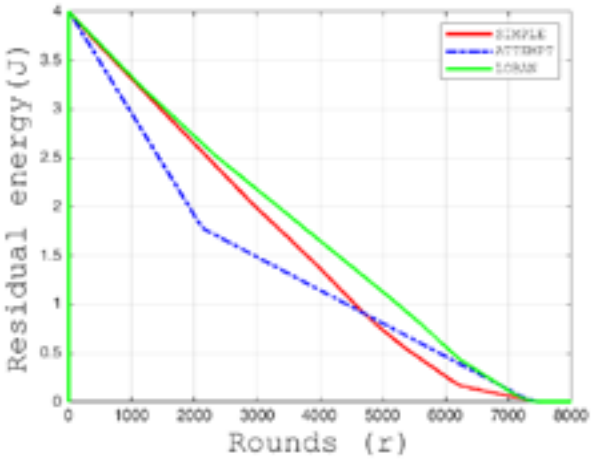

Figure 5: *Residual energy w1=0.2, w2=0.8*

ANALYSIS OF RESULTS

The results of the simulations show significantly better results of the proposed LOBAN algorithm in the second scenario, where we emphasized the importance of residual energy in relation to the distance between the node and the sink.

In the scenario I, SIMPLE gives the best results. The stability period is the longest, and that is the most important thing for WBAN networks.

In scenario II, LOBAN is far better than SIMPLE and especially ATTEMPT.

For LOBAN, the first node shuts down around the 6200th round, while for SIMPLE it shuts down around 5000, and for ATTEMPT already around 2000. Confirmation of the advantages of the LOBAN algorithm in this scenario can also be seen in Figure 5, where we track the change in the residual energy in the network by rounds.

CONCLUSIONS

WBAN networks are one of the most promising applications of short-range WSN networks and one of the most important aspects of future global IoT networking. Health is the most important resource of humanity and deserves worthy attention. Application of modern technology in preserving health is particularly important.

WBAN networks consist of sensors that have their own autonomous power supply. Batteries are not easy to replace, especially if the sensors are implanted inside the patient's body. Most of the energy is spent when sending messages to the sink. Therefore, it is necessary to find such routing protocols that will

reduce this consumption to the smallest extent and thus make the stability period of the network as large as possible.

WBAN networks, unlike some other WSNs, can be considered fully functional only as long as all nodes are active. That is why the time until the first node shuts down needs to be extended as much as possible.

In this paper, we proposed the LOBAN algorithm, which showed very good results in accordance with the set goal. This especially applies to the scenario where we gave importance to the residual energy in relation to the distance between the nodes. The simulations showed advantages compared to the classical SIMPLE and M-ATTEMPT protocols.

In their further work, the authors will try to improve the obtained results by introducing additional parameters into the linear function.

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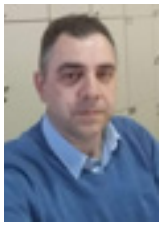

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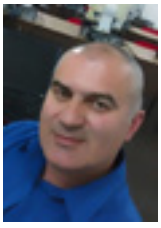

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FULL LINEARIZATION OF RANKING AND UNRANKING OF CATALAN CIPHER VECTORS USING CATALAN TRIANGLE ABSTRACTION

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Abstract: This paper demonstrates how to abstract a version of the Catalan Triangle necessary to compute the rank value from a given Catalan Cipher Vector, which is a process called ranking, and the process of obtaining a Catalan Cipher Vector from a given rank value, which is a process called unranking. That version of the Catalan Triangle is called the Bottom Ones Catalan Triangle and is not required to be computed in its entirety for the purpose of ranking and unranking, but only elements of it that are required for the current computation. A formula is derived to compute each element of this triangle and it is demonstrated how the processes of both ranking and unranking are fully linear.

Keywords: Bottom Ones Catalan Triangle, abstraction, ranking, unranking, Catalan Cipher Vector

INTRODUCTION

The Catalan Triangle is a number triangle which is commonly used when dealing with problems related to combinatorics, in particular the ones involving counting. It is closely related to the Catalan Numbers [1], since, by default, their sequence is found following the first (i.e., longest) and second diagonal of this triangle. Other diagonals of the Catalan Triangle also produce integer sequences of their own [2, 3, 4, 5, 6, 7]. The M-th Catalan Number is computed as

$$C_M = \frac{1}{(M+1)}\binom{2 \cdot M}{M} = \frac{(2 \cdot M)!}{M! \cdot (M+1)!} \quad (1)$$

Besides the version of the Catalan Triangle which is considered the default one [8], other versions of it also exist (e.g., [9, 10, 11] etc). One of the features of every Catalan Triangle is the existence of a sequence of elements all having the value of 1, i.e., *the all 1's sequence* [12], alongside the triangle's row, column or diagonal, depending on the version of the triangle. Thus, both the all 1's sequence and the Catalan Numbers sequence are found in every Catalan Triangle. Each of them can be placed horizontally, vertically or diagonally, depending on the version of the Catalan Triangle being used. Notably, the all 1's sequence and the Catalan Numbers sequence are always placed at extremes of the Catalan Triangle, i.e., at the longest diagonal, the leftmost column and/or the bottom row.

Of interest for this paper is a version of the Catalan Triangle where the longest diagonal is removed, thus leaving only one sequence of the Catalan Numbers instead of two. Three variations of such a triangle can be found: a) where the all 1's sequence is located at the leftmost column in the triangle [13, 14]; b) where the all 1's sequence is located at the longest diagonal of the triangle [15, 16]; and c) where the all 1's sequence is located at the bottom row of the triangle [17]. All of these variations are shown in Figure 1.

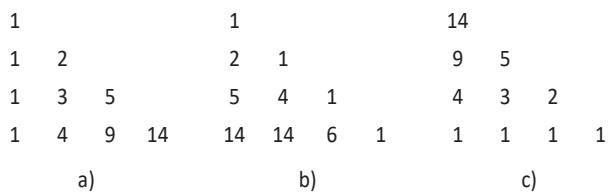

Figure 1. *Three variations of the Catalan Triangle with the first diagonal removed.*

The version of the Catalan Triangle with the first diagonal removed is useful for the purposes of ranking and unranking various enumerations of combinatorial data structures. Of interest for this paper is the ranking of binary trees enumerated by Catalan Cipher Vectors [17]. Catalan combinations [13] and Codewords [18, 19] can also be used as enumerations, as it is possible to directly transform them into Catalan Cipher Vectors and vice versa, as well as each other [17].

The process of obtaining the rank from a given Catalan Cipher Vector, i.e., CCV, is called ranking, whereas the process of obtaining the CCV from a given rank is called unranking. Technically, ranking can be defined as a function by which a number (i.e., integer) is obtained from a vector, and the unranking process is the reverse process. A requirement for both the ranking and unranking processes, i.e., algorithms, of CCVs is that a certain version of the Catalan Triangle – specifically the one displayed in Fig. 1c – be available. This version will be called the **Bottom Ones Catalan Triangle** or **BOCT** in this paper. The general algorithm for obtaining the BOCT, as well as the BOCT itself, have quadratic time and space complexity, respectively [17].

However, the entire BOCT is not required in order to obtain the rank of a CCV, but only elements of it which are linearly dependent on the CCV for which the rank is computed. The same is true for the unranking process as well: only the values of the BOCT that are necessary to generate the CCV from a given rank are needed to be used, depending on the rank value that needs to be unranked. Therefore, the entire BOCT would be abstracted if it were possible to compute only the values of the required elements of the BOCT as they become needed. The purpose of this paper is to demonstrate such an approach.

The side of the Catalan Triangle which contains the all 1's sequence will be referred to as the Edge of the Catalan Triangle, and the side that contains the Catalan Numbers sequence will be referred to as the Diagonal of the Catalan Triangle. This will pertain to both the default Catalan Triangle and the BOCT.

Converting the Default Catalan Triangle into the Bottom Ones Catalan Triangle

Figure 2 shows the default Catalan Triangle and the BOCT compared to each other, both with the size N=4. The row and column indices for the default Catalan Triangle and the BOCT are stated as (n, k) and (r, c), respectively.

*n**k*	*0*	*1*	*2*	*3*	*4*
0	1				
1	1	1			
2	1	2	2		
3	1	3	5	5	
4	1	4	9	14	14

*r**c*	*0*	*1*	*2*	*3*
0	14			
1	9	5		
2	4	3	2	
3	1	1	1	1

Figure 2. *The default Catalan Triangle and the BOCT with N=4.*

Equation (2) shows the formula for calculating the value of the element with indices (n, k) in the default Catalan Triangle [20]:

$$C(n,k) = \frac{n-k+1}{n+1}\binom{n+k}{n} \quad (2)$$

The BOCT is obtained from the default Catalan Triangle by: 1) omitting the longest diagonal from it; 2) transposing it; and 3) inverting it alongside the horizontal. Following are insights in order to be able to perform such a conversion.

In the default Catalan Triangle, on the row with index n=0 there is just one element, which is a part of the longest diagonal. Thus, if the starting rows index in the default Catalan Triangle is set to be 1, this will have the effect of removing the longest diagonal from the default Catalan Triangle. This is the transform that is required to be applied as far as the rows are concerned.

If the starting index of the columns in the default Catalan Triangle is taken to be 1, this has the effect of accessing elements in the subsequent (i.e., „to the right") column to the one of interest, when using (2). One of the features of the default Catalan Triangle is that each internal element (i.e., element not on the Edge or the Diagonal) is a sum of the element to the left of it and above it. In other words, C(n, k) = C(n, k-1) + C(n-1, k). Placing k+1 instead of k results in C(n, k+1) = C(n, k) + C(n-1, k+1), or, stated differently,

$$C(n,k) = C(n,k+1) - C(n-1,k+1) \quad (3)$$

However, if k starts from 1 instead of 0, then k+1 becomes k in the right-hand side of (3). So, if the k+1 on the right-hand side of (3) is replaced with k, it will be a valid substitution, provided that 1 is used for the

starting index for the columns of the default Catalan Triangle instead of 0.

Restating (3) by replacing k+1 with k, implementing (2) into it and using the factorial representation of the combination term produces

$$C(n,k) = \frac{(n-k+2)\cdot(n+k-1)!}{(k-1)!\cdot(n+1)!} \quad (4)$$

Thus, it is possible to compute the value of an element in the Catalan Triangle using the values of the elements in the adjacent column. So, if the starting column of the default Catalan Triangle is 1 instead of 0, (4) should be used instead of (2) to compute the value of each element of the triangle. This is the transform that is required to be applied as far as the columns are concerned.

This way, all of the requirements can be met: 1) the effect of omitting the first diagonal from the Catalan Triangle can be achieved by having the starting index of the default Catalan Triangle be (1, 1) instead of (0, 0), provided that (4) is used to compute the value of the required element; 2) the transposition effect can be achieved by exchanging the values for the row and column in (4); and 3) the inversion effect can be achieved when substituting $n = N - r$ and $k = N - c$. After implementing these transformations, the final formula for calculating the value of the element in the BOCT with indices for the row and column (r, c) becomes

$$BOCT(r,c) = \frac{(r-c+2)\cdot(2\cdot N-r-c-1)!}{(N-r-1)!\cdot(N-c+1)!} \quad (5)$$

It is now possible to display an example of a BOCT and compare its indices with those of a default Catalan Triangle. Figure 3 shows the case for the size N=4. The indices of the BOCT range from (0, 0) to (3, 3), whereas those of the default Catalan Triangle, because of the inversion transformation, range from (4, 4) to (1, 1). The transposition is demonstrated by the switched indices in the default Catalan Triangle.

k\n		*4*	*3*	*2*	*1*
	r\c	*0*	*1*	*2*	*3*
4	*0*	14			
3	*1*	9	5		
2	*2*	4	3	2	
1	*3*	1	1	1	1

Figure 3. *A BOCT with size N=4, superimposed with the corresponding indices of the default Catalan Triangle of the same size.*

For r=c=d, where $0 \le d \le N-1$, (5) transforms into

$$BOCT(d,d) = \frac{2\cdot(2\cdot(N-d)-1)!}{((N-d)-1)!\cdot((N-d)+1)!} \quad (6)$$

which is the formula for obtaining the values of the elements along the diagonal of the BOCT (which is the reason for the bounds $0 \le d \le N-1$). Those elements are the Catalan Numbers, and substituting $M = N-d$ gives

$$C_M = \frac{2\cdot(2\cdot M-1)!}{(M-1)!\cdot(M+1)!} \quad (7)$$

which is another formula for computing the Catalan Numbers. Multiplying by M in the numerator and denominator on the right hand side of (7) transforms it into (1).

Abstraction of the Bottom Ones Catalan Triangle

As can be seen in (5), the factorial function needs to be invoked three times in order to compute the value of the BOCT element with indices (r, c). The algorithms for ranking and unranking are linear, provided that the BOCT had already been generated and its elements are available for access [17]. Since the factorial is a compounding function and is linear by itself as well, the goal becomes to make it possible to access the factorial of a given number in constant time, so that the ranking and unranking algorithms remain linear.

An analysis of (5) shows that the largest factorial term is $(2\cdot N-1)!$, which is found in the numerator, and is obtained for r=c=0; the factorial terms in the denominator thus become $(N-1)!$ and $(N+1)!$ respectively. Given that the definition of the factorial is $N! = N\times (N-1)!$, where $0! = 1$, it follows that it is necessary to compute the value of $(N-1)!$ in order to compute the value of $(N+1)!$, which in turn needs to be computed in order to compute the value of $(2\cdot N-1)!$. The aforementioned holds true for $N \ge 2$, which is a necessary requirement for a Catalan Triangle to exist (a Catalan Triangle of just one element is essentially just the number 1).

Thus, if the values of the factorials of all positive integers up to and including $(2\cdot N-1)!$ are available to be used on demand, the computation of (5) is done in constant time. This can be achieved using a linear data structure which can access the values of its elements using indexing, e.g., an array. Given that $0! = 1$, the value of the element with index 0 is initially set to

be 1, whereas the value of each subsequent element is computed as per the factorial function definition. Both the process of populating such a structure and the structure itself have linear time and space complexities. Figure 4 shows an example of such a structure for $N = 4$.

$f[0]$	$f[1]$	$f[2]$	$f[3]$	$f[4]$	$f[5]$	$f[6]$	$f[7]$
1	1	2	6	24	120	720	5040

Figure 4. *An example for N = 4: an array of all factorials up to and including (2×4 – 1)! = 7! would be sufficient to compute the values of all the elements of the BOCT required to rank and/or unrank any CCV of size N = 4.*

Fully Linear Algorithms for Ranking and Unranking of Catalan Cipher Vectors

The following algorithms are modifications to the ranking and unranking algorithms found in [17], which are shown to be linear there. The algorithms in this paper focus on the ranking and unranking processes instead on the full generation of binary trees using the CCVs. They also utilize the abstraction approach explained in the previous sections. They are presented as functions and pseudocode (which resembles the C++ language) is given for each of them.

During the ranking and unranking processes, the elements in a Catalan Cipher Vector are sequentially read and updated, respectively. In both cases, the size of the CCV is taken to be N, and this value is assumed to be known and stored in the variable N. The array variable *CCV*, of size N, which stores the elements of the CCV currently being processed, is also assumed to be initialized and populated with valid values, as defined in [17].

The Bottom Ones Catalan Triangle Element Value Computation Function

Pseudocode 1 presents the function for computing the value of the BOCT element that is needed for the ongoing ranking or unranking process. This function is auxiliary but is called during both the ranking and unranking process. The parameters are: N (the size of the CCV, as previously introduced); r – the row index of the element in the BOCT being accessed; and c – the column index of the element in the BOCT being accessed.

Pseudocode 1. *The function for the calculation of the BOCT element given the size of the BOCT N, the row of the element r and the column of the element c.*

```
function BOCTel(N, r, c)
{
    num = (r-c+2) * f[2*N-r-c-1];
    den = f[N-r-1] * f[N-c+1];
    return num / den;
}
```

The Ranking Function

Pseudocode 2 shows the ranking function for a given array parameter *CCV*. Variables additional to the ones already known are: v – the index in the *CCV* array; and *rank* – the value of the rank being computed during the ranking process.

Pseudocode 2. *The ranking function.*

```
function Rank(CCV)
{
    r = 0;
    c = 0;
    rank = 0;
    for(v = 0; v < N; ++v)
    {
        while (CCV[v] > (r + c))
            rank += BOCTel(N, r, c++);
        ++r;
    }
    return rank;
}
```

The Unranking Function

Pseudocode 3 shows the unranking function for a given parameter *rank*.

Pseudocode 3. *The unranking function.*

```
function Unrank(rank)
{
    r = 1;
    c = 0;
    v = 0;
    CCV = new array[N];
    CCV[v++] = 0;
    while(v < N)
    {
```

```
        while (BOCTel(N, r, c) <= rank)
            rank -= BOCTel(N, r, c++);
        CCV[v++] = r++ + c;
    }
    return CCV;
}
```

Analysis of the Algorithms

Both the ranking and unranking algorithms traverse the CCV linearly and they access only the elements of the BOCT that are required during the corresponding process [17]. For each element of the CCV being processed, a corresponding element in each of the rows on the BOCT is accessed. Depending on the value of the element in the CCV, there is either no displacement from the left vertical (i.e., the Edge) of the BOCT, or there is some, up to at most the value of the index of the row (i.e., the element on the Diagonal). However, once that displacement occurs when processing an element of the CCV, the displacement is not reset in the subsequent row.

This means that the required elements in the BOCT are traversed in a single line, without segments of the line being repeated or intersected. This ensures that, in the best case, only the elements of the leftmost column will be traversed, so the time complexity of both the ranking and unranking algorithm will be $\Omega(N)$. In the worst case, the full lengths of both the column and the bottom row will be traversed, so the time complexity for both algorithms will be $O(2 \cdot N) = O(N)$. Thus, the time complexity of both algorithms is $\Theta(N)$, even though that may not be apparent upon initial overviews of their respective pseudocodes. Given that the preliminary process of generating the array of factorials for positive integers from 0 to 2·N–1 is also linear, this means that the full processes of both ranking and unranking, alongside all of their necessary algorithms and data structures, are linear for both time and space complexity.

