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Electrooculography Signal Acquisition and Processing for Real-Time Virtual Keyboard

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ABSTRACT

In cases of disease or trauma, individuals may lose the ability to communicate through conventional means such as speech or typing. Eye movements often remain one of the few active muscle capabilities for people with neurodegenerative disorders, such as amyotrophic lateral sclerosis (ALS), or those experiencing paralysis. Additionally, eye movement-based systems can be beneficial for privacy, security, or convenience when hands-free communication is necessary. This study aims to control a virtual keyboard using EOG signals, derived from the cornea-retinal standing potential between the front and back of the eye. Electrodes placed around the eye capture these signals, enabling text input based on eye movements. The system successfully recorded messages by detecting the desired letters during periods of sustained gaze. Further improvements could be achieved by incorporating blinking detection algorithms to refine letter selection and enhance system accuracy.

Keywords: EOG, ALS, Virtual Keyboard, Recorded Message.

1. Introduction

The eye is an organ that performs visual functions in humans. The eye movements are examined by using small-amplitude biological signals that occur during the movement of the eyes [1]. The signals mentioned are called electrooculogram (EOG) which are obtained by recording the potential difference between the eyes in two separate channels: horizontal and vertical [2]. EOG signals have a frequency range of 0.1 - 20 Hz and low amplitude values such as 100 - 3500 microvolts in amplitude [1]. Many studies are using EOG signals. For example, there are studies about the processing of signals received with electrodes placed around the eye, understanding the state of the eye, and studies in different areas such as sleep examination with the help of EOG signals, EOG-based eye movement detection and gaze estimation for an asynchronous virtual keyboard [3]. EOG-based computer control systems have been developed, such as a novel efficient human-computer interface and an EOG-based virtual keyboard [4]. Other advancements include adaptive virtual keyboards that minimize keystrokes for EOG-based control [5], continuous eye-writing recognition systems for assistive communication [6], directional eye

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movement detection systems for virtual keyboard controllers [7], and further eye movement detection algorithms [8]. Additionally, wearable forehead EOG measurement systems have been developed for practical applications [9].

This study aimed to develop a communication method for individuals with Amyotrophic Lateral Sclerosis (ALS) and paralysis, as well as for security purposes, using electrooculogram (EOG) signals to create an EOG-based virtual keyboard. The system operates by employing a typing method that utilizes specific directions and timings to select individual letters based on the keyboard design. EOG signals are captured through electrodes placed around the eyes, detecting the electrical activity generated by eye movements. These signals are then processed and translated into cursor movements on the virtual keyboard. Users can type by moving their eyes in specific directions, allowing them to select characters without needing physical input. This innovation not only provides a valuable tool for individuals with severe motor impairments but also offers potential applications in secure communication systems where traditional input methods might be compromised.

2. Material And Methods

2.1. Experimental Procedure

In this study the signals were acquired using electrodes placed around the eyes, after that a Measurement System was used which is KL-730 Biomedical Measurement Training System (Figure 1). It provides a platform for students to learn how to extract various body signals using bioelectronics sensors [10].

Figure 1: Biomedical Measurement Training System KL-75003 [10].

Measurements were performed in the Biomedical Technologies Research and Application Center (BIYOTAM) at Sakarya University of Applied Sciences. Figure 2 shows the whole process of the experiment starting from the capturing EOG signals to the treatment of the signals in the machine, to the wave form and data and the virtual keyboard till the result which is the recorded message.

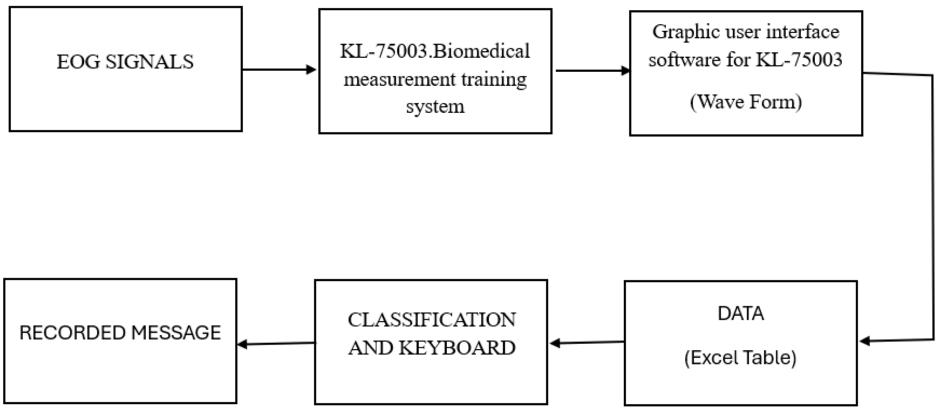

Figure 2: Block Diagram for an EOG Based Keyboard.

Both horizontal and vertical EOGs are measured as voltages using electrodes. For horizontal EOG measurements, electrodes are placed as close as possible to the canthus of each eye. For vertical EOG measurements, electrodes are placed just above and below the eye. The reference electrode is placed on the forehead [11]. For this preliminary measurement, the EOG data was recorded once from a single volunteer student. Figure 3 shows electrode placements and figure 4 displays disposable electrodes for the measurements.

Figure 3: Placement of Electrodes for EOG Recording.

Figure 4: 50mm-Round-Medical-Disposable-Electrode.

2.2. Acquisition and Processing

Raw signal was acquired and merged with noises coming from various sources, power-line interference, cables, skin resistance. It also had a very low amplitude (in the range of microvolts), making it too difficult to detect the change in the signal. For treating this signal KL- 75003 Electrooculogram module was used which is seen in Figure 5.

Figure 5: KL-75003 Electrooculogram (EOG) Module.

The Specifications for Electrooculogram EOG Module is a surface electrode and gain with range of 5~3000. Adding an isolation circuit and a band-pass filter with from 0.05~30Hz. Also 2 outputs one for horizontal signal and one for vertical signal [10]. GUI for KL-75003 is displayed in Figure 6.

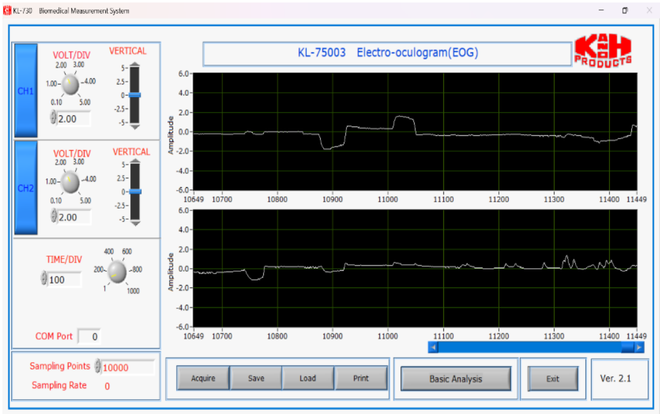

Figure 6: Graphic User Interface Software for KL-75003.

The EOG data was then stored in an Excel file with two columns for horizontal and vertical EOG signals, with a total of 1501 data points captured. Thirteen rows from our captured data are shown in Table 1.

Table 1: *Table for EOG Data*

Vertical	Horizontal
1.2	-10.72
1.28	-10.72
1.28	-10.72
1.28	-10.8
1.28	-10.72
1.28	-10.72
1.2	-10.72

1.28	-10.72
1.2	-10.72
1.2	-10.72
1.2	-10.8
1.28	-10.72

During the measurements, analog filtering was utilized with the device. EOG signal information is mainly contained in low frequencies. For this reason, a band-pass filter, which combines both high-pass and low-pass filtering, allowing only a specific range of frequencies between 0.1 and 30 Hz to pass through, was applied to isolate the frequency band where the EOG signal is most prominent, with a sample rate of 128 Hz. Then, an average filter was applied to remove some noise components [12]. The original and filtered EOG signals are displayed in Figure 7.

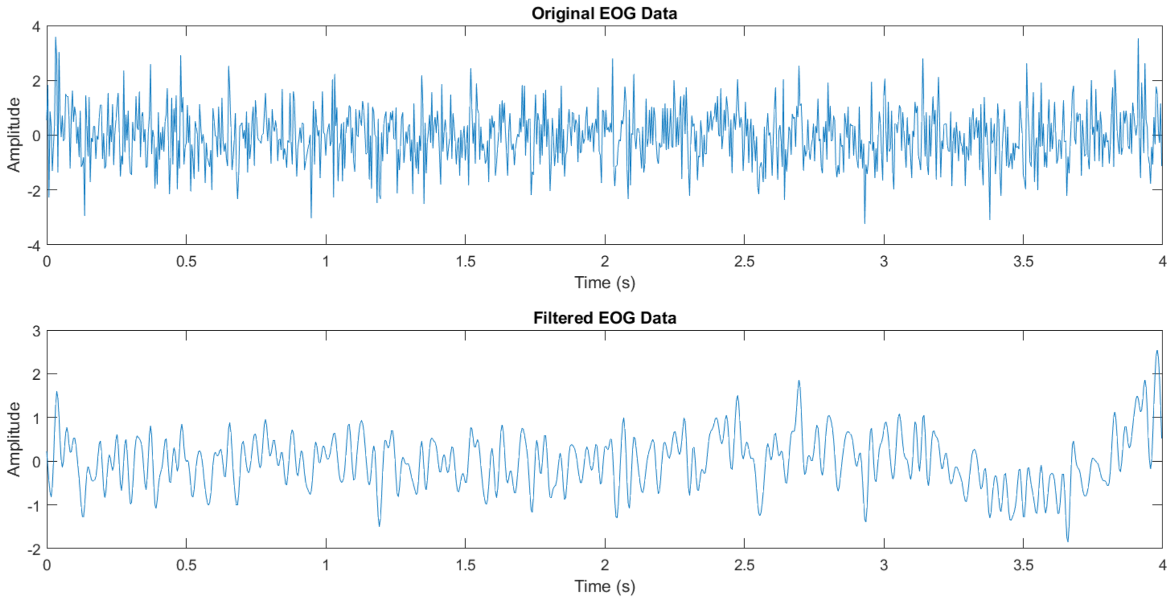

Figure 7: Original EOG Data with Filtered EOG Data.

2.3. Assistive Keyboard Design

The virtual keyboard is a 5x5 grid. Cursor movement is determined by comparing EOG signal deviations against set thresholds: exceeding positive or negative thresholds for horizontal signals shifts the cursor right or left, while vertical signal thresholds move the cursor up or down. An initial stabilization period minimizes transient noise by allowing the EOG signals to settle. Real-time position updates are displayed on the graphical user interface (GUI). When the EOG signals stabilize within a narrow range, indicating a steady gaze, the character at the current cursor position is selected and added to the output message. This method ensures reliable text entry by interpreting only significant and deliberate eye movements, demonstrating the effectiveness of EOG-based input systems. Designed virtual keyboard is displayed in Figure 8.

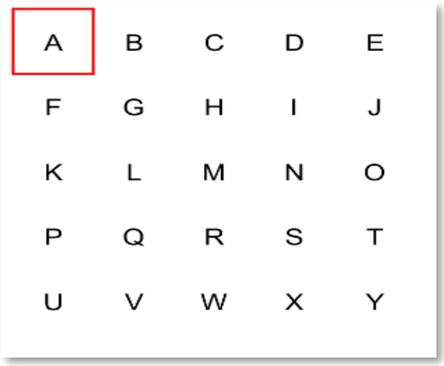

Figure 8: Virtual Keyboard Designed in MATLAB.

Where there another keyboard example that is different starting from the matrix to choosing letters by double blinking and the red rectangle highlight is created to show the currently selected key [13]. This variation provides another efficient method for selecting characters using eye movements.

3. Results

The captured EOG data was successfully translated into text messages, demonstrating the system's capability to control the virtual keyboard through eye movements. The virtual keyboard responded to the EOG signals by navigating according to the detected directions, with letters being selected when the gaze remained fixed longer on specific letters (e.g., U, Y, E, A). This approach was employed to evaluate the system's effectiveness in different scenarios. Notably, the letter 'X' was initially missed but subsequently recorded, which may be attributed to transient or uncontrolled eye movement steps.

As a result of the measurement, a message was successfully recorded based on the selected directions and the letters on the virtual keyboard model, as depicted in Figure 9.

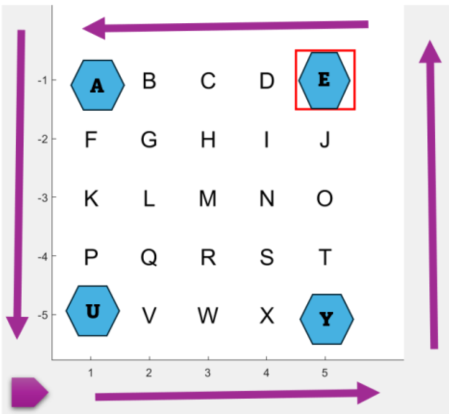

Figure 9: Virtual Keyboard with the Chosen Directions.

Due to the inherent difficulty in capturing each letter in precise order, some unintended letters appeared in the message. For instance, the letter 'X' was initially skipped but subsequently included, likely due to uncontrolled eye movement during the process. This observation highlights the challenges in achieving exact letter selection and suggests areas for improving system accuracy. Sample recorded message is shown in Figure 10.

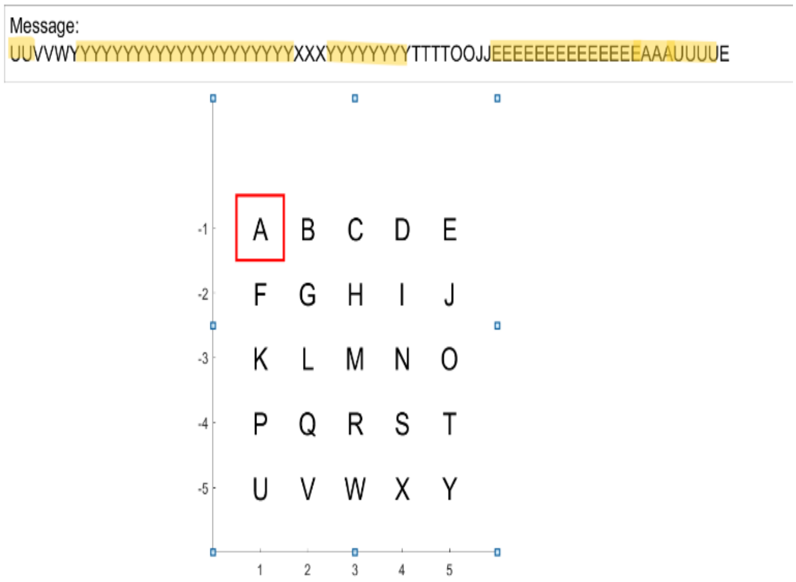

Figure 10: A Message Recorded by EOG Showing the Wanted Letters Followed by the Chosen Directions.

4. Discussion

The EOG signals captured during this study demonstrated good quality post-filtration, as illustrated in Figure 7 and summarized in Table 1. The initial results, based on data from a single participant, underscore the system's potential. However, greater efficacy can be achieved through training in a specific keyboard layout. This contrasts with the study by Keskinoglu and Aydın, where repeated trials by the volunteer led to improved control and accuracy in recording specific messages [1].

While our 5x5 grid keyboard is straightforward, it requires enhancements to broaden its functionality, such as incorporating numbers. This is similar to the approach taken by Teja et al., who used a 5x6 grid with an additional column for control functions [14]. Other studies, like those by Barbara et al., employed standard QWERTY keyboard layouts, organizing various symbols into comprehensive menus, demonstrating diverse design possibilities for virtual keyboards [3]. Furthermore, integrating our keyboard with a computer system for varied applications could enhance its utility, as seen in the work by Donchin et al., where eye movements controlled computer operations [15]. Additional improvements can be made by focusing on increasing accuracy and speed. This aligns with findings from studies achieving near-perfect accuracy and typing speeds of up to 10 characters per minute [16]. For instance, Tangsuksant et al. reported an average typing speed of 129.35 seconds per word for the word "HELLO" [7].

Although our system could capture the letters by employing a method that follows specific directions and timings to select letters based on the keyboard design, it is evident that further refinements are needed. Future investigations should focus on optimizing the system for faster eye movements and more precise control over virtual environments, with the goal of achieving higher accuracy and greater typing speeds. This will involve additional experiments with multiple volunteers to validate and enhance the system's performance.

5. Conclusions

This study focused on developing novel techniques to facilitate communication through speech or typing by translating EOG signals into messages. The result was a message recorded by EOG, displaying the desired letters according to the chosen directions. These preliminary results indicate that with repeated measurements, especially for individuals diagnosed with eye diseases, the system could be significantly improved.

The success of this work opens new possibilities for enhancing the quality of life for people with disabilities and improving the robustness of security protocols. The EOG-based virtual keyboard system offers notable advantages, particularly in providing a non-invasive, cost-effective communication method for individuals with severe physical disabilities. It enables text input using eye movements, making it accessible and customizable to individual needs. The system is portable and provides real-time feedback, enhancing usability. However, the system has drawbacks, including susceptibility to signal noise and artefacts, which can lead to incorrect inputs. Additionally, the input speed is slower than traditional methods, and prolonged use may cause eye strain. Despite these challenges, refining the technology and training protocols can significantly enhance its effectiveness as a communication aid.

Future research could focus on further improving the accuracy and user-friendliness of the system, as well as exploring additional applications of EOG-based technology.

6. Declarations

6.1. Study Limitations

Data (preliminary results of the system, limited number of volunteer data).

6.2. Acknowledgements

The authors thank to BIYOTAM researchers and students for their contributions at Sakarya University of Applied Sciences.

6.3. Funding source

There is no Funding source.

6.4. Competing Interests

There is no conflict of interest in this study.

6.5. Authors' Contributions

All authors: developing ideas for the research, planning the materials and methods to reach the results, taking responsibility for the experiments, organizing and reporting the data, taking responsibility for the explanation and presentation of the results, taking responsibility for the literature review during the research, taking responsibility for the creation of the entire manuscript, reworking not only in terms of spelling and grammar but also intellectual content or other contributions.

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Comparison of Deep Learning and Yolov8 Models for Fox Detection Around the Henhouse

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ABSTRACT

Human beings, who have been engaged in agriculture and animal husbandry for centuries, have to constantly track, take care and maintain their own agricultural lands and animals. This requires constant labor and time. The aim and originality of this study is to identify foxes that threaten, harm or kidnap animals such as chickens, geese, ducks and turkeys that live in the coops of individuals engaged in poultry farming. In this way, even if the farmer is not in the henhouse at that moment, material and moral losses to the farmers will be prevented. To achieve this purpose, many images were collected to form dataset. The collected dataset was classified according to whether the fox was in the henhouse or not. Then, the outputs of DenseNet, MobileNet, ResNet50, VGG16, VGG19, Xception and Yolov8 architectures were fine tuned to be performed in transfer learning to detect existence of a fox in the henhouse. Then, the models were trained, and their performances were compared in terms of performance metrics such as loss, accuracy, precision and F1. In the results, Yolov8 architectures generally have demonstrated the best performances.

Keywords: Poultry Farming, Deep Learning, Yolov8

1 Introduction

Human beings started their agricultural activities in 9000 BC in order to survive in many parts of the world, and together with the Sumerians, they carried out many agricultural techniques and plant products as well as animal activities [1]. When the research is examined, crop production activities came before livestock activities [2]. Animals have been the most important source of protein for human beings, who have benefited from animals for centuries. For this reason, animals have been domesticated and made more productive through breeding efforts. Today, livestock activities are grouped as cattle breeding, sheep farming, poultry farming, beekeeping, and aquaculture [2]. In this study, foxes attack especially domesticated poultry, killing or kidnapping poultry, causing financial damage to farmers. In order to

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prevent this, artificial intelligence models DenseNet, MobileNet, ResNet50, VGG16, VGG19, Xception and Yolov8 models for detecting foxes around the chicken coop were trained with the transfer learning method and their performances were compared. In this way, it is aimed to contribute to preventing farmers from suffering material and moral damage.

Livestock has an important place in terms of meeting the nutritional needs of the increasing population and providing a source of raw materials for industrial activities based on livestock. One of the important criteria used in determining the development levels of countries is the amount of animal food consumed per capita [3]. In economically developed industrial countries, there is generally intensive animal husbandry. In this method, meat and milk yield per animal is also higher. In underdeveloped and developing countries, animal husbandry is done using extensive methods. Meat and milk yield per animal remains low, veterinary services are either not provided at all or at a limited level [2]. Poultry farming, which is one of the sectors most suitable for technological developments among animal husbandry activities, has an important place in meeting the need for animal protein. Products such as eggs and white meat obtained from poultry are highly preferred animal foods because they are rich sources of protein and are more affordable [2].

In rural areas, poultry is raised in quantities that meet the needs of each family. Although the income from backyard chickens is lower than that of intensively produced chickens, the costs for housing, disease control, rearing practices and supplementary feeding are very low [4]. Poultry farming, which provides real economic income, is structured in modern large-scale facilities [5]. Except for chicken farms, poultry farming is carried out for subsistence purposes in extensive methods rather than for commercial purposes [6].

Village poultry farming in Turkey is carried out with the aim of producing eggs at a level that meets the needs of the family, having an egg to break and a chicken to pouch when they have guests, and to meet some small needs with excess production [13, 14]. Kristjanson et al. stated that low-income people owning poultry can help them escape poverty [9]. In addition, Riise stated in his study that women's ownership of poultry increases their self-confidence and is effective in increasing their status in society [10] According to Copland and Alders; farms engaged in backyard poultry farming are generally located in rural areas. They are generally family businesses and operate to meet the meat and egg needs of family members. It plays a vital role in the livelihood of families in rural areas. In addition to meeting the egg and meat needs of families, village chickens also meet the family's medicine, clothing and school needs by selling some of them [11].

In Turkey, Bolu and Sakarya are provinces where poultry farming is developed. In this area, there are facilities that make contracted production with large companies in these provinces. Düzce's ease of transportation to both Bolu and Sakarya and to big cities with large market areas positively affects the development of poultry farming in the province [2]. Düzce's ease of transportation to both Bolu and Sakarya and to big cities with large market areas positively affects the development of poultry farming in the province [2].

According to TUIK, data on Meat Poultry and Egg Poultry farming for the years 2013-2023 are given in Figure 1 and Figure 2 [12]. As can be seen, although meat and egg poultry farming has remained stable in recent years, it may increase in the coming years with the increase in population, birth rates and migration.

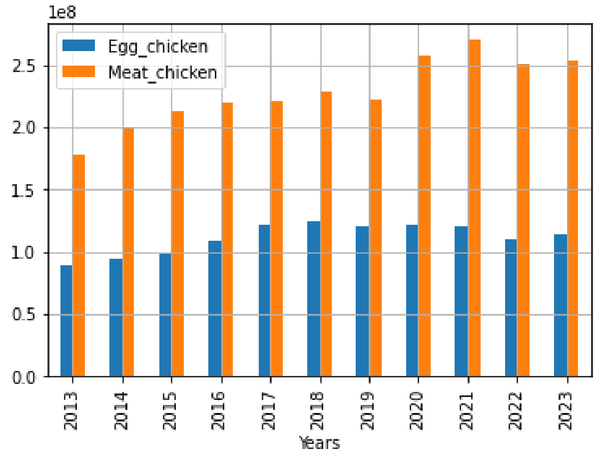

Figure 1: Poultry (Egg and Meat Chicken) Farming data in Turkey

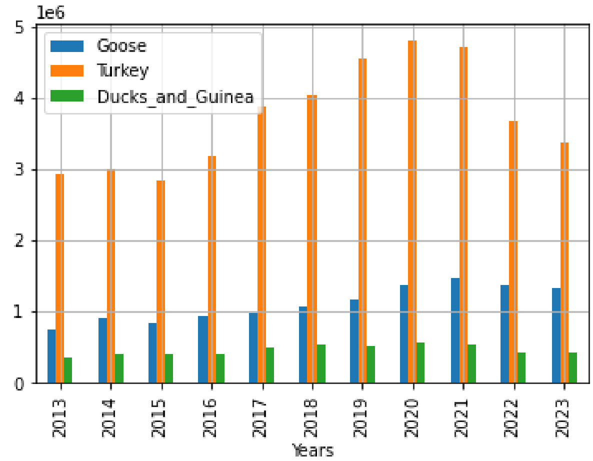

Figure 2: Poultry (Goose, Turkey, Ducks and Guinea) Farming data in Turkey

Permaculture is suitable for places that engage in this type of production, as it is an interdisciplinary system that creates living spaces that have the ability to be permanent in harmony with nature by blending ancient knowledge and experience, technology and science while creating these living spaces [13]. In this regard, combining poultry farming and artificial intelligence technology will increase efficiency. Artificial intelligence is like human brain that learn and make inferences based on data by imitating the human neural structure. Recently, it has become applicable to almost many fields. The success stories of deep learning in various domains include object detection [20, 21], character recognition [16], speech recognition [17], time series prediction [18], [19] and stock market prediction [20], tumor segmentation [21], many more.

In terms of poultry farming, as an image processing and real-time application, Prasetyo et al. stated that the behavior of chickens in the flock is important in determining meat production and stress levels. In this direction, they implemented an application that detects chickens using morphological image processing methods [22]. Karadöl et al. Have implemented a PLC-based and Web-based application to monitor the humidity, temperature and CO2 rates of the environment where broiler chickens are raised [22]. Sasirekha et al. Have implemented an application for monitoring conditions such as internet of things, temperature, humidity, liquid height and servo motor, light and buzzer control in a poultry house [23].

Diwan et al. have conducted a review study on Yolov1-v4 models used in object detection. They also mentioned challenges, architectural, successors, datasets and applications about Yolo [24]. Erin et al. Have used YoloV4 model to classify waste and implemented a real-time application. They compared their results in terms of sensitivity, precision F1, IOU and mAP metrics [25]. Bharadiya have explained classification with Convolutional Neural Networks (CNN) in his study. He specifically mentioned that in modeling, transfer learning can be done through models such as AlexNet, GoogLeNet and ResNet50, or points that can be taken into consideration when training models while building them [26]. Şafak et al. have trained deep learning models for fire and smoke detection using transfer learning method MobileNet, original MobileNet, MobileNetV2, EfficientNetB0, ShuffleNet, NASNetMobile and PeleeNet convolutional neural networks [27]. Eryılmaz et al. have trained MobileNetV2, NASNetMobile, Xception and DenseNet121 deep learning models with the transfer learning method for Covid19 detection [28]. Yücel and Çetintas have developed an automatic system using YOLO architecture for classification of blood cell types using blood cell images [29]. Kumral and Küçükmanisa have carried out a study on behaviour of drivers using CNN networks [30]. Dereli et al. have conducted a study on the recognition of jellfish on the shores using data collected from unmanned aerial vehicles. They said that in this system, by using hardware from NVIDIA, it can be used in unmanned aerial vehicles and warn the authorities according to the density [31]. Hussain have gave information about the development and architecture of Yolov8 from Yolov1, which is used in image processing. These methods have given examples of industrial deployment for surface defect detection in the industry [32]. Karaca et al. Have collected data for the classification of waste. They labeled the data they collected and trained them with Yolov3 [33]. Similarly, Uzun and Dilara have collected data for Autonomous Garbage Collection Vehicles. They trained this dataset on SequeezeNet, VGG19 and GoogleLeNet and compared the results in terms of Accuracy, Precision Sensivity and Specificity [34]. Daş et al. Have used the Faster-R-CNN model in the Tensorflow library in Google's open source library. First, they collected data and carried out the labeling process. Then, they trained the images and achieved successful results [Recognition and Tracking of Objects in Pictures and Videos with Deep Learning]. Öztürk et al. have carried out the classification of vehicles, pedestrians and traffic signs on the road using CNN networks [35]. Again, Gülyeter et al. have implemented the lane detection, and detection of vehicle, traffic sign, pedestrian application using the computerized Yolov5 model [36]. Talat and ZainEldin have proposed a fever detection approach for smart cities using the Yolov8 model. They stated that the method they proposed to recognize fires that may occur in smart cities will reduce damage to property and harm to people [37]. Ergönül et al. have classified the traffic in the network in real time using deep learning [38]. On the other hand, Sütçü et al. have estimated the amount of electrical load consumed using deep learning [39].

Bao et al. have carried out to detect sick and dead chickens in chicken farms with artificial intelligence [40]. Triyanto et al. have stated that broiler flock movements and health conditions in the poultry house are generally done manually by the farmers, but this requires a large amount of time and labor. To automate this process, they have developed an automatic recognition and tracking system using the Yolo v4 model [41]. Chen et al. have developed a warning system based on the movements and distribution of poultry in the chicken house using deep learning and machine learning methods [42]. Bingöl and Bilgin have used transfer learning to identify diseased chickens based on their feces on ResNet50, InceptionV3, InceptionResNetV2, Xception and MobileNetV2 architectures [43].