CONCLUSION

The process of obtaining an integer for a given Catalan Cipher Vector is called ranking, and the reverse process is called unranking. This paper presents the principle and algorithms for abstraction of the Bottom Ones Catalan Triangle, which is a version of the Catalan Triangle that is used for the processes of ranking and unranking of Catalan Cipher Vectors. A formula is presented that computes the values of the elements of the Bottom Ones Catalan Triangle as they become necessary during the ranking and unranking processes. This way, the triangle doesn't need to be generated fully and is therefore abstracted during the ranking and unranking processes, thus circumventing the default quadratic time and space requirements for its computation. Instead, a linear data structure, such as an array, is used for storing values of factorials necessary for such computations, thus making both the ranking and unranking processes fully linear for both time and space complexity.

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Professor Veno Pačovski, who passed away in 2020, was the third author in the paper that has introduced the Catalan Cipher Vectors in 2013. The authors of this paper would like to remember him as a person full of vitality, energy and drive to promote and improve Computer Science, like he used to be back then.

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ON UNDERWATER DATA CENTERS: SURVEILLANCE, MONITORING, AND ENVIRONMENTAL MANAGEMENT IN THE BALTIC SEA

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Abstract: This article analyzes underwater surveillance and monitoring technologies aimed at enhancing security and environmental management, using a hypothetical underwater data center in the Baltic Sea as a case study. It explores cutting-edge solutions such as remotely operated vehicles (ROVs), autonomous underwater vehicles (AUVs), and smart buoys, focusing on their integration for monitoring underwater infrastructure and safeguarding against infrastructural threats. With rising concerns over maritime security due to recent events like the Nord Stream outage, this research highlights the need for advanced technological systems to address such a kind of vulnerabilities. The analysis also considers multi-layered potential of these systems for security, safety, and environmental resilience. Consequently, this study provides insights into the feasibility, challenges, and future directions for deploying underwater data centers as a sustainable alternative to traditional land-based facilities of this type, contributing to the broader discourse on securing critical underwater infrastructure and promoting eco-friendly data storage solutions.

Keywords: underwater data center, Baltic Sea, surveillance, monitoring, maritime infrastructure, security

INTRODUCTION

The concept of underwater data centers has gained significant attention in recent years as a potential solution to the growing challenges associated with traditional land-based facilities. The development of underwater data centers is primarily driven by the need to address high energy consumption, environmental impact, and security concerns inherent to conventional data center operations.

This study uses a qualitative research approach to assess the feasibility and risks of deploying underwater data centers, with a focus on the Baltic Sea. A PESTLE - Political, Economic, Social, Technological, Legal, and Environmental analysis framework was employed to evaluate external factors influencing underwater data center deployment. Additionally, a risk matrix assessment was conducted to prioritize potential threats based on their likelihood and impact.

Data was collected through literature reviews, expert interviews, and analysis of industry reports, providing a comprehensive understanding of the political, environmental, and technological challenges specific to underwater data centers. Using the PESTLE framework helped to identify the critical issues.

The rest of the paper is organized in a way that it:

- Gives an overview of history and evolution of underwater data centers;
- Highlights current developments in this domain;
- Underscores the threats to which the Baltic Sea region is currently exposed to;
- Elaborates the role of surveillance and monitoring technologies including Remotely Operated Vehicles (ROVs), Autonomous Underwater Vehicles (AUVs), or, Unmanned Aerial Vehicles (UAVs), and smart buoys, including their integration;
- Analysis the conditions for the development of an underwater data center in the Baltic Sea, concerning environmental, geopolitical, and security risks, along with the legal and regulatory challenges.
- These subtopics are framed at the end with the conclusion part.

Underwater Data Centers

The idea of placing data centers underwater is not entirely new, but it has only recently been pursued on a larger scale. The early 21st century saw increasing awareness of the environmental and economic drawbacks of conventional data centers, which consume vast amounts of electricity for cooling, e.g. As the demand for digital services continued to grow, the industry began to explore alternative approaches to cooling and energy efficiency. One innovative solution emerged in the form of underwater data centers, which leverage the natural cooling properties of the ocean to maintain optimal operating temperatures for servers. For example, over the past few years, data center electricity consumption has accounted for a relatively stable 1% of global electricity usage, excluding cryptocurrency mining [1].

Microsoft's Project Natick, which began in 2013, marked a turning point in the development of underwater data centers [2]. The project aimed to investigate whether a sealed container filled with servers could operate efficiently underwater. The first phase of Project Natick, launched in 2015 off the coast of California, involved a small, prototype data center placed 30 feet underwater for several months. This initial test demonstrated the feasibility of the concept and showed promising results in terms of energy efficiency and reliability.

In 2018, Project Natick entered its second phase with the deployment of a larger underwater data center off the coast of Scotland's Orkney Islands. This new unit, which was the size of a standard shipping container, housed 864 servers and operated entirely on renewable energy sourced from nearby wind and solar farms. The data center was submerged approximately 117 feet below the ocean's surface, where it remained for two years. During this period, the underwater data center exhibited a failure rate that was significantly lower than traditional land-based data centers. The cooler, stable environment and the absence of human interference contributed to the improved performance.

The successful results of Project Natick's second phase solidified the viability of underwater data centers as a sustainable and resilient alternative to conventional approaches (Fig. 1).

Fig. 1. *Microsoft Project Natick 2. Source: [2]*

Existing Underwater Data Centers

Following the success of Microsoft's Project Natick, other companies and organizations have started to explore the potential of underwater data centers. For instance, Subsea Cloud, founded by Maxie Reynolds, offers a commercial underwater data center service that uses liquid immersion cooling technology. Unlike Project Natick, which used a sealed nitrogen-filled environment, Subsea Cloud employs dielectric liquids to cool servers directly, providing even greater efficiency in heat dissipation. Subsea Cloud has active projects the Gulf of Mexico and is looking to expand to the North Sea and the Pacific Ocean [3].

Another major player in the field is the Chinese company Highlander, which, with the backing of the Chinese government, launched the world's first commercial underwater data center near Hainan Island in 2021. The facility can support large-scale computing, and storage needs while utilizing the surrounding seawater for cooling. The 1 400-tonne system is submerged 35 meters on the seafloor and the water is used as natural cooling. Further plans indicate that 100 modules are planned to deploy at the site. It means that it would save 68 000 square meters of land, along with 122 million kilowatt-hours of electricity and 105 000 tons of freshwater per year [4].

These developments highlight the increasing interest in underwater data centers, not just as experimental projects, but as commercially viable and scalable solutions. Albeit, the deployment of underwater data centers introduces challenges, particularly in regions with complex environmental and geopolitical dynamics, such as the Baltic Sea.

Baltic Sea Challenges

The Baltic Sea presents a unique set of challenges for the deployment of underwater data centers due to its environmental characteristics, strategic significance, and actual geopolitical tensions.

The Baltic Sea is a semi-enclosed body of water bordered by several countries, including Estonia, Latvia, Lithuania, Finland, Sweden, Denmark, Germany, Poland, and Russia (Fig. 2). It has distinct environmental features, such as low salinity, limited water exchange with the Atlantic Ocean, and relatively shallow depths. These factors can influence development, operation and maintenance of underwater infrastructure.

One of the cases was Balticconnector gas pipeline and communication cables failure (Fig. 3). Stockholm investigators confirmed that damage to an undersea cable was caused by "means of external force or tampering" [5].

The authorities believe the damage to the pipeline was likely caused by the ship's anchor, but it is not yet known if it was deliberate or unintentional [6]. Therefore, this remains at the level of a suspicion.

Fig. 2. *Underwater telecomunication cables in Europe. Source: [7]*

Fig. 3. *The damaged offshore Balticconnector gas pipeline. Source: [8]*

Furthermore, due to some recent Twitter (https://x.com/auonsson) reports numerous security incidents are suspected to be sabotage. The Chinese ship, Yi Peng 3, crossed C-Lion 1 and BSC cables at times these were broken (Fig. 4). Then, this ship has been detained by Danish navy on November 19, 2029 (Fig. 5).

However, this is still in a grey area and at the level of a security incident suspected to be sabotage. There have been no official reports from the authorities.

Fig. 4. *Auonsson's post on November 19, 2024. Source: https://x.com/auonsson*

Fig. 5. *Auonsson's post on November 20, 2024. Source: https://x.com/auonsson*

Environmental Factors

The unique environmental conditions of the Baltic Sea, including its low salinity and temperature variations, can affect the performance of underwater data centers. Low salinity may impact the cooling efficiency, while temperature fluctuations could influence the stability of the underwater environment. Additionally, the seabed in some areas is characterized by a mixture of soft sediments, which could pose challenges for anchoring or installing underwater infrastructure. Biofouling, or the accumulation of organisms on submerged structures, is another concern, as it could affect the efficiency of cooling and increase maintenance requirements.

The Baltic Sea is also home to significant marine ecosystems and protected areas, which necessitates careful planning to minimize the environmental impact of underwater installations. The deployment of underwater data centers must consider regulations related to marine conservation, and impact assessments may be required to evaluate potential effects on local wildlife and habitats [9].

Geopolitical and Security Concerns

The strategic significance of the Baltic Sea has been highlighted in recent years due to geopolitical tensions and incidents such as the Nord Stream pipeline outage. As a result, underwater data centers in this area would be exposed to potential security threats, including sabotage, espionage, and cyber-attacks. The security of underwater data centers is a critical consideration, as these facilities could be targeted to disrupt communication networks or compromise sensitive data. Physical security measures, such as surveillance systems and protective enclosures, are essential to safeguard the infrastructure from sabotage. Additionally, robust cybersecurity measures and protocols are needed to prevent unauthorized access to the data center's systems.

Legal and Regulatory Challenges

The legal framework governing underwater infrastructure in the Baltic Sea is complex, with overlapping jurisdictions and international agreements. Countries bordering the Baltic Sea have established Exclusive Economic Zones (EEZs) that grant them certain rights over marine resources and infrastructure.

Involvement of the international waters and shared boundaries complicate the regulation of underwater installations. Regulatory compliance is necessary for the deployment of underwater data centers, and stakeholders must navigate a range of legal requirements related to maritime law, environmental protection, and data security. Coordinating with multiple governments and regulatory bodies can be challenging, especially in a region where political relations may fluctuate.

Surveillance and Monitoring

The use of advanced surveillance and monitoring technologies in undersea area becomes crucial. Technologies such as Remotely Operated Vehicles (ROVs), autonomous underwater vehicles (AUVs), and smart buoys can help detect physical threats, monitor environmental conditions, and ensure compliance with legal and regulatory standards.

An underwater robot connected to a mother ship by a network of cables is called a ROV. An AUV, on the other hand, completes its survey mission without the assistance of an operator. At the end of a mission, the AUV returns to a pre-programmed location so that the data can be downloaded and processed. For monitoring the sea environment (temperature, salinity, or currents), smart buoys serve as stationary or partially mobile nodes. They relay data in real time and assist ROVs and UAVs with navigation. These technologies work together through complementary roles, tasks sharing, and synchronized communication.

The ROVs can examine underwater effects, buoys gather water quality data, and UAVs "keep an eye" on surface algal blooms, e.g. The ROVs find and retrieve underwater targets, while smart buoys offer real-time environmental data and detect surface debris. Smart buoys gather long-term data, while the UAVs map coral reefs and inspect surface infrastructure. The ROVs carry out usually in-depth underwater surveys [10; 11], etc.

Remotely Operated Vehicles (ROVs)

The ROVs are underwater robots that can be controlled from the surface to inspect and maintain underwater infrastructure. Equipped with cameras, sonar, and various sensors, ROVs provide high-resolution imagery and real-time data on the condition of underwater facilities. They are particularly useful for

conducting detailed inspections of underwater data centers, identifying physical threats, and performing maintenance tasks. The ROVs require human operators and they are limited by tether lengths, which can restrict their operational range in deeper waters. Estonian company Flydog Marine has profiler buoy "Mona" and submerged profiler "Salla" (Fig. 6). Technical specification of "Mona" is given in Table 1.

Fig. 6. *Submerged profiler „Salla". Source: [12]*

Autonomous Underwater Vehicles (AUVs)

AUVs operate independently of surface control, using pre-programmed missions and onboard sensors to navigate underwater. For example, ECA Groups A18-M has applications for the defense and security sector encompass: Rapid Environment Assessment (REA); Intelligence, Surveillance and Reconnaissance (ISR); organic underwater mine warfare: mine countermeasures mission module for large multipurpose vessel and mission module for oceanic mine warfare, and conventional underwater mine warfare: detection and classification [12]. They can conduct extensive surveys over large areas, making them ideal for monitoring the surrounding environment and detecting potential threats such as unauthorized vessels. The AUVs are advantageous for long-duration missions and can cover greater distances than ROVs. However, their autonomy poses challenges in real-time communication and data transfer, particularly in deep-sea or high-turbidity conditions. The AUVs are versatile tools for marine surveillance, capable of operating independently across diverse missions, from scientific research to defense applications. The COMPASS2020 project, e.g., showcases AUVs like the A27 and A9-E, highlighting their robust design and advanced capabilities. For instance, the A27 operates at depths up to 300 meters and can carry high-performance payloads, including Synthetic Aperture Sonar (SAS) and multi-beam echo sounders, with a speed range of 3-6 knots. Similarly, the A9-E is optimized for environmental monitoring, offering real-time data on water conditions such as turbidity and pH levels, and features low acoustic signatures to avoid mine detection. These AUVs navigate using Inertial Navigation Systems (INS), Doppler Velocity Logs (DVL), and periodic Global Positioning System (GPS) resurfacing. Equipped with communication options like acoustic, WiFi, and Ethernet channels, AUVs represent a crucial asset for sustained and stealthy underwater operations in complex environments [13].

Table 1. *Technical specifications of a profiler buoy „Mona". Source: [12]*

• Profiling depth – *200m* • Length – *4 m* • Height above water – *2 m* • Diameter – *1,2 m* • Weight – *450 kg* • Comms - *GPRS* • Construction – *float from polyurethane foam covered with hard polyurethane coating, with autonomous lantern and passive radar deflector*	• Hardware Controller & Data-Logger – *integrated* • Software – *web-based user interface for controlling the buoy in real-time* • Customization – *can be altered for specific needs* • Cost – *start from 74 995 €*

The Unmanned Aerial Vehicles (UAVs) are a sort of AUVs. They are invaluable assets in maritime missions, offering real-time surveillance and enhanced situational awareness. The Airbus Zephyr S HAPS, for instance, operates in the stratosphere at altitudes up to 70,000 feet with an impressive endurance of nearly 25 days, combining satellite-like persistence with UAV flexibility. Meanwhile, the Tekever AR5 Life Ray Evolution, a medium-endurance UAV, supports maritime patrols with a 50 kg payload, 16-hour endurance, and a cruise speed of 100 km/h, effectively covering large surveillance areas with EO/IR sensors. These UAVs improve maritime security by tracking illegal activities, monitoring environmental changes, and ensuring rapid response in emergencies. Notwithstanding, challenges such as high operational

costs, vulnerability to adverse weather, and integration complexity must be addressed to optimize UAV deployment in maritime operations. Future advancements in UAVs autonomy, durability, and communication capabilities will be essential for even more reliable and resilient maritime surveillance [14; 15].

Smart Buoys

Smart buoys serve as stationary surveillance platforms that can be deployed around underwater data centers to monitor environmental conditions and detect anomalies. Equipped with various sensors, including hydrophones, cameras, and water quality detectors, smart buoys can continuously gather data on water temperature, salinity, and acoustic signals. This capability enables early detection of intrusions or environmental hazards (Fig. 7). Smart buoys are effective for monitoring fixed areas, their coverage is limited, and they may require periodic maintenance and calibration [16; 17].

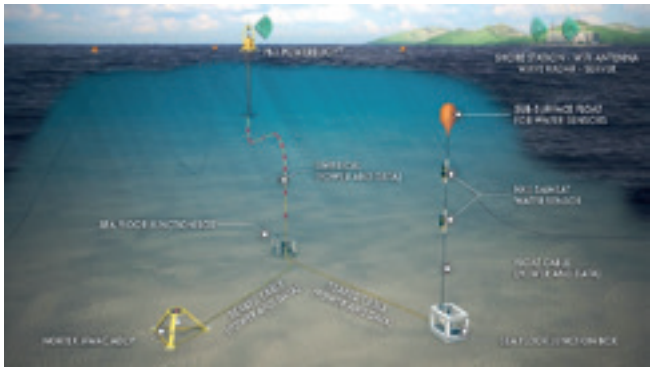

Fig. 7. *Illustration of PB3 Power Buoy environment. Source: [16]*

Underwater Infrastructure Support

The need for specialized monitoring and support services has become essential. Maritime research and surveillance companies offer vital expertise in surveying, inspection, and environmental monitoring for underwater infrastructure. For instance, Reach Subsea [18] company provides comprehensive geophysical and environmental monitoring, leveraging advanced subsea technology to ensure safety, stability, and operational compliance. Its Reach Remote Project emphasizes sustainable, low-emission operations, enhancing access to remote areas. Through real-time and autonomous monitoring solutions, companies like Reach Subsea, help maintain underwater infrastructure integrity in challenging marine environments. Their wide portfolio includes environmental and geophysical monitoring, remote and autonomous fleet, survey and positioning.

Since NATO's inception in 1949, collaborations among the Baltic Sea countries have bolstered environmental and military standards to maintain regional stability. The 2022 Nord Stream outage incident heightened the need for robust security, leading to creation of the Maritime Centre for the Security of Critical Undersea Infrastructure in 2023. Key initiatives include increased patrols, minehunters, drones, and advanced surveillance by NATO and individual Baltic countries. Estonia's "MEREHUNT" smart buoy project also supports coastal monitoring and maritime environmental data, while NATO's Digital Ocean program integrates digital solutions to enhance situational awareness from seabed to space [19; 20]. A map application with an overview of Estonian coastal and offshore stations. Indicative locations and test areas of the new smart buoys are marked with blue circles (Fig. 8).

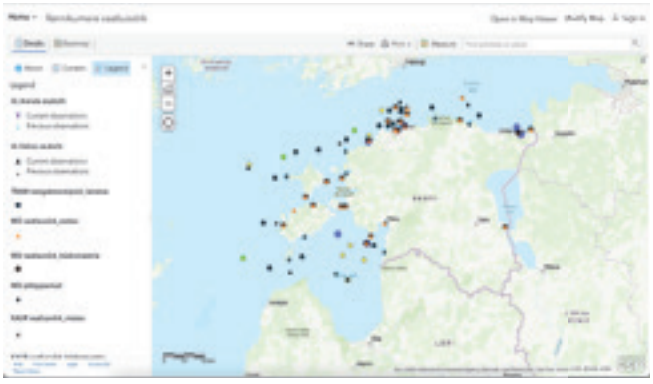

Fig. 8. *Indicative locations and test areas of the new smart buoys. Source: [18]*

The Baltic Sea is subject to various national jurisdictions and international agreements, making legal compliance a significant concern. Surveillance and monitoring systems should be designed to meet the environmental regulations of all bordering countries, including requirements for marine conservation and underwater infrastructure safety. Therefore, compliance with international maritime law is necessary, particularly regarding data center deployment in the EEZs (Fig. 9).

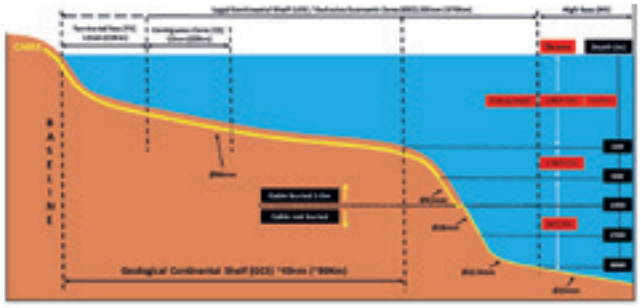

Fig. 9. *Different zones of juridical zones for coastal competence. Source: [21]*

Security Threats

Given the operational and environmental constraints of underwater data centers, international sabotage targeting these facilities can have serious consequences. Due to their heavy reliance on underwater infrastructure, these data centers—which are built for effective cooling and minimal environmental impact—are susceptible to sabotage in several ways. Some examples of sabotage are as follows:

- To cut or damage the communication and power cables that connect it to the shore.
- The use of explosives to breach the data center's pressure vessel or protective casing.
- Interference with pipelines or cooling systems that are utilized for operations and maintenance, etc.

The impacts might be disconnection, which makes the data center unusable; permanent harm from water intrusion to delicate servers and equipment; high expenses for service restoration, recovery and repair, etc. For instance, even sounds from military-grade sonar on ships, submarines, or even whales could interfere with underwater data centers being built off the coasts of China, the US, and Europe [22].

CONCLUSION

The concept of underwater data centers represents a promising alternative to traditional land-based facilities, offering benefits in energy efficiency, environmental sustainability, and security. The successful implementation of projects like Microsoft's Project Natick has demonstrated the feasibility of using underwater environments to reduce cooling costs and improve the resilience of data storage infrastructure. However, deploying a such facility in the Baltic Sea, requires careful consideration of environmental, legal, cyber, and geopolitical issues.

The underwater data center enables comprehensive monitoring, real-time data acquisition, and prompt detection of potential threats, thereby enhancing the security and operational stability of the underwater infrastructure. Security measures must account for the potential risks of sabotage, espionage, and legal disputes. A robust surveillance system that integrates multiple technologies, such as ROVs, AUVs and smart buoys, is crucial for ensuring the data center's safety.

While underwater data centers offer significant advantages, their deployment in sensitive regions requires a careful balance between technological innovation, cyber-risks, environmental protection, and geopolitical challenges. The recommended multi-tiered surveillance strategy can mitigate risks, support legal compliance, and contribute to the sustainable development of a such data center in the Baltic Sea.

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NEW NEURAL PLL ARCHITECTURE

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Abstract: A PLL or phase-locked loop is a control system that creates an output signal whose phase is related to the phase-locked loop and represents controlled input signal. The goal of this research is to first investigate the functioning of new PLL neural networks and then, in the research section, explore an approach involving the extraction of neural symmetrical voltage components. The architectural characteristics of phase-locked loops (PLLs) typically include capture and lock ranges, bandwidth, and transient response. The new neural PLL architecture offers several advantages, such as low noise performance, reduced silicon area, and compatibility with low supply voltages. However, it may also present disadvantages, including hardware dependency and potential design complexity compared to traditional PLL architectures. Evaluating these factors is crucial, depending on the specific needs of the application.

In this paper, we present the scientific research included in the experimental part where we investigate the performance of the proposed neural PLL, for which experimental comparisons with the conventional PLL in a distorted reference frame are necessary. Structural columns or structural circles will be used for graphic display.

The following research methods and techniques will be applied: instruments, basic methods and data processing procedures - if they are foreseen. What makes this work a scientific research work is a descriptive method that will be used.

To better understand how PLLs work, we propose an original three-phase neural approach for components of the system's phase and symmetry. The quality of the electricity can be assessed and managed with this framework. Our study shows that the full neural architecture may be applied to three-phase power systems because it is based on DSP supplies. Additionally, we present the performance of the PLL system in a three-phase power supply context. Different regulators, such as PI and RST based on phase logic, are incorporated into the PLL scheme. The results suggest that the neural PLL could make a significant contribution in applications where the quality and efficiency of three-phase power systems are essential.

Keywords: Neural Phase-Locked Loop (PLL), electroenergetic system, neural network, neural architecture

INTRODUCTION

A controlled system known as a phase-locked loop (PLL) produces an output signal that is both phase and frequency synced with an input reference signal. As integrated circuits have advanced, the PLL has emerged as a crucial component for numerous applications, including signal processing boards, three-phase power systems, and contemporary communication systems [1].

PLLs play a crucial role in power systems. Among the uses are drive control, harmonic current detection, unbalance compensation in three-phase systems, and sinusoidal inverter control.

The proposed neural phase-locked loop (NPLL) employs a neural algorithm capable of decoding time-coded information and converting it into a rate code. This advance suggests improvements in the ability to efficiently track and process signals, leveraging neural networks for better performance in systems that rely on phase-locked loops. Recently, dedicated PLLs have been designed, comprising a three-phase PLL designed to calculate the phase angle of direct sequence components and the system frequency. APF methods have effectively employed this strategy in situations involving severely distorted voltage [1].

The subject of this research is the application of new neural PLLs as symmetrical components to estimate system frequency and the phase angle of direct sequence components, which are used in APF schemes.

The goal of the research is to first investigate the functioning of the new PLL neural networks, includ-

ing their characteristics, advantages, and disadvantages. In the research phase, the focus is on the extraction of neural symmetrical voltage components, neural phase detection techniques, and functional tasks that are decomposed and approximated using Adaline neural networks are used. The complete neural architecture is applied to a three-phase power supply system and implemented on a digital signal processor (DSP).

Characteristics of Pll

Architecture characteristics of Phase Locked Loops (PLLs) typically include capture and lock ranges, bandwidth, and transient response. The capture range is generally smaller than the lock range, which defines how well the PLL can stabilize the output frequency against changes in the reference signal. PLLs are widely used every day in many areas of high frequency system design.

According to its various operating principles and methods, a phase-locked loop (PLL) refers to a control system that can generate output signals according to certain rules. By comparing the different operating principles, it can be determined that the basic principle of PLL is to realign the phase of the input signal. This mode of PLL operation is significantly different from traditional output signals, which is achieved by adjusting the local frequency of the generated signal, which in turn adjusts its phase [1].

Feedback control in a PLL circuit

In a phase-locked loop (PLL), the phase and frequency of the output signal are aligned with the input signal through a phase- and frequency-locking mechanism. This process is achieved by a closed-loop control system, which uses feedback to continuously adjust the phase and frequency of the local oscillator to match those of the input signal, thereby maintaining system stability. The feedback control in a PLL is based on phase detection, where a phase detector generates an error signal proportional to the phase difference between the input and local oscillator signals. This error signal is then processed through a low-pass filter, which eliminates high-frequency components, before being fed back to the local oscillator. As the local oscillator frequency adjusts, the phase difference decreases, and the error signal diminishes. This iterative process continues until the phases and frequencies of the output signal are synchronized with those of the input signal.

Clock distortion generation and elimination

Clock skew is a timing error that can occur in digital systems due to various factors. Before we explain how PLLs lead to clock skew, here are some common reasons why this happens:

- A delay in the transmission of the clock signal through the transmission line can lead to clock distortion. When clock signals travel through a transmission line, various delays can occur due to factors such as the length of the transmission line, the impedance of the line, and depending on what kind of material is used to make the line [2]. This delay can cause clock signals to arrive at different times and ultimately result in clock skew.
- Temperature and voltage variations can also cause clock skew in digital systems. The delay of the clock signal can vary with temperature and voltage changes, which can lead to clock distortion.Treperenje sata je još jedan faktor koji može uzrokovati iskrivljenje sata. Treperenje sata je varijacija u vremenu signala sata zbog nastanka šuma ili smetnji. Ovo takođe može prouzrokovati odstupanje dolaska signala do sata.

However, PLL can solve the clock skew problem in digital systems. It can generate a clock signal that is synchronized with an input clock signal or a reference clock signal, and then eliminate any timing differences between these signals. To do this, the PLL compares the phase and frequency of the input clock signal or reference clock signals with phase and frequency [3]. This comparison is performed by a phase detector, which generates signal errors proportional to the phase and frequency difference between the signals. By using feedback control to adjust the frequency and phase of the locally generated clock signal, the PLL will be able to eliminate any timing differences between the input clock or clock signal. This ensures that the clock signals in the digital system are properly synchronized [4].

Frequency multiplication

A frequency multiplier in a PLL can take an input signal and produce an output signal whose frequency

is a multiple of the input frequency. It can be implemented using a variety of circuit techniques, such as doublers, triplers, or higher-order multipliers. In the context of a PLL, a frequency multiplier is usually implemented using a nonlinear device, such as a diode, transistor, or mixer, that performs a multiplication operation on the input signal. The multiplication factor (M) of the frequency multiplier determines how many times the frequency of the locally generated clock signal is increased. For example, if the input clock signal has a frequency of 10 MHz and the frequency multiplication factor is 4, the output clock signal would have a frequency of 40 MHz.

Components of PLL

Figure 1 illustrates the fundamental circuit of the PLL, highlighting its unique characteristics, operational principle, and structural design. Through detailed investigation and analysis, it was determined that this configuration offers strong resistance to external disturbances and fluctuations, thereby ensuring the stability of the entire system.

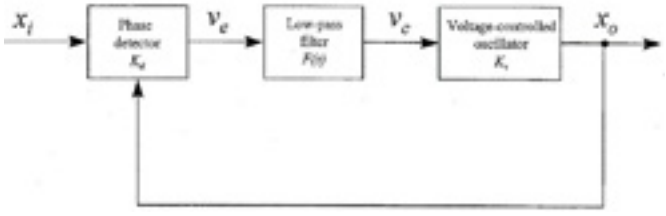

Figure 1. *Basic PLL circuit*

Phase detector

The phase detector plays a crucial role in the system. As a central component in the control process, its primary function is to detect signal errors, ensuring the system maintains high accuracy and precision at all times. This prevents performance degradation caused by excessive errors. For instance, the square PD (phase detector) signal is commonly utilized in PLL design. The characteristics of the square signal PD have a linear type over the detection phase, while the triangular PD and the sawtooth PD have different types of phase detection [5].

Low pass filter

Among all the structural components of the PLL, there is a (one) very important one that plays a role in eliminating noise and ensuring the stability of the output signal current of the entire system. The low-pass filter is a very important component, so it is necessary to select relevant parameters and a reasonable working environment during selection and design. The output of the phase detector, which is proportional to the phase error, contains high frequency components that need to be filtered out before they are used to tune the voltage controlled oscillator (VCO). If these high-frequency components are not filtered, they will cause instability of the VCO output signal, which then results in frequency instability [6].

Voltage controlled oscillator

A voltage controlled oscillator (VCO) plays a role in generating output signals with a frequency that is synchronized with the reference input signal. By applying voltage control to the resonant circuit, the frequency of the output signal can be adjusted. A VCO works by generating a sinusoidal waveform, with a frequency that is a function of the input voltage applied to it. The frequency range of the output signal is typically determined by components in the circuit resonance, such as inductors and capacitors [7].

NEW ARCHITECTURES USED IN PLL ARCHITECTURE

Over the years, various new architectures have been proposed for the design of phase-locked loops (PLLs) to overcome the challenges faced by traditional PLLs and to improve their performance. Here are some examples of new PLL architectures:

(1) Fractional-N PLL: Fractional-N PLL is a modified version of the traditional integer-N PLL that allows the PLL to generate frequencies that are not integer multiples of the reference frequency.

(2) All-digital PLL: An all-digital PLL (ADPLL) uses only digital circuitry, eliminating the need for analog components such as VCOs and filters [8]. ADPLLs offer several advantages over traditional PLLs, including better scalability, lower power consumption, and higher noise immunity.

(3) Bang-Bang PLL: Bang-Bang PLL uses digital phase detector and switched capacitor filter to achieve high frequency resolution and low phase noise. This architecture is suitable for low power applications and is used in frequency synthesizers for wireless communication systems.

These new PLL architectures contributed to the advancement of PLL technology and enabled the de-

sign of PLLs with improved performance, scalability, and energy efficiency [9].

Advanced loop filters and improved phase detectors in PLL design

Loop filters and phase detectors are critical components of a Phase Locked Loop (PLL) because they determine the stability, noise performance, and lock time of the PLL. Over the years, several advanced loop filters and improved phase detectors have been developed to address the challenges faced by traditional PLLs and improve their performance [10]. Here are some examples:

(1) Proportional-Integral (PI) Loop Filters: PI loop filters are commonly used in PLLs due to their simplicity and good stability characteristics. However, they can have poor transient response and phase noise. To solve this, advanced PI loop filters have been developed that use non-linear elements such as RC filters, resonators or active elements to improve the performance of the PLL.

(2) Phase charge detectors: Phase charge detectors are widely used in PLLs because of their simplicity and good performance. However, they can be prone to errors, which can cause phase noise and thus limit the lock range of the PLL. To solve this problem, improve this phase, detectors using current mirror techniques, self-calibration circuits or multilayer quantization to reduce displacement errors have been developed [11].

(3) Digital phase detectors: Digital phase detectors offer several advantages over analog phase detectors, including better accuracy, programmability, and noise performance. But they can be affected by delay errors and quantization noise [12]. To solve this problem, digital phase has been improved and phase detectors have been developed that use delay-locked loops, dynamic latches, or multiphase clocking to improve their performance. These advanced loop filters and improved phase detectors have contributed to the development of PLLs and significantly improve performance, stability and noise characteristics, making PLLs more suitable for a wide range of applications in communication systems, radars, instrumentation and other fields.

After describing the new neural PLLs in the research section we will explore how the IPT-based PLL works. This approach is derived as a lead in a new formulation of current powers used by Adalin's neural network[13]. Adaline is a straightforward, easily learned design that is effective at online linear connection estimation. This served as a powerful incentive for the use of digital technologies in PLL implementation. As a result, the novel neural PLL and its improved digital signal processor (DSP) implementation are ideally suited for a full neural APF scheme and can meet real-time limitations [14].

Advantages and Disadvantages of the new Neural PLL Architecture

The new neural PLL (Phase-Locked Loop) architecture offers several advantages, including low noise performance, reduced silicon area, and compatibility with low supply voltages. However, it can also have disadvantages such as hardware dependency and potential complexity in design compared to traditional PLL architectures. It is important to evaluate these factors based on the specific needs of the application.

Advantages

The most popular PLL architecture is the fully differential PLL [15]. This architecture offers several advantages in terms of low noise performance, reduced silicon area and compatibility with low supply voltages. In addition, it is well suited to meet the demanding requirements imposed by modern wireless devices. Another popular architecture is the digital PLL, which can be either fully digital or include a VCKSO for low jitter requirements [16]. A digital PLL overcomes the limitation of hard-to-change design parameters when the PCB is mounted. Commonly used for clock recovery and cleanup in transmission media. Another proposed architecture is a modified architecture that allows full monolithic integration [17]. This design employs a switched capacitor filter in place of a passive filter and a phase frequency detector that operates at a 90 degree phase shift [17]. It achieves the same performance as conventional solutions with a significantly lower capacity.

The new neural PLL (Phase-Locked Loop) offers several advantages, including improved flexibility in handling different types of data, improved self-learning capabilities, and better performance even with sparse data. This approach also simplifies un-

derstanding how neural networks produce outputs, making artificial intelligence more understandable.

Disadvantages

Disadvantages of the new phase-locked neural loops (PLLs) may include the following:

- Complexity: Neural PLLs can be more complex to design and implement compared to traditional PLLs, making them more difficult to understand and use effectively.
- Computational overhead: These can require significant computing resources for training and inference, leading to increased latency and power consumption.
- Overfitting: As with many machine learning models, there is a risk of overfitting the training data, which can lead to poor generalization in real-life scenarios.
- Black-box nature: The "black-box" nature of neural networks can make it difficult to interpret how decisions are made, complicating debugging and optimization efforts.

Always consider verifying information based on context and specific applications.

NEW ARCHITECTURE OF NEURAL PLL

We will go over how to keep an eye on a measured three-phase voltage system's fundamental frequency. The two stages of the suggested method, which is depicted in Figure 2, are the extraction of symmetrical voltage components and the current phase identification algorithm. The problem that leads to the initial signal decomposition that is, current powers and voltages is formalized for each stage. In any case, we demonstrate that Adaline neural networks can be used to learn these phrases. As a result, the entire strategy is quite flexible and can accommodate for shifting factors.

Method of extraction of symmetrical neural components

IPT serves as the foundation for the symmetric component extraction concept. This theory states that the pk-powers are computed and that their AC and DC terms are instantly separated. The direct voltage components are then determined by converting the DC-terms to the current reference frame, as seen in Figure 3. The instantaneous powers in IPT are computed using the αβ–frame.