In this study, a dataset containing 1789 images has been collected to identify fox arouund poultry. The collected dataset has been trained to DenseNet, MobileNet, Resnet50, VGG16, VGG19, Xception, Yolo8m, Yolo8n and Yolo8X models via transfer learning. The performances of these trained models were compared and successful results were obtained.

2 Material and Method

2.1 Deep Learning Models

The first structure of CNN modeling was proposed by Fukushima in the 1980s [44]. The concepts of feature extraction, pooling layers, and using convolution in a neural network were introduced and finally recognition or classification at the end was proposed in the Neocognitron. Generally speaking, while conventional neural networks work with one-dimensional feature vectors, CNNs receive data in matrix format and process it with trainable filters in each convolution layer. CNN can successfully capture spatial and temporal dependencies in an image using relevant filters. To create a simple CNN architecture, three main types of layers are mainly used, namely convolution layer, pooling layer and fully connected layer, as shown in Figure 3. CNN processes the input data it receives by using filters in successive layers. Filters learn their values during training and reveal certain patterns in the data. The pooling layer reduces the size of the data coming from the convolution layers using certain methods to ensure ease of processing the data. As the last layer, the obtained data is converted into vectors and the result is obtained using multilayer sensors. An error occurs equal to the difference between the obtained result and the desired result. It is desired that this error to be minimum. To reduce the error by updating the weights, the backpropagation algorithm or others can be used. At last, the error is minimized by updating the weights with each iteration [20, 51, 52].

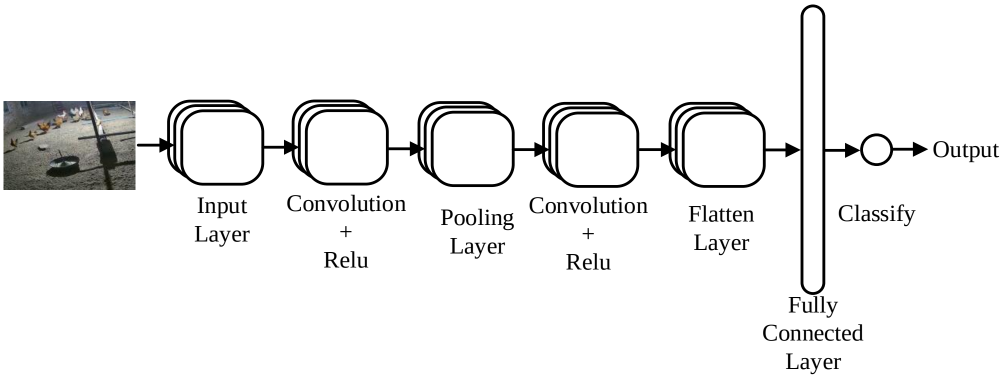

Figure 3: CNN Arhitecture

The main heading of the paper should be written in both Turkish and English if the paper is prepared in Turkish, while it should be written in only English if it is prepared in English. Moreover, the main heading of the paper should be 14 pt and be centered at the top of the paper. VGG (Visual Geometry Group) network architecture is the well-known CNN model. The VGG network has 16 to 19 learnable layers [47]. 19-layer VGG networks were used in this study. VGG19 is a pre-trained 19-layer deep convolutional neural network model that can classify images into several class categories using visual data. With the support of bounding box structures, this model often plays a vital role in image localization and classification. It uses a stacked architecture consisting of 3x3 convolution layers to increase the depth of the model.

ResNet50 (residual neural network) is derived from the ImageNet database [48] is a type of 50-layer residual network trained on at least one million images. To solve the vanishing gradient problem, ResNet uses skip connections, which allow information to pass directly from one layer to the next layer, in addition to regular information flow. Various ResNet model variations exist [45].

In the DenseNet121 architecture, as all layers are interconnected, each layer takes the feature map of the previous layer as input and adds its own feature map to this accumulation and transmits it to the next layer [49]. Continuously growing features make the applicability of the network difficult. In architecture, this problem has been overcome by applying subsampling to feature maps. In this way, feature maps are kept within limits [50].

InceptionV3 is a complex convolutional neural network model trained by GoogleNet on millions of images from the ImageNet dataset. This model can recognize a wider range of images rather than delving deeper into networks. It differs from others in that it can contain several smaller convolutions with restricted parameter types and sizes, and then combine them, instead of larger filter size convolutions [51]. The main goal of the starter module is to replace small kernels with large kernels to learn multiscale representations, simplify the calculation, and use fewer parameters overall [58, 59].

Francois Chollet introduced Xception architecture, an extension of the Inception architecture [54]. The deep convolutional neural network called Xception included new initial layers [55]. The CNN Xception or Extreme Inception model, which has 36 convolution layers and serves as the basis of the feature extraction block, offers an upgraded version of traditional Inception [56]. A linear stack of deeply separable convolution layers with residual connections forms this architecture [52]. Xception's structure consists of 3 streams: input stream, midstream and output stream. If the input image is not 299x299, it must be adjusted before feeding it into the model. A network now connects and separates these convolution layers [56].

MobileNet is an efficient convolutional neural network model used for mobile and embedded image recognition applications. MobileNet convolutional neural network consists of 28 layers and 4,253,864 parameters. MobileNet uses depth-separable convolutions. In this way, the number of parameters has been significantly reduced compared to networks consisting of regular convolutions with the same depth. Depth-separable convolution allows the depth and spatial size of a filter to be separated. Deep convolution applies a single filter to each input channel. MobileNet provides two simple global hyperparameters that efficiently trade off between latency and accuracy. MobileNet network structure is another factor that increases performance. The MobileNet network can be tuned to trade off between width and resolution, and between latency and accuracy. MobileNet has less computational power to run or implement transfer learning [57].

Yolo is an artificial neural network structure developed for instant object recognition by Joseph Redmon and his colleagues in 2016 [58]. Yolo uses the detection task with a single pass of the network and also uses classifier in its output. Unlike Fast R-CNN, regression for the boxes coordinates and classification for the probabilities are performed at the Yolo output. Yolo V2 was also suggested by Joseph Redomond and Ali Fardadi. They have developed a structure that is faster, stronger and more capable than the original. Unlike Yolov1, batch normalization, high-resolution classifier, fully convolutional, use anchor boxes to predict bounding boxes, dimension clusters, direct location prediction, Finner-grained features, multi-scale training features have been changed in Yolov2. Additionally, the backbone structure is used in Yolov2 [59]. Yolov3 was proposed by Joseph Redomond and Ali Fardadi in 2018. Unlike Yolov2, the Yolov3 they recommend has either added or updated features such as Bounding box prediction, Class Prediction, New backbone, Spatial pyramid pooling (SPP), Multi-scale Predictions, Bounding box priors. After that Yolov4, Yolov5, Yolov6, Yolov7 and Yolov8 have been proposed sequencially. Yolov8 has been proposed by Ultralytics company in January 2023. It has reduced the number of box predictions, speeded up the Non-maximum impression (NMS) and used mosaic augmentation during training.

Yolo versions have gained great popularity in the field of computer vision. The biggest reason is due to high sensitivity and accuracy with small models. For this reason, many people can easily use these models for object recognition, classification and segmentation. Yolo V8 model is anchor-free. This means that instead of estimating the distance of an element from a known anchor box, it explicitly estimates the center of the object. Anchor-free detection reduces the number of box predictions, which speeds up Non-Maximum Suppression (NMS), a demanding post-processing procedure that ranks possible detections after inference. YOLOv8 architecture was depicted at Figure 4 [60].

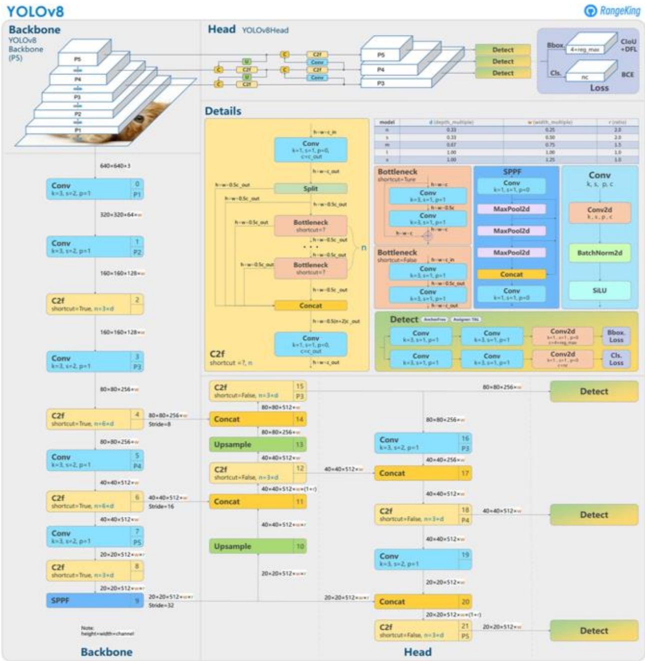

Figure 4: YoloV8 Architecture

2.2 Dataset

In the study, a dataset has been formed to determine the foxes that entered the chicken coop and harmed the poultry. This dataset has been collected especially from videos on the internet and images were taken at regular intervals. A total of 1786 images were obtained. Numerical data regarding the images are given in Table 1. Sample images are shown in Figure 5. After the collected dataset was created, it was classified into 2 categories: tranquil and attack. If there is a fox in the image, the image is classified as "Attacked". If there is no fox in the image, it is classified as "Tranquil". These images were then randomly divided into 20% test and 80% training data to be used in training. Information about the collected dataset is given in Table 1.

Table 1: *Dataset details.*

Classes	Training (Sample, Rate)	Test (Sample, Rate)	Total (Sample, Rate)
Attack	693 %38.8	174 %9.7	867 %48.55
Tranquil	735 %41.1	184 %10.3	919 %51.45
Total	1428 %79.9	358 %20.0	1786 %100

Figure 5: Sample images from the dataset (The ones on the left image there is fox, the ones on the right there is not a fox)

2.3 Transfer Learning

Transfer learning, in which learned knowledge is reused to increase performance on comparable problems, is one machine learning (ML) technique. For example, the artificial intelligence model trained to classify images of cats, dogs, bicycles and cars in Figure 6 can be revised and used to classify just foxes. To achieve this, the output layer of the artificial intelligence model must be revised and learning must be carried out by providing data related to the relevant task. The representative structure of the revised model is again shown in Figure 6. Especially in this study, both the data and the model need to be updated in the context of transfer learning. In this context, the data set collected regarding the problem was given to artificial intelligence models. While performing this process, 1000 neurons were added to the output layers of the DenseNet, MobileNet, Resnet50, VGG16, VGG19 Xception, Yolo8m, Yolo8n and Yolo8X models used in the study and the activation functions were determined as relu. Models were built by assigning a sigmoid function in the output layer. Since classification is a problem, the loss function used in training the models was chosen as binary_crossentropy. For this process, first the model and data set were created as shown in Figure 7. Then the data set was trained. Then the model was tested. As a result of the test, it is determined whether there is a fox in the image.

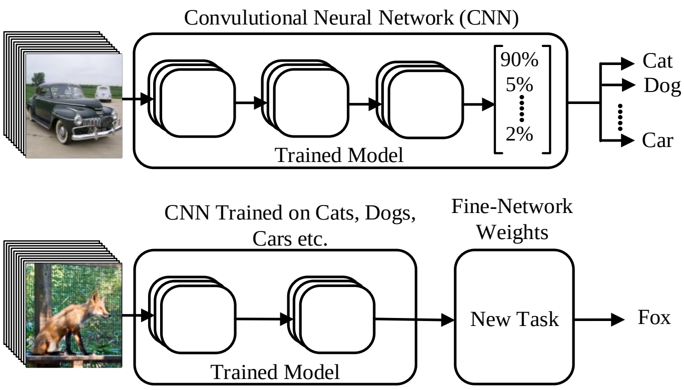

Figure 6: Transfer Learning based on Trained Model

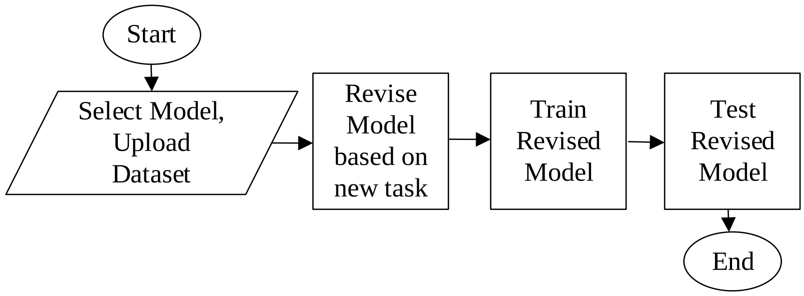

Figure 7: Flow diagram of the process of selecting model, training loading and testing

3 Results and Discussion

In this study, a computer hardware with an Intel i7 11800H 2.3GHz CPU with Windows 11 Home was used to carry out the training and simulations. The computer has 32GB of RAM and the graphics card is NVDIA Geforce RTX 3070. In the software used, the programming language is Python and the program used is Anaconda. Simulation studies were carried out by writing codes in the Spider IDE of Anaconda. In the Spider sofware, DenseNet, MobileNet, Resnet50, VGG16, VGG19, Xception, Yolo8m, Yolo8n and Yolo8X artificial neural network models were trained to identify a fox entering the henhouse. 300 epochs were selected for training. The model size, parameters, and the results of training of model such as accuracy, loss and training duration are given in Table 2. In addition, the evaluations obtained regarding the data set and training are given in Table 4, Table 5, Table 6.

Model parameter numbers and model sizes for the models are given at Table 2. Additionally, loss, accuracy and training duration information regarding the training results of the models are given at Table 2. When the models are examined, the largest model size is Resnet 50, while the smallest model size is YoloV8n. When examined in terms of training results, Yolo V8M produced the best result with the loss value in the objective function. However, the accuracy metric value gives the accuracy of the model. The Yolov8X model produced the best accuracy value.

Table 2: *Model details and their training results.*

Model	Model Size	Total Parametres	Trainable params	Loss	Accuracy	Training Duration (sec)
DenseNet	229.5 MB	58419780	25691137	0.25753	0.88235	18056.929
Resnet50	494.1 MB	126350212	51381249	0.51188	0.74019	19840.519
VGG16	157.9 MB	40406852	12846081	0.28158	0.86834	37499.622
VGG19	178.6 MB	45716548	12846081	0.31783	0.86064	43852.005
MobileNet	213.6 MB	54611140	25691137	0.20207	0.92577	10068.987
Xception	483.3 MB	123623980	51381249	0.23018	0.90756	21152.228
Yolo v8n	2.90 MB	1440850	1440850	0.02419	0.95531	10943.479
Yolo v8m	30.95 MB	15774898	15774898	0.01902	0.95810	20456.899
Yolo v8X	329.3 MB	56144402	56144402	0.02474	0.96369	22450.812

The confusion matrix for the correct classification and incorrect classification of the model is given at Table 3. In fact, all images in the actual class data column are divided into positive and negative. In predicted class, the image is divided into positive and negative on the raw according to the image result evaluated on the model. If the image is positive in the actual class and positive in the predicted class, a true positive (TP) result appears in the confusion matrix. That means model made a correct prediction. If the image is positive in the actual class and negative in the predicted class, a false negative (FN) result appears in the confusion matrix. That means model made a wrong prediction. If the image is negative in the actual class and positive in the predicted class, a false positive (FP) result appears in the confusion matrix. That means model made a wrong prediction again. If the image is negative in the actual class and negative in the predicted class, a true positive (TP) result appears in the confusion matrix. That means model made a correct prediction.

Table 3: *Confusion matrix.*

<table>
<tr><td></td><td></td><td colspan="2">Actual Class</td></tr>
<tr><td></td><td></td><td>Positive</td><td>Positive</td></tr>
<tr><td rowspan="2">Predicted Class</td><td>Positive</td><td>True Positive (TP)</td><td>True Positive (TP)</td></tr>
<tr><td>Negative</td><td>False Negative (FN)</td><td>True Negative (TN)</td></tr>
</table>

All test data for the actual class and predicted class were evaluated on the models. In addition to TN, FN, FP, TP, the arithmatic mean (mAP) values of the accuracy value for classification are given in Table 4. When the results were examined, Yolo v8m produced the best TN values, while Resnet50 produced the lowest performance. While Yolo v8n showed the best result in terms of TP, MobileNet produced the lowest performance. On the other hand, Yolov8n, Yolov8m, Yolov8X values were close to each other and produced the best results.

Table 4: *Model training results with respect to to TN, FN, FP, TP and mAP.*

Model	TN	FN	FP	TP	mAP (%)
DenseNet	103	81	92	82	51.5
Resnet50	64	120	36	138	57.0
VGG16	178	6	21	153	92.3
VGG19	113	71	48	126	66.9
MobileNet	159	25	115	59	60.1
Xception	151	33	43	131	78.6
Yolov8n	177	7	3	171	97.2
Yolov8m	179	5	5	169	97.2
Yolov8X	178	6	4	170	97.2

The results of the models in terms of accuracy, Error Rate, Precision, Recall, F1 are given at Table 5. When the results are examined, Yolo v8n, Yolo v8m, Yolov8X showed the best performances in terms of accuracy, Precision, Recall, F1. Although it showed good results in terms of some performance metrics in VGG16, it fell behind the YoloV8 models.

Table 5: *Model training results with respect to accuracy, precision, recall, F1.*

Model	Accuracy	Error Rate / Misclassification Rate	Precision	Recall	F1 score
DenseNet	0.5167	0.4832	0.4712	0.5030	0.4866
Resnet50	0.5642	0.4357	0.7931	0.5348	0.6388
VGG16	0.9245	0.0754	0.8793	0.9622	0.9189
VGG19	0.6675	0.3324	0.7241	0.6395	0.6792
MobileNet	0.6089	0.3910	0.3390	0.7023	0.4573
Xception	0.7877	0.2122	0.7528	0.7987	0.7751
Yolov8n	0.9720	0.0279	0.9827	0.9606	0.9715
Yolov8m	0.9720	0.0279	0.9712	0.9712	0.9712
Yolov8X	0.9720	0.0279	0.97701	0.9659	0.9714

In addition, True Positive Rate, False Positive Rate, False Negative Rate and True Negative Rate as results of the trained models are given at Table 6. When the results are examined, Yolov8n versions and VGG16 showed the best performances in terms of True Positive Rate, False Positive Rate, True Negative Rate.

Table 6: *Model training results with respect to True Positive Rate, False Positive Rate, False Negative Rate and True Negative Rate.*

Model	True Positive Rate	False Positive Rate	False Negative Rate	True Negative Rate
DenseNet	0.5031	0.4718	0.4969	0.5282
Resnet50	0.5349	0.3600	0.4651	0.6400
VGG16	0.9623	0.1055	0.0377	0.8945
VGG19	0.6396	0.2981	0.3604	0.7019
MobileNet	0.7024	0.4197	0.2976	0.5803
Xception	0.7988	0.2216	0.2012	0.7784
Yolov8n	0.9607	0.0167	0.0393	0.9833
Yolov8m	0.9713	0.0272	0.0287	0.9728
Yolov8X	0.9659	0.0220	0.0341	0.9780

4 Conclusion

Animals have been the most important source of food and livelihood for human beings, who have benefited from animals for centuries. Today, livestock activities are grouped as cattle breeding, sheep farming, poultry farming, beekeeping and aquaculture. In this study, a study was carried out to identify the foxes that attack poultry and cause material and moral damage to farmers. In this regard, a data set for foxes attacking poultry was collected and the images were classified. After the classification process, fine tuning was performed on the outputs of the MobileNet, Resnet50, VGG16, VGG19, Xception, Yolo8m, Yolo8n and Yolo8X models. In this method called transfer learning, models with revised outputs are trained on the collected data set and their performances are compared. When the results were examined, YoloV8 models showed higher performance than other models. As a result, in accordance with the purpose of the study, artificial intelligence models have been able to successfully detect whether there were foxes where there were poultry. On the other hand, considering future studies, this proposed method may have the potential to become a commercial product as it is currently a problem for agriculture and livestock. In addition, new deep learning models developed academically in the future can be applied to the same problem.

5 Declarations

5.1 Competing Interests

There is no conflict of interest in this study.

5.2 Authors' Contributions

Corresponding Author Murat Erhan ÇİMEN: Author has organised the article by himself.

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SAKARYA UNIVERSITY OF APPLIED SCIENCES

Development of an Active Orthosis and Internet of Things (IoT) Application for Lower Extremity

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ABSTRACT

The Internet of Things (IoT) technology has increasingly gained prominence in the field of sports sciences, much like in various other domains, due to its potential to enhance performance, monitoring, and control capabilities. In the context of athlete rehabilitation, IoT presents significant advantages over traditional rehabilitation systems, offering superior capabilities in real-time data collection, feedback, and personalization. This study is organized into three distinct phases, with the primary goal of developing a next-generation active lower extremity rehabilitation system that leverages IoT technology to optimize the rehabilitation process. In the first phase, a design for an active-controlled orthosis for the lower extremity will be created. The control system for the orthosis will implement the admittance control method, which is a crucial technique for regulating the interaction between the user and the robotic system. In this approach, admittance, represented as A, will be adjusted with minimal or zero deviations to control the rapid rise or lifting effect of the device. By manipulating the admittance parameter, the desired force response during rehabilitation can be precisely achieved, ensuring that the patient's movements are well-supported throughout the treatment. This approach allows the system to adapt in real time to the forces applied by the user, enhancing both safety and effectiveness. The admittance control method addresses a critical gap in the current literature by enabling the fine-tuned control necessary for rehabilitation systems that involve active participation from patients. The second and third phases of the study will focus on expanding the orthosis system to integrate adaptability and real-time data transfer capabilities. Specifically, the system will be designed to transmit rehabilitation data to mobile applications, providing a seamless interface for both athletes and sports physicians. This feature allows the system to distinguish itself from other rehabilitation devices, as it can be personalized for individual athletes. Physicians will be able to monitor the recovery progress of multiple athletes remotely via a mobile device, thus enabling them to offer real-time feedback on the patient's use of the orthosis. This function will significantly enhance the efficiency of treatment by allowing physicians to make necessary adjustments to the rehabilitation protocol without requiring in-person interaction. In addition, the system will continuously record the pressure exerted by the patient on embedded sensors. If the applied pressure exceeds a predetermined threshold set by the physician, the system will immediately send notifications and trigger vibrations to alert the athlete. This feature ensures that the rehabilitation process continues safely and effectively, preventing overexertion or injury. Ultimately, the use of IoT technology in this system allows for the continuous, real-time monitoring

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of the athlete's progress, while the adaptive feedback loop ensures that the treatment process is dynamic and responsive to the patient's needs. Consequently, this study presents a significant advancement in athlete rehabilitation, combining cutting-edge mechanical design with the transformative potential of IoT.

Keywords: Internet of things, home based rehabilitation, exoskeleton, lower extremity

1 Introduction

The primary concern addressed in this study is the absence of integration between existing orthoses designed for issues like the low foot syndrome and athlete rehabilitation through IoT. Consequently, the study aims to develop an active lower extremity orthosis specifically targeting ankle joint rehabilitation, potentially applicable in athlete injuries and rehabilitation robotics. The original concept underpinning this work involves controlling post-injury ankle movements via user prompts to achieve optimal recovery. Previous relevant studies, forming the theoretical framework, will be detailed in the subsequent section. Subsequently, the study will undertake application trials for a lower extremity orthosis using outputs from the initial phases, comprising:

• Development of Stimulus Algorithm for Active Orthosis: Experimental testing follows the development using a threshold value and piezoelectric sensor to support walking.

• Development of IoT-based E-health Application: Aimed at enabling both athletes and healthcare professionals to monitor rehabilitation via an Android-based application. Ensuring secure data flow through new-gen IoT technology is a key focus. Forces applied to the ankle joint can be tracked using this system.

• Usability Testing: Planned assessment of system usability by both athletes and healthcare professionals with the adaptation of a usability scale in Turkish for the mobile application. Subsequent testing will involve healthy users.

The central problem statement to be addressed within the scope of these objectives is 'Can a low-cost IoT-supported lower extremity orthosis be developed?' The subsequent sub-problems are enumerated as follows:

• How can a method be devised for the use of a stimulus-supported lower extremity orthosis assuming walking as a periodic movement?

• Is the use of IoT-based mobile applications for smart orthosis systems feasible for athletes and sports physicians (physiotherapists)?

• What factors influence the usability of the mobile application? What modifications are required based on usability outcomes?

• Is the use of Internet of Things (IoT) technology for data flow suitable for this wearable device? Are there any instances of this technology's usage in medical devices?

The first phase of the study focuses on active orthosis control, presenting a gap in the literature despite prior studies. This includes devising methods for utilizing active orthoses, deriving load and motion values for joint control post-injury. Additionally, an emphasis is placed on developing user-compatible models supporting volunteer effort, potentially through admittance control. The absence of advanced control applications for active orthoses is noted in the literature, primarily relying on simple open-close control or neural network-controlled orthoses, indicating the novelty and prospective direction of this study. The second phase of the thesis involves tele-rehabilitation development using IoT-based applications for home-based system usage. While literature exists on IoT in health systems, no instances of IoT-supported studies for athlete rehabilitation were found, marking this study as unique in filling a gap in the literature and pioneering an IoT-based lower extremity orthosis. The research assumptions include biomechanical modeling simplification, assuming user stability, and app usability. Limitations encompass the lack of user testing, constituting the primary constraint for behavior tests.

Within the literature, devices developed for rehabilitation and ankle treatments can be categorized based on degrees of freedom, control types, actuator types, exercise variations, measured parameters, sensor and mechanism structures. Various devices have been classified according to the parameters specified, showcasing their features and historical development concerning their place in the literature. While some facilitate straightforward exercises, others have been specialized through tailored control algorithms to respond to greater needs and elevate the standard of treatment. Developed robots can broadly be categorized into three main groups: passive mechanisms (which do not consume electrical energy), electrically powered passive devices, and intelligent robotic devices, as identified by Yıldırım [1].

Passive devices primarily aim to reduce spasticity. These devices typically cannot perform biomechanical measurements and are generally adjusted to the maximum allowable joint angle, held for a predetermined duration. Through exercises created in this manner, a reduction in spasticity is anticipated. However, for functional improvements, there is a need for specialized test algorithms in intelligent devices. The objective of such robots is not solely to reduce spasticity but also to increase muscle strength, enhance neuronal control, and measure biomechanical parameters. Intelligent devices are utilized not only for recovery but also for measurement, assessment, and diagnostic purposes [2]. Devices developed by researchers such as Neubauer et al. and Ren et al. have led to significant advancements in robotic rehabilitation of the ankle by employing intelligent control strategies and diverse rehabilitation methods [3]-[4].

Ayas et al. developed a parallel-platform ankle rehabilitation device in 2017, designed with 2 degrees of freedom. The system utilized fuzzy logic-based adaptive admittance control within its controller structure. The device operates with a DC electric motor as its actuator, capable of conducting active, passive, isotonic, and isometric exercise rehabilitations. However, it is physically cumbersome, heavy, and impractical for easy patient use in home-based rehabilitation due to its non-portability. The visual representation of the device developed by Ayas is shared in Figure 1 [5].

Figure 1: Device developed by Ayas [5]

Meijneke et al. have developed an exoskeleton named 'Achille' aimed at reducing the metabolic cost of human walking. Figure 2 illustrates the lower extremity treatment device related to Achille AFO. Upon examination, the Achille exoskeleton comprises a backpack and two active AFOs [6]. Each active AFO is powered by a series elastic actuator (SEA) consisting of a ball screw, an electric motor, and a leaf spring. Motor movement is tracked using an incremental encoder, while an absolute encoder is utilized for measuring ankle position angles.

Figure 2: Achille AFO [6]

During the development of active AFOs, various types of actuators have been employed to generate assisting torque. The most crucial criterion in actuator selection is to provide the necessary torque and support to the patient within the walking cycle. While delivering this support, the chosen actuator should also impose a weight and size that are tolerable for the patient and fall within acceptable dimensions, avoiding additional burden beyond the tolerable limits [6-8].

2 Materials and Methodology

Within this section, the systematic approach followed in the design of the developed therapeutic support orthosis is discussed. One of the most significant challenges in creating an original product in design and requirement determination is finding the most suitable path to the optimal solution.