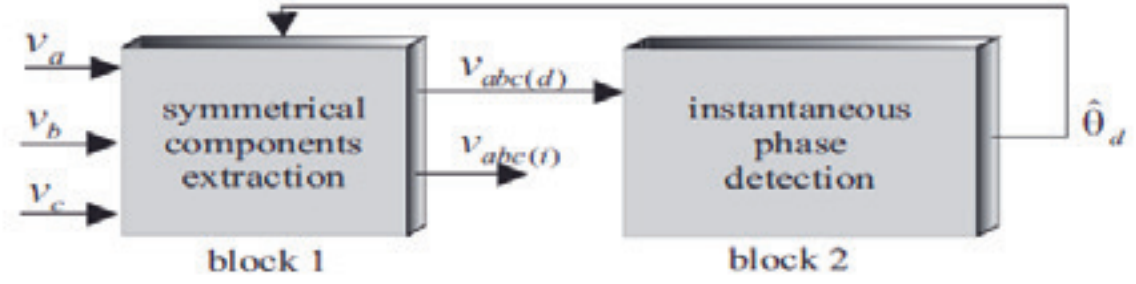

Figure 2. *The basic principle of PLL with two different functional blocks*

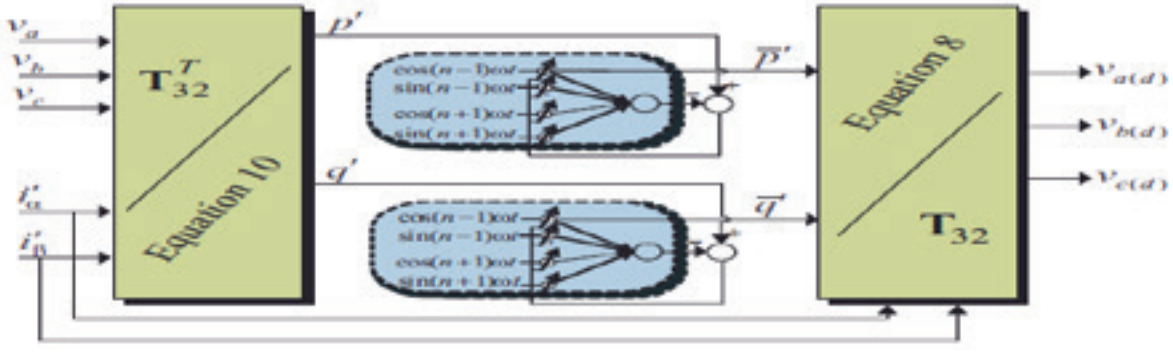

Figure 3. *Symmetrical component extraction system*

The supply voltage in the αβ-frame can be deduced to be:

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \frac{1}{(i_\alpha^2 + i_\beta^2)} \begin{bmatrix} i_\alpha & i_\beta \\ i_\beta & -i_\alpha \end{bmatrix} \begin{bmatrix} p \\ q \end{bmatrix}. \tag{7}$$

Formula (7) is a general formulation that enables the determination of the αβ−voltage. This expression can be used to determine the basic components of the DC voltage using the currents obtained from the direct basic system and the DC-term of the connected powers, ie:

$$\begin{bmatrix} v_{\alpha(d)} \\ v_{\beta(d)} \end{bmatrix} = \frac{1}{(i'^2_\alpha + i'^2_\beta)} \begin{bmatrix} i'_\alpha & i'_\beta \\ i'_\beta & -i'_\alpha \end{bmatrix} \begin{bmatrix} \bar{p}' \\ \bar{q}' \end{bmatrix}. \tag{8}$$

The currents i′α and i′β correspond to basic ic direct currents in the αβ-frame with a phase of zero and an amplitude of unity:

$$\begin{bmatrix} i'_\alpha \\ i'_\beta \end{bmatrix} = \begin{bmatrix} \cos\omega t \\ \sin\omega t \end{bmatrix}. \tag{9}$$

The imaginary powers p' and k' are likewise computed using these currents. These powers are based on observed voltages $vabc$ and i_α^' and i_β^' currents, but they have no actual physical meaning.

$$\begin{bmatrix} p' \\ q' \end{bmatrix} = \begin{bmatrix} v_\alpha i'_\alpha + v_\beta i'_\beta \\ v_\beta i'_\alpha - v_\alpha i'_\beta \end{bmatrix} \tag{10}$$

The following is a detailed description of the fake active power p':

$$\begin{aligned} p' &= v_\alpha i'_\alpha + v_\beta i'_\beta \\ &= \sum_{n=1}^{N} \begin{bmatrix} \cos(n-1)\omega t & \sin(n-1)\omega t \end{bmatrix} \begin{bmatrix} 3V_{dn}\cos\phi_{n(d)} \\ -3V_{dn}\sin\phi_{n(d)} \end{bmatrix} \\ &+ \sum_{n=1}^{N} \begin{bmatrix} \cos(n+1)\omega t & \sin(n+1)\omega t \end{bmatrix} \begin{bmatrix} -3V_{in}\cos\phi_{n(i)} \\ +3V_{in}\sin\phi_{n(i)} \end{bmatrix} \end{aligned} \tag{11}$$

Formula (11) is a sum of harmonic components that can be rewritten by a linearly separable equation:

$$y = x^T W \tag{12}$$

za: $$\mathrm{x} = \mathrm{x}(t) = \begin{bmatrix} \cos(n-1)\omega t \\ \sin(n-1)\omega t \\ \cos(n+1)\omega t \\ \sin(n+1)\omega t \end{bmatrix}; \mathrm{w} = \begin{bmatrix} 3V_{dn}\cos\phi_{n(d)} \\ -3V_{dn}\sin\phi_{n(d)} \\ -3V_{in}\cos\phi_{n(i)} \\ 3V_{in}\sin\phi_{n(i)} \end{bmatrix} \tag{13}$$

Adalin's neural network learns and approximates formula (11). Adaline's input vector is x, which consists of multiples of the fundamental component in the form of synthesized sinusoidal signals, if y in (12) is its output. Adaline's output is compared to an example, which is the intended value obtained with simulated currents and measured voltages v_abc during operation (11). Adaline is based on supervised learning. Error ε=p′−i corrects Adaline's weight v while sampling using an optimal LMS (least mean square) learning technique [9]. The weights of Ada, v, are compelled to converge under these circumstances. The power amplitudes resulting from direct voltages at frequency nω and currents determined by formula (9), after training, are represented by elements v. The three-phase system's fundamental forward voltages, v_(abc(d)), are determined using.

$$\begin{bmatrix} i'_\alpha \\ i'_\beta \end{bmatrix} = \begin{bmatrix} \cos(\omega t) \\ -\sin(\omega t) \end{bmatrix}. \quad (14)$$

The zero-sequence voltage components $vabc(0)$ can be inferred from the fundamental forward and inverse voltage components $vabc(d)$ and $vabc(i)$. A phase detection method can also use them to get a real-time approximation of the power system frequency.

EXPERIMENTAL RESULTS

To evaluate the performance of the proposed neural PLL, experimental comparisons with a conventional PLL in a distorted reference frame are essential. The primary experimental setup is shown in Figure 4. A synchronous generator (SG), driven by a DC motor, supplies the three-phase power distribution system. By adjusting the DC motor's current, the frequency of the three-phase voltages feeding the system can be varied. Figure 5 demonstrates how harmonic distortions affect these voltages.

A DSP dSPACE board (DS1104) with a sampling time Ts = 0.3 ms is used to implement the neural voltage component extraction algorithm and several PLLs. A traditional PLL with a PI controller and the following parameters—Kp = 0,3 and Ki = 0,02—is used to compare the suggested approaches.

The experimental section of the paper details the performance of the proposed neural PLL and its comparison with the conventional PLL in a distorted reference frame.

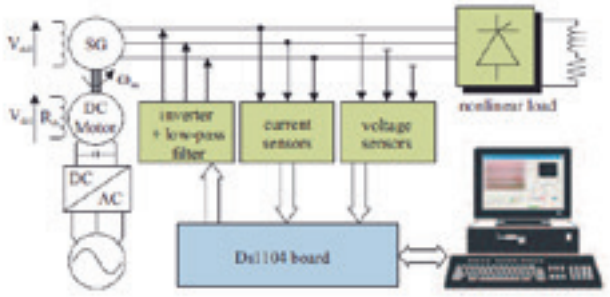

Figure 4. *An experimental platform*

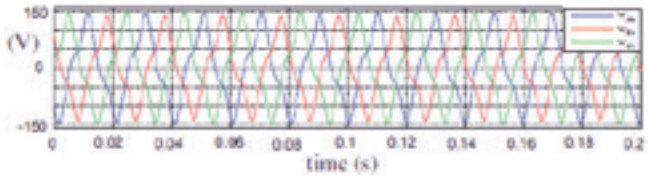

Figure 5. *Waveforms of the supply voltage of a three-phase power system*

Extraction of the inverse voltage component

The inverse voltage components were also extracted by the proposed methods. The results are shown in Figure 6, where the neural symmetric component extraction method outperforms the traditional PLL with LPF and PI controller in terms of speed. Figure 7's spectral representation is used to assess the performance. The basic component is estimated using a neural method with a 1% error and a traditional PLL with a 4% error.

Figure 6 displays the frequency estimation outcomes of the three techniques. In terms of durability, performance, and speed, the neural PLL offers superior estimation compared to the conventional PLL and the suggested instantaneous phase detection approach. The amount of computational time required by any approach has a significant impact on its performance. There are non-negligible processing costs involved in transforming between distinct reference frames (from the ABC-frame to the αβ-frame, and vice versa). Furthermore, temporal delays are a feature of the LPF and PI controller systems. Conversely, the neural PLL has the ability to react instantly. Adaline uses a linear regression function for learning, which converges quickly and iteratively modifies the weights to produce output that is correct and current.

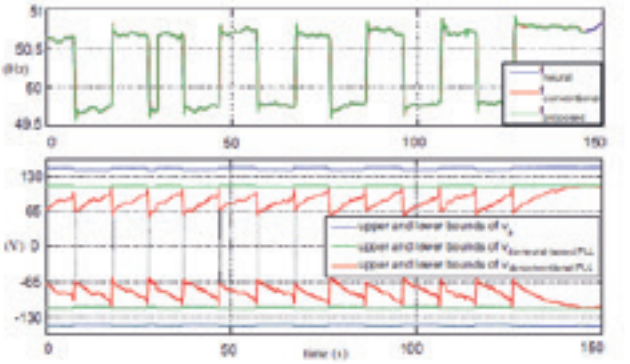

Figure 6. *Frequency monitoring and extraction of direct voltage components*

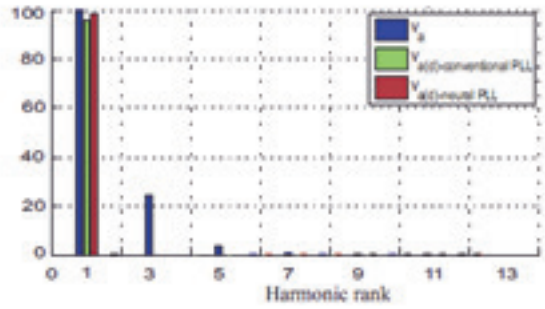

Figure 7. *The frequency spectrum of the DC voltage component*

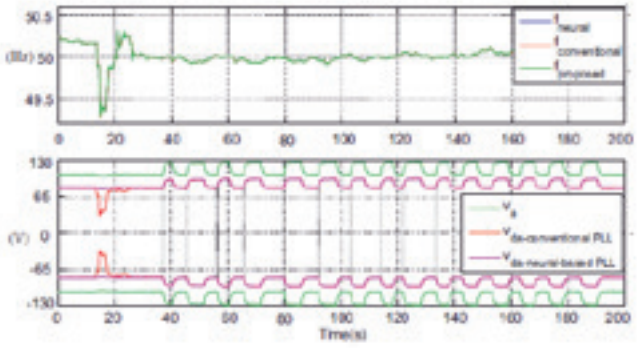

Figure 8. *Estimation of frequency and direct voltage with amplitude variations*

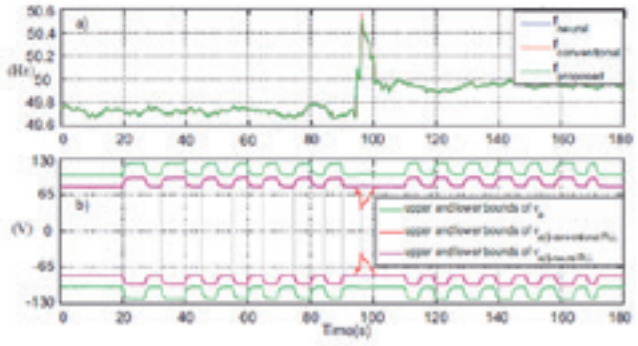

Figure 9. *Estimation of frequency and inverse voltage with amplitude variations*

Neural symmetric components and frequency estimation with voltage drops

Previous experiments used a three-phase constant-amplitude voltage system. In the following experiments, the frequency and three-phase voltages are changed. The voltage amplitude changes The frequency shifts quickly at t = 13 s and fluctuates slightly about 50 Hz.

Evaluating the suggested approaches' resilience under these circumstances is the goal. Figure 8 displays frequency and voltages. For a single phase, voltages are solely depicted by their outlines. Va estimates are provided using both the traditional PLL and the neural symmetric component extraction technique. When the frequency varies significantly, the forward voltage component predicted by the traditional PLL is nearly identical to the estimate achieved with the neural PLL. In contrast to a typical PLL, which requires a few seconds to get an accurate voltage estimate, the neural symmetric component estimator may provide a rapid and precise voltage value instantly in the event of a sudden shift in frequency. In essence, when the frequency is steady, there is no need for the PI controller that is included in a traditional PLL. Conversely, the PI controller causes a time delay because it effectively attempts to cancel out the frequency estimate inaccuracy. The extraction of the inverse voltage components, as shown in Figure 9, is subject to the same remarks. The neural PLL, with its responsiveness and learning capabilities, is the most accurate estimator under voltage and frequency variations, provided that the frequency estimations are acceptable with the methods being studied.

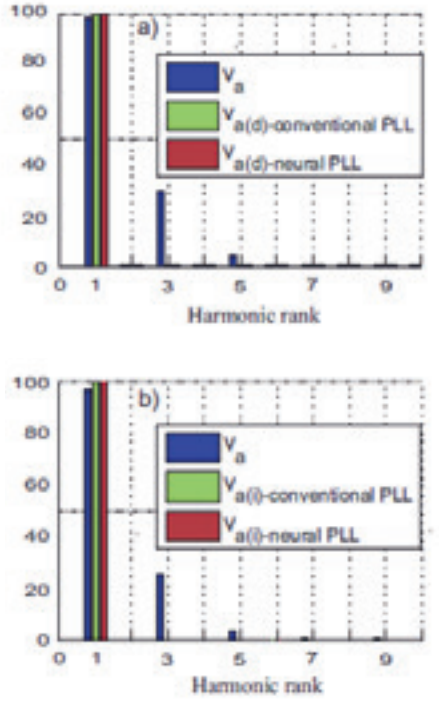

Figure 10. *Frequency spectrum of the estimated voltages: (a) the spectrum of the direct voltage component, (b) the spectrum of the inverse voltage component*

The use of a PI (Proportional-Integral) controller is a key component in control systems for regulating process variables. It improves upon simple proportional control by eliminating steady-state error through the integral component. This ensures a better control of processes that require a consistent output over time. However, PI controllers can introduce overshoot and oscillation if not properly tuned. Alternatives to PI controllers include PID (Proportional-Integral-Derivative) controllers, which adds a derivative component to enhance stability and response time, and advanced control strategies such as adaptive control or fuzzy logic controllers that can deal with more complex systems. Make sure to double-check any technical specifics or implementation details on PI controllers as they can vary widely, based on application.

CONCLUSION

In conclusion, a phase-locked loop (PLL) is a control system designed to generate output signals based on specific principles, primarily by aligning the phase of an input signal. This paper introduces a novel neural PLL architecture that offers significant advantages, such as low noise performance, reduced silicon area, and compatibility with low supply voltages. We describe a three-phase neural approach for estimating phase and symmetrical components, utilizing fictitious expressions of active and reactive powers to train two Adaline estimators, which calculate forward and inverse voltage components. A phase detection method is then applied to these voltages, accurately determining the frequency.

The findings of our scientific research and experimental section of the work confirm (to us) the significant advantages of the new neural PLL architecture, which offers significant advantages, such as low noise performance, reduced silicon area and compatibility with low voltages compared to the conventional PLL architecture.

The trial results demonstrate the effectiveness of this approach, showing that the neural method reliably extracts primary voltage components and estimates the phase of a time-varying three-phase power system under conditions such as voltage dips, random noise, and harmonics. This proposed approach proves suitable for real-time harmonic current compensation in active power filtering systems. The entire neural architecture, implemented on a digital signal processor (DSP), is applied within a three-phase power supply system. The PLL plays a crucial role in power systems, with applications in drive control, harmonic current detection, unbalance compensation in three-phase systems, sinusoidal inverter control, and beyond.

Furthermore, the proposed neural PLL architecture provides a promising direction for future developments in power system control, particularly in enhancing the efficiency and stability of renewable energy integration, smart grids, and other advanced power electronics applications.

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Improving Trust in Information Sources: Serbian Wikipedia Use Case

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Abstract: For almost two decades, Wikimedia Serbia has active collaboration with educational institutions in Serbia, promoting Wikipedia to young people, training and encouraging them to create and edit Wikipedia with special focus on Wikipedia trust concepts as the important factor of every information source. This paper presents our findings on the current level of students' understanding of trust mechanisms in information sources and examines the impact of conducted targeted educational intervention on this domain. This study was conducted as part of the collaboration between Wikimedia Serbia, the Faculty of Computer Science and Informatics at Union Nikola Tesla University, and Šabac Grammar School. We used structured questionnaires to determine the initial state of trust mechanisms awareness in students. After analyzing the obtained results, we organized instructional session which included comprehensive lectures on Wikipedia, its structure, rules and its editing process. Afterwords, students selected Wikipedia-related assignments aligned with their course interests. The follow-up questionnaire revealed great improvement in correct referencing and licensing usage, in both educational institutions emphasizing the importance of proper referencing and licensing as trust mechanism and its influence in digital literacy in general.

Keywords: digital literacy, higher education, secondary education, technology integration in education, Wikipedia

Introduction

Opportunities and Challenges in the Digital Age

In the digital age, the availability of vast amounts of information presents both opportunities and challenges. While the internet provides immediate access to diverse perspectives, the credibility and accuracy of information are frequently questioned, leading to a pressing need for mechanisms that help users discern reliable sources from misinformation[10]. The trustworthiness of online resources has become crucial as individuals rely on digital platforms not only for casual browsing but also for educational, professional, and decision-making purposes [7].

The Role of Wikipedia in Digital Information

Among these platforms, Wikipedia stands out as one of the most popular and widely consulted encyclopedic sources, accessible in multiple languages and open for user contributions worldwide [15]. As one of the most visited language versions in the Balkans, Serbian Wikipedia serves as a significant source of information in Serbia and neighboring countries, with specific relevance to the region's language, history, and culture [5]. However, the credibility and acceptance of Wikipedia, including its Serbian version, continue to be a subject of debate, primarily due to its open editing model, which invites contributions from a wide spectrum of users with varying levels of expertise [9].

Building Trust in Wikipedia

The challenge of building trust in Wikipedia lies in balancing open access with the rigorous standards of quality information. Since its inception, Wikipedia has implemented several mechanisms aimed at

improving the quality and reliability of its content, such as citation requirements, verification of sources, and community oversight through discussion pages and edit histories [6]. Yet, public trust in Wikipedia remains varied, often influenced by factors such as familiarity with its editing processes, awareness of quality controls, and perceived biases [16]. In Serbia, the situation is particularly nuanced, as users often navigate Wikipedia in tandem with other regional and global sources, evaluating it within the broader context of regional media trust issues, political narratives, and historical sensitivities

Evaluating Wikipedia Articles

Wikipedia articles can be evaluated using the CRAAP test, which highlights the importance of currency, relevance, authority, accuracy, and purpose in the evaluation of information sources [2]. The structure of Wikipedia inherently supports the evaluation of four out of these five criteria. For instance, Wikipedia articles provide details on the currency of information (last updated date), authority (author or editor identity), and purpose (educational content). However, accuracy, which reflects trust in the provided information, depends on proper referencing and licensing mechanisms. These mechanisms, when adhered to, ensure that information is evidence-based, sourced, and compliant with intellectual property [14].

Importance of Referencing and Copyright Licensing

While proper referencing and copyright licensing are often regarded as common knowledge, mistakes are still frequently made [17]. These skills are essential and should be explicitly incorporated into academic or professional activities that require proper attribution and responsible use of intellectual property. Incorporating Wikipedia article writing into educational curricula provides an effective avenue to teach these skills.

Prior Research on Trust and Wikipedia

The use of Wikipedia in education has been studied extensively [1][8] [19][20][21], but research focusing on referencing and copyright licensing is limited. Only one prior study has examined the importance of trust concepts in this context but lacked a deep insight [5]. Additionally, studies on trust in Wikipedia often explore its use as a source in scientific papers [3][14][22][23] or its credibility from a user perspective rather than focusing on fostering trust through improved editorial practices [11][12][18].

Focus of This Study

Our research examines trust mechanisms in Wikipedia from two key perspectives: readers, who assess the credibility of content, and content creators, who build trust through proper referencing and copyright practices. This dual approach aims to enhance both the perception and production of trustworthy information on Wikipedia. In this paper, we provide insights into the current state of students' knowledge about referencing and copyright licensing mechanisms. We also examine the influence and power of targeted educational interventions in improving referencing and licensing abilities, focusing on Serbian Wikipedia articles. By addressing the specific challenges faced in this regional context, this research contributes to improving local digital literacy and offers broader insights into enhancing trust in open-access platforms worldwide. This study is based on a pilot test conducted with a small sample, with plans for future expansion in various directions.

Methods and Materials

Research Design

This study utilizes a quasi-experimental design to assess the effectiveness of an educational intervention aimed at improving students' understanding of referencing and copyright licensing mechanisms in the context of Serbian Wikipedia. The research was conducted as part of a collaboration between Wikimedia Serbia, the Faculty of Computer Science and Informatics at Union Nikola Tesla University, and Šabac Grammar School. A pilot study approach was chosen to gather initial insights into the impact of targeted educational sessions on digital literacy, with the intention to expand the scope in future studies.

Participants

The study involved two groups of students:

- Group 1: 20 third-year students from the Faculty of Computer Science and Informatics at Union Nikola Tesla University.

- Group 2: 20 fourth-year students from the information technology program at Šabac Grammar School.

Both groups were selected based on their strong backgrounds in computer science and research skills, ensuring a baseline level of familiarity with academic writing and research practices. All participants voluntarily agreed to take part in the study.

Educational Intervention

The intervention consisted of a series of educational lectures and activities designed to improve participants' understanding of proper referencing and copyright licensing, with a specific focus on the use of these mechanisms in Wikipedia articles.

The intervention was divided into four phases:

1. Initial Phase: Baseline data was collected through a structured questionnaire to assess the students' pre-existing knowledge of referencing, copyright, and the use of Wikipedia.
2. Informative Phase: Lectures and practical workshops were conducted by Wikimedia Serbia representatives. These sessions covered the importance of referencing and copyright in digital platforms, focusing on how Wikipedia incorporates these mechanisms.
3. Proactive Phase: Students were tasked with creating or editing Wikipedia articles, applying the knowledge they had gained during the informative phase. They selected topics related to their academic interests and worked under supervision to ensure proper application of referencing and licensing practices.
4. Evaluation Phase: A post-intervention questionnaire was administered to evaluate changes in students' understanding of referencing and copyright licensing. The responses were compared with baseline data to assess the effectiveness of the intervention.

Data Collection

Data was collected through structured questionnaires administered at two points during the study:

- Pre-Intervention (Initial Phase): A set of 10 questions aimed at gauging students' baseline understanding of referencing, copyright, and digital literacy in the context of Wikipedia.
- Post-Intervention (Evaluation Phase): A follow-up questionnaire containing similar questions to assess changes in students' knowledge after completing the educational intervention.

The questionnaires included both closed-ended questions (with multiple choice, nominal or Likert-scale responses) and two open-ended questions to gather qualitative insights into the students' perceptions of the intervention.

The inclusion of general knowledge and attitudinal questions, in addition to trust-specific items, was designed to capture a comprehensive picture of students' starting points. This broader approach ensures that improvements in trust-related practices can be interpreted alongside changes in overall digital literacy and familiarity with Wikipedia's structure and use.

Questionnaire Design

The questionnaires were designed to assess knowledge in the following key areas:

- Referencing: Questions related to when and how to reference sources in academic and digital contexts, with a focus on Wikipedia (Table 1 and 2).
- Copyright Licensing: Questions regarding the understanding and use of copyright licenses, within Wikipedia articles (Table 3 and 4).
- Students' General Wikipedia Knowledge: Questions aimed at assessing the participants' foundational understanding of Wikipedia. (Table 5 and 6)

Table 1. *Questions IPQ5-IPQ7 from the initial phase questionnaire*

IPQ6: What does referencing consist of?
A1: Citation of information sources
A2: Listing everything we have read that is related to the given topic
A3: Rewriting
A4: A set of rules that makes writing difficult
A5: citation of literature at the end of the essay
IPQ7: When to cite and when not? (multiple answers possible)
A1: Never
A2: When I literally copy a text from a book or textbook
A3: When I literally copy any text
A4: When I literally state something that is common knowledge
A5: When I retell something that is common knowledge
A6: When I retell a text from a book or textbook
A7: When I retell any text
A8: When I literally state something someone told me

A9: When I retell what someone told me
A10: When I retell someone else's ideas
A11: When I literally state someone else's ideas
A12: When I state my ideas
A13: When I copy someone else's entire table
A14: When I copy part of someone else's table

Table 2. *Questions EPQ5-EPQ7 from the evaluation phase questionnaire*

EPQ7: Do you understand the importance of referencing sources of information better now than before writing an article on Wikipedia?
A1: Yes, much clearer
A2: Yes, mostly clearer
A3: Yes, clearer
A4: No, still somewhat unclear
A5: No, still unclear
EPQ8: (the same as in IPQ6)
EPQ9: To what extent do you understand how to reference sources of information?
A1: Completely understand
A2: Mostly understand
A3: Understand
A4: Mostly don't understand
A5: Don't understand

Table 3 *Questions IPQ8-IPQ10 from the initial phase questionnaire*

IPQ8: What is a copyright?
A1: The right that someone claims to their work
A2: Part of intellectual property
A3: A method to prohibit everyone from using a particular source of information
A4: Source of income
A5: The author's right to determine how his work will be used
IPQ9: Which copyright licenses do you know?
A1: Creative Commons
A2: Copyleft
A3: GNU
A4: Public domain
A5: SPARC
A6: Finding Images
A7: Open Educational Resources
A8: Open Access
IPQ10: Have you ever used copyright licenses
A1: Yes
A2: No

Table 4. *Questions EPQ10 from the evaluation phase questionnaire*

EPQ10: Do you understand the importance of using copyright licenses better now than before writing an article on Wikipedia?
A1: Yes, much clearer
A2: Yes, mostly clearer
A3: Yes, clearer
A4: No, still somewhat unclear
A5: No, still unclear

Table 5. *Questions IP1-IPQ4 from the initial phase questionnaire*

IPQ1: To what extent do you find interesting the possibility to edit Wikipedia?
A1: Extremely interesting
A2: Very interesting
A3: Interesting
A4: Little interesting
A5: No interesting
IPQ2: Have you ever tried to edit Wikipedia?
A1: Yes
A2: No
IPQ3: Have you ever successfully edited Wikipedia?
A1: Yes
A2: No
A3: I have never tried to edit Wikipedia
IPQ4: What does Wikipedia represent to you?
A1: Online source of information
A2: Literature for essay writing
A3: Knowledge sharing point
A4: Online searching tool
A5: Internet encyclopedia
IPQ5: For what purpose do you use Wikipedia?
A1: Writing essays
A2: Expanding knowledge
A3: Online searching
A4: Fun
A5: Finding something new

Table 6. *Questions EPQ1-EPQ6 from the initial phase questionnaire*

EPQ1: How would you rate the training on editing Wikipedia?
A1: Excellent
A2: Very good
A3: Good
A4: Satisfactory
A5: Unsatisfactory
EPQ2: How understandable was the training on editing Wikipedia to you?
A1: Extremely clear

A2: Very clear
A3: Clear
A4: Somewhat unclear
A5: Unclear
EPQ3: To what extent was the training on editing Wikipedia useful to you?
A1: Extremely useful
A2: Very useful
A3: Useful
A4: Mostly useless
A5: Useless
EPQ4: To what extent were the instructors available to you during the creation of the article on Wikipedia?
A1: Extremely available
A2: Very available
A3: available
A4: Mostly available
A5: Unavailable
EPQ5: What new things did you learn during the training on editing Wikipedia? (open ended, max 50 words)
EPQ6: How would you describe the process of creating an article on Wikipedia? (open ended, max 50 words)

Data Analysis

The data from both the pre- and post-intervention questionnaires were analyzed using descriptive statistics to summarize participants' responses. To assess the effectiveness of the intervention, statistical tests were conducted using programming language R, including:

- Fisher's Exact Test: To evaluate significant differences between groups and pre- and post-intervention where possible. (fisher.test() function from the stats package)
- Cramér's V: To measure the strength of associations between variables, particularly between education level and changes in understanding. (assocstats() function from the vcd package)

For questions with more than five answers, hierarchical clustering was employed to group similar responses and reveal patterns in participants' answers:

- Distance Matrix: Generated using Gower's distance with the daisy() function from the cluster package.
- Clustering Algorithm: Hierarchical clustering was performed with the hclust() function from the stats package, applying the Ward2 method for optimal grouping.
- Tree Cutting: The resulting dendrogram was cut at a height of 3 using the cutree() function to form distinct clusters.

The results from the questionnaires were compared to determine whether there were statistically significant improvements in participants' knowledge of referencing and copyright licensing after the educational intervention and in between categories.

Ethical Considerations

The study adhered to ethical guidelines to ensure participants' rights and privacy were respected. Informed consent was obtained from all participants, and they were assured that their responses would be confidential and used only for the purposes of this research. Participants were also informed that their involvement in the study was voluntary, and they could withdraw at any time without consequence.

RESULTS

Referencing

Figure 1 illustrates students understanding and perspectives on the importance of accurate referencing.

The answers to question IPQ7 were clustered into four categories (A1; A2, A3, A13, A14; A4, A8, A11, A12; A5, A6, A7, A9, A10).

In Figure 2 are given obtained results in evaluation phase regarding improvement in students abilities in proper referencing.

For question EPQ8, the answers were clustered into four categories (A1, A4, A5, A12; A2, A6; A3, A7, A8, A9, A10, A11, A13, A14). The collected responses show improvement in 64-95% questioned students regarding the Wikipedia's referencing usage and understanding of referencing in general.

We compared the results of questions IPQ7 and EPQ9 for high school and university students.

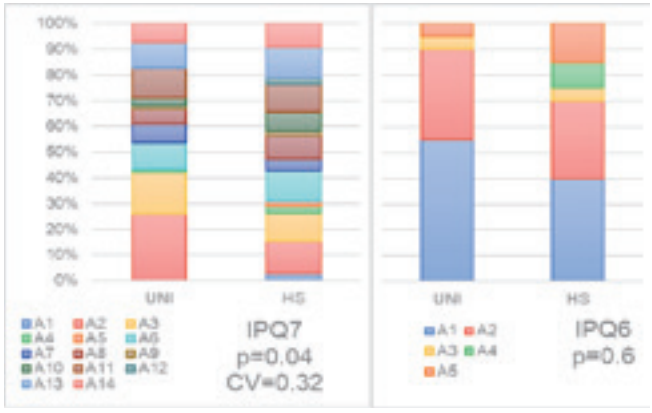

Figure 1. *Visualization of initial phase questions related to referencing*

For high school students, we found a p-value of 0.0004 and a Cramér's V value of 0.46, while for university students, the p-value was 0.0005, and the Cramér's V value was 0.58.

Copyright licensing

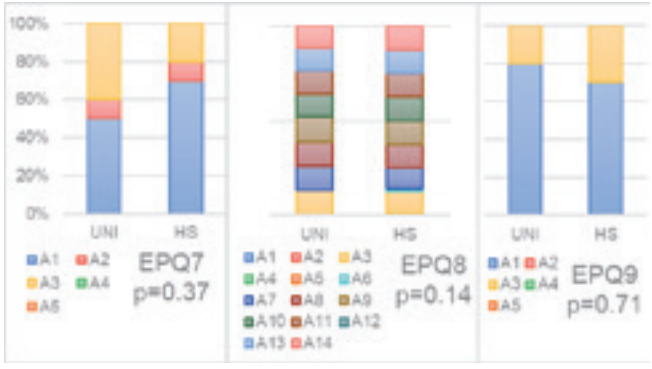

Figure 2. *Visualization of evaluation phase questions related to referencing*

Figure 3 provides an overview of students' perspectives on copyright and licensing practices together with recognition of existing copyright licenses.

Figure 3. *Visualization of initial phase questions related to copyright licenses*

For question IPQ9, the answers were clustered into four categories (A1; A2, A4; A3, A7, A8; A5, A6). None of the students selected answers A3 or A4 for question IPQ8.

Evaluation phase results regarding students overall understanding of copyright licensing are presented in Figure 4.

Also, the results obtained regarding copyright licensing usage indicate significant improvement in this domain where 90-95% of surveyed students completely understood the licensing usage.

Discussion

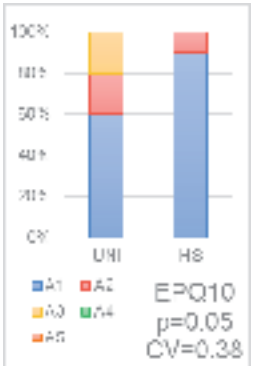

Figure 4. *Visualization of evaluation phase questions related to copyright licenses*

Initial Knowledge Gaps in Referencing and Copyright Licensing

Despite the small sample size in this pilot study, the results were surprising, given that all participants were computer science students. The initial questionnaire revealed a significant lack of awareness about referencing and copyright licensing, as well as the necessity of citations in academic work.

Before the educational intervention, about half of the students were familiar with referencing, but fewer than 10% understood when citations were necessary. Notably, the majority of students from both groups (university and grammar school) indicated they would reference only when directly copying from a source, with the highest percentage observed in university students (26.06%) and grammar school students (12.73%), both when copying from books. While university students showed limited awareness of the need to reference retold information (only 10.14%), a slightly higher percentage of grammar school students (11.82%) acknowledged this need.

Furthermore, the findings revealed that a significant percentage of both student groups (75-80%) had never used copyright licenses, and the meaning of copyright referencing was largely unknown. This was true for 75% of grammar school students and 40% of university students, indicating a general lack of understanding of copyright mechanisms across both groups.

Impact of Educational Interventions

Significant differences in responses between grammar school and university students were found for certain questions (e.g., IPQ7, IPQ8, IPQ9, EPQ10), all with strong associations (Cramér's V = 0.46 for grammar school students and 0.57 for university students). This suggests that education level or academic background plays a substantial role in how students understand and interpret the concepts being assessed.

The statistically significant results ($p = 0.0004$) from Fisher's Exact Test for both groups indicate that the responses before and after the lecture differ significantly. This supports the hypothesis that the educational intervention impacted students' knowledge of referencing and copyright licensing. The stronger effect size (Cramér's V = 0.57 for university students and 0.46 for grammar school students) suggests that university students exhibited a greater change in understanding compared to grammar school students. This could be attributed to their prior knowledge, higher cognitive ability, or more advanced learning skills, which might have helped them engage with the lecture content more effectively.