2.1 Hardware Design

Within this section, the selected materials for the design of the developed lower extremity orthosis and their purposes of use will be discussed. Ultimately, the hardware of the designed system will be delineated. The developed lower extremity orthosis comprises six components: an orthosis, a programmable board, a Bluetooth communication module (4), a DC vibration motor (1), a piezoelectric pressure sensor (3), and a mobile application (6). Powering the design components of the orthosis was achieved through a DC power source, namely a battery, which guided the selection of design equipment. A design model capable of maintaining the foot and ankle joint in the correct position in the intended geometry for the patient undergoing treatment was realized.

This orthosis provides the desired environmental conditions for rehabilitation by maintaining the foot in the desired geometry during the treatment process. Materials used in the fabrication of the developed orthosis have been modelled to be composite, semi-flexible, or different material alloy types, ensuring strength without compromising human health or causing harm to the skin [9]. Flexibility has been imparted to the device through Velcro straps (5), enabling adaptation to anatomical structures of different individuals. The developed design utilized an Arduino Uno (2) microcontroller board for programming. The preference for this board was driven by its small dimensions in response to increasing demands for wearable technologies, its ability to operate on low voltage, and its capacity to provide low-power desired voltage outputs. The hardware components of the developed lower extremity orthosis assembled into a device are depicted in Figure 3. To facilitate comprehension of its physical components, they are represented as follows. The system structure and connections were assembled according to parameters defined for the user's specific criteria.

Figure 3: The Hardware Components of the Developed Orthosis

The piezoelectric sensor model has been used to grant the device functionality according to the parameters set during exercise stages, enabling the desired level of monitoring and progression. It features a surface area of approximately 35mm in diameter with positive (+) and negative (-) wiring connections. It possesses a voltage sensitivity of 5V/μƐ and can operate within temperatures ranging from approximately -20°C to +60°C. It is capable of producing values within the range of 0 to 1000.

2.2 Software Design

A mobile application with an APK extension has been developed for the control and monitoring of the designed orthosis. This application has been created to serve exercises to be performed in a home setting, a necessity heightened due to recent pandemic situations. Developed using the MIT App Inventor platform, this application offers different interfaces for use by both the patient and the doctor. Real-time data transmission has been enabled through the Internet of Things (IoT) [10]-[11]. Data generated based on parameters defined during patient exercises is transmitted to the cloud via IoT, and the application developed for the physiotherapist pulls this data [12]. Figure 4 displays the patient interface screen of the developed application.

Figure 4: Patient Screen Mobile Application Interface

The patient initially wears the orthosis on their foot and opens the application, entering personal information and establishing Bluetooth pairing between the device and the application. Starting the weight-bearing exercises while maintaining a standing position, the patient begins to exert pressure on the foot. The pressure generated at the heel during this exercise is measured by the sensor and transmitted to the Arduino board where the program is written. Analog sensor data received here is utilized to alert the user via vibration based on device operating conditions. Simultaneously, these real-time data during the exercise are sent to the application via the HC-05 Bluetooth module [13]. These transmitted data to the patient screen are then transferred in real-time to the cloud in the Firebase platform. The data sent to the cloud is instantly accessible to the doctor through the dedicated application. This process ensures that exercises conducted in a home setting are supervised and controlled by the doctor. Figure 5 illustrates the system's data flow.

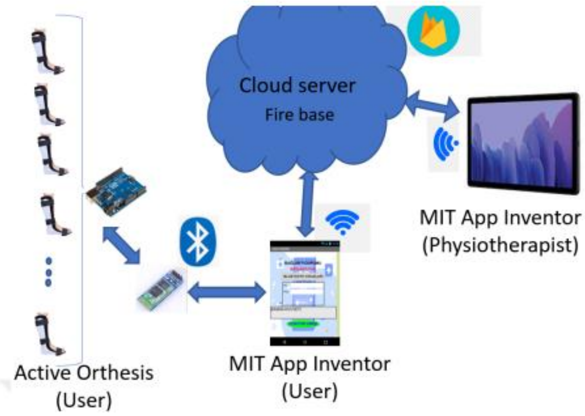

Figure 5: Data Flow Diagram

2.3 Manufacturing and Controller Design

A piezoelectric sensor is positioned in the insole area to gauge the pressure on the sole. The program board (Arduino Uno), DC power supply, Bluetooth module, and the actuator related to the design are positioned in the midfoot transition area. The device's straps allow for personalized adjustments of the orthosis. Its absence of articulated structures enhances both device and user safety. During exercises, the DC vibration motor delivers vibration alerts to the midfoot transition area, aiming for effective and efficient use. The physical dimensions of the components used in the structure of the developed orthosis are provided in the appendix [14]. Figure 6 displays the assembled device.

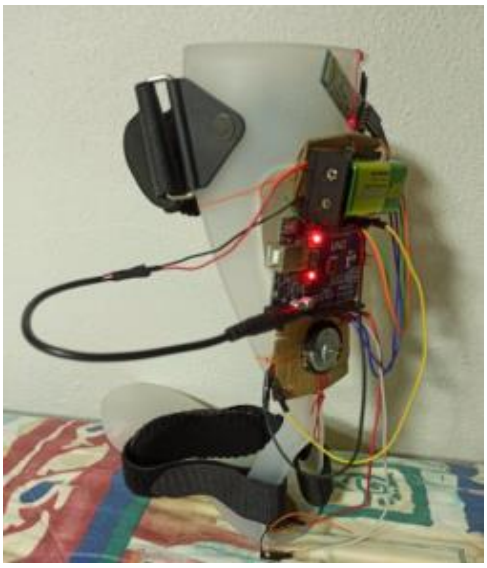

Figure 6: Assembled Foot Orthosis

In the scope of this implemented study, the system incorporates an admittance control structure for system control. The mechanical equation of this control structure, the inverse of impedance control, is demonstrated in Equation (1) [15]. X represents the rotation position of the motor, F represents the pressure force on the heel ankle, and A represents the admittance control value.

$$A = \frac{X}{F} \tag{1}$$

Here, X represents the motor's rotational position, while F denotes the pressure stress at the ankle heel region. The variation of motor position concerning the pressure stress at the heel is considered as the admittance error value.

The developed device depicts system measurement data in red, corresponding to the system outputs displayed in blue. The measurement range of the sensor used is 10 bits, which means it operates within the range of 0-1023 values, while the system output, the actuator's working range, is 8 bits, namely 0-255 values. The linearity of the system's response within these measurement and response ranges has been observed. Figure 7 illustrates the system's measurement and response responses.

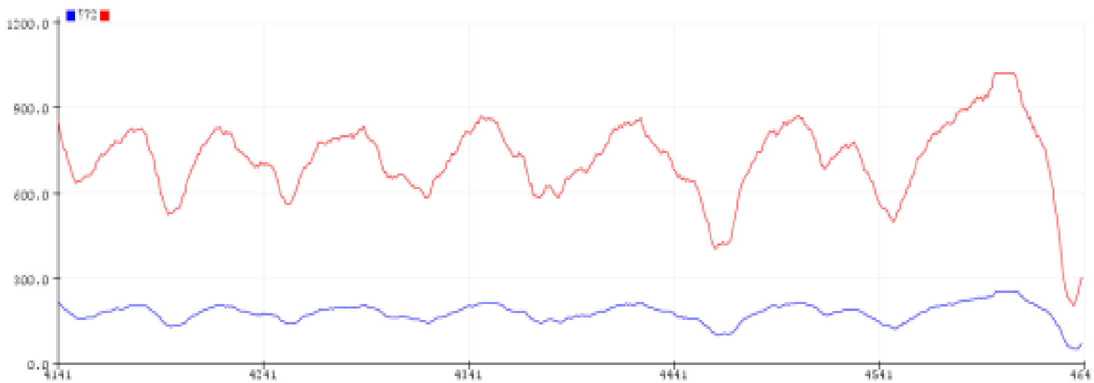

Figure 7: System Controller Output

During the walking step phase, the measurement values corresponding to the maximum output of the actuator's operating range are shown in Figure 8. Here, the system response reaching the desired range at the maximum level corresponds to the maximum pressure force generated in the ankle joint's heel area.

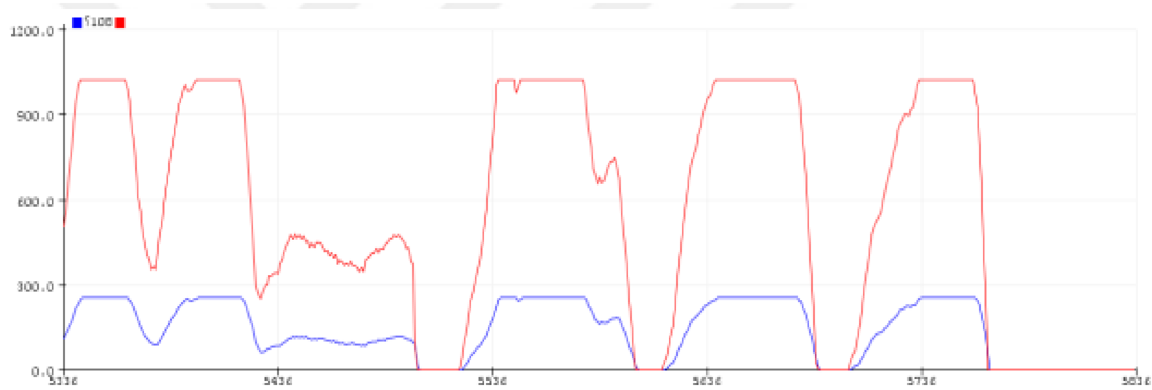

Figure 8: System Phase Response During Walking

3 Results and Discussion

The final structure of the orthosis was designed with minimal connections and using materials that don't pose a threat to human health. Care was taken to ensure the chosen materials were easily accessible and not specialized or custom-made, resulting in a low-cost device. Hardware elements selected for the device were those that wouldn't disrupt communication networks and had minimal magnetic and disruptive effects on the selected electronic components. Consequently, this conceptual study demonstrates the feasibility of developing a wearable, lightweight, cost-effective device capable of meeting rehabilitation exercise needs in a home environment. This device allows both active and passive exercises, ensuring an anatomically correct posture without causing harm to any nerve or muscle structures. It can be used in the treatment of individuals with weakened nerve and muscle cells, aiding in the recovery of lost functions and in athlete rehabilitation.

In this realized orthosis model, standard and commonly available hardware equipment have been preferred. This offers a significant advantage in terms of the device's production and procurement. The adjustable Velcro straps on the device provide flexibility, enabling usage for individuals with different anatomical structures. The absence of any hinged connection on the device ensures both the device's security and the patient's safety in unexpected circumstances. Upon examining similar devices and applications developed so far, this device stands out for its user-friendly, easily accessible, portable, and wearable features, providing significant advantages for home rehabilitation. A low-cost piezoelectric sensor has been used to measure pressure on the ankle heel region. For the control output of the device, a DC actuator has been chosen due to its low cost and capacity to perform at the desired level. Its low cost and compact size contribute to reducing the device's overall cost and ensuring portability. However, when considering the device's drawbacks, despite its suitability for the specified concept, a more robust orthosis structure, a stronger stimulating actuator, and a more sensitive sensor with a wider measurement range for force measurement need to be selected to make it more suitable for patient use. By establishing these criteria and obtaining experimental data, it appears feasible to create a more functional device within this concept. To further enhance its rehabilitation capabilities, additions based on specific needs can be made to the device. For instance, a hinged connection can be added to the joint for ankle plantar flexion and dorsiflexion movements, providing different stimuli.

The mobile application developed for device control and activation is user-friendly and compatible with smartphones, an integral part of the modern age. The interfaces created have been designed to be understandable by the general public. The application accommodates both patient dashboard panels and physiotherapist panels. Modifications can be made to the application based on specific needs, and different operating parameters can be added.

4 Conclusions

The realized device's data flow benefits from the Internet of Things (IoT) technology, which has become increasingly popular and utilized in various fields recently. Leveraging the IoT technology, a cloud network developed on the Firebase platform ensures real-time and rapid data flow. Sustainable and wearable kits have been preserved by choosing cheaper hardware equipment that can perform similar functions, which is one of the most significant parameters in the device's manufacturing cost.

5 Declarations

5.1 Competing Interests

There is no conflict of interest in this study.

5.2 Authors' Contributions

Emre YILMAZ: Developing ideas or hypotheses for the research and/or article, planning the materials and methods to reach the results, taking responsibility for the experiments.

Mert Süleyman DEMİRSOY: Organizing and reporting the data, taking responsibility for the explanation and presentation of the results.

Muhammed Salih SARIKAYA: Taking responsibility for the creation of the main part.

Mustafa Çağrı KUTLU: Taking responsibility for the literature review during the research.

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Control and Synchronization of a Memristor-based Hyperchaotic Lorenz System using Sliding Mode Control

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ABSTRACT

We studied some new findings on the sliding mode control, that have been derived for the chaos synchronization of memristor – based hyperchaotic Lorenz systems. Nonlinear property has shown that the memristor can be used in chaotic circuits and the latest memristor-based chaotic circuits with different nonlinear equations at times its design attracts quite a lot of attention. The reason why the sliding mode control method is preferred is due to the fact that it is a robust approach and thus less susceptible to the external disturbances. In fact it is affected in a very little range. Numerical simulations of the synchronization of the proposed control methods with the studied system here, have proved to be largely valid.

Keywords: Memristor, lorenz chaos system, sliding mode control

1 Introduction

Inductors, resistors and capacitors are known as circuit elements. These elements are expressed in terms of the relationship between the four fundamental circuit variables: magnetic flux *(φ)*, electric charge *(q)*, current *(i)* and voltage *(v)*. There are six possible combinations of these four fundamental circuit variables. Two of these combinations, *(v-φ)* and *(i-q)*, are familiar from basic circuit theory. The other three relationships are represented by the inductor *(L)*, which describes the relationship between current and magnetic flux *(dφ = Ldi)*; the capacitor *(C)*, which describes the relationship between voltage and charge *(dq = Cdv)*; and the resistor *(R)*, which describes the relationship between voltage and current *(dv = Rdi)*. As understood from these relationships, there are six different combinations of the fundamental circuit variables. However, according to these definitions, only five combinations are specified.

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In 1971, Leon Chua came with a new definition of a fourth circuit element to represent the recently undefined relationship between charge and magnetic flux, thus completing the sixth combination. Chua named this proposed element the memristor [1]. In 2008, researchers at HP Labs discovered the fundamental *i-v* characteristics of the memristor in a nanoscale device [2]. Memristors, which appear as two-terminal passive circuit elements, exhibit a nonlinear relationship between charge and flux. Due to their characteristic properties resembling synaptic actions, memristors are frequently seen in studies of synapses and artificial neural networks. Other applications include analog circuits, memory elements and sensors [3-8].

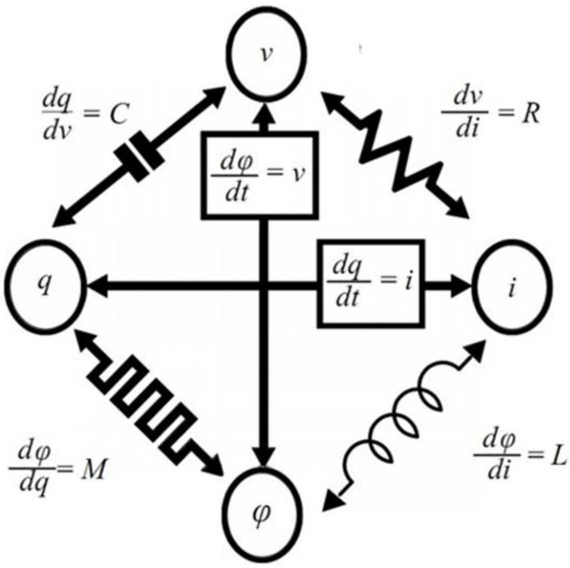

Figure 1. Relationship between current, voltage and electrical charge [2]

The HP memristor, defined by a nonlinear constitutive relation, is expressed in terms of voltage and current as follows [9]:

$$v = M(q)i \tag{1}$$

or

$$i = W(\varphi)v \tag{2}$$

Here, $\varphi = \int v dt$ terminal voltage refers to the relationship between v and i terminal current. The memristance $M(q)$ is expressed as a piecewise function as follows:

Memristance:

$$M(q) = \frac{d\varphi(q)}{dq} = \begin{cases} \alpha, |q| \le 1 \\ \beta, |q| > 1 \end{cases} \tag{3}$$

One of the most common applications of chaos theory lies in secure communication, where chaos synchronization plays a critical role. Synchronization, in this context, involves the matching and overlaying of two distinct chaotic signals, enabling the synchronization of a chaotic receiver and transmitter system. If we can use a chaotic signal in the form of a large masked chaotic signal, we can resend it using a chaotic mask. Because chaotic systems are highly sensitive to initial conditions, even a slight change in initial conditions can lead to completely different trajectories. The first study on synchronization was conducted by Pecora and Carroll, who proposed that it is possible to synchronize two chaotic systems with different initial conditions under certain conditions [10]. In this paper, we present new control results for memristor-based hyperchaotic Lorenz systems using the sliding mode control method. This method is widely favored due to its inherent advantages, including insensitivity to parameter uncertainties and external disturbances, ease of implementation, fast response, and strong transient performance.

2 Memristor-based Hyperchaotic Lorenz System

The state equations of a new type of memristor-based Lorenz system are provided below. The memristor-based Lorenz system can be defined as follows [11]:

$$\begin{cases} \dot{\chi}_1 = -\omega_1\chi_1 - W(\chi_4)\chi_1 + \omega_2\chi_2 \\ \dot{\chi}_2 = \omega_3\chi_1 - \chi_2 - \chi_1\chi_3 \\ \dot{\chi}_3 = \chi_1\chi_2 - \omega_4\chi_3 \\ \dot{\chi}_4 = -\chi_1 \end{cases} \tag{4}$$

Here $\chi_1, \chi_2, \chi_3, \chi_4$ are the state variables and $\omega_1, \omega_2, \omega_3, \omega_4$ are the constant parameters of the system. We can define the piecewise linear function $W(\chi_4)$ as follows:

$$W(\chi_4) = \begin{cases} \alpha, |\chi_4| \le 1; \\ \beta, |\chi_4| > 1. \end{cases} \tag{5}$$

As shown in Figure 2, when the parameters are chosen as $\omega_1 = 8, \omega_2 = 15, \omega_3 = 28, \omega_4 = 8/3,$ $\alpha = 5\, and\, \beta = 8$ the system Equation (4) exhibits chaotic behaviour under the initial conditions of $(10^4, 0, 0, 0)$.

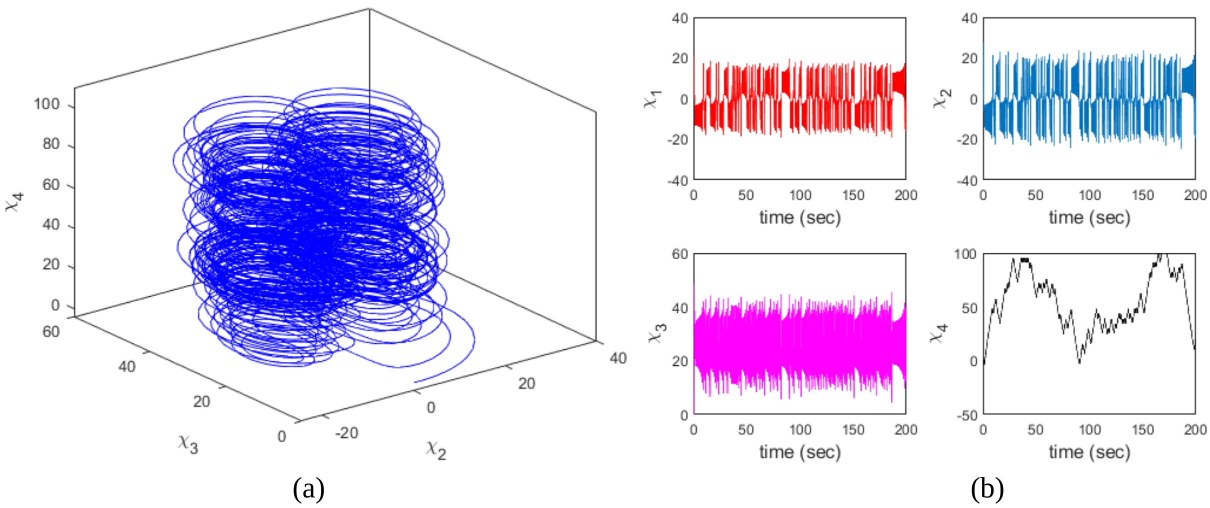

Figure 2. Memristor attractor: (a) State trajectories of memristor-based hyperchaotic lorenz system and dynamical behaviors: (b) Phase portraits of memristor-based hyperchaotic lorenz system

The Lyapunov exponents of the system, whose temporal variations are presented in Figure 3, have been calculated as $L_1 = 1.768023, L_2 = -0.004860, L_3 = 0.005835, L_4 = -25.789058$. The presence of at least two positive exponents (L_1 *and* L_3) indicates that the system is hyperchaotic.
The Lyapunov fractal dimension (Kaplan-Yorke) of the memristor-based hyperchaotic Lorenz system has been calculated using Equation (6).

$$D_{KY} = j + \frac{\sum_{i=1}^{j} L_i}{\left|L_{j+1}\right|} = 3 + \frac{L_1 + L_2 + L_3}{\left|L_4\right|} = 3.07 \tag{6}$$

As can be seen, the fact that the result is fractional indicates that the system exhibits chaotic behaviour.

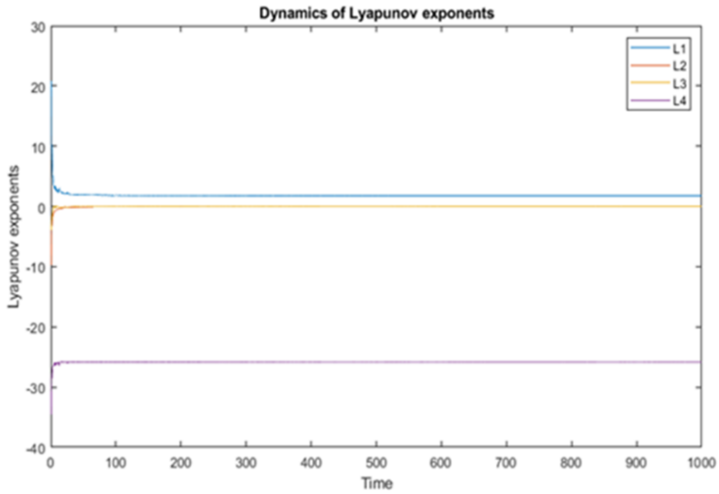

Figure 3. Graph of lyapunov exponents of the system

3 Results and Discussion

In this section, we will examine the synchronization of two identical memristor-based hyperchaotic Lorenz systems.

Taking Equation (4) as the master system [11],

$$\begin{cases} \dot{\chi}_1 = -\omega_1\chi_1 - W(\chi_4)\chi_1 + \omega_2\chi_2 \\ \dot{\chi}_2 = \omega_3\chi_1 - \chi_2 - \chi_1\chi_3 \\ \dot{\chi}_3 = \chi_1\chi_2 - \omega_4\chi_3 \\ \dot{\chi}_4 = -\chi_1 \end{cases}$$

the slave system is given as follows,

$$\begin{cases} \dot{\gamma}_1 = -\omega_1\gamma_1 - W(\gamma_4)\gamma_1 + \omega_2\gamma_2 + u_1, \\ \dot{\gamma}_2 = \omega_3\gamma_1 - \gamma_2 - \gamma_1\gamma_3 + u_2, \\ \dot{\gamma}_3 = \gamma_1\gamma_2 - \omega_4\gamma_3 + u_3, \\ \dot{\gamma}_4 = -\gamma_1 + u_4, \end{cases} \tag{7}$$

Here, $\gamma_1, \gamma_2, \gamma_3, \gamma_4$ are the state variables and u_1, u_2, u_3, u_4 are the controllers.

The chaos synchronization error is defined as follows,

$$e = \gamma - \chi \tag{8}$$

The error dynamics equations can be easily obtained as follows,

$$\begin{cases} \dot{e}_1 = -\omega_1 e_1 + \omega_2 e_2 - W(\gamma_4)\gamma_1 + W(\chi_4)\chi_1 + u_1 \\ \dot{e}_2 = \omega_3 e_1 - e_2 - \gamma_1\gamma_3 + \chi_1\chi_3 + u_2 \\ \dot{e}_3 = -\omega_4 e_3 + \gamma_1\gamma_2 - \chi_1\chi_2 + u_3 \\ \dot{e}_4 = -e_1 + u_4 \end{cases} \tag{9}$$

We write the matrix representations of the error dynamics Equation (9) as follows.

$$\dot{e} = Ke + \eta(\chi, \gamma) + u \tag{10}$$

here

$$K = \begin{bmatrix} -\omega_1 & \omega_2 & 0 & 0 \\ \omega_3 & -1 & 0 & 0 \\ 0 & 0 & -\omega_4 & 0 \\ -1 & 0 & 0 & 0 \end{bmatrix}, \eta(\chi, \gamma) = \begin{bmatrix} -W(\gamma_4)\gamma_1 + W(\chi_4)\chi_1 \\ -\gamma_1\gamma_3 + \chi_1\chi_3 \\ \gamma_1\gamma_2 - \chi_1\chi_2 \\ 0 \end{bmatrix} and\ u = \begin{bmatrix} u_1 \\ u_2 \\ u_3 \\ u_4 \end{bmatrix} \tag{11}$$

Firstly, we set *u* as follows,

$$u = -\eta(\chi, \gamma) + Lv \tag{12}$$

Here, *L* is chosen such that *(K, L)* is controllable.

We select L as follows:

$$L = \begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \end{bmatrix} \tag{13}$$

When the sliding mode variable is chosen as follows:

$$s = Ce = \left[-2 \; -3 \; -1 \; 4\right] e = -2e_1 - 3e_2 - e_3 + 4e_4 \tag{14}$$

And when the sliding mode variable is chosen as follows. Here C is a constant vector.

We choose the sliding mode gains as $k = 5$ ve $q = 0.2$.

According to the sliding mode control method's characteristic, the control signal is given as follows [12-18].

$$v(t) = -(CL)^{-1}\left[C(kI + K)e + q\,\mathrm{sign}(s)\right] \tag{15}$$

Here, k and q are the sliding mode control parameters. A high value of k tends to create problems which resut in chattering. An acceptable value of q suppresses chattering and shortens the time to reach the sliding surface. In this paper, the constants k and q for sliding mode control are determined by the author.

Now, the control signal *v(t)* becomes as follows,

$$v(t) = -41e_1 - 21e_2 - 1.1670e_3 + 10e_4 - 0.10\,\mathrm{sign}(s) \tag{16}$$

Therefore, the sliding mode controller is as follows:

$$u = -\eta(\chi, \gamma) + Lv \tag{17}$$

Here, $\eta(\chi, \gamma)$, L and *v(t)* are written as in equations Equations (11), (13) and (16).

The initial values for the master system Equation (4) are taken as follows:

$$\chi_1(0) = -5,\ \ \chi_2(0) = 30,\ \ \chi_3(0) = 8,\ \ \chi_4(0) = 20.$$

The initial values for the slave system Equation (7) are taken as follows:

$$\gamma_1(0) = -8,\ \gamma_2(0) = 12,\ \gamma_3(0) = -38,\ \gamma_4(0) = 16.$$

Figure 4 illustrates the complete synchronization of two identical memristor-based hyperchaotic Lorenz systems Equations (4) and (7).

Figure 5 shows the error states approaching zero for $e_1(t),\ e_2(t),\ e_3(t),\ e_4(t)$, $t \to \infty$.

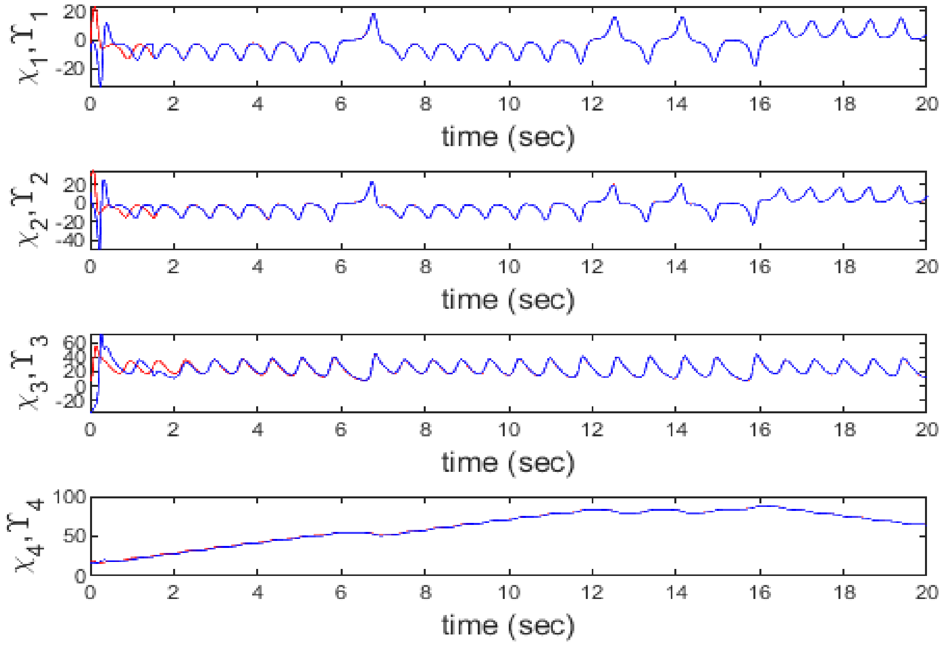

Figure 4 Synchronization of memristor-based hyperchaotic lorenz system

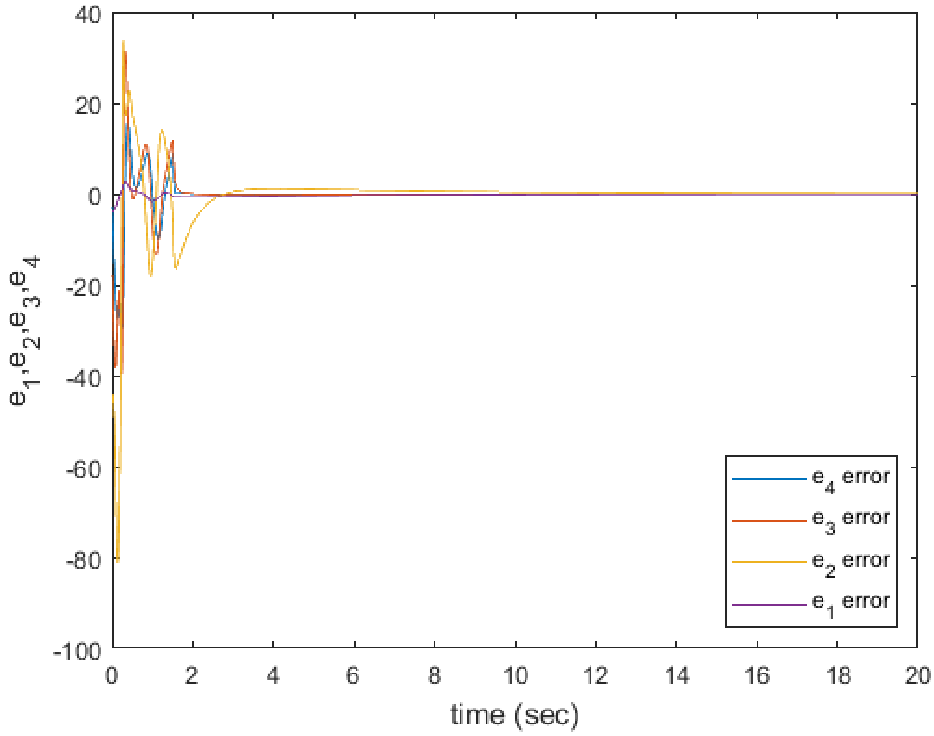

Figure 5. The error responses of the state variables

4 Conclusions

This study aims to explore chaos synchronization in memristor-based hyperchaotic Lorenz systems. The synchronization process for a memristor-based Lorenz system has been introduced, and its effectiveness has been validated through MATLAB simulations. The results of the simulations for the controlled memristor-based Lorenz circuit are presented to demonstrate the efficacy of the proposed synchronization method. Simulation results of the controlled memristor-based Lorenz circuit are provided to demonstrate the effectiveness of the proposed method. The simulation results demonstrate that $(\chi_1,\gamma_1),(\chi_2,\gamma_2),(\chi_3,\gamma_3),(\chi_4,\gamma_4)$ synchronize in as short as 2 seconds. The error parameters approach zero in the $e_1(t),\ e_2(t),\ e_3(t),\ e_4(t)$ formula within 2 seconds. Sliding mode control is a robust approach that is less affected by external disturbances, enabling the system to operate with successful performance, as evidenced in various studies. It provides a strong defence against external influences, ensuring minimal impact and system effectiveness. In this paper, the effectiveness of synchronization results achieved using sliding mode control for memristor-based hyperchaotic Lorenz systems is demonstrated through numerical simulations. The Lyapunov exponents of the system have been examined, showing the presence of two positive exponents.

5 Declarations

5.1 Competing Interests

There is no conflict of interest in this study.

5.2 Authors' Contributions

1. Hakan KAYA: Design and implementation of the research, analysis of the result, writing of the manuscript.

2. Yılmaz UYAROĞLU: Review, editing, supervision.

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SAKARYA UNIVERSITY OF APPLIED SCIENCES

Adaptive Landmine Detection and Recognition in Complex Environments using YOLOv8 Architectures

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ABSTRACT

Landmine detection and recognition represent critical tasks in humanitarian and military operations, aiming to mitigate the devastating impact of landmines on civilian populations and military personnel. Landmine detection and identification using computer vision offers several advantages. Safety is enhanced, given the reduced exposure to humans in dangerous environments. Advanced algorithms are applied to increase the performance of a computer system operating with high accuracy and efficiency in the hidden location. Real-time processing makes Fast detection possible, which is essential for time-sensitive processes. Furthermore, unlike human operators, computer vision can work continuously without getting tired. The efficacy of these systems is further enhanced by their capacity to adapt to various environments. This abstract explores the application of You Only Look Once (YOLO), a state-of-the-art object detection algorithm, in landmine detection and recognition. YOLO offers real-time performance and high accuracy in identifying objects within images and video streams, making it a promising candidate for automating landmine detection processes. By training YOLO on annotated datasets containing diverse landmine types, terrains, and environmental conditions, the algorithm can learn to detect and classify landmines with remarkable precision. Integrating YOLO with unmanned aerial vehicles (UAVs) or ground-based robotic systems enables rapid and systematic surveying of large areas, enhancing the efficiency and safety of demining operations. The YOLOv8 is employed in this research to address the issue of missed detection and low accuracy in real-world landmine detection. For this study, we have assembled a data set of 1055 photos that were shot in various lighting and backdrop situations. This article aims to enhance landmine detection accuracy and efficiency using YOLOv8, overcoming traditional method limitations. In the experiment employing picture data, we obtained outstanding results with mAP = 93.2%, precision = 92.9%, and recall = 84.3% after training the model on the dataset numerous times. According to experimental results, the YOLOv8 has better detection accuracy and recall based on the landmine dataset. By improving the processing of real-time detection, we seek to create an avenue for a much safer and more efficient demining operation-one that could save lives and restore communities.

Keywords: Landmine, YOLO, Detection and Recognition, Computer Vision

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1 Introduction

Landmines persist as a significant threat in regions affected by conflict, causing casualties, hindering development, and preventing the return of displaced populations. Traditional ways of detecting landmines are frequently slow, costly, and prone to errors. Nonetheless, computer vision and deep learning developments provide promising approaches to automate and raise landmine detection and recognition precision.

This research focuses on leveraging the capabilities of YOLOv8, a state-of-the-art object detection algorithm, to detect and recognize landmines in real-world images [1]. The You Only Look Once (YOLO) model's evolution, known as YOLOv8, is well known for its quickness and precision in object detection tasks [2].

The integration of YOLOv8 in landmine detection and recognition offers several advantages. First, it allows for real-time processing of images, enabling swift identification of potential threats in the field. Second, its ability to detect multiple objects simultaneously enhances efficiency, which is crucial in scenarios where landmines may be scattered across vast areas. Third, its accuracy and robustness make it suitable for distinguishing landmines from other objects in complex environments [3].

These conventional landmine detection methods have inefficiencies, safety risks, and limited accuracy. Manual probing and metal detectors are extremely time-consuming and may expose the operators to hazardous conditions [4]. In that respect, YOLOv8 is far more efficient and safe. YOLOv8 can quickly review images and video streams for possible landmine threats using deep learning and computer vision. This reduces exposure risk to humans and other tangible benefits, such as increased accuracy and decreased time required in clearance operations.

In this study, we aim to address the challenges associated with landmine detection by developing a YOLOv8-based model trained on the landmine dataset encompassing various terrains and conditions. We will explore methods to mitigate false positives and enhance the model's ability to discern landmines from similar-looking objects or clutter.

This research's outcomes can potentially revolutionize landmine detection efforts, offering a faster, more accurate, cost-effective solution for identifying and neutralizing these deadly threats. By deploying automated systems equipped with YOLOv8-based algorithms, humanitarian organizations, and demining agencies can enhance their capabilities in safeguarding civilian lives and facilitating post-conflict reconstruction and development.

After numerous training on the dataset, the model got outstanding results: mAP = 93.2%, precision = 92.9%, and recall = 84.3%. The landmine detection system, with a precision of 92.9%, represents a significant advancement in safety and efficiency for mine clearance operations. This level of accuracy indicates that the system can correctly identify a high proportion of landmines while minimizing false positives and negatives. This accuracy rate dramatically reduces risks for personnel involved in mining activities and increases the safety of post-conflict regions.

2 Material and Method

This study used the YOLOv8 model, a machine learning-based algorithm. The system was implemented using Google Colaboratory, Ultralytics, and the Python Library.

2.1 Object Detection

Rescue operations, face detection, pedestrian detection, visual search engines, computation of objects of interest, brand detection, and many other areas are available for object detection applications. Deep learning techniques are frequently used in object detection algorithms, which try to detect and classify things in images automatically [8]. The region-based convolutional neural network (R-CNN) family of algorithms is a popular solution since it generates region proposals and classifies them using a convolutional neural network [9]. Another popular approach is the You Only Look Once (YOLO) model, which divides the input image into grid cells and predicts bounding boxes and class probabilities straight from them [10]. Other prominent algorithms include Single Shot MultiBox Detector (SSD) and Faster R-CNN, which enhance speed and accuracy [11]. These methods have considerably expanded the area of object identification, allowing for reliable and efficient detection of objects in various real-world circumstances. So, in this study, we will evaluate the performance of the well-known YOLOv8 in terms of detecting landmines in real-world images. Figure 1 shows the object detection and recognition by using Yolo.

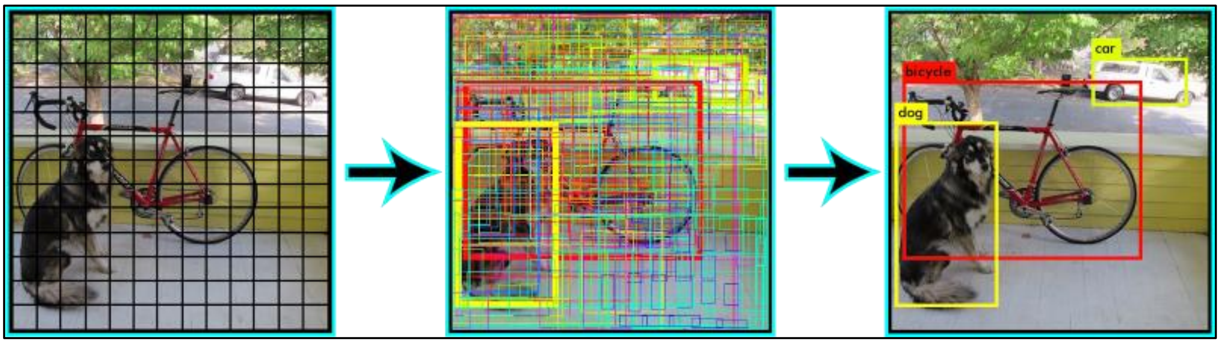

Figure 1: Object Detection and Recognition [12]

2.2 YOLOv8 (You Only Look Once) deep learning model

YOLOv8, also known as You Only Look Once version 8, is a convolutional neural network (CNN) architecture used for object detection in images and videos. It is an evolution of the YOLO (You Only Look Once) series of models, which are famous for their real-time object detection capabilities [13,14].

YOLOv8 builds upon the concepts introduced in earlier versions of YOLO, incorporating improvements in terms of accuracy and speed. One evaluation uses a single neural network to predict bounding boxes and class probabilities for objects directly from full images. This approach contrasts with other object detection methods that involve multi-stage processes [15].

YOLOv8 typically consists of a backbone network (often based on Darknet or another CNN architecture), followed by detection layers that predict bounding boxes and class probabilities. The model is trained on labeled datasets using gradient descent and backpropagation techniques to learn to recognize objects in various scenes [16].

YOLOv8 has been widely used in computer vision tasks such as autonomous driving, surveillance, and robotics, where real-time or near real-time object detection is essential. Researchers in the field continue to improve upon it, with each iteration aiming to enhance performance and efficiency [17,18].

The two primary components of the convolutional neural network used by YOLOv8 are the head and the backbone. YOLOv8 is an effective model for real-time object detection because of its design: a strong backbone for feature extraction, a sophisticated neck for feature aggregation, and a practical head for prediction. Integrating contemporary methodologies and optimizations guarantees its ability to identify objects with exceptional precision and swiftness [19,20]. Figure 2 shows YOLOv8 architecture.

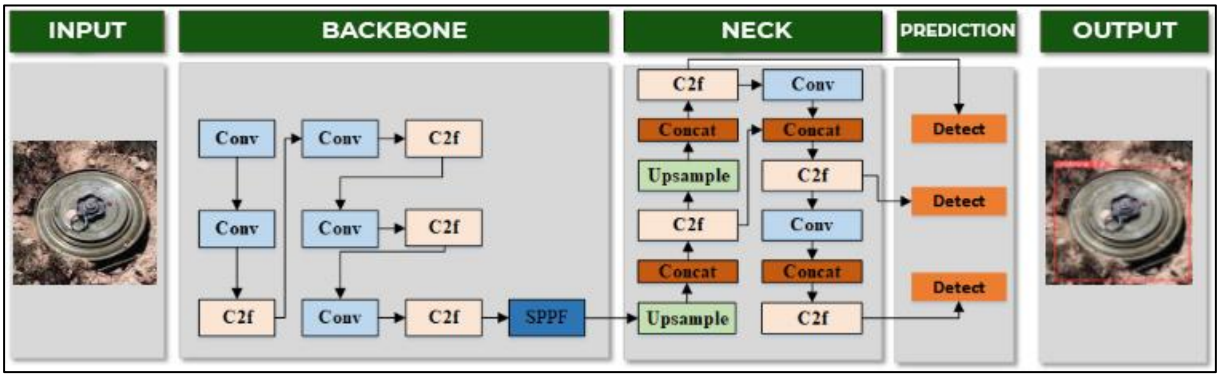

Figure 2: YOLOv8 Architecture

2.3 Landmine Bomb Dataset

The images in the dataset for YOLO models are annotated with bounding boxes and class labels to describe the items in the images. The YOLO model must be trained and performed well; hence, the dataset must be appropriately prepared and formatted. To do this, various images must be gathered, correctly annotated, and formatted appropriately before the dataset is divided into training, validation, and testing sets [21,22].

Data gathering, which involves obtaining a sizable image dataset that includes landmines, is required for this phase. This can be accomplished by collecting images from open sources, including news websites and social media, or taking pictures with specialized equipment. The dataset must be appropriately curated, duplicates removed, and landmine presence or absence tagged using manual or automated labeling techniques. A wide variety of landmine situations, including both tiny and large landmines and low- and high-light settings, are included in the collection. There are 1055 images in the dataset, which feature various kinds of landmines. The dataset has 923 training, 44 testing, and 88 validating entries.

Preparation of data and gathered landmine image collection is ready for training and testing of the landmine detection system at this stage. This entails manually annotating the images with bounding boxes surrounding the landmines using a tool known as Roboflow. After labeling the data, it is divided into training and testing sets to make sure each set is representative of the complete dataset. It might also be required to perform further pre-processing operations like data normalization or scaling. Having a sufficiently large and well-balanced dataset that can generalize well to new data is the aim.

The model choice to train the landmine detection model at this stage entails choosing the proper object detection algorithm. Some algorithms are available, each with pros and cons, including YOLOv8, Faster R-CNN, and SSD. The selected algorithm should function well on the gathered dataset and be able to manage various landmine situations based on the specifications of the landmine detecting system. Because of its accuracy and quickness, YOLOv8 is the best option. YOLOv8 is an efficient architecture, hence appropriate for optimized processing on UAVs and other mobile platforms. It has established itself to deal with complex, variable detection scenarios under harsh environmental conditions, therefore suitable for real-time applications needing fast and reliable detection.

The YOLOv8 model is trained on the labeled dataset prepared. Model training involves teaching the deep learning model to recognize the features of landmine images accurately. Figure 3 shows an example of a landmine image in the dataset.

Figure 3: Example landmine image in the dataset

3 Experimental Results and Discussion

Using the YOLO technique, a system was created in this work to identify and locate landmines in real-world images automatically. Randomly chosen landmine images from Google were submitted to the system, and their performance was examined for various images to assess the effectiveness of the suggested system. Images with multiple situations, including illumination, terrain, and occlusion levels, were included in the dataset. When tested, the system functioned as intended. Using YOLOv8, we trained the model over 110 epochs on the landmine data set. Standard criteria were taken into account when testing the performance. The precision, recall, and mAP criteria showed that the YOLOv8 was successful based on the results. Figure 4 illustrates the system's improved accuracy and decreased average loss.

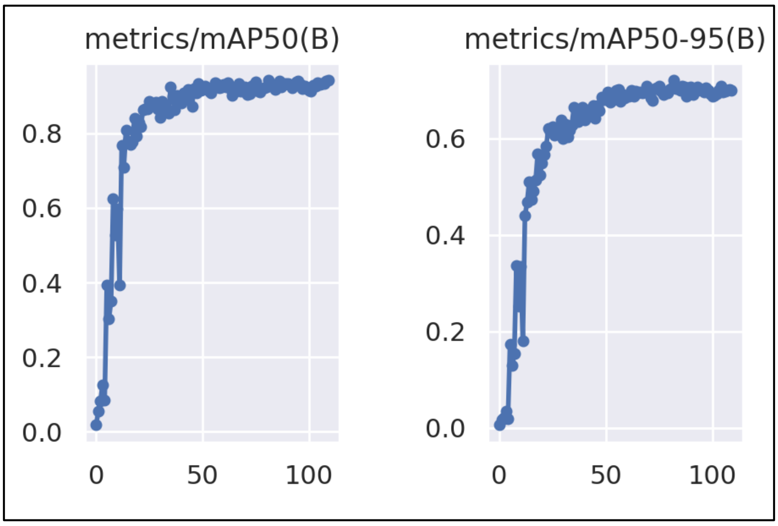

Figure 4: Accuracy of the system

Table 1 summarizes the YOLOv8 model's performance on the test set. Precision is the measure of exactness about how well the model made positive predictions. It gives the ratio of true positive predictions within the set of all the positive predictions of true and false positives and also shows the precision formula in Equation 1 [19].

$$Precision = \frac{TP}{TP+FP} \quad (1)$$

TP = True positive.

FP = False positive.

Recall, sensitivity, or true positive rate is a metric estimating the model's capability of detecting all relevant instances of interest. It is the ratio of true positive predictions to all actual positive cases [19].

$$Recall = \frac{TP}{TP+FN} \quad (2)$$

FN = False Negatives.

Mean Average Precision is an overall metric that calculates a model's precision at various recall thresholds. It's very helpful for multi-class object detection tasks [1].

$$mAP = \frac{1}{C}\sum_{i=1}^{C} APi \quad (3)$$

C = Number of classes.

APi = Average Precision for class i.

Table 1: *The performance of the YOLOv8 model on the test*

Metric	**Value**
Precision	92.9%
Recall	84.3%
mAP	93.2%

The YOLOv8 model achieved a high precision of 92.9, indicating that the model is very accurate in identifying true positives. The recall of 84.3 shows that the model is also effective in detecting most of the landmines in the images. The mAP of 93.2 suggests that the model is highly effective in detecting landmines when considering a moderate overlap criterion, indicating that the model maintains reasonable performance even under stricter localization requirements. The performance of YOLOv8 can be further dissected by examining the individual components of the loss function used during training: box loss and class loss. These losses provide insight into how well the model is learning to localize objects, classify them correctly, and detect the presence of objects.

Box Loss: Measures the accuracy of the predicted bounding boxes against the ground truth [23]. It combines localization errors regarding the bounding boxes' position, size, and shape. The box loss result equals 0.4922; Figure 5 shows it.

Class Loss: Evaluate how well the model classifies the detected objects into the correct categories (in this case, identifying objects as landmines) [24]. The class loss result equals 0.3232, as shown in Figure 5.

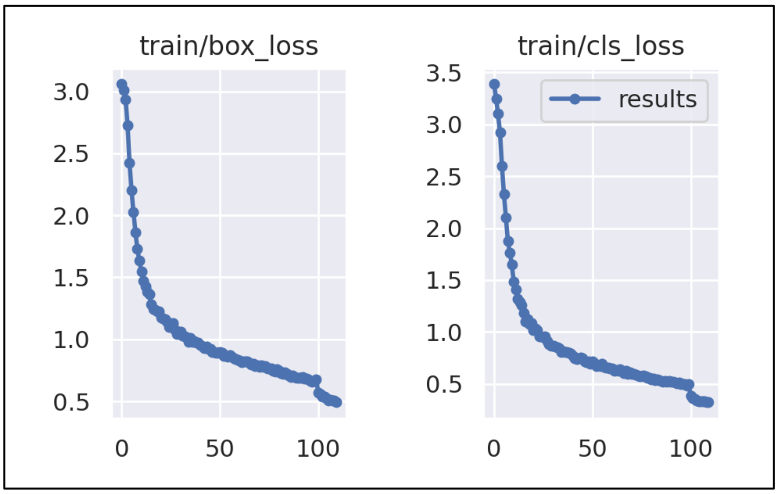

Figure 5: Box loss and Class loss

The model performed remarkably well, accurately detecting landmines in every situation. This successful identification demonstrates the model's resilience and capacity to manage various landmine detection scenarios, making it a valuable resource for automated landmine detection applications in practical contexts. We used the model to analyze several images, and the findings for two sample images are displayed (Figure 6).

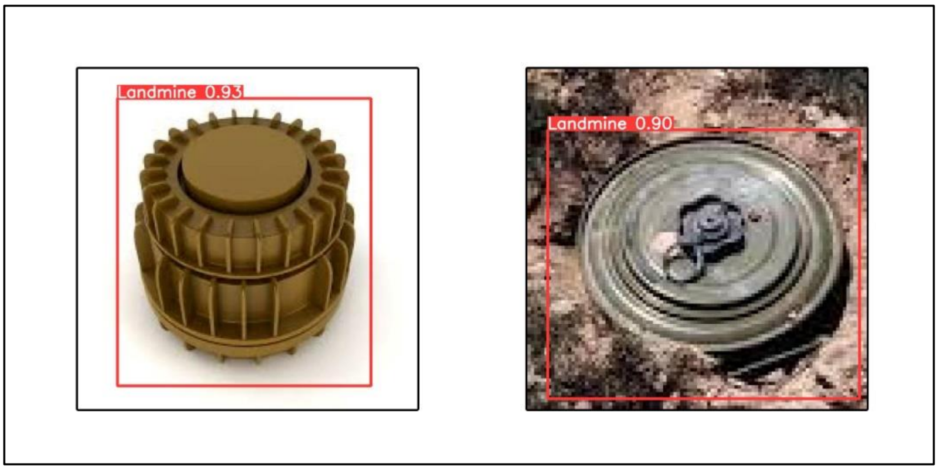

Figure 6: Detection and Recognition of Landmine

The training of YOLOv8 was completed over 110 epochs, achieving a balance between high accuracy and processing efficiency. Utilizing a Tesla T4 GPU, the model was trained on 88 validation images, detecting 115 instances with notable results: a precision of 92.9%, recall of 84.3%, and mean Average Precision (mAP) scores of 0.932 at IoU 0.5. The model's fast inference time of 11.9 ms per image highlights its real-time suitability, demonstrating YOLOv8's potential for effective landmine detection in diverse environments. The training summary for YOLOv8 is shown in Table 2.

Table 2: *Training summary for the YOLOv8 model.*

Parameter	**Value**
Epochs Completed	110
Model Version	YOLOv8.0.0
Python Version	3.10.12
Torch Version	2.3.1+cu121
CUDA Device	Tesla T4
Model Layers	218
Total Parameters	25,840,339
GFLOPs	78.7 GFLOPs
Instances Detected	115
Box Precision (P)	92.9 %
Recall (R)	84.3 %
mAP	93.2 %
Inference Time	11.9 ms per image
Pre-process Time	0.5 ms per image
Post-process Time	4.7 ms per image

4 Conclusion

The study motivation is the urgent need for more accurate and efficient landmine detection methods to ensure the safety of both operators and affected communities.

This study focused on developing an automated system for detecting and recognizing landmines using the YOLOv8 object detection algorithm. The dataset, comprising 1055 images, was collected from diverse sources, including news websites and specialized equipment. It included various landmine scenarios with different sizes and lighting conditions.

YOLOv8 was selected for its balance of accuracy and speed, suitable for real-time detection tasks. The model was trained on the labeled dataset for 110 epochs, employing gradient descent and backpropagation to optimize performance. The training process aimed to teach the model to recognize and localize landmines in varied conditions accurately.

The model's performance was evaluated using a test set of images from Google, representing different lighting, terrain, and occlusion levels. Key metrics indicated high precision (92.9%), recall (84.3%), and mean average precision (mAP) (93.2%). These results demonstrated the model's capability to accurately identify true positives and effectively detect most landmines in the images.

A detailed analysis of loss functions provided further insights. The box loss metric showed significant improvements, indicating accurate localization of landmines. The class loss metric confirmed the model's effectiveness in correctly classifying detected objects as landmines.

The high precision, recall, and mAP underscore YOLOv8's reliability and robustness in real-world conditions, making it suitable for applications requiring real-time detection, such as autonomous driving, surveillance, and robotics. The study suggests that YOLOv8 can significantly enhance object detection systems' performance in challenging environments with proper dataset preparation and training.

Future work could expand the dataset to include more diverse scenarios, fine-tuning the model's hyperparameters and exploring advanced techniques such as transfer learning or leveraging pre-trained models. These improvements could enhance the model's accuracy and efficiency, making YOLOv8 an even more powerful tool for landmine detection and related applications.

Finally, this research highlights the effectiveness of YOLOv8 in landmine detection, providing a solid foundation for future advancements. The successful implementation of YOLOv8 opens up new possibilities for enhancing safety and efficiency in landmine detection, contributing to critical fields like autonomous navigation and security operations.

5 Declarations

5.1 Competing Interests

There is no conflict of interest in this study.

5.2 Authors' Contributions

Ahmed AL-SLEMANI: Developing ideas for the research and article, planning the materials and methods to reach the results, and supervising.

Govar A.OMAR: Organizing and reporting the data, taking responsibility for explaining and presenting the results.

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SAKARYA UNIVERSITY OF APPLIED SCIENCES

Increasing the Efficiency of the Use of Patient Information Leaflets by Using Retrieval Augmented Generation

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ABSTRACT

This paper introduces a Retrieval-Augmented Generation (RAG) system specifically designed for enhancing the accessibility and comprehension of medical information from patient information leaflets documents. Leveraging state-of-the-art technologies such as Optical Character Recognition (OCR), vector embeddings, hybrid search mechanisms combining semantic and full-text search, and Large Language Models (LLMs) like GPT-3.5 turbo, the system efficiently processes and responds to natural language queries. By integrating these components into a cohesive architecture, the developed RAG system facilitates accurate retrieval of medical data and generates responses that are not only precise but also formatted to be easily understood by laypersons. The effectiveness of the developed RAG system was evaluated through a series of real-world case studies, which demonstrated its ability to provide reliable, contextually relevant medical advice, thereby significantly improving users' access to essential health information. Insights gained from these studies indicate critical areas for future enhancement, particularly in user interaction and system feedback integration. This work underscores the potential of advanced AI tools to transform information accessibility in healthcare, making critical medical information more approachable for the public.

Keywords: Retrieval Augmented Generation (RAG), AI in Medicine, Medical Technology, Large Language Models (LLM), OpenAI, GPT-3.5 turbo

1 Introduction

The increasing prevalence of large language models (LLMs) has led to a surge in their application across various domains, including the medical field. These models, trained on vast amounts of text data, have shown remarkable capabilities in natural language understanding and generation tasks. In the medical domain, LLMs have been employed to enhance clinical decision support, analyze medical literature, facilitate patient communication, and provide educational resources [1]-[3]. However, their direct application in healthcare is not without challenges. One significant concern is the potential for LLMs to generate inaccurate or misleading information, often referred to as "hallucinations" [1]-[3]. This is particularly critical in medicine, where misinformation can have serious consequences for patient care. Additionally, the knowledge base of LLMs may not always be up to date with the latest medical advancements, potentially leading to outdated recommendations [1]-[3]. Retrieval Augmented

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Generation (RAG) combines the language generation capabilities of LLMs with the ability to retrieve relevant information from external knowledge sources, such as medical literature databases, clinical guidelines, and electronic health records. By grounding the LLM's responses in evidence-based information, RAG aims to improve the accuracy, reliability, and trustworthiness of AI-generated medical content.