Strengthening Digital Literacy Through Targeted Education

The educational intervention successfully improved students' knowledge of referencing and copyright licensing, as evidenced by the significant changes observed in the responses. Over 85% of students reported an improvement in their ability to reference correctly, and nearly all students gained a clearer understanding of copyright licensing. The stronger effect observed among university students is likely due to their higher pre-existing knowledge and academic maturity, which may have allowed them to grasp the material more effectively. Grammar school students, though showing improvement, had a moderate change in understanding, indicating that additional instructional support may be necessary to enhance their comprehension.

These findings underscore the importance of targeted educational interventions to improve students' digital literacy, particularly in areas like referencing and copyright licensing. Given that a significant portion of both groups started with little knowledge in these areas, the educational phases (informative and proactive) were essential in bridging these gaps.

Localized Context: Serbian Wikipedia as a Case Study

The findings of this study extend beyond the Serbian Wikipedia to provide insights into global trust-building efforts in digital resources. The Serbian edition's unique cultural and historical context highlights the importance of tailoring trust-building strategies to specific user communities. Factors such as political sensitivities, regional media trust issues, and language-specific challenges influence users' perceptions of digital platforms like Wikipedia.

The Serbian Wikipedia plays a dual role as both an educational tool and a cultural repository, emphasizing the need for localized strategies to build trust. This study highlights the challenges faced in this context and demonstrates that fostering digital literacy through tailored educational programs can address such issues effectively.

Global Implications for Trust in Open-Access Platforms

While rooted in the Serbian context, the findings have broader implications for other language-specific Wikipedia editions and open-access platforms. Educational interventions that improve referencing and licensing skills have the potential to enhance trust across diverse user groups. By addressing local challenges, this study offers a replicable framework for global efforts, bridging the gap between regional nuances and universal strategies for fostering trust in digital information systems.

By connecting local challenges with global solutions, this research emphasizes that understanding the unique dynamics of user communities can significantly enhance the credibility and utility of open-access knowledge systems. The Serbian Wikipedia, in this context, serves as a vital case study for illustrat-

ing how localized efforts contribute to a global movement toward reliable, accessible, and trustworthy digital resources.

The findings align with [14] who emphasize that the quality of citations is a critical factor in enhancing Wikipedia's trustworthiness.

Conclusion

Referencing and copyright licensing are typically considered common knowledge, but the practical findings from this research suggest otherwise.

This study highlights the importance of tailored educational interventions in enhancing digital literacy, particularly in trust mechanisms related to referencing and copyright licensing. The findings provide valuable insights into how educational background influences the effectiveness of these interventions. While previous studies have highlighted the potential mistrust stemming from Wikipedia's open-access model [13], [24],[25], this research demonstrates that improving the referencing and copyright licensing skills of Wikipedia editors can significantly contribute to the creation of more trustworthy Wikipedia articles. Educating users on evaluating sources, recognizing authoritative references, and understanding copyright licensing will ultimately strengthen trust in Wikipedia as a reliable information source.

After completing the first year of this pilot research successfully, we achieved promising outcomes. Initial phase showed that many students were only superficially familiar with trust concepts, and fewer had a practical grasp of their importance in evaluating information quality. Findings from the initial phase guided the study, enabling us to address emerging issues effectively. The evaluation phase results showed a significant improvement in students' ability to critically assess Wikipedia articles, indicating that structured guidance can effectively enhance digital literacy. Key outcomes include better awareness of when and why to cite sources, how licensing impacts content use, and how collaborative efforts on Wikipedia support information reliability. As more students gained familiarity with these concepts, they expressed increased confidence in using Wikipedia responsibly, suggesting that such educational programs could be a model for similar initiatives elsewhere.

According to aforementioned, we can answer the main research question by stating that many of the surveyed students initially have a limited understanding of trust mechanisms, underscoring the value of targeted educational interventions. Such interventions play a crucial role in enhancing students' digital literacy and their ability to critically evaluate online information sources, which is beneficial for developing responsible information consumption habits and fostering greater trust in credible content.

The findings from this study offer an insights for other Wikipedia language editions and similar open-access projects aiming to increase their credibility among diverse user bases. By addressing the unique needs of the Serbian-speaking audience and understanding the factors that influence trust, this case study underscores the role that localized efforts can play in enhancing the global movement for reliable and accessible knowledge. Ultimately, the Serbian Wikipedia serves not only as a tool for information but also as a vehicle for fostering media literacy, critical evaluation skills, and a collaborative approach to knowledge-sharing, all of which are essential to building trust in information sources in today's digital environment.

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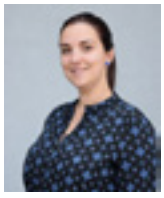

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FOR CITATION

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Revitalisation of Old Hydraulic Press Brake Machines Through Novel Software Solutions

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Abstract: In the era of Industry 4.0, the modernization of traditional machines has become crucial for maintaining competitiveness and enhancing production capacities. Hydraulic CNC press machines manufactured in the Balkans, particularly in the former Yugoslavia, renowned for their robustness and reliability, are increasingly falling behind in terms of the technological innovations required to meet modern production demands. Rather than being replaced by expensive new machines, this paper presents a transformative approach to the digital upgrade of existing systems. By employing advanced software solutions and novel control methods, older presses are converted into high-precision, intelligently managed machines capable of automatically adjusting operating parameters according to material and task specifications. This system not only significantly reduces operational costs but also extends the lifespan of these machines, increases production speed and minimizes errors. The core innovation of the system is its adaptability, enabling continuous evolution and seamless integration of new technological advancements without requiring substantial investments in entirely new equipment. This paper offers a vision of the future where digital transformation allows traditional machines to become part of smart, interconnected production lines.

Keywords: Hydraulic Press Brake Machine; ESP32; NodeMCU; Desktop Application; C# .NET; WPF

Introduction

Over the past few decades, industrial manufacturing has undergone profound and continuous changes, primarily driven by rapid technological advancements. With each new wave of innovation, companies around the world are challenged to optimize production capacity, enhance efficiency, and reduce operational costs, all while adapting to the demands of an increasingly dynamic and competitive global market. In this context, the concept of *Industry 4.0* has emerged as a key driver of industrial transformation. *Industry 4.0* integrates technologies such as automation, the Internet of Things (IoT), artificial intelligence (AI) and digital connectivity into traditional industrial processes, creating smart, interconnected systems that can independently manage, adjust, and optimize operations in real-time.

Within this technological framework, digital transformation becomes an essential tool for companies seeking to remain competitive, reduce costs, and improve performance. It facilitates the transition from manual and often imprecise processes to fully automated, intelligent systems that optimize production capacities, increase manufacturing speed and enable more efficient use of resources. These benefits allow companies to meet the increasingly complex demands of consumers and markets. However, despite the clear advantages, industrial businesses are struggling with digital transformation. [1]

The research presented in this paper aims to address key questions related to the challenges and opportunities of industrial machine digitalization, with a focus on CNC hydraulic press machines:

1. How can software enhance press machine operation?

2. What components were utilized and how was the software developed?

3. How can digital transformation reduce operational costs and increase press efficiency without requiring significant financial investments?

METHODS AND MATERIALS

In modernizing hydraulic CNC press machines, an integrated approach utilizing both hardware and software advancements was employed to achieve precise control, enhanced automation, and increased operational efficiency.

The ESP32 microcontroller functions as the primary control unit for the CNC hydraulic press machine, managing real-time control tasks and interfacing directly with the machine's critical operational components. ESP32 is ideal for precise adjustments and control necessary for high-precision hydraulic press operations, supporting the automation and accuracy required in industrial environments.

Closed-loop stepper motors were selected for accurate backgauge positioning. Unlike open-loop systems, closed-loop control detects and adjusts any deviation from the intended position, which is critical in maintaining the accuracy required for high-production environments. These motors reduce errors in positioning, ensuring consistent precision without needing continuous manual adjustments.

For effective data exchange between the application and the press hardware, the UART (Universal Asynchronous Receiver-Transmitter) protocol was implemented. This asynchronous protocol facilitates reliable, serial communication, ensuring that commands and responses are transmitted accurately between the microcontroller and control interface. The use of UART in this setup allows for real-time data flow essential to maintain synchronization between software commands and hardware responses.

The GUI (Graphical User Interface) plays a pivotal role in operator interactions, enabling straightforward control over press functions. Designed with an intuitive layout, it includes combo boxes for tool selection and numeric keypads for setting precise measurements. The GUI simplifies operator tasks by automatically adjusting tool parameters and incorporating real-time validation checks, enhancing usability.

To ensure operational safety and accuracy, the software incorporates input validation for key parameters, such as position limits (e.g., the 0-800 mm range for backgauge movement). This functionality prevents erroneous inputs, minimizing operational risks, and contributing to system reliability. Error messages or warnings are generated when values exceed permissible limits, helping maintain machine integrity.

For hands-free operation, especially useful when handling large materials, a foot switch system was integrated. The dual-switch setup allows operators to select preconfigured register settings with one switch and confirm execution with the other, providing flexibility in control without compromising safety.

Safety mechanisms were also incorporated, such as automated shutdown in the event of malfunction or irregular operation. These features align with safety standards, ensuring that the system complies with industrial safety requirements.

Each of these technologies was selected based on its ability to meet the demands of high-precision, efficient, and reliable hydraulic CNC press operation. The combined use of these hardware and software components ensures that the system operates within optimal parameters, enhancing both functionality and operator control.

DISCUSSION

Modern industry faces a significant challenge in updating legacy production machinery, which has been fundamental to manufacturing operations for decades. Hydraulic press machines, crucial tools in fields such as metalworking, automotive manufacturing and heavy machinery, serve as a prime example of this issue. These machines are valued for their robustness, durability, and longevity, allowing them to function effectively for many years with minimal maintenance. However, even though their mechanical performance remains commendable, they have become technologically outdated when compared to contemporary CNC (Computer Numerical Control) systems, which deliver superior precision, speed, and flexibility through digital control.

The Industry 4.0 trend poses many challenges for the manufacturing industry and societies generally. [2] The trend presents new challenges and opportunities related to industrial competitiveness and sustainability, as industrial firms adopt digital technologies to change how they interact and exchange data across their industrial network. [3] The challenge many enterprises face is how to retain the advan-

tages of their existing hydraulic press machines while simultaneously improving efficiency, accuracy and productivity to meet the demands of modern market. Traditional hydraulic press machines often depend on manual controls, which can be slow, prone to errors as well as limited in accuracy and speed when adjusting to different materials and production conditions. In contemporary production environments, such systems can create bottlenecks that limit flexibility and diminish overall productivity.

For firms dealing with industrial customers, Industry 4.0 is about how firms can create solutions that help their industrial customers increase their own productivity. [4] Acquiring new CNC machines equipped with the necessary digital functionalities is not always a feasible option, particularly for small and medium-sized enterprises. Even after more than a decade from the start of the fourth industrial revolution, manufacturing industry still struggles to upgrade to Industry 4.0-compliant technologies and standards. [5] High costs associated with purchase, implementation and staff training to operate new machines often pose significant obstacles for companies and enterprises pursuing modernization. In this context, the digital upgrade of existing hydraulic press machines offers a more cost-effective alternative. Such solutions facilitate the integration of modern software systems, sensor networks, and automated control mechanisms into existing machines, significantly enhancing their performance without the need for complete system replacement.

The digital transformation of hydraulic presses facilitates the automation of processes that previously required manual intervention. For instance, key parameters, such as backgauge movement, can now be automatically controlled by software, resulting in significantly greater speed and efficiency in operation. Additionally, sensor networks that collect real-time data allow the machines to adapt automatically to changing production conditions without manual adjustments. This optimization not only accelerates the production process but also considerably reduces the risk of errors and improves material utilization.

While modernization through digitalization offers numerous benefits, significant challenges persist. Integrating new digital systems with older mechanical components can be technically demanding, requiring a high level of expertise in design and implementation. Careful analysis and adaptation of the compatibility between new control systems and existing mechanical parts are essential to ensure reliable operation. Furthermore, training staff who are accustomed to manual processes can be challenging, as it requires a fundamental shift to entirely new ways of working and thinking. The goal of smart manufacturing or its synonym “Industry 4.0” is to automate manufacturing processes, were fully integrated and collaborative manufacturing systems rapidly can respond to meet the demand and conditions. [6]

This study investigates the potential for the digital transformation of hydraulic press machines, aiming to integrate them into smart production systems within the Industry 4.0 framework. The emphasis will be on the development and implementation of software and hardware solutions that not only enhance efficiency, precision and productivity but also enable significant cost savings through the modernization of existing systems, thereby avoiding substantial financial investments in new machines.

The objective of the research was to develop and implement a software and hardware solution that enables the digitalization of press machine operations, thereby improving efficiency, precision, and productivity while reducing costs and operational errors. This work combines engineering techniques and software development with practical applications in real industrial settings.

This research is focused on a hydraulic CNC press machine produced in the 1990s, which features a traditional manual control system for managing the backgauge position and other operational parameters. This machine, still commonly found in many industrial facilities in the countries of the former Yugoslavia due to its robustness and longevity, lacked capabilities for digital control, remote operation or real-time monitoring.

Prior to digitalization, the machine’s operation relied entirely on manual processes, including the manual adjustment of the backgauge. This method was not only slow and time-consuming but also prone to errors, leading to delays that are far from cost-effective in today’s industrial landscape.

After thoroughly assessing the existing issues and challenges associated with the manual control of the machine, a comprehensive software and hardware upgrade was implemented. This process involved de-

veloping software to enable automated control of the press machine's key operations, including precise adjustments of the backgauge and other operational parameters. As part of the upgrade, guides, lead screws, closed-loop stepper DC motors as well as ESP32 microcontroller using the NodeMCU (Node Microcontroller Unit) development environment were integrated. This enhancement significantly improved the efficiency, precision, and speed of operation, reducing operational errors and downtime, ultimately resulting in an optimized production process without the need for complete machine replacement.

Hardware upgrade

To facilitate the complete digitalization and modernization of the hydraulic press machine, several hardware elements and components were introduced to enable automatic control and monitoring of operational parameters. The key components of the hardware upgrade include the following:

Microcontroller ESP32: The ESP32 microcontroller was selected for its specific features and the NodeMCU (Node Microcontroller Unit) development environment. Its main advantages include the capability to handle multiple tasks simultaneously as well as the inclusion of built-in Wi-Fi and Bluetooth modules, enabling wireless connectivity. This integration facilitates precise control over all aspects of the press machine's operation.

Stepper motors (Closed-Loop): These motors have replaced manual systems for adjusting the backgauge. By utilizing feedback from encoders, the stepper motors enable precise positioning of the backgauge without manual intervention, significantly reducing the time required for adjustments and enhancing operational accuracy.

Guides: Guides were integrated to ensure stable and precise movement of the press's key components, thereby enhancing accuracy during operations and extending the system's lifespan.

Lead screws: Lead screws are essential for transmitting power and movement within the system. Their implementation facilitates precise positioning and minimizes friction and wear during operation.

Software upgrade

The software developed for controlling the hydraulic press employs advanced algorithms to automate and optimize work operations. It was created in the C# .NET environment and features an intuitive user interface based on WPF (Windows Presentation Foundation) technology.

Desktop application for managing the CNC hydraulic press machine

The desktop application developed for managing the hydraulic CNC press machine serves as a critical component of the digitalization and automation process. Developed using the C# programming language as part of the .NET framework, the application utilizes WPF (Windows Presentation Foundation) to create an intuitive user interface. Communication with the hardware components of the CNC press machine is facilitated through the ESP32 microcontroller, which is connected using a serial communication port (Figure 1).

Figure 1. *Press Brake Software. Source: author's contribution*

Main functionalities of the application include (Figure 2):

Automatic backgauge positioning: The application sends commands to the microcontroller for the precise movement of the backgauge according to the input parameters. By utilizing data from position sensors (encoders), the backgauge is automatically positioned correctly, enabling accurate alignment for each operation.

Error handling and exception management: The implementation of try-catch blocks within the soft-

ware code allows the application to efficiently manage errors related to communication or the operation of hardware components.

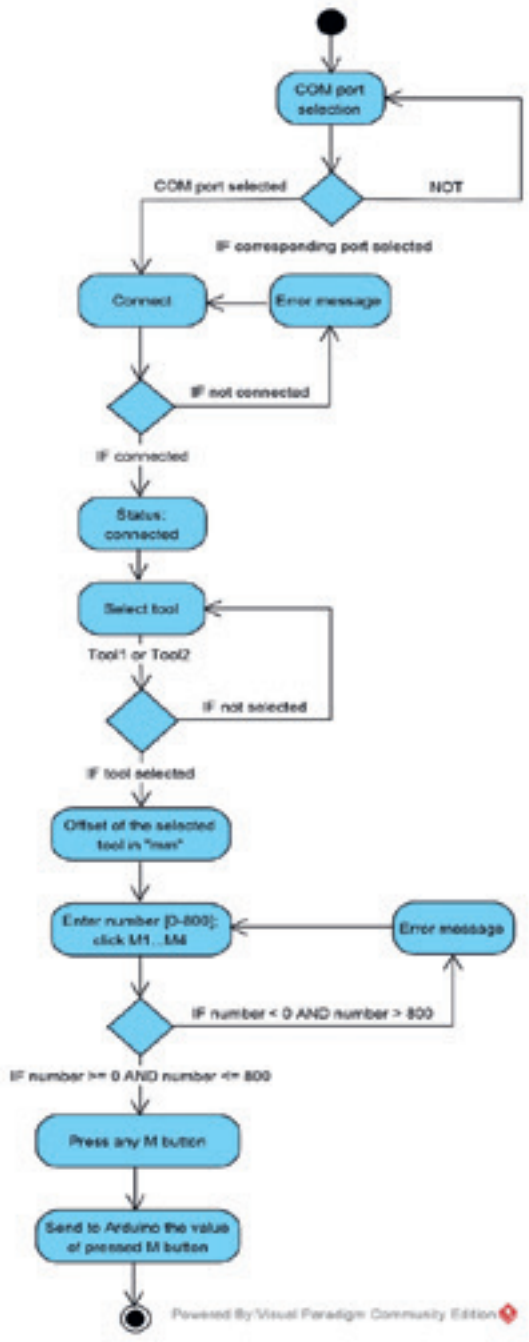

Figure 2. *Flowchart diagram of the PressBrake Software. Source: author's contribution.*

Initialization routine: When the application is launched, a key-value request is generated and sent to the microcontroller. This request initiates the machine's homing sequence, which is carried out using limit switches placed at the ends of the x-axis, where the backgauge moves. The automatic positioning to the home position functionality significantly improves the system initialization process, increasing the speed at which the press machine is prepared for operation and making the process more intuitive and user-friendly for the operator.