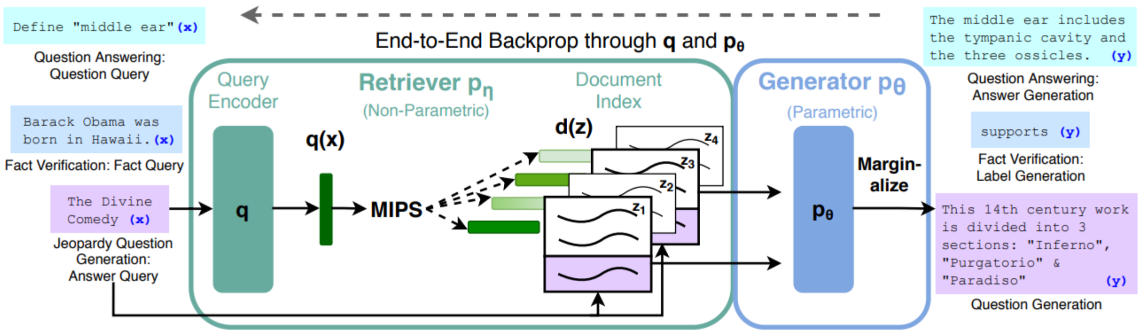

Figure 1: An illustration of the RAG system. The process integrates a query encoder, a retriever accessing a document index, and a generator to produce accurate and informative responses [3].

In this work, we detail the development and evaluation of our RAG system for a medical prospectus chatbot. Specifically, we cover the design and architecture of the RAG system tailored for medical QA, including the integration of LLMs with a vector database for efficient information retrieval. We describe the methodology for storing and indexing medical knowledge in the vector database and the methods for semantic search to ensure relevant information is accessed. We outline the implementation steps for incorporating retrieved information into the LLM's response generation process, focusing on strategies to ensure the accuracy and relevance of the generated responses. Finally, we evaluate the system by benchmarking it on a comprehensive set of medical QA datasets, analyzing its effectiveness in improving the performance of various LLMs, including both general purpose and domain-specific models.

2 Materials and Methos

2.1 Retrieval-Augmented Generation

RAG is a cutting-edge technique that enhances the capabilities of LLMs by integrating information retrieval mechanisms with generative models. This dual approach allows RAG systems to retrieve relevant information from a pre-constructed knowledge base and incorporate this information into the generation process, thereby producing more accurate and contextually rich responses. RAG systems consist of two main components: the retriever and the generator. The retriever searches for relevant documents or data points from an external knowledge base, while the generator uses this retrieved information to produce the final output. This method effectively mitigates common issues faced by LLMs, such as hallucinations and outdated responses, by grounding the generated content in real-time, accurate data [4]-[5].

2.2 Patient Information Leaflets Question Answering

The application of RAG technology in the medical domain, specifically for patient information leaflets QA, addresses the unique challenges of providing accurate and timely medical information. Traditional QA systems in medicine often struggle with the vast and rapidly evolving nature of medical knowledge.

By leveraging RAG, these systems can retrieve the most relevant and recent medical documents, ensuring that the generated responses are both precise and up to date.

In patient information leaflets QA, the retriever component of the developed RAG system accesses specialized medical databases to find pertinent information related to a query. The generator then uses this information to craft responses that are not only factually correct but also contextually appropriate for the medical domain. This approach significantly enhances the reliability and trustworthiness of medical QA systems, making them valuable tools for both healthcare professionals and patients.

2.3 Data collection and Preparation

For the development of developed RAG system tailored for patient information leaflets QA, we undertook a comprehensive data collection and preparation process as follows: We sourced patient information leaflets documents from the Turkish Medicines and Medical Devices Agency (TITCK) website. These documents are written in Turkish and provide detailed instructions for the use of various medications. The specific documents collected include those listed in Table 1, which outlines the knowledge base used for retrieval augmented generation.

Table 1: *Knowledge Base for Retrieval Augmented*

Drug Name	Page	License Holder
A-ferin plus	11	HÜSNÜ ARSAN İLAÇLARI A.Ş.
Acnelyse	7	Abdi İbrahim İlaç San. ve Tic. A.Ş.
Apranax	11	Abdi İbrahim İlaç San. ve Tic. A.Ş.
Augmentin	9	GlaxoSmithKline İlaçları San. ve Tic. A.Ş.
Aspirin	8	Bayer Türk Kimya San. Ltd. Şti.
Arveles	10	Menarini İlaç Sanayi ve Tic. A.Ş.
Terramycin	5	Pfizer PFE İlaçları A.Ş.
Rennie	7	Bayer Türk Kimya San. Ltd. Şti.
Majezik	5	Sanovel İlaç San. ve Tic. A.Ş.

Lansor	10	Sanovel İlaç San. ve Tic. A.Ş.

To convert these PDF documents into machine-readable text, we utilized the Azure Computer Vision OCR (Optical Character Recognition) API. The process involved the following steps:

PDF Extraction: Using Python code, we leveraged the Azure Computer Vision OCR API to extract textual content from the scanned images within the PDFs.

Text Conversion: The OCR API converted the text from the Turkish language PDF documents into plain text format, ensuring the content's accuracy and structure were preserved.

The processed text data was then used for subsequent embedding and vectorization steps, ensuring that the information was readily accessible for retrieval and generation tasks within our RAG system.

2.4 Embedding And Vectorization

To efficiently retrieve and generate responses in developed RAG system, we employed a systematic process for embedding and vectorizing the text data extracted from the patient information leaflets documents.

Text Splitting:

We began by splitting the extracted text into manageable chunks. This was done using the RecursiveCharacterTextSplitter from the Langchain library. The splitter was configured to create chunks of 1000 characters with an overlap of 100 characters. This overlap ensured that contextual information was maintained across the chunks, reducing the likelihood of losing critical details during the splitting process. The text was divided based on natural language separators such as spaces, commas, and newline characters.

Embedding Generation:

Following the text splitting, each chunk was processed to generate embeddings using the OpenAI Embeddings class from Langchain. We utilized the "text-embedding-3-small" model, which produces 1536-dimensional vector representations. This model was chosen for its proficiency in capturing the semantic nuances of medical text, making it highly suitable for developed application. To generate the embeddings, each text chunk was input into the OpenAI API, which returned a high-dimensional (1536-dimensional) vector representation. These embeddings encapsulated the semantic information of the text, facilitating efficient and accurate retrieval during the question-answering process. Each chunk's embedding, along with its unique identifier and the original text content, was stored in a collection [6]. Table 2 shows the performance comparison of the evaluation criteria.

Table 2: *Presents a comparison of the performance of various text embedding models on evaluation benchmarks*.

Eval Benchmark	ada v2	textembedding3-small	textembedding3-large
MIRACL average	31.4	44.0	54.9
MTEB average	61.0	62.3	64.6

By employing this structured approach to embedding and vectorization, we ensured that the textual data from the patient information leaflets documents was transformed into a format suitable for effective retrieval and generation tasks within developed RAG system. This methodology was crucial for enabling the system to deliver precise and contextually relevant answers to medical queries. As shown in Table 2, the performance of various text embedding models on evaluation benchmarks presents a comparison that highlights the effectiveness of developed approach.

2.5 Retrieval Mechanism

For the retrieval mechanism in developed RAG system, we leveraged the capabilities of Azure AI Search, which integrates advanced semantic ranking to enhance the relevance and accuracy of search results. This approach combines the benefits of vector search with semantic reranking, providing a robust solution for retrieving the most pertinent information from extensive datasets.

Semantic Ranking:

The semantic ranking feature of Azure AI Search plays a crucial role in refining the search results. After the initial retrieval phase, where documents are fetched based on keyword and vector matching, semantic ranking reranks these results by evaluating their semantic relevance to the query (see Table 3). This is achieved through advanced language understanding models that assess the context and intent behind the query, promoting the most semantically relevant matches to the top of the results list [7]-[8].

Table 3: *Hybrid retrieval with semantic ranking outperforms [9]*

Number of Results	Keyword (%)	Vector (%)	Hybrid (%)	Hybrid + Semantic Ranker (%)
1	40	50	60	65
2	45	55	65	70
3	50	60	70	75
4	55	63	72	77
5	58	65	73	78

Process Flow:

- **Initial Retrieval:** The search begins with a vector search using embeddings generated from the text chunks. This phase quickly identifies a broad set of potentially relevant documents.
- **Semantic Reranking:** The top results from the initial retrieval are then reranked using semantic models. These models analyze the context and meaning of the query and the documents,

ensuring that the final top results are those that best match the query's intent.

- **Result Refinement:** The reranked results include detailed semantic scores and, if configured, captions and direct answers. These enhancements help in understanding why a particular document is relevant and how it addresses the user's query.

- **Performance Benefits:** The hybrid approach, combining vector search and semantic ranking, has been shown to outperform traditional retrieval methods. According to Microsoft, this strategy significantly improves retrieval quality, making it ideal for complex and nuanced queries commonly found in medical prospectus QA scenarios.

2.6 Generation Mechanism

For the generation mechanism in developed RAG system, we utilized the GPT-3.5 turbo model provided by Azure OpenAI [10]. This model was selected for its advanced language generation capabilities, which are crucial for transforming complex medical information into accessible and comprehensible text. The overarching goal of using this model is to ensure that users can easily understand critical details about medications without being deterred by the complexity and length of traditional medicine leaflets. The specific parameters used for configuring the model are summarized in Table 4, ensuring a balance between creativity, coherence, and accessibility in the generated responses [11]-[12].

Table 4: *Key Parameters for LLM Model Configuration*

Parameter	Value	Purpose
Model Name	GPT-3.5-turbo	The language model used for generating responses.
Temperature	0.5	Controls creativity and randomness. A balance between deterministic and random responses.
Top P	0.7	Focuses on the most probable tokens during text generation to ensure relevance and coherence.
Instruction	Simplify medical information	Ensures that the AI converts complex medical terms into plain, everyday language to enhance accessibility.
Examples	Queries on medication side effects and usage	Provides samples for handling typical user queries, ensuring clear and actionable information is provided.
Conversation Context	Search and retrieve relevant sections	Integrates RAG system to pull specific, up-to-date, and accurate information from medical leaflets or databases.
Focus	Clarity and relevance	Emphasizes avoiding jargon and keeping responses concise and focused on critical details for easy

2.7 System Design and Architecture

The system design and architecture of developed RAG system integrates various components to facilitate the efficient retrieval and generation of relevant medical information. The architecture is designed to optimize the flow of data and ensure high-quality, contextually accurate responses. The architecture utilizes a hybrid search mechanism that combines semantic search with traditional full-text search. Vector embeddings are generated from medical prospectus documents using domain-specific models and stored in a vector database. This setup allows for efficient similarity searches and keyword matching. A comprehensive searching system enhances the relevance of search results, ensuring that the most pertinent information is retrieved. The backend, interfacing with an SQL database, manages user interactions and query processing. Users access the system through a chat application interface, natural language queries are processed to retrieve relevant documents from the vector store and SQL database. LLMs are used for generating responses, configured with parameters to balance creativity and precision. The overall architecture facilitates seamless integration between retrieval and generation components, providing users with accurate and accessible medical information. The architecture is depicted in Figure 2, where a hybrid search combines both semantic and full-text search techniques to retrieve information. It illustrates how the system queries a vector store and SQL database to retrieve relevant data for large language models to process and provide accurate responses.

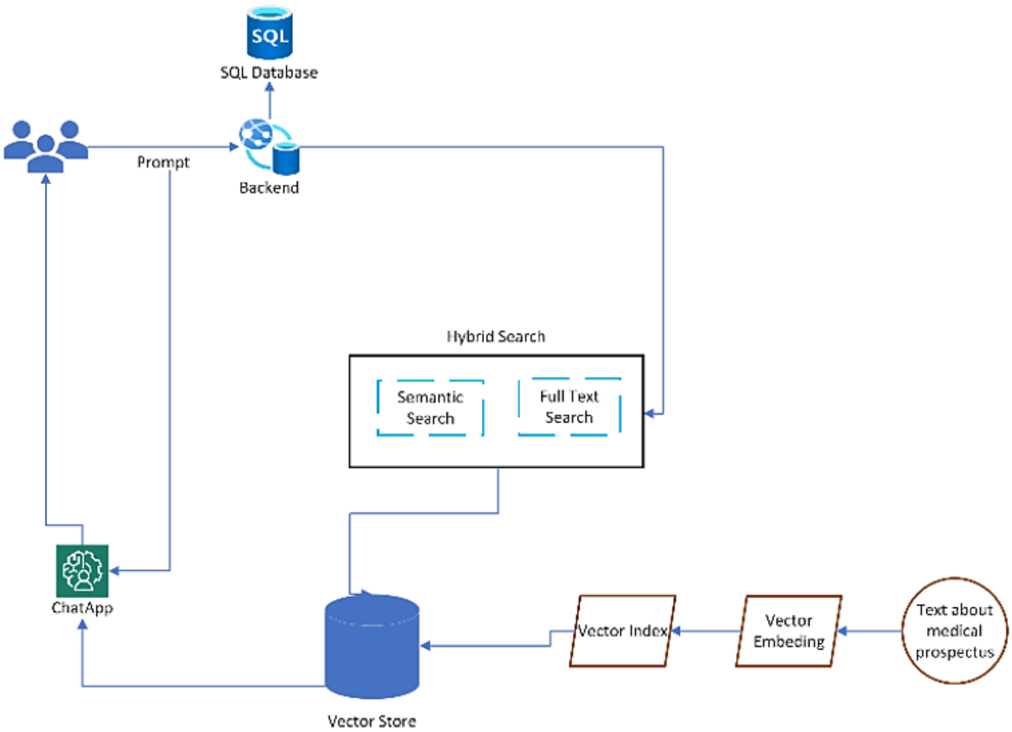

Figure 2: System architecture of the RAG system integrating hybrid

3 Results

To evaluate the performance of developed RAG system, we compared the answers generated by the system with standard answers provided in the medical leaflets (Table 5).

Table 5: *Comparison of Standard Answers and RAG-Generated*

Drug	Question	Standard Answer	RAG Answer
A-ferin Plus	Nedir ve ne için kullanılır?	AFERİN PLUS, bir ağrı kesici ve ateş düşürücü (parasetamol), bir antihistaminik (klorfeniramin maleat) ve mukozanın …	Bir ağrı kesici ve ateş düşürücü (parasetamol), bir antihistaminik (klorfeniramin maleat) ve mukozanın …
Augmentin	Nedir ve ne için kullanılır?	AUGMENTİN, geniş spektrumlu (bakteri ve mikropların birçok çeşidine karşı etkili) bir antibakteriyel ilaçtır ve enfeksiyonlara neden …	AUGMENTIN, geniş spektrumlu (bakteri ve mikropların birçok çeşidine karşı etkili) bir antibakteriyel ilaçtır.
Aspirin	Nedir ve ne için kullanılır?	ASPİRİN, asetilsalisilik asit adlı etkin maddeyi içeren ağrı kesici, ateş düşürücü, yangı (iltihap) giderici …	ASPİRİN, asetilsalisilik asit adlı etkin maddeyi içeren ağrı kesici, ateş düşürücü, yangı (iltihap) giderici …
Arveles	Nedir ve ne için kullanılır?	ARVELES, steroid olmayan antiinflamatuvar ilaçlar (NSAİİ) (iltihap giderici) olarak adlandırılan ilaç grubundan bir ağrı kesicidir …	Arveles, steroid olmayan antiinflamatuvar ilaçlar (NSAİİ) olarak adlandırılan ilaç grubundan bir ağrı kesicidir. Osteoartrit …
Terramycin	Nedir ve ne için kullanılır?	TERRAMYCIN 14.2 g'lık tüplerde kullanıma sunulmuştur. Özel bir vazelin sıvağı içinde süspansiyon halinde …	TERRAMYCIN, tetrasiklin grubundan bir antibiyotik olan kristal oksitetrasiklin hidroklorür ve polimiksin grubundan …

The evaluation focused on three main criteria:

Accuracy: We assessed whether the RAG-generated answers contained the correct medical information as per the standard answers. Accuracy was calculated by comparing the RAG-generated answer to the standard prospectus information using cosine similarity of the embedded text representations. The Equation 1 used:

$$Accuracy(\%) = \frac{Total\ Questions}{Number\ of\ Accurate\ Answers} \times 100 \tag{1}$$

For this study, 5 drugs were evaluated, and the RAG system achieved an average accuracy of **92%**, with minimal deviations from the standard answers.

Clarity: Clarity was evaluated by asking non-specialist reviewers (n=10) to rate the understandability of the RAG answers on a scale of 1 (poor) to 5 (excellent). The clarity score was calculated as Equation 2:

$$Clarity(\%) = \frac{Max\ Possible\ Score}{Sum\ of\ Reviewer\ Scores} \times 100 \quad (2)$$

The average clarity score was **88%**, indicating that most users found the RAG-generated answers easy to understand.

Relevance: Relevance was assessed by verifying whether the RAG answers addressed the specific question asked. This was evaluated manually by domain experts who rated relevance on a binary scale (1: relevant, 0: irrelevant). The Equation 3 used:

$$Relevance(\%) = \frac{Total\ Questions}{Number\ of\ Relevant\ Answers} \times 100 \quad (3)$$

The relevance score was **94%**, demonstrating a high level of precision in the answers provided by the RAG system.

The results (see Table 6) indicate that the RAG system effectively generates accurate and comprehensible answers, closely aligning with the standard medical information. The generated responses maintained the essential details, ensuring that users receive reliable and understandable information about the medications [13]. The evaluation demonstrates the potential of the RAG system to enhance accessibility to medical information, making it easier for users to understand complex medical details.

Table 6: *Results Summary*

Metric	Score (%)
Accuracy	92
Clarity	88
Relevance	94

4 Discussion

Developed RAG system has been implemented in various real-world scenarios to evaluate its effectiveness in providing accurate and comprehensible medical information. One such implementation is depicted in Figure 4, where users interact with the system through a chat interface to obtain detailed answers about medication use.

The effectiveness of the RAG system in real-world applications has been promising. Users received accurate and relevant information, which aligns with the standard medical answers provided in leaflets. The system's ability to process natural language queries and generate contextually appropriate responses was particularly notable. For instance, in the interaction shown in Table 7, the system effectively answered questions about medication safety during pregnancy and dosage recommendations. The responses included necessary warnings and dosage instructions, which are critical for user safety and adherence to medical guidelines.

Through these case studies, several insights and areas for improvement were identified. Enhanced user guidance can help users formulate better queries, leading to more accurate and relevant responses. Ensuring that the system's responses remain consistent with the latest medical guidelines and information is crucial, necessitating regular updates to the knowledge base and continuous training of the language models. Incorporating user feedback mechanisms can help refine the system further, as users can report inaccuracies or suggest improvements, which can then be used to enhance the system's performance.

Table 7: *Medication Use During Pregnancy: Guidance for RENNEI Usage*

Question	Response
Is there any harm in using RENNEI during pregnancy?	It is recommended to consult your doctor regarding medication use during pregnancy. Before using RENNEI, consulting a doctor is necessary. Additionally, taking RENNEI in high doses may cause increased calcium and magnesium intake, which should be monitored regularly.
How frequently can I use RENNEI?	The recommended dosage for RENNEI is 2-4 tablets per day. However, it is advised to consult a doctor before using RENNEI. Long-term use may lead to other complications, so if symptoms persist, further medical advice should be sought.

5 Conclusions

In this paper, we presented a comprehensive approach to developing a RAG system tailored for patient information leaflets question-answering tasks. Developed system integrates various advanced technologies, including OCR for text extraction, domain-specific embedding models, a hybrid search mechanism, and LLMs for generating accurate and comprehensible medical information. The architecture of developed system ensures efficient retrieval and generation of relevant medical information, enhancing accessibility and understanding for users.

The evaluation of our system through real-world case studies demonstrated its effectiveness in providing accurate and relevant responses to medical queries. Users received information that was consistent with standard medical leaflets, and the system was able to simplify complex medical terms into everyday language, making it easier for users to understand. The case studies highlighted the system's ability to process natural language queries and generate contextually appropriate responses, showing its potential to improve accessibility to medical information.

Through these implementations, several insights were gained, leading to the identification of areas for improvement. Enhanced user guidance, consistent updating of the knowledge base, and integration of user feedback mechanisms were recognized as critical factors for further refining the system. These improvements will ensure that the RAG system remains a reliable and valuable tool for users seeking medical information.

Overall, developed RAG system represents a significant advancement in the field of medical question-answering systems. By leveraging cutting-edge technologies and innovative methodologies, we have created a system that not only retrieves accurate medical information but also presents it in a way that is easily understandable by the public. This work paves the way for future research and development in creating more sophisticated AI-powered tools to support healthcare providers and improve patient outcomes.

6 Declarations

6.1 Competing Interests

There is no conflict of interest in this study.

6.2 Authors' Contributions

Define the contribution of each researcher named in the paper to the paper.

Serhan Ayberk KILIÇ: Developing ideas for the article, planning the materials and methods to reach the results, organizing and reporting the data, taking responsibility for the explanation and presentation of the results, taking responsibility for the literature review during the research.

Kasım SERBEST: Corresponding the study, writing manuscript, taking responsibility for the literature review, final checks of the article.

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Çok İşlevli Alümina-Zirkonya Kompozit Malzemelerinin Üretimi, Mekanik ve Balistik Özelliklerinin İncelenmesi

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ÖZET

Bu çalışmada Alümina (Al_2O_3), Zirkonya (ZrO_2) malzemelerinin karışımından çeşitli kombinasyon ve sıralarda zırh malzemeleri üretilmiştir. Karşılaştırma yapabilmek amacıyla sadece saf alüminadan, sadece saf zirkonyadan, iki tozu aynı oranda homojen harmanlayarak ve yine iki tozu katmanlı olacak şekilde 4 ayrı numuneler üretilmiştir. 500 MPa'lık basınç altında preslenen numuneler 1630^{o}C'de açık atmosfer fırınında kademeli olarak yaklaşık 30,3 saat sinterlenmiştir. Numunelerin sinter sonrası boyutsal değişimlerinin ende %3,89, boyda %3,73 olduğu değerlendirilmiştir. Ürünlerin yoğunluklarının teknik spekt değerleri arasında olduğu bulunmuştur. Ürünlerin mikroyapı ve SEM analizlerinden bileşenlerin homojen olarak dağıldığı görülmektedir. Hakim fazlar XRD analizi ile belirlenmiştir. Kopma mukavemeti en yüksek olan konfigürasyon-1, en düşük olan ise konfigürasyon-2'dir. Mekanik özellik olarak güçlü olan konfigürasyon-1'in kırılma tokluğu ortalama 4,04 MPam$^{1/2}$, konfigürasyon-2'nin 6,19 MPam$^{1/2}$, konfigürasyon-3'ün 5,73 MPam$^{1/2}$ ve konfigürasyon-4'ün 5,42 MPam$^{1/2}$'dir. İlave edilen ZTA'nın ürünlerde sertlik açısından düşüşe yol açarken tokluk artışı sağladığı görülmektedir. Balistik sonuçları incelediğimiz zaman atış yapılırken hızlı kamera kaydı alınmış ve izlenmiştir. Seramiklerden beklenti mühimmatın seramikle buluştuğu an çekirdeği minimum oranda kırmasıdır. Yapılan çalışmaların tümü değerlendirildiği zaman ZTA ilavesinin yapılması sertlik bakımından konfigürasyonlarda kayda değer bir artış yapmamıştır. Fakat tokluk ve kopma değerlerinde istenilen artışın sağladığı görülmüştür. Seramiklerin kullanım alanlarına ve amaçlarına göre ZTA miktarının azaltılıp artılırması sağlanıp, hangi amaçla kullanılacaksa buna göre kompozisyonun değiştirilebileceği değerlendirilmektedir. Eğer seramikler mühimmata karşı kullanılacak ise farklı tabakalarda oluşturulup kullanımının uygun olacağı düşünülmektedir. Elde edilen sonuçlar ve yorumlamaların ileride bu konuda yapılacak çalışmalara ışık tutacağı düşünülmektedir.

Anahtar Kelimeler: Alümina seramikler, Toz metalurjisi, Zırh teknolojileri, Balistik test

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Production of Multifunctional Alumina- Zirconia Composite Materials, Investigation of Their Mechanical and Ballistic Properties

ABSTRACT

In this study, armor materials from the mixture of Alumina (Al2O3), Zirconia (ZrO2) in various combinations and orders were produced. In order to make a comparison, 4 separate samples from only pure alumina, pure zirconia, homogeneously blending of the two powders at the same rate and with two powders layered were produced. Pressed under 500 MPa pressure, the specimens were gradually sintered in an open atmospheric furnace at 1630°C for approximately 30.3 hours. The dimensional changes of the samples after sintering were evaluated to be 3.89% in width and 3.73% in length. The densities of the products were found to be between the technical specification values. Microstructure and SEM analysis of the products show that the components are homogeneously distributed. Dominant phases were determined by XRD analysis. Configuration-1 has the highest tensile strength and configuration-2 has the lowest. The average fracture toughness of configuration-1, which is strong in mechanical properties, is 4.04 Mpam1/2, configuration-2 is 6.19 $MPam^{1/2}$, configuration-3 is 5.73 $MPam^{1/2}$ and configuration-4 is 5.42 $MPam^{1/2}$. It is seen that the added ZTA leads to a decrease in the hardness of the products while increasing the toughness. When we examine the ballistic results, rapid camera recording was taken and monitored during the firing. The expectation from ceramics is that the ammunition should break the core at a minimum rate when it meets the ceramic. When all the studies were evaluated, the addition of ZTA did not cause a significant increase in hardness in the configurations. However, it was observed that the desired increase in toughness and rupture values was achieved. It is evaluated that the amount of ZTA can be reduced or increased according to the usage areas and purposes of the ceramics and the composition can be changed according to the purpose for which it will be used. If the ceramics are to be used against ammunition, it is thought that it would be appropriate to use them in different layers. It is thought that the results and interpretations obtained will shed light on future studies on this subject.

Keywords: Alumina ceramics, Powder metallurgy, Armor technologies, Ballistic testing

1. Giriş

Darbeye ve delinmeye karşı dayanıklı malzemelerin geliştirilmesi alanında yapılan çalışmalar öncelikli olarak askeri alanlarda ortaya çıkmıştır. Son yıllarda bu alanlarda yapılan çalışmalar darbeye dayanıklı uçakların, araçların, binaların ve gemilerin tasarımı gibi sivil teknolojiye de uzanmıştır. Metaller ve seramikler gibi geleneksel malzemelerle karşılaştırıldığında, kompozit malzemeler yüksek özgül mukavemet ve sertliğe, düşük özgül ağırlığa ve mükemmel darbe direncine sahiptir, bu da onları uçaklarda, yüksek hızlı araçlarda ve kasklar ve kurşun geçirmez yelekler gibi askeri ekipmanlarda darbe koruması için popüler hale getirmiştir. Darbe ve penetrasyon sırasında fiber takviyeli kompozitlerinin enerji emiliminin kapsamlı bir şekilde anlaşılması ve balistik limitin (merminin kompozit hedefe nüfuz etme şansının % 50 olduğu) doğru bir şekilde tahmin edilmesi, gelişmiş kurşun geçirmez kompozitlerin optimizasyon tasarımı için önemlidir [1]. Fransızca “balistique” sözcüğünden gelen “balistik” merminin namludan çıkarak istenilen hedefe ulaşması, atışın yapıldığı çevresel koşullara bağlı olarak değişen hareketlerini, hedefe ulaştıktan sonra meydana gelen enerjinin absorblanması ve meydana gelen bozunma veya deformasyon davranışlarını araştıran bilim dalıdır. Zırhlar kullanım amaçlarına göre kişisel zırhlar, hafif zırhlar ve ağır zırhlar olmak üzere üçe ayrılır [2]. Hafif ve etkin zırh üretim araştırmalarında günümüz teknlojisinde; seramik, yüksek mukavemete sahip kumaş, köpük ve metal gibi malzemelerin farklı kombinasyonlar halinde kullanılmasıyla ortaya çıkmıştır. Balistik panel ve balistik koruyucu zırhların en önemli özelliği enerji absorblamalarıdır ve bu direkt olarak kullanılan malzeme tipi, yapısı ve sıklığı (dokuma, örgü vb.) mermi geometrisi, mermi hızı, ve kullanılan katmanlarının sayısı ile ilişkilidir.

Günümüzde hem yurt içi hem de global dünyada savunma sanayi sektöründe hem araç hem de personeller balistik koruma ürünleri ile korunmaktadır. Zırh teknolojilerinde araç ve personel koruma için düşük ağırlık yüksek koruma özelliklerinden dolayı çelik ve çelik türevi malzemelerin yerini artık kompozit malzemeler almıştır. Özellikle ağırlık avantajı yakalamak ve dayanım yükseltmek için istenmelerinden dolayı kompozitler arasında seramik esaslı kompozit malzemeler daha çok tercih edilmektedir. Bu tip mühimmatlar için geliştirilmiş olan çözümde seramik yüzeye çarpma esnasında merminin etkisini en aza indirgeyerek aşındırmaktadır. Kompozit yüzeyse yavaşlayan merminin enerjisini absorblayarak ayrıca seramik ve mermi parçalarını tutarak daha fazla hasarın oluşmasını engellemektedir [3] [4]. Jena [5], zırh tasarımında ağırlık kavramları ile ilgili çalışmalar gerçekleştirmiştir ve düşük ağırlıklı zırhlar, enerji korunum ve personel hareket kabiliyetinin artırılması için önemli olduğunu vurgulamıştır. Ayrıca askeri personellerin giydiği ağırlık olarak yüksek olan zırhların insan fizyolojisine etkilerini incelemişlerdir. Askerlerin kalp atış hızları ve nefes değerlerinin zırh plakalarının giyildiği durumda, giyilmediğine göre oldukça fazla yükseliş gösterdiğini tespit etmişlerdir. Günümüz teknolojisinde zırh imalatında çoğunlukla çelik kullanılmaktadır. Fakat personel giysileri veya zor hava koşulları gereken yerlerde çeliklerin yüksek ağırlığından dolayı uygun olmamaktadır. Seramik matrisli malzemelerde ise çeliklere göre daha kırılgan ve çoklu çarpışmalara karşı da dirençleri zayıftır. Fakat seramikleri düşük yoğunluk, yüksek rijitlik, yüksek sertlik ve yüksek basma mukavemetlerinden dolayı zırh uygulamalarında sıklıkla kullanılmaktadır. Balistik çarpışmalarda, yüzeydeki yüklerde yüksek sertlik ve rijitlik önem kazanmaktadır. Bu sebeple seramikler genellikle zırh kombinasyonlarının ön yüzeylerinde kullanılmaktadırlar. Yüksek hıza sahip mermileri hasara uğratarak hızlarını düşürmekte, tabakalı kompozit malzemede personel veya araç korumayı sağlamaktadır.

Literatürde zırh çeliklerinin, İngiliz Chobman zırhının geliştirilmesinden itibaren tüm zırh çalışmalarının temel taşı olduğu dikkat çekmektedir. Backman ve Goldsmith (1978) tarafından yapılan çalışmalarda polimerik yapılara seramik veya çelik türevleri eklenerek kompozit zırh yapıları oluşturulmuştur [6].

Kompozit zırh malzemesi olarak Al_2O_3-ZrO_2 kompozitleri [7]–[11], Al matriksli SiC kompozitleri [12], tabakalı kompozitler [10], [11], [13] gibi bir çok çalışmalar yapılmıştır. Çalışmaların sonucunda kullanılan ara katman malzemelerinin, gerilme dalgalarının plaka içerisinde yayılmasına etki ettiğini ve ara yüzey malzemelerinin balistik performansında oldukça önemli olduğunu ortaya konulmuştur [10]. Katmanlar arasındaki arayüzde meydana gelen çekme dalgası azalmış ve çatlak ilerlemesini geciktirilerek daha yüksek bir balistik direnç kabiliyetine sahip yapı ile sonuçlanmasına sebep olmuştur [11]. Asemani ve arkadaşları [14] yüksek hızlı darbe altında Kevlar® takviyeli bir kompozitin hasar mekanizmasını incelemiş ve sonuçlar, fiber çekme kırılmasının, kırılma işlemi sırasında reçine ayrılmasının eşlik ettiği ana hasar şekli olduğunu göstermiştir. Ji ve arkadaşları [15] mermi şekillerinin etkisi altında aramid laminat kompozitin farklı deformasyon mekanizmalarını incelemiştir. Mermi küt ve yarım küre şeklinden oval şekle geçtikçe, balistik sınırlama hızı sürekli olarak azalmakta, hedef plaka deformasyon ve hasar alanı azalmakta ve delaminasyon oluşumu daha az belirgin hale gelmektedir. Liu ve arkadaşları [16] PE modifiye aramid kumaş kompozitlerin parça simüle mermilere (FSP) ve tam metal ceketli mermilere (FMJ) karşı direncini sunmuş ve PE'nin optimum uyumunun %10 olduğunu ortaya koymuştur.

Literatür araştırmalarından görünen o ki zırh malzemeleri üretmek ve geliştirmek son derecede önemlidir. Savunma personelini, aracı, yapıyı veya bir tesisi korumak bunları koruyabilecek yapıları tasarlamak tümüyle mümkün değildir. Bu sebeple üretilen koruyucu zırh ile istenilen seviyede koruma sağlamak, gelebilecek tehdit seviyeleri göz önünde bulundurularak en optimum çözümü ağırlık, maliyet, performans üçlemesiyle bulmak mümkündür. Zırh teknolojisinin gelişmesi gibi mühimmat güçlerinin de sürekli gelişmesi ile yeni malzeme veya var olan malzemeyi geliştirme çalışmaları tüm hızıyla devam edecektir.

Yapılan çalışmalarda farklı mekanik özelliklere sahip malzemelerin, bu malzemelerin farklı açılarla dizilimlerinin, kullanılan katman sayılarının, farklı bağlantı şekillerinin ve bu şekillerin mühimmat kaşısındaki enerjilerinin detaylıca ele alındığı ve bu noktların zırh malzemesinde ait olan balistik performanslarındaki etkileri incelenmiştir. Balistik geçirmez malzemeler için hibrit kompozitte sandviç yapı, genellikle iki kat dış plaka ve ortada bir çekirdek malzemeden oluşan iyi bir yapıdır. Plakanın dış katmanı darbe kuvvetini etkili bir şekilde dağıtabilirken, ortadaki çekirdek malzeme tamponlama rolü oynayarak darbenin plakanın yapısına verdiği zararı daha da azaltır [15]. Zırh malzemesi oluşturulurken ara yüzey malzemelerinin ve katmanlı bir şekilde oluşturulan tabakaların çıkan son ürünün balistik performansını artırdığı görülmüştür. Bu konularla ilgili yapılan çalışmalar kısıtlı olup, elde edilen bulgular çalışmalar son derece kıymetlidir.

2 Metodoloji

2.1 Deneysel Çalışmada Kullanılan Malzemeler

Deneysel çalışmalarda piyasa isimleri

- NM9916F olan % 99,5 saflıktaki alümina ve
- NMZTA12 olan ağırlıkça % 88,5 Al_2O_3 ve % 11,5 ZrO_2

içeren bileşenler kullanılmıştır. İki toza ait teknik özellikler aşağıdaki Tablo 1'de verilmiştir.

Tablo 1: *NM9916F ve NMZTA12 tozlarının özellikleri*

	NM9916F	NMZTA12
Yoğunluk	2,31 g/cm^3	1,11 g/cm^3
Sinterleme Yoğunluğu	3,88 g/cm^3	4,1 g/cm^3
Büzülme Oranı	% 17,6	% 18
Tozun Granül Büyüklüğü	2,2 nm	2,1 nm

2.2 Yöntem

Çok tabakalı zırhlar kullanılan malzemelere göre farklı yöntemlerle üretilebilir. Katmanlar ayrı ayrı üretilip yapışkanla yapıştırılabilir. Tüm yığın, basınçlı kalıplama işlemi kullanılarak yüksek sıcaklık altında preslenebilir. Entegre zırhlı büyük kompozit yapılar, vakum destekli reçine transfer kalıplama (VARTM), reçine film infüzyon (RFI) işlemleri ve bunların varyantları kullanılarak ek yapıştırma olmadan tek parça olarak yapılabilir [4]. Bu yöntemler kullanılan malzemelere ve onlara uygun üretim yöntemlerine göre değişiklik göstermektedir. Mevcut çalışmada başlangıç malzemelerimiz seramik tozları önce preslenmiş sonra sinterlenerek tek parça plakalar elde edilmiştir.

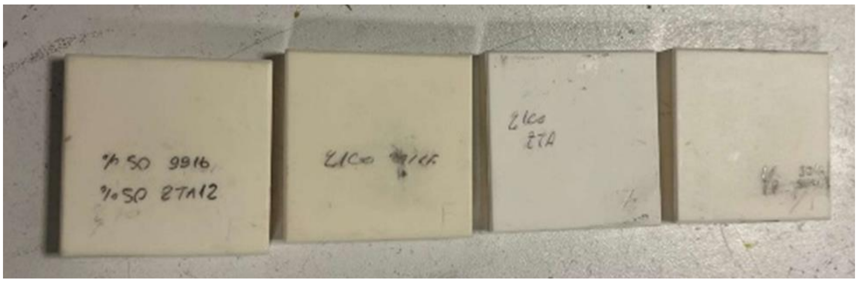
Deneysel çalışmalarda aşağıda bileşimleri verilmiş 4 ayrı konfigrasyon kullanılmıştır. Saf Alümina, ağırlıkça % 88,5 Al_2O_3- % 11,5 ZrO_2 Zirkonya toz karışımı, her iki tozun homojen karışımı ve katmanlı olarak üst üste yığınları önce eksenel preste sıkıştırılarak sonrasında literatürle uyumlu olarak [17] belirlenen sinterleme sıcaklığında kademeli olarak sinterlenmiştir.

Tozlar 52,5x52,5x10 mm boyutlarındaki çelik kalıplarda, 500 tonluk preste cm^2'ye 117 MPa altında eksenel olarak preslenmiş ve sonrasında açık atmosferli fırınında 1630^{o}C'de kademeli olarak toplam 30.3 saat sinterlenmiştir. Sinter fırınında ürünler, 0^{o}C'den 600^{o}C'ye 20.3 saatte getirilmiş ve bu sıcaklıkta 1 saat bekletilmiştir. 600^{o}C'den 1000^{o}C'ye 1,5 saatte getirilmiş burada da 1 saat bekletilmiştir. 1000^{o}C'den 1630^{o}C'ye ise 1,5 saatte getirilmiş bu sıcaklıkta da 5 saat bekletilmiştir. Toplam 30,3 saat sonrasında ürünler kademeli olarak soğutularak testler yapılmak üzere ayrılmıştır. Sinterleme sonrası numunelerin boyutları büzülme oranı nedeniyle yaklaşık 50x50x10 olarak ölçülmüştür. Farklı konfigürasyonda olan ürünlerden 5'er adet üretilmiş bunlar mekanik ve balistik testlere tabi tutulmuştur.

Deneysel çalışmada kullanılan 4 ayrı konfigürasyon şu şekildedir;

- Konfigürasyon 1: Saf alümina tozu ile (NM9916F),
- Konfigürasyon 2: Saf ZTA12 tozu ile (NMZTA12),
- Konfigürasyon 3: İki tozu homojen olarak karıştırarak,
- Konfigürasyon 4: İki tozu 5'er mm olacak şekilde presleyerek.

4 ayrı konfigürasyon üretildikten sonra numunelere mekanik ve balistik testler yapılmıştır. Ürünlerin optik mikroskop ve SEM analizleri gerçekleştirilmiş, sertlik, kopma ve atış testleri yapılmıştır. Üretilen seramik kompozitlere ait görseller aşağıdaki Şekil 1'de gösterilmektedir.



Şekil 1: Üretilen seramik kompozitlerin fotoğrafları.

3 Bulgular ve Tartışma

3.1 Sinterleme sonrası boyutsal ölçüm

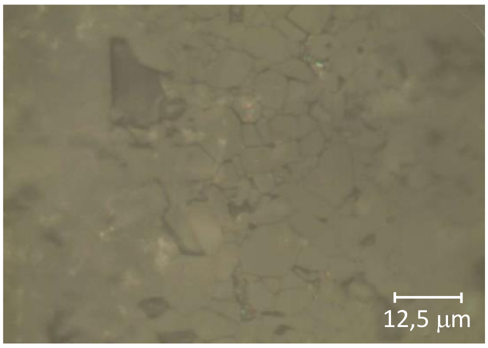
52,5x52,5mm çelik kalıbında preslenen 20 adet numune 500 tonluk güç altında 10 saniye süre ile işleme tabi tutulmuştur ve kumpasla boyutları ölçülmüştür. Pres sonrası sinter fırınında 30,3 saat 1630^oC'de tutulan seramikler işlem sonrası aynı kumpas yöntemiyle ölçülmüştür. Her konfşigrasyon için 5 adet numunenin boyutsal değişimleri ölçülerek ortalamaları alınmıştır. Ürünlerin boyutları incelendiğinde en ölçüsünde yaklaşık %3,89, boy ölçüsünde %3,73 çekme görülmüştür. Büzülme oranları beklenen tolerans aralığında gerçekleşmiştir. (Son ürün toleransı kabul kriteri ± 2,5 mm olarak belirlenmiştir.

3.2 Sinterleme sonrası yoğunluk ölçümü

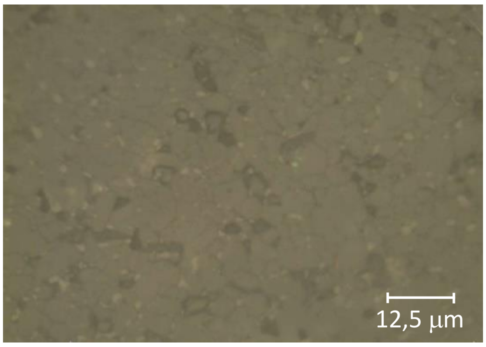
Ürünlerin yoğunlukları Arşimet yoğunluk ölçümüne göre yapılmıştır. Tüm deneysel çalışmalarda olduğu gibi yoğunluk ölçümlerinde de her konfigrasyon için 5 adet numunenin yoğunlukları ölçülerek ortalamaları alınmıştır. Konfigürasyon 1 için ortalama yoğunluk değeri 3,827 g/cm^3, konfigürasyon 2 için değer 4,106 g/cm^3, konfigürasyon 3 için 3,921 g/cm^3, konfigürasyon 4 için 4,228 g/cm^3 bulunmuştur. Ürünlerin yoğunlukları konfigürasyon 1 ve 2 için teknik spekt değerleri arasında olup konfigürasyon-2 ve 3 için beklenen değerlerde olmuştur.

3.3 Mikroyapı ve faz analizi

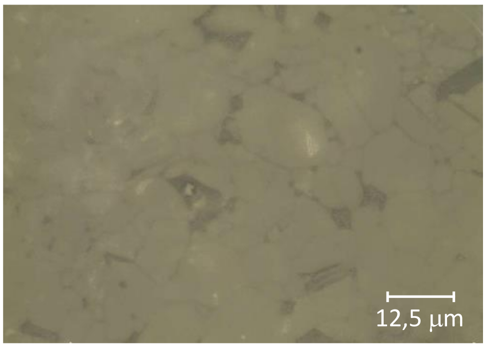
Sinterlenmiş seramiklerin mikroyapılarını incelemek için ilk önce tüm konfigürasyonlar termal dağlanmak üzere hazırlanmıştır. Bunun için ürünler önce kesme cihazı ile kesilmiş, bakalite alınmış, zımparalanmış ve parlatma işleminin ardından ürünlerin bakalitleri kırılmış sinterleme sıcaklığının 150^oC altı olan 1480^oC sıcaklıkta 10 dk süre ile sinter fırınına atarak termal dağlama işlemi gerçekleştirilmiştir. Termal dağlanmış 4 konfigürasyon için rastgele numuneler seçilmiş ve her birinin optik mikroskop görüntüleri alınmıştır (Şekil 2a-d) Tüm numuneler incelendiğinde konfigürasyon 1 ve 2 için mikroyapı dağılımı başarılı olmuş, yapısal olarak kararlı olduğu gözlemlenmiştir. Konfigürasyon 3 ve 4'te ise tane boyutu açısından farklılıklar gözlemlenmiştir. Mikroyapıya bakıldığı zaman ürünlerin hiçbirinde çatlak ve laminasyon sorunları gözlemlenmemiştir. Konfigürasyon 1 ve 2 yapısal olarak homojen, konfigürasyon 3 ve 4'ün ise homojen olmadığı belirlenmiştir.



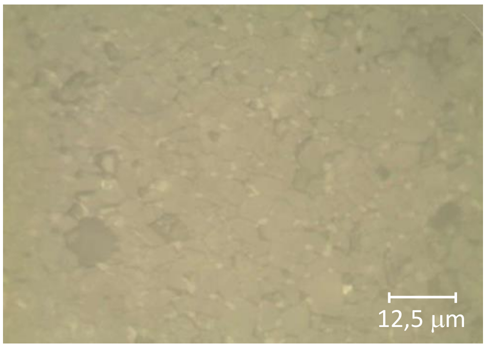
a) Konfigürasyon-1 (%100 Al_2O_3)



b) Konfigürasyon-2 (%100 ZTA12)



c) Konfigürasyon-3 (1:1 Al_2O_3-ZTA12)

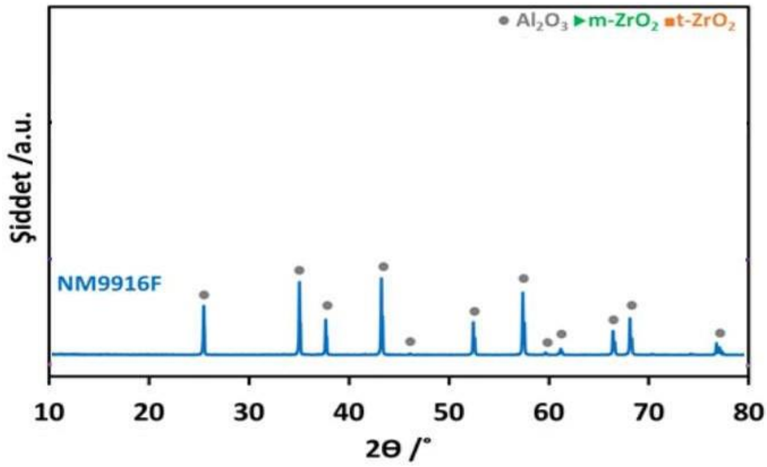


d) Konfigürasyon-4 (Katmanlı)

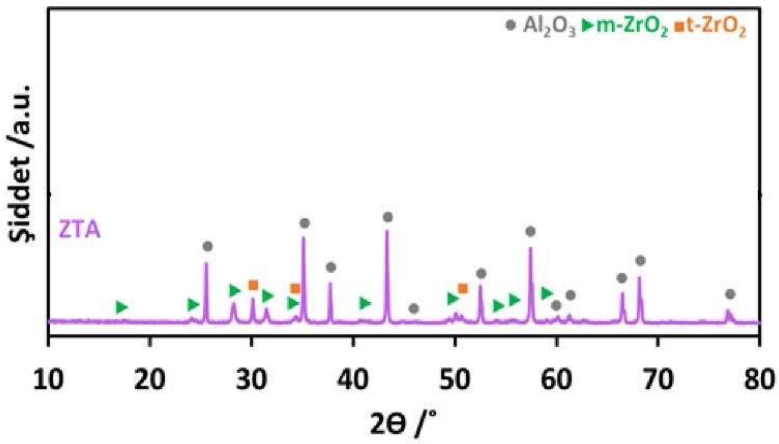
Şekil 2: a) Konfigürasyon-1 (%100 Al_2O_3), b) Konfigürasyon-2 (%100 ZTA12), c) Konfigürasyon-3 (1:1 Al_2O_3-ZTA12) ve d) Konfigürasyon-4 (Katmanlı) numunelerin sinter sonraso optik mikroskop görüntüleri.

Sinter sonrası numunelerin XRD analizleri yapılmış, bileşimleri belirlenmiş ve ürünlere ait teknik bilgiler doğrulanmıştır. Konfigürasyon-4, 5'er mm Al2O3 ve ZTA üst üste basıldığı için XRD analizine bakılmamıştır. XRD analizleri lisanslı uygulama olan Match-3-windows-x64-installer programına aktarılmış, içinde yer alan pikler renklendirilerek Şekil 3'te verilmiştir. konfigürasyon 1 ve 2 için piklerde beklenen sonuçlar elde edilmiştir. Konfigürasyon 3'te ZTA12 ilavesi monoklinik yapıdan tetragonal yapıya doğru eğilim olduğu izlenmiş, beklenen polimorfik dönüşüm gerçekleşmiştir.

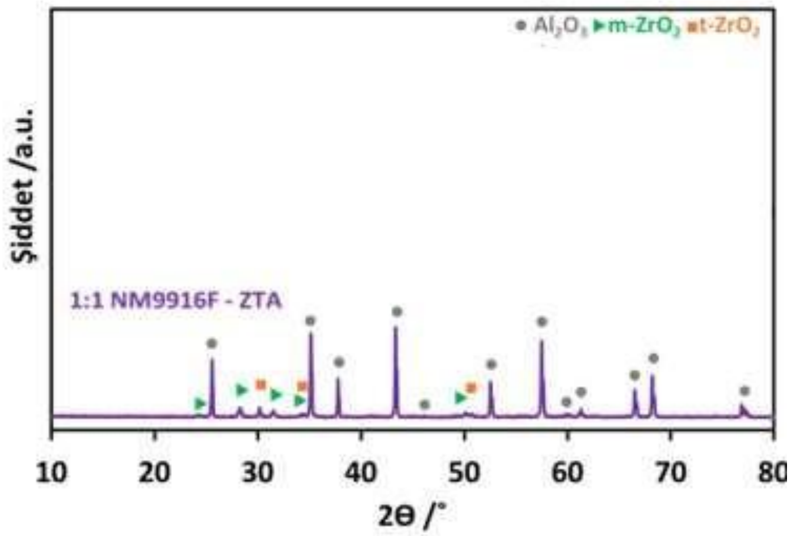
Üretilen seramiklerin 4 kofigrasyon için taramalı electron mikroskobu (SEM) görüntüleri Şekil 4'te verilmiştir. SEM görüntüleri incelendiği zaman sinterleme işleminin başarıyla gerçekleştiği görülmektedir. Optik mikroskop fotoğraflarını destekleyip; detaylandırmaktadır. Şekil 4a' dan Alüminanın tane boyutunun yaklaşık 5µm olduğu görülmektedir. Şekil 4b,c ve d'de Zirkonya beyaz renkte gözükmektedir ve nispeten homojen olarak dağılmıştır. Konfigürasyon 4 için iki farklı malzemenin birbiri içinde kaynaştığı değerlendirilmektedir. Konfigürasyon 3'te tozlar homojen olarak karıştırılmasına rağmen birbiri içinde dağılmadığı gözlemlenmektedir. İki ayrı malzemenin birbirleri içinde tabaka arayüzü oluşturduğu kompozisyonel olarak farklılık olduğu gözlemlenmektedir. Literatür çalışmalarında [5] da katmanlı basılan alaşımda iki katmanın homojen olarak dağıldığı görülmektedir. Konfigürasyon-3'te ise iki tozun belli oranlarda homojen olarak karıştırma yapılmasına rağmen ürünün homojen olarak yayılmadığı tespit edilmiştir. Aynı konfigürasyon-4'teki gibi tabakalar oluşmuştur. Bu sebeple pres içinde yer alan karıştırma sisteminin daha uzun çalıştırılması homojen dağılmasında daha etkili olabileceği değerlendirilmektedir.



a) Konfigürasyon-1 (%100 Al_2O_3)

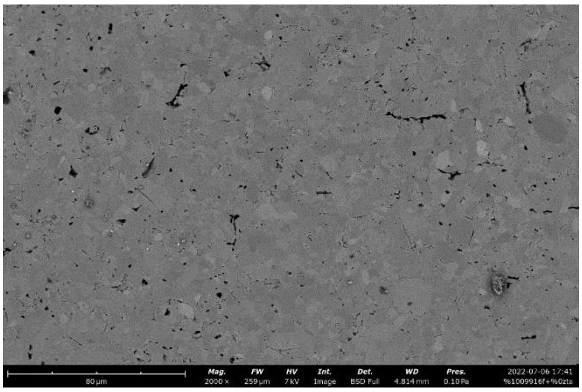


b) Konfigürasyon-2 (%100 ZTA12)

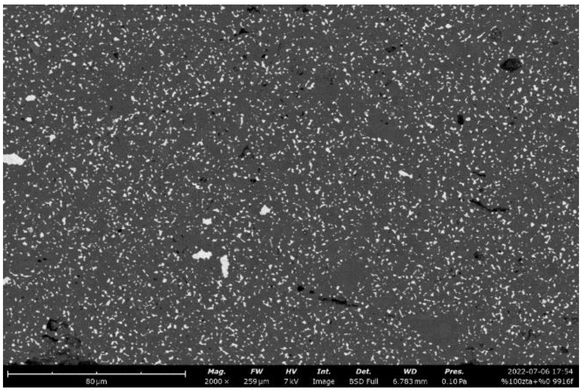


c) Konfigürasyon-3 (1:1 Al_2O_3-ZTA12)

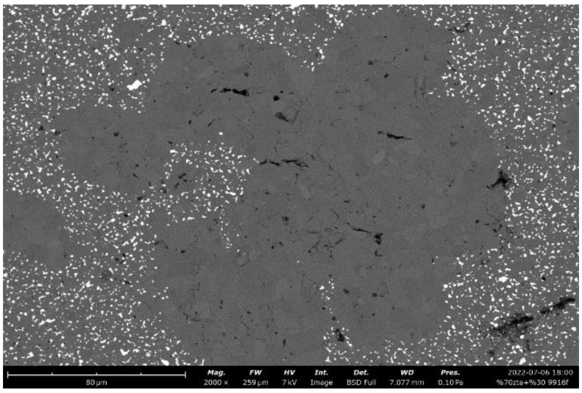
Şekil 3: a) Konfigürasyon-1 (%100 Al_2O_3), b) Konfigürasyon-2 (%100 ZTA12) ve c) Konfigürasyon-3 (1:1 Al_2O_3-ZTA12) numunelerinin sinter sonrası XRD analizleri.



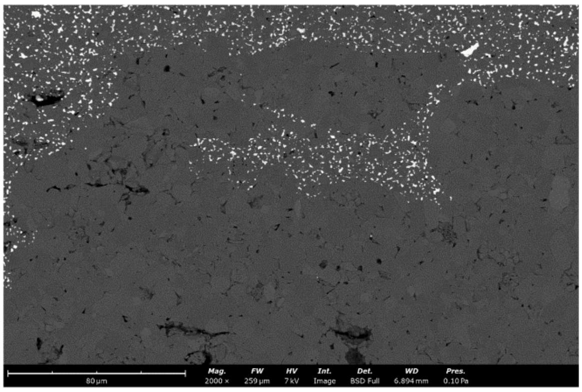
a) Konfigürasyon-1 (%100 Al_2O_3)



b) Konfigürasyon-2 (%100 ZTA12)



c) Konfigürasyon-3 (1:1 Al_2O_3-ZTA12)



d) Konfigürasyon-4 (Katmanlı)

Şekil 4: a) Konfigürasyon-1 (%100 Al_2O_3), b) Konfigürasyon-2 (%100 ZTA12), c) Konfigürasyon-3 (1:1 Al_2O_3-ZTA12) ve d) Konfigürasyon-4 (Katmanlı) numunelerin sinter sonraso SEM görüntüleri.

3.4 Sertlik sonuçları

Numunelerin sinter sonrası sertlikleri Vickers indentasyon yöntemi ile gerçekleştirilmiştir. Her bir konfigürasyon için test 5 kez tekrarlanmıştır. Ayrıca Konfigrasyon 4 için 2 farklı noktadan 5 ayrı ölçüm gerçekleştirilmiş ve sonuçların ortalamalrı standart sapma değerleri ile birlikte Tablo 2 ve 3'te verilmiştir.