Precision and positioning speed: The application is optimized to enable the backgauge to reach the desired position in approximately 2 seconds, with slight variations depending on its current position and the specified input interval. The movement range of the backgauge spans from the machine's home position to a maximum of 800 mm, ensuring consistent precision across its entire range. This functionality is essential, as it allows operators to perform high-precision operations without the need for manual adjustments to the backgauge.

Tool input and selection: The application enables operators to pre-configure and save two tools within the system, each with predefined parameters. These tools can be easily selected through a combo box, which reduces the need for manual parameter input for each task. This functionality facilitates smooth transitions between different types of operations without requiring additional setup, thereby improving work efficiency and reducing cycle time.

User experience is enhanced through the implementation of an intuitive graphical user interface, allowing operators to quickly access key functionalities. The combo box for tool selection enables rapid tool changes with automatic parameter adjustments, minimizing the need for additional calculations during operation. This streamlined interface simplifies the workflow, making the operation more efficient and user-friendly.

Application operation principle

The hydraulic CNC press control application allows users to manage the machine's operational parameters intuitively and efficiently, leveraging modern digital infrastructure. The connection to the press machine's hardware components — such as sensors, motors, and backgauges — is established through a serial communication port, utilizing the UART (Universal Asynchronous Receiver-Transmitter) asynchronous serial protocol to ensure reliable data exchange between the computer and the microcontroller.

Microcontroller connection process

When the application is launched, the user selects the appropriate communication port to establish a connection between the application and the microcontroller. Upon clicking the "CONNECT" button, its color changes from gray to green, indicating that the system is prepared for connection. This visual cue provides the operator with a clear indication of the system's status.

Once the "CONNECT" button is pressed, the application sends an initial request to the microcontroller through the serial port to confirm successful communication. If the microcontroller responds positively, the application displays a message confirming the connection. At this point, the "CONNECTED" button becomes inactive, while the "DISCONNECT" button becomes active and is marked in red, enabling the operator to disconnect the system as needed. This functionality ensures that communication with the microcontroller is correctly established before proceeding with further operations.

In the event of a connection error, the application generates an error message, prompting the user to select a different port. This process, referred to as "handshaking," allows the application to identify the correct device connected to the serial communication port.

Backgauge and tool management

After establishing the connection, the user can select between two predefined tools using the combo box in the application. Each tool is associated with its own specific parameters, including an offset in millimeters from the machine's zero point. For example, "Tool 1" has a zero offset (0.00 mm), while "Tool 2" has an offset of 10.00 mm. This functionality allows the operator to manage tool positioning accurately without the need to manually enter complex parameters, thereby reducing errors and increasing efficiency.

Once a tool is selected, a numeric keypad facilitates the input of the desired position in millimeters. The entered parameters are stored in one of the four available registers (M1, M2, M3, M4) by pressing the "SET" button. After the values are stored in a register, the application transitions to standard operating mode, where the operator can select one of the registers and send the corresponding data to the microcontroller (Figure 3).

The microcontroller subsequently uses this data to position the backgauge according to the entered values. The backgauge operates at a speed of approximately 200 mm/s, with gradual acceleration during the initial 10 mm and deceleration in the last 10 mm before reaching the desired position. This process ensures smooth and precise positioning without abrupt changes, which reduces the risk of material damage.

Limits and input validation

The application incorporates an input validation mechanism to ensure the accuracy and correctness of the press machine operation. If the user enters a value beyond the allowable range (e.g., greater than 800 mm, which is the maximum backgauge movement range), the application generates an error message notifying the user that a valid value must be entered. Similarly, if the user inputs a negative value, the program will display a warning indicating that the value is outside the permissible range (0–800 mm).

This functionality ensures that the machine operates within predefined limits, thereby reducing the likelihood of errors and malfunctions during operation.

Operation using the Foot Switch

An additional feature of the application enables users to control the press using a foot switch. The operator can select one of the four registers with the left foot switch, while the right switch confirms the selected position and triggers the backgauge to move to the specified location. This mode of operation allows operators to control the machine without needing to interact with the screen, which is particularly beneficial when working with large pieces of material that may obstruct access to the screen.

Once the operator finishes using the foot switch, the "Foot Switch" button function allows the application to automatically revert to the standard touch screen operating mode, enhancing the flexibility of machine control.

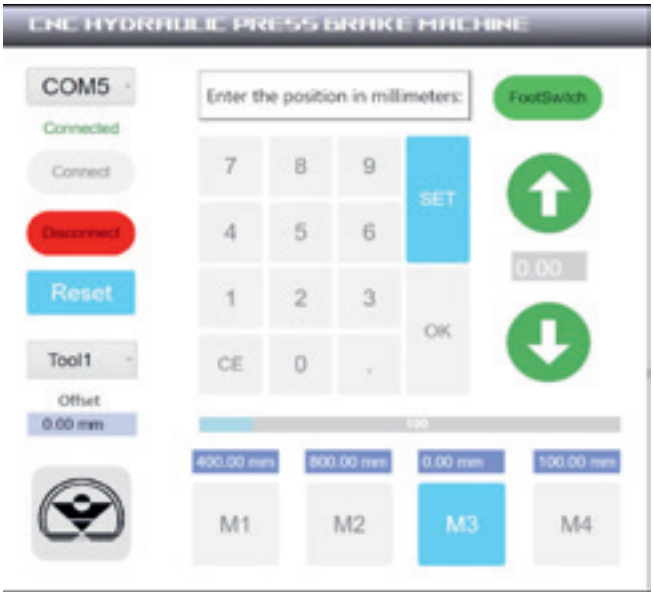

Figure 3. *User interface of the desktop application. Source: author's contribution*

Reset and error clearing

In the event of an error or the need to restore the system to its default settings, the application includes a "RESET" button that resets all parameters to their initial values. This functionality is particularly useful in situations where previous inputs need to be quickly cleared or when the system requires resetting due to a change in the operational task.

Results

During the modernization process of hydraulic CNC press machines, extensive tests were conducted to evaluate the system's performance and optimize functionality. The tests have revealed significant improvements in the following key areas:

Precision: The system's automation has enabled high positioning accuracy, significantly reducing the likelihood of errors during machine operation.

Operational speed: The optimization of the backgauge and automation of processes have led to a substantial decrease in task completion time, resulting in increased overall machine productivity.

Energy Efficiency: The introduction of new control systems has optimized energy consumption, contributing to reduced operational costs.

System Longevity: Improved control and automatic adjustment of key parameters have minimized the need for frequent manual interventions, thereby extending the machine's lifespan and decreasing the frequency of breakdowns.

Technical architecture of the solution

The digital transformation of industrial machines necessitates the careful and strategic integration of hardware and software components into a cohesive system. The technical architecture of the solution encompasses microcontrollers, actuators, and an advanced software interface, facilitating automatic control and monitoring of the press's operations. This approach enhances efficiency, precision, and overall control of machine operations.

Economic viability of digitalization

Although the digitalization of hydraulic CNC press machines necessitates initial investments in hardware components and software systems, a return on investment (ROI) analysis clearly illustrates the economic benefits. In the first year following implementation, companies can anticipate a reduction in operational costs of up to 30%. Furthermore, increased productivity, reduced downtime and decreased material waste further validate the economic viability of digitalization. Digital transformation requires not only selecting the right technology but also implementing this technology in a company's core. [7]

System safety and security

Safety is a paramount concern when implementing new technologies in industrial machines. All digital systems must be certified in accordance with applicable safety standards. For instance, the automatic machine shutdown system, activated in the event of a malfunction or improper operation, is a crucial component of the safety strategy. Additionally, control systems must be safeguarded against potential hacking attacks to ensure the security of data and machine operations.

This digital transformation provides industrial enterprises with significant enhancements in operational efficiency, long-term cost-effectiveness, and improved safety.

During the digitalization of hydraulic press machines, we encountered several technical challenges, which were successfully addressed through an iterative development approach. One of the main challenges was ensuring the accuracy of backgauge positioning using closed-loop stepper motors.

Testing the system under real industrial conditions confirmed that the automation of backgauge

adjustments significantly accelerated the machine's setup process. Prior to modernization, every operational change required manual intervention, which slowed down the production cycle. In contrast, the digitalized system enables faster and more accurate adjustments, directly enhancing productivity.

Feedback from operators who tested the modernized press machine was particularly valuable. Their responses indicated that the new software interface is user-friendly, intuitive and provides greater control over the process. This has reduced the need for extensive training and the introduction of new operating procedures, making the transition from a manual to a digital system smoother.

Although we achieved excellent results, potential for further improvements still remains. For instance, in future iterations, we could explore additional automation possibilities by integrating more sensor networks, allowing for even more precise control of the machine under specific production conditions.

Overall, the modernization of the press machines significantly improved efficiency, reduced costs and provided operators with greater flexibility in their work, enabling companies to leverage modern technology without the need to invest in entirely new machines.

CONCLUSION

The results of this study confirm that the digital transformation of hydraulic CNC presses is a crucial step toward enhancing performance and efficiency in industrial production. By utilizing modern software and hardware solutions, older machines can be significantly upgraded, extending their operational lifespan and achieving high levels of precision and speed without necessitating substantial capital investments in new equipment.

The implementation of automated systems for backgauge positioning and operational parameter adjustment has led to a reduction in errors and an acceleration of the production process. These advancements enable small and medium-sized enterprises to remain competitive in today's market while also reducing maintenance costs and increasing operational flexibility.

In recent years, Smart Manufacturing which is the core idea of the Fourth Industrial Revolution (Industry 4.0) has gained increasing attentions worldwide. [8] Future development should focus on enhancing algorithms for energy consumption optimization as well as integrating new technologies such as artificial intelligence. This would facilitate even greater automation and real-time adjustments of operational parameters. Recent advancements of several information technologies and manufacturing technologies, such as Internet of Thing (IoT), Big Data Analytics, Artificial Intelligent (AI), Cloud Computing, Digital Twin, Cyber-physical System, etc. have motivated the development of Smart Manufacturing. [9] Further research in these areas could contribute to increased efficiency and longevity of existing industrial machines, making them an integral part of smart production systems within the Industry 4.0 framework, while promoting sustainable development practices.

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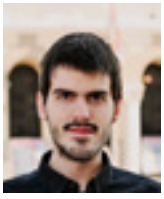
Jelena Radanović, a dedicated and accomplished student of Programming and Software Engineering at Paneuropean University Apeiron, is widely recognized for her innovative contributions and exceptional achievements in the field. She has received the prestigious Butterfly Innovation Award and the INOST Medal for her project Press Brake Software, showcasing her expertise in software development and creative problem-solving.



Nikola Račić, a talented and forward-thinking student of Programming and Software Engineering at Paneuropean University Apeiron, has earned recognition for his exceptional achievements in innovation and technology. Among his achievements is the prestigious Butterfly Innovation Award, which highlights his outstanding contributions to creative problem-solving and technological advancement. Currently, Nikola is conducting research in robotics and automation, continuing to push the boundaries of innovation and strengthening his position as a key contributor to technological advancements with practical real-world applications.

Dr. Branimir Trenkić, Full Professor in Computer Sciences, was born in Ćuprija, Serbia, in 1961. Dr. Trenkić joined the Faculty of Computer Sciences in Belgrade as associate professor in 2011. In 2013 he became a full professor at the Faculty of Computer Sciences and in 2016 he joined the School of Electrical and Computer Engineering of Applied Studies. Throughout his career, he has authored numerous impactful publications in peer-reviewed journals, contributing valuable insights to the scientific community, projects etc. Area of work: performance analysis of communication networks, high-performance systems (HPC), IoT, queueing strategies for communication networks, software development and testing.

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YOUNG LEARNERS' USE OF GOOGLE TRANSLATE AND GLOSBE IN A WRITING TASK: A CASE STUDY

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Abstract: The aim of this study was to examine the use of digital translation tools by near-beginner adolescent foreign language learners and their beliefs about the potential of these tools for language learning. A group of 15 participants, aged 13 and 14, enrolled in a German language course at a language studio, completed a writing task using the Google Translate and Glosbe tools. Semi-structured interviews provided insight into their usage of these tools and revealed contrasting beliefs. Some learners, in favor of using digital translation tools in language classes, argued that the tools facilitated communication and helped them acquire new vocabulary, conjugation patterns, and syntax. In contrast, others expressed that they had learned little, were critical of translating entire texts, and were concerned about becoming dependent on the tools and developing a false sense of competence. The lack of reflexivity and the challenges faced by some students underscore the importance of providing guidance and support to learners at this stage when using digital translation tools.

Keywords: digital tools, machine translation (MS), online dictionary, language teaching, foreign language learners

INTRODUCTION

Machine translation (MT) tools have undergone significant advancements over the past decade. For instance, Google Translate, which was launched in 2006 with support for just two languages and a relatively small user base, has now expanded to include 133 languages and serves hundreds of millions of users globally [1]. This rapid growth reflects the increasing demand for cross-linguistic communication in our interconnected world and highlights the substantial improvements in MT technology. Notably, the transition from statistical machine translation (SMT) models to neural machine translation (NMT) in recent years has significantly enhanced the quality and accuracy of translations provided by these tools [1] [2].

These advancements have also significantly impacted the field of research. In the initial years following the introduction of MT, studies primarily focused on its limitations and the potential risks it posed to foreign language education [3] [4]. However, the qualitative improvements in MT over the past decade have shifted the research focus. Increasingly, scholars are exploring the potential applications of MT as a tool for enhancing language teaching and learning, recognizing its value in supporting multilingual communication and language acquisition [5] [6]. Current research typically examines several aspects of how MT impacts language learning. This includes investigating the qualitative differences in learners' text production with and without the assistance of MT, exploring the effectiveness of text editing strategies such as pre-editing and post-editing with MT [7], and analyzing the beliefs and attitudes of both learners and educators toward the integration of MT in the language learning process [8] [9] [10].

Studies on the use of digital translation tools and online dictionaries in foreign language learning (FLL) indicate that the majority of learners regularly utilize these resources, particularly when writing in the target language or to address gaps in their lexical knowledge [9] [11] [12]. This trend has grown significantly over the past 15 years [12]. In general, users appear to recognize that digital translation tools are a permanent part of language learning [13]. However, teachers hold divergent views on how to integrate these tools into FLL. While some advocate for the constructive use of these resources, emphasizing their advan-

tages and disadvantages in the classroom, others argue for a complete ban on digital translation aids in FLL [3] [4]. There is currently no definitive empirical evidence to confirm whether digital translation tools directly promote language learning. However, existing studies suggest that these tools can contribute to the development of metalinguistic awareness [6] and improve outcomes in foreign language writing [14]. It is also hypothesized that learners with high levels of language learning anxiety could particularly benefit from digital translation tools. The ability to resolve linguistic ambiguities allows them to gain confidence, which, in turn, may help alleviate negative emotions associated with FLL [15]. Additionally, various studies suggest that the use of these tools in the classroom enhances the quality of texts and translations, a factor shown to positively impact students' self-confidence [6] [16] [17].

Notably, most existing studies predominantly focus on the use of MT tools by university-level learners. However, primary school students are also part of this increasingly interconnected world and are frequently exposed to diverse languages and cultures. This exposure occurs through various channels such as interactions with multilingual peers, social media, music, video games, and travel experiences, highlighting the need to consider younger learners in MT research.

The research gap is primarily attributed to the limited technological infrastructure in foreign language classrooms within public schools, a challenge evident in Bosnia and Herzegovina as well. Excluding the most developed countries in Europe and globally, the majority of public schools lack essential resources such as language laboratories, individual computers for students, and consistent internet access. Consequently, conducting the study in public primary schools was not feasible. Instead, the focus shifted to private language institutes, where many school-aged children enroll in courses, particularly in English and German, even though these subjects are part of the regular school curriculum.

In those increasingly tech-equipped classrooms, young learners have widespread access to the internet and, consequently, to MT tools. Regardless of whether a child learns a foreign language in a public school or a private language institute, the use of MT tools raises several critical questions for foreign language education. To what extent can learners at this age, often with relatively low proficiency in the target language, use these tools in a reflective and purposeful manner? How does the use of MT tools influence their language acquisition and motivation to learn a foreign language? Are certain translation tools more effective or appropriate for classroom use than others? Moreover, what are students' perceptions of using MT tools as part of their language learning experience?

Limited insights into the usage behaviors of younger learners are provided by the study conducted by Vázquez-Calvo and Cassany [18], which explored the application of MT among 11- to 17-year-old students in foreign language classes within the Catalan primary school context. In their analysis, Vázquez-Calvo and Cassany drew on a comprehensive dataset, including 1,020 minutes of classroom observations, 17 screen recordings of three distinct online activities, and insights from semi-structured interviews with 12 learners. This data was gathered as part of a broader study investigating the use of online language resources in the classroom. The findings of Vázquez-Calvo and Cassany's study indicate that learners utilized machine MT for a range of tasks, including understanding, producing, and revising texts, with varying levels of success and complexity. The most frequent use of MT involved fully translating foreign language texts to achieve a general understanding. Additionally, learners often employed MT unconsciously as a writing aid, composing texts in their first language (L1) and then translating them into the target language without reviewing or revising the output. At the sentence level, MT was also used to look up vocabulary and resolve grammar-related queries. The study did not identify any notable differences in the use of MT tools based on the age or foreign language proficiency of the learners, despite the wide age range of participants. This is particularly intriguing and suggests a potential area for further investigation. Additionally, the study did not explore the learners' underlying considerations, beliefs, or emotions when employing these MT methods, highlighting a significant gap in the current research literature.

To explore this specific student perspective, a case study was conducted in October 2023 at the Mirelingua German and English Language Studio in Banja Luka. The study involved a group of students who

completed a writing task, followed by recorded semi-structured interviews. This research was part of a broader doctoral study project. The writing task was partially completed using two widely utilized translation tools in the Serbian-speaking world: Glosbe and Google Translate. These tools were deliberately selected for their distinct functionalities. Glosbe serves as an online dictionary, offering a search function for individual words along with supplementary information such as example sentences and conjugation. In contrast, Google Translate is a neural machine translation tool capable of translating entire sentences and texts, providing alternative translation suggestions with a simple mouse click.

Glosbe is a multilingual, community-driven dictionary platform similar to Wikipedia, supporting all major world languages. It offers free access to dictionaries with in-context translations through a „translation memory" feature, providing users with translated sentences. Beyond simple translations, Glosbe delivers extensive resources, including thousands of example sentences, pronunciations, images, and illustrations to assist users in finding accurate translations. The platform also includes conjugation and declension tables, which are particularly useful for languages with complex grammatical structures [19]. Despite its numerous advantages, Glosbe's primary limitation is often attributed to its community-driven nature. The platform's creators are unable to fully verify all user-generated content, including example sentences, which can lead to inconsistencies in quality. However, the active involvement of Glosbe's community, comprising over 600,000 users, is also considered one of its unique strengths. This extensive user base allows for real-time corrections and improvements, providing an opportunity for continuous enhancement of translations.

Google Translate is a free, web-based translation service capable of translating various types of text and media, including words, phrases, and entire webpages. Initially launched as a statistical machine translation (SMT) system, it required input text to be translated into English first before being converted into the target language. Due to the predictive algorithms used in SMT, the service initially struggled with grammatical accuracy, often resulting in less precise translations. In 2016, the quality of machine translation significantly improved as Google Translate and other translation services moved away from the traditional word-for-word translation approach and adopted neural network-based systems. This shift marked a transition to the use of artificial intelligence, where the system mimics the structure of the human brain and is trained on large volumes of data. Each sentence is translated multiple times, allowing the model to refine its accuracy. Google Translate transitioned to neural networks in October 2016, and the improvement in translation quality was immediately evident, particularly for language pairs involving English [1]. A major challenge for machine translation had been the sentence structure of languages like German, where the verb's position often led to numerous translation errors. With the integration of neural networks, the software can now recognize these and other grammatical variations from an extensive database and apply them to improve translation accuracy.

Despite its vast database, Google Translate still lacks the capability to translate entire Word and PowerPoint documents. Additionally, a small test example highlights a limitation in its translation accuracy. The German sentence „Du hattest Schwein" was literally translated as „You had a pig", whereas the correct meaning is „You were lucky". This example underscores the challenges that machine translation systems still face in capturing idiomatic expressions and context. The same sentence was entered into Glosbe, where the translation provided was also inaccurate. However, the platform offered numerous correct examples of translations in the example sentences below, which highlights the value of community-driven dictionaries.

The following two research questions were defined for this study:

How do primary school learners use the translation tools Glosbe and Google Translate to complete a criterion-based writing task, and what emotions are associated with their use?

What are learners' beliefs about the effectiveness of translation tools, particularly Glosbe and Google Translate, in supporting their language learning progress, and how do they feel about the potential for future use in foreign language lessons?

Methods and materials

Task and Participants

This study involved a writing task conducted with 15 learners of German (10 female, 5 male) enrolled in the A2.2 German course at the Mirelingua Language Studio in Banja Luka. The participants, aged 13 and 14, were in the eighth or ninth grade of primary school. The task was completed over two sessions, each lasting 45 minutes, with a one-day interval between the sessions.

In the writing task, learners were asked to describe the best weekend they had ever experienced. The task was structured into three variants, each differing in the timing and use of the two translation tools, Glosbe and Google Translate:

Variant 1:

In the first step, students wrote a German text without any external aids. In the second step, they revised their original text using either Glosbe, Google Translate, or both tools.

Variant 2:

In the first step, students composed a German text using Glosbe. In the second step, they rewrote the same text using Google Translate.

Variant 3:

In the first step, students wrote a German text without any external aids. In the second step, they used Google Translate to translate their text from German back into Serbian and checked if the Serbian translation accurately conveyed their intended meaning. In the final step, they revised their original text using Glosbe, Google Translate, or both tools.

The variation in the tasks was designed to diversify the user experience while also aiming to reveal potential influences of each variant on the learners' affective user experience and beliefs.

The two translation tools and the writing task were presented to the students in detail before they began. To assess the suitability of the concept and the three task variants, a preliminary test round was conducted in the course prior to the main study. In this phase, students were asked to translate 10 sentences into German using the tools. This initial round also allowed students to reflect on which variant they preferred to use during the main task.

The writing task was designed based on specific criteria. At the teacher's request, recently covered topics were incorporated, including the use of the *Perfekt* tense, modal verbs, subordinate clauses (particularly causal clauses to explain why it was the best weekend), and expressions of location. This criterion-based approach aimed to provide students with guidance and ensure the task was not overly open-ended. Conversely, the degree to which students adhered to the given criteria was also intended to offer insights into the reflectiveness of their tool usage. The requirement to use the *Perfekt* tense posed a specific challenge, as machine translation programs like Google Translate often render the *Perfekt* as the *Präteritum* - a grammatical structure that is not yet familiar to the learners.

Conducting and Evaluating the Interviews

Following the writing task, learners were interviewed about various aspects of their tool usage and overall task experience. The interview format combined elements of a semi-structured interview and stimulated recall [20]. Gass & Mackey [21] advocate for minimizing the structure during the recall process, allowing participants to verbalize their thoughts during the task or reflect on their actions without external influence. Given the learners' limited verbalization skills at this age, some guiding questions were employed to help steer the recall process and facilitate the articulation of their thoughts. This approach involved accepting a certain degree of deviation from a purely introspective process, as well as the potential influence of the guiding questions on the learners' responses. The texts produced during the writing task served as stimuli for this retrospective survey.

The 15 interviews were recorded, with each session averaging 15 minutes in length. The audio transcripts were then analyzed using Mayring's qualitative content analysis [22]. This method involves a coding process aimed at categorizing the data to systematically address the research question. The analysis can be conducted deductively, using a theoretically based category system, or inductively, allowing categories to emerge directly from the data. This study employed Mayring's inductive category formation process model, resulting in a category system comprising 10 codes. These codes were subsequently interpreted in relation to the research questions.

Table 1: *Overview of the Codes Used*

Code	Category	Subcategories
C01	Experience with Translation Tools	C01.1 Experience at home C01.2 Experience from class C01.3 Experience with the dictionary C01.4 No experience
C02	Beliefs about the Usefulness of Translation Tools	C02.1 General usefulness C02.2 Usefulness of Glosbe (advantages over Google Translate) C02.3 Usefulness of Google Translate (advantages over Glosbe)
C03	Choice of Translation Tool	C03.1 Preference for Glosbe C03.2 Preference for Google Translate C03.3 Use of both tools (Glosbe and Google Translate)
C04	How Glosbe is Used	N/A
C05	How Google Translate is Used	N/A
C06	(Un)Critical Use of Translation Tools	N/A
C07	Beliefs about the Usefulness for Learning Progress	C07.1 Useful for learning C07.2 Not useful for learning C07.3 Conditional usefulness for learning
C08	Affective Experience During Task Completion	C08.1 Uncertainties, excessive demands C08.2 Enjoyment, interest C08.3 Other emotions
C09	Feedback on Tasks and Materials	C09.1 Feedback on the tasks C09.2 Feedback on tutorials C09.3 Feedback on criteria grid
C10	Ideas and Attitudes Regarding Future Use	C10.1 Suggestions for future use C10.2 Opposition to future use in language teaching

The following excerpts from the interview with participant P01 illustrate the application of this coding system in the transcript:

1. *It was so great to have a tool to help me write a good text without always having to think: What is that word? (C08.2) I would love to have that in school too! (C10.1)*
2. *But sometimes I was thinking: Am I really allowed to use all of this? (C06)*

The coded text passages were gathered for each analysis category, summarized, and attributed to the individual participants to identify trends and connections. As a result, statements such as the one in example (2) were categorized under C06, labeled as „critical use".

The student texts were not subject to a systematic evaluation; however, they were included in the analysis of the transcripts to gain a more comprehensive understanding of the students' statements. Furthermore, each text was examined to determine whether any tenses were used that contradicted the specified requirements.

RESULTS

Usage of Translation Tools and Task Experience

The analysis of the transcriptions revealed that the surveyed learners predominantly utilized translation tools to look up unfamiliar words or to verify the accuracy of words or sentences they had composed. Both Glosbe, an online dictionary primarily designed for word searches, and Google Translate were employed for searching individual terms. Additionally, Glosbe was used to verify specific verb conjugations, noun articles, and to cross-check the translations suggested by Google Translate. Several learners reported entering multiple words or entire sentences into Google Translate, noting that they found this tool more effective than Glosbe for such tasks. Additionally, two learners expressed a preference for Google Translate when translating individual words, as it provides a single translation option, whereas they felt overwhelmed by the extensive list of translation suggestions offered by Glosbe.

For five learners, the choice of translation tool was predetermined by the specific variant of the writ-

ing task (variant 2). In the final sub-steps of variants 1 and 3, where the tool or the combination of tools could be freely chosen, the analysis of text production and conversational data indicated a clear preference for Google Translate, with Glosbe being used only minimally. Some statements suggest that the learners' choice of tool was partially influenced by a misunderstanding of the tools' functionalities. For instance, three learners believed that Google Translate provides only a single correct translation, which was perceived once as a disadvantage and twice as an advantage. Additionally, one participant noted that Google Translate was deemed effective only for translating individual words or a single sentence, as the translation output changes when additional sentences are entered.

The ability to choose between various translation suggestions was perceived differently among learners, with some considering it advantageous, while others viewed it as challenging. One strategy mentioned for handling search results on Glosbe was to select the top-listed word. Notably, the example sentences, despite being demonstrated during the trial lesson prior to the writing task, were not utilized by the learners. However, three participants reported that they had explored alternative translation suggestions on Google Translate by clicking on specific words and found this feature beneficial.

The students' own text production was not solely compared with suggestions from a single tool; in some instances, both tools were used complementarily. Three respondents indicated that they utilized Glosbe to verify or better understand translations of passages suggested by Google Translate that appeared unclear or questionable. Additionally, Google Translate was employed for back translations into Serbian, a procedure explicitly included in variant 3 of the writing task. One participant (P02) engaged in back translation, despite this not being specified in their assigned task variant. Three learners reported mentally translating their German text into Serbian before entering it into Google Translate. They then compared the German translation provided by Google Translate with their own original German version. Consequently, one participant adjusted the Serbian input until the resulting German translation was coherent. Similar strategies were identified in the study by Vazquez-Calvo and Cassany [18] among learners at this level, where they were categorized as uses involving a higher level of complexity. However, the data do not allow for a determination of whether there is a relationship between the complexity of tool usage and learners' beliefs about the effectiveness of these tools for language learning.

In the interviews, 9 out of the 15 students indicated an awareness of the importance of a critical approach when using translation tools. Six students, for instance, expressed a level of mistrust towards the translations suggested by Google Translate. However, a comparison with the learners' text productions suggests that this critical approach was likely confined mainly to checking the meaning of individual words. For example, two-thirds of the participants either accepted or did not notice an incorrect verb tense (typically the *Präteritum*) in their texts, despite the criteria grid specifying the use of the *Perfekt*. One participant (P10) candidly admitted to translating as much as possible and directly copying the output. These findings align with the conclusions of Lidström's study [10], which noted that learners at this level experience challenges in critically evaluating suggested translations.

Regarding the affective experience of completing the task, participants reported both positive and less favorable feelings. Some described the task as engaging, educational, a refreshing change, and an exciting experience. Two participants noted increased confidence and satisfaction with the quality of their text after using the translation tool - sentiments that have also been reported by advanced university students in previous studies [9] [8]. Conversely, some learners found it challenging to write a text in German without the assistance of translation tools during the initial phase of the task (variants 1 and 3) and perceived the use of the tool as beneficial in successfully completing the assignment. The advantage of being able to produce longer and higher-quality texts with the assistance of translation tools was frequently mentioned in relation to their perceived usefulness, a benefit previously highlighted in the study by Jolley and Maimone [12]. The criteria grid was viewed variably by participants; some found it supportive, while others perceived it as an additional challenge. Three learners reported feelings of uncertainty or confusion when faced with selecting a translation from multiple, sometimes unfamiliar, suggestions.

Additionally, significant discrepancies between their own versions and the Google Translate output were experienced as unsettling.

Beliefs about the Usefulness of Using Tools for Learning

The analysis of the learners' statements revealed a range of beliefs, some of which were contradictory. However, the findings also indicated that very few learners viewed the use of translation tools as unequivocally beneficial or detrimental to their learning. Ten out of the 15 respondents identified both opportunities and risks associated with the use of these tools for their learning progress. The reasons cited for the perceived usefulness of translation tools included the ability to check their own texts, as well as the opportunity to learn new words, sentence structures, and verb conjugations. Advanced university learners in other studies have also acknowledged the usefulness of translation tools for this purpose [9] [12] [8] [6]. However, seven participants in this study identified the potential risk of relying on a tool like Google Translate to copy translations without critical thinking, thus failing to learn effectively. While this behavior represents a conscious decision to limit cognitive engagement, three of these participants went a step further, arguing that using such tools diminishes their cognitive involvement. They contended that the mental effort required to select the correct words and construct sentences accurately is supplanted by tools like Google Translate. From their perspective, using the tool thus hinders the development of the ability to express oneself successfully with existing linguistic resources. In this context, one participant expressed concern about becoming dependent on translation tools, potentially fostering a distorted perception of their own language competence. These feared negative outcomes align with the risks identified in studies by Jolley & Maimone, Knowles, and Steding [12] [3] [4].

For these reasons, several learners linked the usefulness of translation tools to the condition that their use occurs within a controlled environment, such as a language school, and is limited to individual passages. A third of the learners also considered using an online dictionary, such as Glosbe, to be more beneficial, as it does not allow entire sentences to be copied and focuses on individual words, which are easier to remember. To enhance the likelihood of retaining the words or constructions encountered, learners emphasized the importance of paying additional attention to them, both within and outside of the exercise. This aligns with findings from other research on the effectiveness of tools for vocabulary learning, which similarly suggests that retention is improved when learners engage actively with the material [5]. Participants in this study mentioned strategies such as writing down the words they looked up or using them repeatedly as potential methods to reinforce learning.

Regarding the future use of translation tools in foreign language teaching, seven learners considered the tasks used in this study - particularly writing a story - to be useful, and they also viewed these tools as valuable aids for preparing presentations and understanding texts. However, one third of the participants expressed opposition to the continued use of translation tools in teaching, citing concerns about the potential negative effects of relying on these tools.

The data do not suggest any correlation between the variant of the writing task and the learners' beliefs about the usefulness of translation tools.

DISCUSSION

This article began by noting that advancements in the field of MT also raise important questions for foreign language teaching, particularly with primary school students. As highlighted in the overview of the current state of research, there is a notable lack of studies examining the use of translation tools by younger learners in foreign language education. The study presented in this article serves as an exception in this regard, offering initial insights into the use of translation tools by primary school students and the perceptions of their use by teachers at this level [10] [18]. By describing how primary school students use the translation tools Glosbe and Google Translate, this article addresses this research gap and contributes to a better understanding of the student perspective, particularly by shedding light on learners' feelings and beliefs.

Previous studies have demonstrated that translation tools enable learners to produce higher-quality and more extensive written work [9] [12]. This communicative potential was also reflected in the statements of the learners in this study. Several participants reported difficulty in writing their text without

the assistance of the tools but expressed greater confidence and satisfaction with the quality of their revised text when using the tools.

Nevertheless, most learners in this study expressed mixed feelings about the inclusion of translation tools in language teaching. On one hand, many participants found the tools helpful for learning new words or constructions, a finding consistent with that of advanced university learners in other studies [9] [12] [8]. On the other hand, many learners emphasized certain conditions for their use and expressed concerns about the potential for mindless copying of suggested translations. Additionally, some learners associated the use of these tools with reduced cognitive engagement and the risk of dependency, issues also addressed in the studies by Knowles and Steding [3] [4]. As a result, one third of the participants did not view the future inclusion of translation tools in foreign language teaching as beneficial.

The partially uncritical and thoughtless use of the two tools suggests that the concerns raised by these learners are not unfounded. The use of unfamiliar or incompatible tenses in two-thirds of the texts indicates that learners at this age struggle significantly with critically analyzing the suggested translations. This observation aligns with assessments made by teachers at this level in Lidström's study [10]. Additionally, some students reported feeling unsettled when using the translation tools, due to the sometimes significant deviations in the suggested translations, or because of misunderstandings regarding how these tools function.

The results indicate that primary school students are not yet highly competent in using translation tools and tend to use them without critical reflection. Given the more positive assessments found in studies with advanced learners [9] [12] [8], it is reasonable to infer that a certain minimum level of foreign language proficiency is necessary to effectively benefit from independent use of tools for language learning. However, it appears questionable whether the learners' sometimes contradictory views on the usefulness of translation tools can be explained solely by differences in their language proficiency. The findings suggest that the reflective nature of tool use plays a significant role in this process. Several studies also emphasize the importance of metalinguistic awareness in the effective use of translation tools [7] [5] [6].

Conclusion

Given the continuous advancements and improvements in the field of MT, it is anticipated that the role of translation tools in foreign language teaching will attract increasing research attention in the coming years. Future studies could explore the effects of regular tool use on learners' motivation to learn a foreign language. Additionally, there is a growing need for concrete teaching concepts and materials designed to address the use of these tools. The results of this study suggest that it would be beneficial to train learners of this age in the critical use of translation tools, enabling them to utilize these tools more effectively and in ways that support learning and enhance communication in foreign language acquisition.

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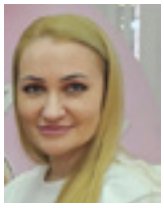

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