Konfigürasyonların mekanik testlerinde konfigürasyon-1 ve 2'nin sertlik değerlerinin birbirinden farklı olduğu olduğu görülmektedir. 1 için ortalama değer 1746,6 HV iken konfigürasyon-2 için ortalama değer 1645,8 HV ölçülmüştür. Homojen karıştırılan konfigürasyon-3 için ortalama değer 1648,0 HV ölçülmüştür. Konfigürasyon-4'te katmanlı basıldığı için iki noktadan ölçüm alınmış olup ortalama değerler 1676,6 HV ve 1632,4 HV'dir.Tabakalı olan yapıda katmanlar arası sertlik farklılığı gözlemlenmiştir. ZTA ilavesinin olması Saf Al_2O_3'ten sertlik olarak düşük ama saf ZTA'dan da yüksek olduğu gözlemlenmiştir. İpek M. ve arkadaşlarının [9] yaptığı çalışmalar incelendiği zaman Zirkonya etkisinin alüminanın mekanik özelliklerini iyileştirdiği yönünde olmuş bu çalışma da bulunun sonuçla desteklenmiştir.

Tablo 2: Konfigrasyon 1,2 ve 3 numunelerinin Mikrosertlik değerleri

Numune	**Sertlik (HV)**
Konfigrasyon 1 (%100 Al_2O_3)	1746 ± 39.5
Konfigrasyon 2 (%100 ZTA)	1645.8 ± 45.3
Konfigrasyon 3 (Homojen %100 Al_2O_3 + %100 ZTA)	1648 ± 24.23

Tablo 3: Konfigrasyon 4 numunelerinin mikrosertlik değerleri.

Numune	**Sertlik (HV)**	**Sertlik (HV)**
Konfigrasyon 4 (Katmanlı %100 Al_2O_3 + %100 ZTA)	1677 ± 48.6	1632.4 ± 33.5

3.5 3 nokta eğme analizleri/kırılma tokluğu analizi

Numunelerin eğme basma analizi için Zwick roell markalı test cihazı kullanılmıştır. Test TS EN ISO 7438 standardına göre gerçekleştirilmiştir. 2 noktadan sabitlenen numuneye orta noktasından uygulanan 100kN yük sayesinde meydana gelen deformasyon ve hasarın değerleri ölçülerek numunelerin eğilme karşısında direnci belirlenmiştir. Tüm numunelerin kopma mukavemetleri Tablo 4' te verilmiştir.

Saf alüminanın kopma değerleri diğer numuneler arasında en yüksek değere sahiptir. ZrO2'ye ait değerler ise alümina karşısında oldukça düşüktür. Al2O3'e ZrO2 ilavesi kopma mukavemeti açısından oldukça başarılı olduğu değerlendirilmiştir. Kırılma tokluğu testi ISO 28079:2009 standardı referans alınarak gerçekleştirilmiştir. 3 noktadan eğme testi gerçekleştirilirken oluşan çatlak boyutu test cihazı tarafından hesaplanarak tokluk değerleri belirlenmiştir. Elde edilen sonuçlar Tablo 5'de verilmiştir. Kırılma toklukları ise bize en önemli sonucu vermektedir. Mekanik özellik olarak güçlü olan konfigürasyon-1'in kırılma tokluğu ortalama 4,04 $Mpam^{1/2}$, konfigürasyon-2'nin 6,19 Mpam1/2, konfigürasyon-3'ün 5,93 Mpam1/2 ve konfigürasyon-4'ün 5,40 $Mpam^{1/2}$'dir. İlave edilen ZTA'nın ürünlerde sertlik açısından düşüşe yol açarken tokluk artışı sağladığı görülmektedir. Taşdemirci V.D'nin yaptığı çalışma da katmanların arayüzeylerde toplanarak tokluk artışı sağladığını gözlemlemiştir [10]. Bulunan sonuçta çalışmayı destekler pozisyondadır.

Tablo 4: Konfigrasyon 1, 2, 3 ve 4 numunelerinin Kopma mukavemeti değerleri.

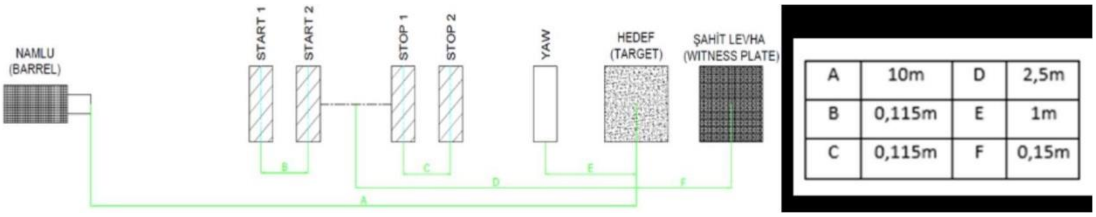
Numune No	Kopma Mukavemeti (MPa)
Numune 1 (%100 Al_2O_3)	50380 ± 1826
Numune 6 (%100 ZTA)	44180 ± 1907
Numune 11 (Homojen %100 Al_2O_3 + %100 ZTA)	49598 ± 1384
Numune 16 (Katmanlı %100 Al_2O_3 + %100 ZTA)	50326 ± 1311

Tablo 5: Konfigrasyon 1, 2, 3 ve 4 numunelerinin Kırılma tokluğu sonuçları.

Numune No	**Kırılma Tokluğu (Mpam$^{1/2}$)**
Konfigrasyon 1 (%100 Al_2O_3)	4,0488 ± 0.035
Konfigrasyon 2 (%100 ZTA)	6,198 ± 0.176
Konfigrasyon 3 (Homojen %100 Al_2O_3 + %100 ZTA)	5,9382 ± 0.61
Konfigrasyon 4 (Katmanlı %100 Al_2O_3 + %100 ZTA)	5,40 ± 0.32

3.6 Balistik sonuçlar

Bu çalışmada TS EN 1522 ve NIJ 0101.06 test standartları referans alınarak atış numuneleri hazırlanmıştır. TS EN 1522'ye göre FB7 ve NIJ 0101.06'ya göre seviye III balistik koruma seviyesine göre numuneler hazırlanarak test gerçekleştirilmiştir. Test düzeneği görseli Şekil 5'de gösterilmektedir. Chu ve arladaşları CFRP/AFB Sandviç Plakanın Balistik Performanslarını gerçekleştirdikleri deney düzeneği de bizim çalışmamıza benzer olarak üç kısımdan olşmaktadır. Birinci kısım bir mermi fırlatıcı, ikinci kısım bir hız ölçüm cihazı ve üçüncü kısımda bir balistik geri kazanım cihazıdır [15].



Şekil 5: Balistik atış test düzeneği

Balistik testte atış silahı olan namlu 50 m ye kadar uzaklaşıp yakınlaşabilen bir yapıdadır. Namlu 9,19 kalibreden 14,5x114 kalibre olan mühimmatları atma kapasitesine sahiptir. Test yapılan laboratuvar gerekli tüm standartlarda akreditedir. Laboratuvara ait görsel aşağıdaki Şekil 6'da verilmektedir.

Şekil 6: Balistik test laboratuvarı görseli.

Laboratuvarda yer alan hız kamerası sahip olduğu ışık bariyeri sayesinde merminin hız ölçümünü yapabilmektedir. Kullanılan mühimmat Makine Kimya Endüstri'si tarafından tedarik edilmiş, 60 HRC çekirdek sertliğine sahip 9,7 gr'dır. Kullanılan mühimmatın ucu kurşun kaplamalı, sertleştirilmiş çelik çekirdekli, pirinç kasa içerisinde bakır kılıflı zırh delici mermiye sahip bir mühimmat türüdür. 20 mm boyuna sahiptir. Atış numunesi düzeneğe bağlandıktan sonra TS EN 1522 FB7 koruma seviyesine göre 10 metrelik mesafeden uzaktan kumanda ile atış gerçekleştirilmiştir.

Atış sırasında test düzeneğinde yer alan hız okuma sensörlerinden 2 metre mesafeden hız değerleri okunmuş ve tüm atış hızlı kamera ile kayıt edilmiştir. Atışlara ait hız sonuçları aşağıdaki Tablo 6' da verilmiştir.

Tablo 6: Balistik atış sonuçları

No	Test No	Seri No	Mühimmat	Numune Adı	Kompozit			Barut Miktarı (g)	Mermi Ağırlığı (g)	Hız (m/sn)
					En (mm)	Boy (mm)	Ağırlık (g)			
1	NTG-22-0245-1	1	7,62x63M2AP	Çıkış Hızı Ölçümü	50	50	91	49,15	10,544	881,88
2	NTG-22-0245-1	2	7,62x63M2AP	Çıkış Hızı Ölçümü	50	50	92	49,15	10,524	891,51
3	NTG-22-0245-1	3	7,62x63M2AP	Çıkış Hızı Ölçümü	50	50	95,1	49,15	10,631	881,84
4	NTG-22-0245-1	4	7,62x63M2AP	Çıkış Hızı Ölçümü	50	50	94,5	49,15	10,626	879,8

Atış yapılırken hızlı kamera kaydı alınmış ve izlenmiştir. Seramiklerden beklenti mühimmatın seramikle buluştuğu an çekirdeği minimum oranda kırmasıdır.

Hız testleri incelendiği zaman Konfigürasyon-1'de 20 mm olan çekirdek boyu seramiğe çarptıktan sonra arkada tarafa geçen mesafesi 12 mm ölçülmüştür. Konfigürasyon-2'de 20 mm olan çekirdek boyu seramiğe çarptıktan sonra 15 mm, Konfigürasyon-3'te 20 mm olan çekirdek boyu seramiğe çarptıktan sonra 6 mm ve Konfigürasyon-4'te 20 mm olan çekirdek boyu seramiğe çarptıktan sonra 8 mm olarak ölçülmüştür. Seramikler atış testlerinde beklenen performansları göstermiştir. Seramikler yüksek sertlikleri ile merminin ucunu aşındırırıp deforme ederek; hızını ve etkinliğini azaltmaktadır [18]. Mevcut çalışmada benzer olarak alümina'nın sertliğinin yüksek ve tokluğun düşük olması çekirdeği deforme etmiş ve boyunu çok kısaltmıştır. Bu sebeple seramiğin arkasına konabilecek polietilen plakanın daha kalın olması gerektiği veya seramiğin daha kalın bir şekilde basılması gerektiği düşünülmektedir. Akdoğan ve arkadaşları [19] gerçekleştirdikleri çalışmada Alümina önyüzlü polietilen destekli kompozit zırhın balistik davranışlarını incelemişlerdir. Zırh malzemesi olarak tek katmanlı kompozit malzemelerdense ön yüzeyi seramik katmandan oluşan tabakalı kompozitlerin daha başarılı sonuçlar verdiğini belirtmişlerdir. Ön yüzeydeki seramik katman merminin uç kısmı deforme etmekte ve buda kinetik enerjisini azaltmaktadır.

Konfigürasyon-2 için çekirdek boyu atış sonrası 15 mm'e düşmektedir. ZTA malzemesi tok bir malzeme olduğundan dolayı mermi deformasyonu beklenildiği gibi Konfigrasyon-1' e kıyasla daha az olmuştur. Fakat ZTA yoğunluğu yüksek bir malzeme olduğu için ağırlık dezavantajı yaratmaktadır.

Konfigürasyon-3 incelendiği zaman 20 mm olan çekirdek boyu 14 mm'e düşmüştür. 1:1 oranında karışım olan malzemede mühimmat, hem alümina hem ZTA ile karşılaştığı için iki konfigürasyonun ortasında bir değer gelmesi beklenmekteydi. Beklenti 14 mm olarak gerçekleşmiştir.

Konfigürasyon-4'te ise atış yönü önde alümina arkada ZTA olacak şekilde seramik yerleştirilmiş ve atış yapılmıştır. 20 mm olan çekirdek boyu 12 mm olarak ölçülmüş mühimmatın ilk sert malzeme olan alümina ile karşılaşması sağlanmıştır. Bu sebeple çekirdek boyu 20 mm'den 12 mm'e düşmüş, konfigürasyon-1'den iyi konfigürasyon- 2'den daha az başarılı olduğu gözlemlenmektedir. Bu da bir önceki madde de belirtildiği gibi ilave edilen ZTA ürünlerde sertlik açısından düşüşe yol açarken tokluk artışı sağladığı görülmektedir. Huang, C.Y ve arkadaşının [11] yaptığı çalışmada alüminaya zirkonya katkısının balistik test sonucunda katmanlı seramikte çatlak ilerlemesini geciktirmiş balistik direncini artırmıştır. Bu çalışma sonucu da homojen 1:1 oranı ve katmanlı seramiğin balistik performansıyla örtüşmüştür.

4 Sonuçlar

Bu deneysel çalışmada çeşitli amaçlarla kullanılan seramiklerin farklı konfigürasyonları incelenmiş, 4 ayrı konfigürasyon oluşturulup (Konfigürasyon- 1: Saf Al2O3, Konfigürasyon-2: Saf ZTA12, Konfigürasyon-3: Al2O3 ve ZTA12 homojen karışım, Konfigürasyon-4: Katmanlı basılan Al2O3-ZTA12) mekanik ve balistik testler yapılarak farklılıkları ortaya konmuştur.

Boyutsal değişim ende %3,89, boyda %3,73 olduğu değerlendirilmiştir. Büzülme oranları beklenen tolerans aralığında gerçekleşmiştir. Ürünlerin yoğunlukları ortalama değerler konfigürasyon-1 için 3,82 g/cm3, konfigürasyon-2 için 4,10 g/cm3 konfigürasyon-3 için 3,92 g/cm3 ve konfigürasyon-4 için 4,22 g/cm3 olarak ölçülmüştür. Konfigürasyonların mekanik testlerinde konfigürasyon-1 ve 2'nin sertlik değerlerinin birbirinden farklı olduğu olduğu görülmektedir. 1 için ortalama değer 1746,6 HV iken konfigürasyon-2 için ortalama değer 1645,8 HV ölçülmüştür. Homojen karıştırılan konfigürasyon-3 için ortalama değer 1648,0 HV ölçülmüştür. Konfigürasyon-4'te katmanlı basıldığı için iki noktadan ölçüm alınmış olup ortalama değerler 1676,6 HV ve 1632,4 HV'dir. Numunelerin kopma mukavemetleri incelendiği zaman kopma mukavemeti en yüksek olan konfigürasyon-1, en düşük olan ise konfigürasyon-2'dir. Homojen ve tabakalı ilave edilen konfigürasyon-3 ve konfigürasyon-4'te elde edilen veriler iki konfigürasyonun arasında bulunmuştur. Kırılma toklukları ise bize en önemli sonucu vermektedir. Mekanik özellik olarak güçlü olan konfigürasyon-1'in kırılma tokluğu ortalama 4,04 Mpam1/2 , konfigürasyon-2'nin 6,19 Mpam1/2, konfigürasyon-3'ün 5,73 Mpam1/2 ve konfigürasyon-4'ün 5,42 Mpam1/2'dir. İlave edilen ZTA'nın ürünlerde sertlik açısından düşüşe yol açarken tokluk artışı sağladığı görülmektedir.

Balistik sonuçları incelediğimiz zaman atış yapılırken hızlı kamera kaydı alınmış ve izlenmiştir. Seramiklerden beklenti mühimmatın seramikle buluştuğu an çekirdeği minimum oranda kırmasıdır. Konfigürasyon-1'in hız kamerası incelendiği zaman 20 mm olan çekirdek boyunu 8 mm'e düşürdüğü gözlemlenmiştir. Bu da Alümina'nın sert bir malzeme olmasından kaynaklı tokluğun düşük olması çekirdek boyunu çok kısaltmış bu sebeple arkasına konabilecek polietilen plakanın daha kalın olması gerektiği veya seramiğin daha kalın bir şekilde basılması gerektiği düşünülmektedir.

Konfigürasyon-2 için çekirdek boyu atış sonrası 15 mm'e düşmektedir. ZTA malzemesi tok bir malzeme olduğundan dolayı beklenen çekirdek kırma boyutu başarılı olmuş fakat ZTA yoğunluğu yüksek bir malzeme olduğu için ağırlık dezavantajı yaratmaktadır.

Konfigürasyon-3 incelendiği zaman 20 mm olan çekirdek boyu 14 mm'e düşmüş 1:1 oranında karışım olan malzemede mühimmat hem alümina hem ZTA ile karşılaştığı için iki konfigürasyonun ortasında bir değer gelmesi beklenmekteydi. Beklenti 14 mm olarak gerçekleşmiştir.

Konfigürasyon-4'te ise atış yönü önde alümina arkada ZTA olacak şekilde seramik yerleştirilmiş ve atış yapılmıştır. 20 mm olan çekirdek boyu 12 mm olarak ölçülmüş mühimmatın ilk sert malzeme olan alümina ile karşılaşması sağlanmıştır. Bu sebeple çekirdek boyu 20 mm'den 12 mm'e düşmüş, konfigürasyon-1'den iyi konfigürasyon-2'den daha az başarılı olduğu gözlemlenmektedir. İlave edilen ZTA ürünlerde sertlik açısından düşüşe yol açarken tokluk artışı sağladığı görülmektedir.

Yapılan çalışmaların tümü değerlendirildiği zaman ZTA ilavesinin yapılması sertlik bakımından konfigürasyonlarda kayda değer bir artış yapmamıştır. Fakat tokluk ve kopma değerlerinde istenilen artışın sağladığı görülmüştür. Seramiklerin kullanım alanlarına ve amaçlarına göre ZTA miktarının azaltılıp artılırması sağlanıp, hangi amaçla kullanılacaksa buna göre kompozisyonun değiştirilebileceği değerlendirilmektedir. Eğer seramikler mühimmata karşı kullanılacak ise farklı tabakalarda oluşturulup kullanımının uygun olacağı düşünülmektedir. Elde edilen sonuçlar ve yorumlamaların ileride bu konuda yapılacak çalışmalara ışık tutacağı düşünülmektedir.

5 Beyanname

5.1 Teşekkür

Yazarlar deneysel çalışmaların gerçekleştirildği Nurol Teknoloji San ve Madencilik Tic. A.Ş.' ye teşekkür eder.

5.2 Rakip Çıkarlar

Bu çalışmada herhangi bir çıkar çatışması yoktur.

5.3 Yazarların Katkıları

Burcu BÜYÜKDOĞAN: Makaleye katkısı. (Araştırma ve/veya makale için fikir ya da hipotezin oluşturulması, deneysel çalışma sonuçlarının yorumlanması, makalenin düzenlenmesi ve makalenin gönderilmesi.)

Gözde ÇELEBI EFE: Makaleye katkısı. (Araştırma ve/veya makale için fikir ya da hipotezin oluşturulması, Sonuçlara ulaşmak için gereç ve yöntemlerin planlanması, deneylerin yapılması, verilerin düzenlenmesi ve bildirilmesi için sorumluluk almak, bulguların mantıklı açıklanması ve sunumu için sorumluluk almak, araştırma sırasında literatür taraması ile ilgili sorumluluk almak, yazının tümü veya asıl bölümün oluşturulması için sorumluluk almak, makaleyi teslim etmeden önce sadece imla ve dil bilgisi açısından değil aynı zamanda entelektüel içerik açısından yeniden çalışma yapmak.)

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A Comprehensive Analysis through Kinematic Approaches of Bobillier's Theorem

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ABSTRACT

This paper presents a comprehensive examination of curvature theory through the lens of kinematic approaches, with a particular focus on the applications of Bobillier's Theorem. In differential geometry, curvature theory serves as a foundation for understanding the behavior of curves and surfaces under transformations, providing insight into local and global geometric properties. Curvature measures, such as normal curvature and geodesic curvature, are critical in describing the bending and shape of curves and surfaces within a given space. By adopting a kinematic perspective, we interpret these curvature properties as functions of motion, allowing for a deeper analysis of dynamic systems where trajectories and curvature paths vary over time. This approach enables the exploration of curvature in contexts that extend beyond static geometric structures, encompassing dynamic applications in fields such as physics, engineering, and robotics, where the behavior of objects in motion is governed by the principles of differential geometry. By integrating Bobillier's Theorem, we introduce a novel framework for understanding the interactions between curvature and kinematic properties, enhancing the classical curvature analysis. This study employs a kinematic approach to curvature theory, emphasizing Bobillier's Theorem to connect classical geometric analysis with dynamic applications. Our approach also extends classical curvature concepts by examining their implications in systems where velocity, acceleration, and angular momentum interact with the geometric curvature of trajectories. By linking Bobillier's polar concepts with the path and directional properties of objects in motion, we can derive new insights into how curvature affects the stability and orientation of trajectories in dynamic environments. This is particularly valuable in applications where precise control over trajectory curvature is needed, such as in robotic path planning, spacecraft navigation, and automated vehicle steering systems. Here, the polar line, as defined by Bobillier's construction, corresponds to the optimal path of curvature, offering potential applications in the optimization of these systems.

Keywords: Curvature, evolute, involute, Bobillier's design, Hartmann's rule, enveloping curve.

1 Introduction

Curvature theory is a fundamental aspect of differential geometry, serving as a critical tool in the study of geometric properties of curves and surfaces [1]-[12]. It has profound implications in various applied fields, from robotics to physics, where understanding the behavior of objects in motion is essential [13]. Classical studies on curvature primarily focus on intrinsic geometric properties, examining static aspects of curves and surfaces. However, incorporating kinematic approaches introduces a dynamic perspective,

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allowing for a richer interpretation of curvature in real-world applications where motion and external forces play a significant role [14].

One of the pivotal concepts in curvature theory, especially in the study of trajectories and normal curvature relationships, is Bobillier's Theorem. Originally formulated in the context of curve analysis, Bobillier's Theorem establishes essential connections between the curvature center's path and normal curvature properties. This theorem proves particularly valuable in kinematic analysis, as it links curvature behavior to object movement, providing insights into how external forces influence trajectories [15]. Such insights are indispensable in applications like path optimization in robotics and the design of curved surfaces in engineering [16].

In this paper, we adopt a kinematic approach to curvature theory, focusing on Bobillier's Theorem to bridge classical geometric analysis and dynamic applications. By applying this theorem within the framework of kinematic analysis, we aim to enrich traditional interpretations of curvature and extend their applicability to contexts involving motion. This approach not only enhances the theoretical understanding of curvature but also opens up new perspectives in fields requiring precise curvature manipulation.

2 Preliminaries

This section presents the foundational concepts necessary for an in-depth analysis of curvature theory from a kinematic perspective, with a particular focus on Bobillier's Theorem and its geometric interpretations. By laying out these preliminaries, we aim to clarify the interplay between geometric properties of curvature and kinematic analyses, setting the stage for a comprehensive exploration of Bobillier's Theorem within the broader context of curvature theory.

Theorem 1 (Bobillier's Theorem)**.** Consider a triangle ABC and a point P located on its circumcircle (the circle passing through the vertices A, B, and C). If we consider the polar of P with respect to a conic section defined by ABC (often a circumcircle or a special conic section with respect to the triangle), then this polar passes through the points where the tangents drawn from P meet the extensions of the sides of the triangle.

Bobillier's Theorem is a classical result in differential geometry that provides a relationship between the curvature and the properties of the evolute, or the center of curvature path, of a given curve. It gives conditions under which the center of curvature traces a specific trajectory relative to the original curve. A structured explanation of the theorem and its mathematical formulation as follows:

2.1 Curve and Evolute

Let $\gamma(s)$ be a regular, smooth plane curve parameterized by arc length s, with curvature $\kappa(s)$. For any point $P(s)$ on γ, the center of curvature $C(s)$ is located at a distance $R = 1/\kappa(s)$ along the normal vector $N(s)$ to the curve at s. The center of curvature $C(s)$ traces out a new curve known as the evolute of $\gamma(s)$.

The position of the center of curvature C(s) can be represented as:

$$C(s) = \gamma(s) + [1 / \kappa(s)]\, N(s) \tag{1}$$

where $N(s)$ is the unit normal vector to the curve at $\gamma(s)$. The path traced by $C(s)$ forms the evolute of $\gamma(s)$.

2.2 Kinematic Interpretations of Curvature

A kinematic perspective to Equation 1, curvature represents the rate of change in the direction of velocity along a path. For a particle moving along a curve with a velocity $\mathbf{v} = d\gamma / dt$, the curvature κ can also be expressed in terms of the velocity and acceleration vectors:

$$\kappa = \|\mathbf{v} \times a\| \,/\, \|v\|^3 \tag{2}$$

where $\mathbf{a} = d\mathbf{v} / dt$ is the acceleration vector. This kinematic interpretation in Equation 2 is particularly useful in contexts where an object's trajectory under the influence of forces is of interest, such as in robotics and mechanical engineering, allowing for a dynamic understanding of curvature.

2.3 Bobillier's Theorem

Bobillier's theorem states that the curvature of the evolute C(s) at any point s is given by:

$$\kappa_C(s) = \kappa(s) \,/\, |\kappa'(s)| \tag{3}$$

where:

$\kappa(s)$ is the curvature of the original curve $\gamma(s)$,
$\kappa'(s)$ is the derivative of $\kappa(s)$ with respect to arc length s,
$\kappa_C(s)$ is the curvature of the evolute C(s) at the corresponding point.

In other words, the curvature of the evolute at any given point is inversely proportional to the rate of change of curvature of the original curve.

2.4 Proof and Geometric Interpretation

We assume that the position vector is given by Equation 1 and compute the derivative of C(s) with respect to s:

$$C'(s) = \gamma'(s) + (1 / \kappa(s))' \, N(s) + [1 / \kappa(s)] \, N'(s).$$

Since $\gamma'(s) = T(s)$ (the tangent vector) and $N'(s) = -\kappa(s)\, T(s)$, this expression can be simplified further by substituting these values.

By further differentiation, we obtain an expression for the second derivative $C''(s)$ and thus for the curvature

$$\kappa_C(s) = \|C'(s) \times C''(s)\| \,/\, \|C'(s)\|^3.$$

Upon simplification of this result, it can be shown that Equation 3, confirming Bobillier's Theorem.

3 Geometric Interpretation of the Result Theory and Calculation

The key geometric insight provided by Bobillier's Theorem is that the trajectory of the curvature center can be analyzed similarly to the original curve's geometry, allowing for a layered understanding of curvature behavior. For instance, if the curvature of the original curve changes smoothly, the curvature center's trajectory forms a smooth path. However, if there are abrupt changes in the curvature of the original curve, the curvature center's path will reflect these discontinuities, providing insight into the overall dynamics of the motion.

This geometric perspective is especially useful in kinematics, as it enables the prediction of how a moving point on the curve will respond under specific conditions of motion and force. In robotics, for example, understanding the path traced by the curvature center can inform path-planning algorithms, particularly in situations where smoothness and precision are required.

Bobillier's Theorem provides an elegant geometric insight into the relationship between a curve and its evolute. Specifically:

Definition 1.

a) When the curvature $\kappa(s)$ of the original curve changes slowly (i.e., $|\kappa'(s)|$ is small), the curvature of the evolute $\kappa_C(s)$ becomes large, meaning the evolute is highly curved.

b) Conversely, if the curvature $\kappa(s)$ changes rapidly (i.e., $|\kappa'(s)|$ is large), the curvature of the evolute $\kappa_C(s)$ is small, and the evolute becomes flatter.

3.1 Bobilier Design

Theorem 2 (Bobillier's Design)**.** For a state of motion, if the centers of curvature of the pol points at A, B on the pol lines are known, then for the tangent t pol at QAB = ([AB][A* B*]), it holds that

$$\sphericalangle [PA]\, t = -\sphericalangle [PB]\, [PQAB]. \tag{4}$$

Let points A, B, C and their corresponding curvature centers A*, B* be defined. We will utilize Bobillier's theorem to ascertain the center of curvature of C in C*:

Utilizing the Bobillier Design given by Equation 4 consecutively allows for the straightforward acquisition of C* by transferring the angle with the auxiliary points QAB for A, B and QAC for A, C (Figure 1).

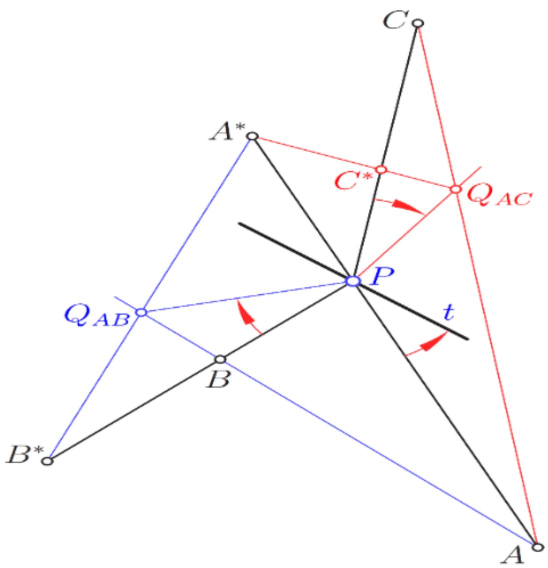

Figure 1: Bobillier design

3.2 Hartmann's Rule

Let P and P's velocity vector P$\tilde{\mathbf{v}}$, A and A's velocity vector A$\tilde{\mathbf{v}}$, be specified. Let us determine the center of curvature of the orbit of A*.

Let us define P$\tilde{\mathbf{v}}^{f}_{10}$, which is oriented perpendicularly to the pol lines [PA] originating from P$\tilde{\mathbf{v}}$. The line joining the endpoints of the vectors P$\tilde{\mathbf{v}}^{f}_{10}$ and A$\tilde{\mathbf{v}}$ intersects at A*. The peaks of P$\tilde{\mathbf{v}}^{f}_{10}$ for different polar lines lie on the Thales circle above P$\tilde{\mathbf{v}}$, the Hartmann circle. (Figure 2).

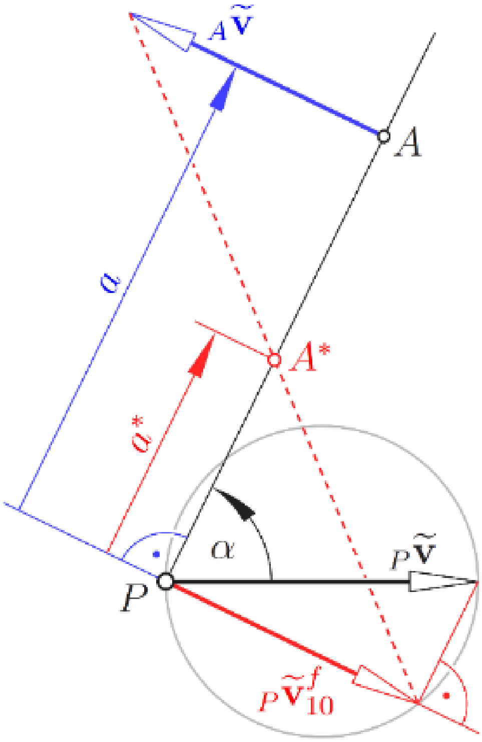

Figure 2: Hartmann's circle

Thus, Bobillier's Theorem reveals that the shape of the evolute is directly influenced by the rate at which the curvature of the original curve changes. This provides a deeper understanding of how curves evolve under geometric transformations, with significant implications in applications such as path optimization and motion analysis in fields like robotics and physics.

4 Results and Discussion

Bobillier's Theorem has several practical applications, particularly in fields that require precise control over curvature and trajectory. Some notable applications are:

In robotic motion planning, path smoothness is critical for efficiency and accuracy. Bobillier's Theorem helps engineers analyze the curvature of a robot's path and its center of curvature, ensuring smooth transitions that avoid abrupt changes in direction. By understanding the curvature center's path, roboticists can optimize movement to minimize energy consumption and avoid mechanical stress.

In systems involving rotating or moving components, such as gears or levers, controlling curvature properties is essential for stability. Bobillier's Theorem aids in designing components with predictable curvature dynamics, ensuring that motion remains smooth and controlled under varying loads.

In physics, especially in projectile motion and orbit mechanics, understanding curvature changes under force fields can provide accurate predictions about trajectories. Bobillier's Theorem offers a framework to analyze the effects of forces on curvature behavior, helping physicists anticipate how objects will move in response to external forces.

5 Declarations

5.1 Study Limitations

None.

5.2 Acknowledgements

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5.3 Funding source

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5.4 Competing Interests

There is no conflict of interest in this study.

5.5 Authors' Contributions

Engin Can wrote and reviewed the article.

6 Human and Animal Related Study

For this type of study, formal consent is not required.

6.1 Ethical Approval

For this type of study, formal consent is not required.

6.2 Informed Consent

Informed consent was obtained from all individual participants included in the study.

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Generative Artificial Intelligence (GenAI) in Business and Industry: A Systematic Review on the Threshold of Transformation

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ABSTRACT

This systematic review examines the transformative potential of Generative Artificial Intelligence (GenAI) across diverse sectors, including information technology, education, manufacturing, creative industries, healthcare, transportation, management, marketing, finance, energy, law, media, agriculture, and e-commerce. By analyzing its applications, the study highlights how GenAI enhances efficiency, fosters innovation, and addresses sector-specific challenges. Key benefits include the automation of complex processes, optimization of resource use, and acceleration of decision-making. However, delayed adoption risks such as workforce displacement and ethical dilemmas are also discussed. The review identifies critical barriers like data privacy concerns, algorithmic bias, and regulatory challenges.

Practical strategies for successful GenAI integration are explored, emphasizing infrastructure readiness, workforce upskilling, and ethical governance. This includes leveraging generative models such as Generative Adversarial Networks (GANs), Transformer-based models, Variational Autoencoders (VAEs), and diffusion models to adapt to industry-specific demands. Furthermore, the study underscores the necessity of balancing technological advancements with responsible AI deployment to minimize risks and maximize societal benefits.

By synthesizing existing research, this review provides actionable insights for stakeholders aiming to leverage GenAI's transformative capabilities responsibly. It emphasizes the urgency of adopting GenAI technologies to maintain competitiveness and sustainability in rapidly evolving markets. As the study concludes, it advocates for cross-sectoral collaboration to address the complex challenges posed by this paradigm-shifting technology and calls for adaptive policies to align innovation with ethical principles and societal values.

Keywords: GenAI, Industry transformation, Artificial intelligence strategy**,** AI-Driven Innovation, Ethical AI Governance

1 Introduction

GenAI represents a paradigm shift in the world of AI, reshaping how businesses operate, innovate, and compete. Unlike traditional predictive AI, which analyzes past data to predict future trends, GenAI can

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generate entirely new, contextually relevant content in formats such as text, images, audio, video, and programming code [1]. By synthesizing human feedback and leveraging vast datasets, this technology not only augments human creativity but also automates complex processes, enabling unprecedented levels of efficiency and innovation. GenAI's transformative potential spans across a variety of industries, including information technology, education, manufacturing, healthcare, creative industries, transportation, and finance. In these industries, GenAI accelerates innovation, optimizes decision-making, and enables businesses to achieve significant cost savings by reducing their reliance on manual intervention. For example, it automates routine and creative tasks, improves product design through generative modeling, and supports real-time decision-making in dynamic environments. However, these benefits come with challenges, such as ethical dilemmas, workforce displacement, and regulatory uncertainty.

Whether businesses are ready for this change or not, the integration of GenAI across industries is no longer a matter of choice, but a necessity to survive in today's highly competitive environment. The rapid adoption of this technology by early adopters is setting new benchmarks and making it imperative for organizations to proactively embrace this transformation. In an environment where technological advancements define competitive advantage, failure to adapt to GenAI-driven changes risks making businesses obsolete. Therefore, for organizations, this transition is not a luxury, but a critical necessity to ensure their sustainability and relevance in a rapidly evolving market.

This review systematically examines the status, applications, and emerging trends of GenAI across key industries, highlighting both opportunities and challenges. It explores how businesses can leverage GenAI to increase productivity, drive innovation, and meet industry-specific needs while mitigating risks such as ethical concerns, workforce skill gaps, and compliance issues. The analysis highlights the importance of readiness strategies such as workforce upskilling, ethical governance, and robust infrastructure development to responsibly leverage the full potential of GenAI. By synthesizing insights from a wide range of industries, this article aims to provide actionable guidance for stakeholders navigating the complexities of GenAI adoption. It highlights the urgency of a timely transformation and the need for businesses to adopt a forward-looking approach to remain competitive and sustainable. As GenAI continues to redefine industry norms and practices, this article aims to contribute to the ongoing discourse on how organizations can adapt and thrive in this era of intelligent automation and innovation.

2 Fundamentals: Generative Artificial Intelligence (GenAI)

GenAI refers to AI systems capable of creating text, visuals, or other types of media. These systems learn patterns and structures in training data through models commonly referred to as "generative models" and use this knowledge to produce new, similar content. Key types of GenAI include GANs, Transformer-Based Models (TBMs), VAEs, and Diffusion Models [2]. GANs: GANs are a type of deep learning architecture that generates new data through a competitive process between two neural networks. One network creates data samples, while the other discriminates between real and generated data. This adversarial process continues until the discriminator can no longer differentiate between real and generated data. For example, GANs can create original images from an image database or produce unique music pieces from a collection of songs [3]. TBMs Introduced in 2017, TBMs have become a cornerstone in natural language processing (NLP) and have expanded to various machine learning applications. These models can translate text and speech in real-time, enabling, for instance, tourists to communicate with locals in their native language. They are also utilized in DNA research, drug design, and fraud detection in finance and security. Vision-based Transformer models are applied in computer vision tasks. OpenAI's popular text-generation tool ChatGPT leverages Transformer architectures for tasks like text prediction, summarization, and question answering. "GPT" stands for "Generative Pretrained Transformer," highlighting these models' ability to predict the next word in text sequences based on large and complex datasets, advancing the development of text-based GenAI tools [4]. VAEs are powerful generative models that combine elements of statistics and information theory with the flexibility of deep learning. They can handle high-dimensional data by learning the latent distribution of the data and generating new, meaningful samples. This approach has fostered a research field called "unsupervised representation learning," leading to the design of much novel architecture [5]. Diffusion models operate in two phases: forward diffusion and reverse diffusion. During forward diffusion, Gaussian noise is added to the inputs, progressively degrading the data. In the reverse diffusion phase, the model learns to reconstruct the original data step by step. While diffusion models are praised for the quality and diversity of their generated samples, their computational challenges—such as high step counts—can lead to slower processing speeds. Despite these challenges, diffusion models have achieved remarkable success in applications such as image synthesis, video generation, and molecular design [6]-[7]. A study has shown that GenAI is effective in sequential processes such as text or speech analysis, as well as various image-related tasks such as object detection and classification, and applications are increasing in various disciplines[1].

Comparison of Generative and Discriminative AI: GenAI iteratively generates outputs based on user-defined inputs to achieve the desired results. These models are designed to produce diverse and probabilistic outputs by leveraging large datasets. Discriminative AI, on the other hand, analyzes data to define boundaries and make decisions. The primary difference between the two lies in the role of data: while GenAI relies on vast datasets for production, discriminative AI uses pre-trained algorithms to classify and analyze existing data. The differences in function between GenAI and discriminative AI are shown in Figure 1[8].

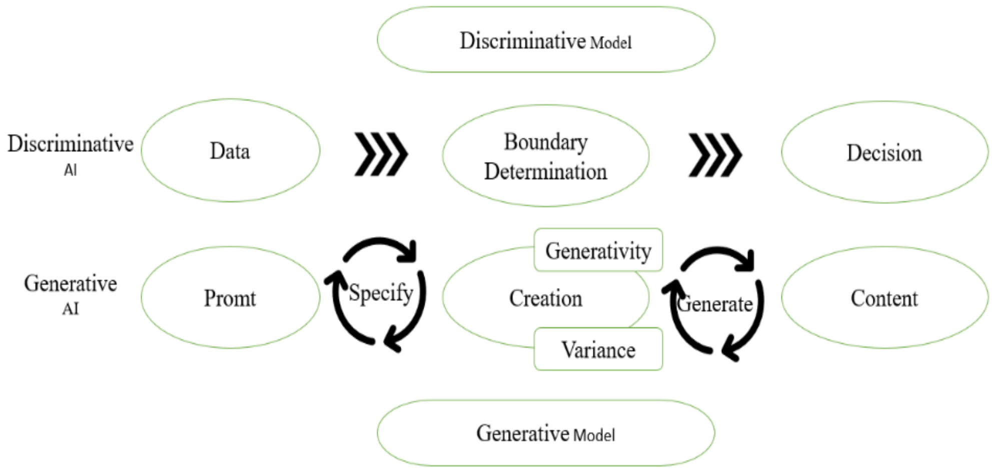

Figure 1: Procedural differences of GenAI and discriminative AI [8]

3 Sector-Specific Analyses

The transformative potential of GenAI extends across a diverse array of industries, each with unique challenges and opportunities. This section delves into sector-specific analyses to systematically explore how GenAI is reshaping practices, enhancing efficiency, and driving innovation in distinct fields. From augmenting creativity in the arts to optimizing operational processes in manufacturing, GenAI serves as a catalyst for innovation and efficiency in areas as varied as healthcare, finance, transportation, and education[9]-[11].

The sectoral applications of GenAI underscore its adaptability, offering tailored solutions that align with industry-specific demands. For instance, in healthcare, GenAI enhances diagnostic precision and personalizes treatment plans, while in agriculture, it supports precision farming and sustainable resource management. Similarly, its ability to generate personalized content and automate workflows is revolutionizing e-commerce, media, and marketing, fostering enhanced customer engagement and operational efficiency. Beyond these applications, GenAI also addresses critical challenges, including ethical concerns, workforce displacement, and the need for robust regulatory frameworks.

This section provides a comprehensive analysis of 14 key sectors, highlighting the transformative role of GenAI in addressing contemporary challenges and redefining traditional paradigms. By examining the implications and applications of GenAI in each sector, this chapter aims to provide a nuanced understanding of its potential to foster innovation, sustainability, and resilience across the global business landscape.

3.1 Information Technology and Technology Development

GenAI is emerging as a critical force reshaping the field of Information Technology (IT). Its ability to create new content, analyze vast datasets, and automate complex processes positions it as a transformative tool in IT systems. GenAI has significantly enhanced IT operations by detecting anomalies and potential cybersecurity threats through real-time data analysis. Predictive analytics capabilities allow organizations to identify vulnerabilities in advance, strengthening data protection measures and optimizing tasks such as routine maintenance, software updates, and resource allocation. This reduces operational costs while enabling IT professionals to focus on strategic projects. The automation provided by GenAI extends to the predictive maintenance of IT infrastructure. By analyzing historical performance data, AI algorithms can predict hardware or software failures, minimizing downtime and optimizing resource utilization. This proactive approach extends the lifecycle of IT assets, ensuring high operational efficiency. Additionally, through NLP and intuitive interfaces, GenAI facilitates access to advanced technologies, not only improving accessibility for non-technical users but also fostering collaboration between human experts and AI systems in developing innovative solutions. Such advancements underscore the increasing role of AI in bridging technological gaps across various industries. GenAI also plays a critical role in the evolution of IT development tools and platforms. By automating code generation, simplifying debugging, and creating software prototypes, it accelerates processes while improving accuracy and efficiency. For instance, AI tools like OpenAI's Codex enable developers to expedite their coding workflows. Moreover, AI-powered platforms significantly enhance software design through capabilities like automated interface creation and user experience optimization, However, the integration of GenAI into IT development faces several challenges. Concerns such as data privacy, ethical usage, and the carbon footprint of AI operations remain critical issues that need to be addressed. Overcoming these challenges requires robust cybersecurity frameworks and sustainable strategies [9]-[11].

As a result, the role of GenAI in IT and technological development profoundly impacts automation, innovation, and user interaction. As technology continues to evolve, its integration into IT systems is expected to drive unprecedented advancements in efficiency and creativity, laying the foundation for a future defined by intelligent and adaptive technologies

3.2 Education

GenAI is revolutionizing the field of education by reshaping traditional teaching and learning paradigms. Its capabilities range from creating personalized learning environments to alleviating administrative burdens, thereby enabling a more dynamic and inclusive educational experience. GenAI serves as a powerful tool for fostering educational engagement, accessibility, and effectiveness across diverse student populations.

One of the most impactful applications of GenAI in education is its role in creating tailored learning experiences. Through advanced NLP and data analysis, AI systems can generate personalized study plans and provide targeted feedback on student assignments. This adaptability allows educators to cater to individual learning styles, ultimately enhancing students' cognitive and creative capacities. Virtual interactive tutors powered by GenAI provide real-time responses to student queries, enabling continuous support beyond traditional classroom hours. These tutors are particularly beneficial for self-paced learners, offering adaptive learning paths that align with their specific needs. Moreover, GenAI significantly reduces educators' workload by automating routine tasks such as grading, lesson planning, and assessment design. For instance, it can generate diverse examination formats, from multiple-choice questions to open-ended essays, saving valuable time for teachers to focus on more strategic aspects of instruction. Additionally, AI tools assist in creating educational content, such as lecture notes and multimedia resources, which enhance the teaching process while simplifying complex subjects for students. Beyond classroom applications, GenAI plays a critical role in promoting research and academic writing. It aids students and researchers in summarizing complex texts, structuring essays, and conducting literature reviews. By automating these processes, AI not only enhances efficiency but also empowers learners to delve deeper into academic exploration. However, these advancements also present challenges, such as concerns about originality and the potential misuse of AI tools in producing academic work. Ensuring ethical usage through clear guidelines and robust plagiarism detection mechanisms is essential for maintaining academic integrity. The integration of GenAI in education also prompts critical ethical considerations. Issues such as data privacy, algorithmic bias, and the transparency of AI processes necessitate the development of comprehensive regulatory frameworks. Educators and policymakers must work collaboratively to ensure that the adoption of AI in education aligns with principles of inclusivity, equity, and accountability[12]-[14].

In terms of pedagogy, GenAI fosters a collaborative learning environment by bridging the gap between students and teachers. Its ability to analyze and respond to real-time data enables the identification of learning gaps, which educators can address proactively. Furthermore, AI supports inclusive education by providing resources and tools tailored for students with disabilities, thus contributing to a more equitable learning landscape[15].

In conclusion, GenAI holds transformative potential for education, reshaping traditional methodologies and paving the way for innovative learning experiences. While challenges persist, the thoughtful integration of AI tools can significantly enhance educational outcomes, making learning more accessible, personalized, and effective. As the field continues to evolve, sustained research and ethical practices will be paramount in harnessing the full potential of GenAI in education.

3.3 Manufacturing and Industry

GenAI has emerged as a transformative force in manufacturing and industrial processes, playing a crucial role in enhancing productivity, efficiency, and sustainability. By leveraging advanced algorithms and data-driven approaches, GenAI is revolutionizing traditional manufacturing systems and enabling Industry 4.0 and 5.0 paradigms to thrive.

One of the most significant applications of GenAI in manufacturing lies in process optimization. By analyzing historical and real-time data, AI systems can predict energy consumption patterns, optimize production cycles, and forecast demand. This capability not only makes manufacturing processes more efficient but also reduces waste and promotes sustainable practices. GenAI also facilitates design and development optimization. Engineers and designers can use AI-driven tools to create innovative prototypes, refine designs, and optimize manufacturing processes. For instance, generative design software has enabled the development of lightweight, high-performance components in industries such as automotive and aerospace. By allowing the exploration of multiple design iterations based on specific constraints, AI systems empower designers to achieve superior results in less time. Predictive maintenance is another critical area where GenAI has shown immense potential. By combining sensor data with machine learning algorithms, AI systems can anticipate equipment failures and recommend maintenance schedules, reducing unplanned downtime and extending the lifespan of machinery. This proactive approach leads to substantial cost savings and improved operational efficiency. In the context of human-robot collaboration, GenAI fosters more seamless interactions between human workers and machines. Collaborative robots (cobots) equipped with AI can adjust their operations based on human inputs, ensuring safety and enhancing productivity. This integration of AI into robotics enables more adaptive and flexible production environments, aligning with the human-centric principles of Industry 5.0. However, the adoption of GenAI in manufacturing is not without challenges. Key issues include data availability and quality, the integration of AI with existing legacy systems, and the need for robust cybersecurity measures. Furthermore, the reliance on large datasets raises concerns about data privacy and the ethical implications of AI-driven decisions. Addressing these challenges requires significant investments in infrastructure, workforce training, and the development of comprehensive regulatory frameworks[9]-[12]-[16].

In conclusion, GenAI is redefining the manufacturing landscape by enabling smarter, more efficient, and sustainable industrial processes. Its applications span from design and maintenance to real-time decision-making and human-machine collaboration, driving innovation and competitiveness. As industries continue to integrate AI technologies, fostering a balance between technological advancement and ethical considerations will be critical for realizing the full potential of GenAI in manufacturing.

3.4 Design and Creative Industries

GenAI is revolutionizing the design and creative industries by introducing tools that enhance innovation, streamline workflows, and expand the boundaries of artistic expression. Leveraging advanced algorithms and data processing capabilities, GenAI has proven instrumental in creating unique and tailored content across diverse creative domains.

One of the most impactful applications of GenAI lies in creative content generation, where AI tools produce novel and diverse outputs such as digital art, music compositions, and multimedia content. This capability has significantly transformed industries like advertising, entertainment, and fashion, enabling creators to experiment with unprecedented designs and storytelling formats. For instance, GenAI models like GANs and VAEs are employed to produce realistic visual content and explore new aesthetic possibilities, thus inspiring innovation in both virtual and physical mediums. Collaborative creativity is another area where GenAI is reshaping the creative industries. By enabling human-AI collaboration, these tools allow designers to refine ideas iteratively and align outputs with their vision. Platforms like ChatGPT and DALL-E facilitate dynamic communication and conceptual visualization, bridging gaps between stakeholders in complex projects[17]-[19]. In design processes, GenAI assists designers by generating initial concepts, prototypes, and design variations based on specified constraints. This functionality accelerates the creative process and allows professionals to explore multiple possibilities efficiently. For example, in architecture and urban planning, AI-driven tools simulate optimized layouts and energy-efficient designs, taking into account environmental data and regulatory compliance[16].

Moreover, GenAI has become a cornerstone in the gaming and virtual reality sectors, where it generates immersive environments, lifelike characters, and engaging narratives. These innovations have elevated the interactive experience for users, making AI an integral part of modern entertainment ecosystems. Despite its transformative potential, the use of GenAI in creative industries raises critical concerns. Ethical issues such as the ownership of AI-generated content, potential job displacement, and the dilution of human creativity remain challenges that need to be addressed. Additionally, the opaque nature of AI algorithms can undermine transparency and accountability in creative processes, necessitating the establishment of comprehensive governance frameworks[12]-[20]-[21].

In conclusion, GenAI is revolutionizing the design and creative industries by empowering professionals with innovative tools and techniques. While challenges persist, the careful integration of AI into these industries promises to enhance productivity, foster collaboration, and push the boundaries of creativity.

3.5 Healthcare and Medicine

GenAI is transforming healthcare and medicine, offering advanced tools for diagnostics, treatment planning, and patient care. By harnessing sophisticated algorithms and deep learning models, GenAI addresses the complexities of medical processes and enhances the efficiency of healthcare delivery.

One of the critical applications of GenAI in healthcare is medical imaging and diagnostics. AI systems can analyze radiological images such as X-rays, MRIs, and CT scans to detect anomalies, tumors, and fractures with high accuracy. Additionally, these systems assist in generating 3D models from 2D medical images, improving the visualization of complex anatomical structures and aiding healthcare professionals in precise diagnoses. In the field of personalized medicine, GenAI facilitates drug discovery and treatment customization. By predicting interactions between chemical compounds and biological targets, AI accelerates the development of new medications. Furthermore, AI models analyze genetic data, medical history, and lifestyle factors to create tailored treatment plans, ensuring optimal therapeutic outcomes for patients. GenAI also powers virtual health assistants, which interact with patients to monitor symptoms, provide preliminary diagnoses, and offer mental health support. These AI-driven assistants enable continuous patient monitoring and deliver real-time feedback, particularly benefiting those with chronic conditions. Additionally, AI chatbots and systems like ChatGPT enhance patient-provider communication by summarizing complex medical information and offering multilingual support, which is especially valuable for non-native healthcare professionals [10]-[12]. Operational efficiency in healthcare is another domain significantly influenced by GenAI. AI systems optimize hospital resource management, automate administrative workflows such as patient data entry and billing, and predict maintenance schedules for medical equipment. These advancements streamline healthcare operations and reduce costs, allowing professionals to focus more on patient care. Despite its transformative potential, GenAI in healthcare presents several challenges. Concerns about data privacy, ethical use, and algorithmic transparency remain significant. Errors in AI-driven diagnoses or treatment recommendations can have severe consequences, necessitating robust validation and oversight frameworks. Moreover, addressing biases embedded in training datasets and ensuring equitable access to AI technologies are essential for maintaining trust in AI-assisted healthcare[22]-[23].

In conclusion, GenAI is revolutionizing healthcare by enhancing diagnostic accuracy, personalizing treatments, and improving operational efficiency. While challenges persist, the thoughtful integration of AI tools promises to advance patient care and healthcare delivery, shaping a more efficient and equitable medical ecosystem.

3.6 Transportation and Logistics

GenAI is profoundly transforming the transportation and logistics sectors by optimizing operations, enhancing efficiency, and addressing complex challenges. The integration of GenAI in these fields is revolutionizing route planning, fleet management, supply chain operations, and autonomous vehicle systems, contributing to the advancement of Industry 4.0 and beyond.

One of the most significant applications of GenAI is in route optimization and traffic management. AI-powered systems analyze traffic conditions, weather patterns, and delivery schedules to determine the most efficient routes, minimizing fuel consumption and reducing delivery times. This optimization not only enhances cost efficiency but also reduces the environmental impact of transportation systems[20]. Predictive models also enable better management of traffic congestion by adjusting signal timings in real-time and predicting potential bottlenecks[24]-[20]. In fleet management, GenAI improves operational efficiency by monitoring vehicle health and scheduling maintenance proactively. By analyzing sensor data, AI systems predict mechanical failures, reducing downtime and extending the lifespan of transportation assets. This capability ensures reliable fleet performance while lowering overall maintenance costs[25]-[26]. GenAI also facilitates the development of autonomous vehicles. AI-driven systems enable real-time navigation, obstacle detection, and adaptive route adjustments, which are essential for the deployment of self-driving cars and delivery robots. These innovations are poised to enhance road safety and operational efficiency while reducing the dependency on human intervention [16]-[27]. In the logistics domain, AI-powered autonomous robots streamline warehouse operations, including inventory management, picking, and packing, further increasing accuracy and productivity[20]. Another critical application of GenAI is in supply chain management. AI systems predict demand fluctuations, optimize inventory levels, and streamline delivery schedules, reducing lead times and transportation costs. Real-time data analytics enables supply chains to adapt quickly to disruptions, ensuring resilience in volatile global markets. This adaptability is essential for maintaining service levels and responding to shifting customer demands[28]-[25]. Despite its transformative potential, the adoption of GenAI in transportation and logistics is not without challenges. Key concerns include data privacy, cybersecurity risks, and ethical considerations in decision-making processes. Additionally, regulatory hurdles and public acceptance of autonomous systems remain significant barriers to widespread adoption[24]-[27].

In conclusion, GenAI is redefining the transportation and logistics sectors by introducing innovative solutions for route optimization, fleet management, and supply chain operations. While challenges persist, the thoughtful integration of AI technologies promises to enhance efficiency, sustainability, and customer satisfaction, paving the way for a smarter and more interconnected transportation ecosystem.

3.7 Management and Business Administration

GenAI is transforming management and business administration by enabling more efficient decision-making, improving organizational performance, and enhancing employee engagement. By integrating

AI-driven insights into business processes, organizations can innovate, streamline workflows, and adapt to dynamic market environments.

One significant application of GenAI is in strategic decision-making. AI systems analyze large datasets to identify trends, forecast market changes, and recommend optimal strategies. For instance, AI-powered tools can predict customer preferences and market dynamics, allowing managers to develop data-driven business strategies. This capability enhances organizational agility and supports long-term planning[25]-[29]. In the realm of human resource management (HRM), GenAI streamlines recruitment, talent acquisition, and employee engagement. AI-driven systems optimize hiring processes by screening resumes, matching candidates to roles, and conducting initial interviews. Additionally, AI tools enhance employee experience by providing personalized career development plans and training programs tailored to individual growth trajectories[30]-[20]. GenAI also plays a crucial role in business process automation. By leveraging robotic process automation (RPA) and AI-driven chatbots, organizations can automate repetitive tasks, reduce operational costs, and enhance productivity. For example, AI-powered chatbots handle customer inquiries efficiently, ensuring improved customer satisfaction and operational scalability. These tools are instrumental in transforming customer service into a more personalized and responsive domain[29]-[25]. Risk management is another area where GenAI provides significant value. AI systems generate risk scenarios, simulate outcomes, and recommend mitigation strategies. This capability is particularly valuable in crisis management and contingency planning, enabling organizations to build resilience and ensure continuity during disruptions. AI-driven insights help organizations proactively address vulnerabilities in supply chains and operational workflows[31]-[20]. Despite its transformative potential, GenAI adoption in management and business administration poses challenges. Key concerns include data security, ethical implications, and resistance to change within organizational cultures. Addressing these challenges requires robust governance frameworks, continuous employee training, and transparent AI systems to build trust and ensure accountability[29].

In conclusion, GenAI is redefining management and business administration by fostering innovation, enhancing decision-making, and improving efficiency. As organizations continue to integrate AI technologies, balancing innovation with ethical considerations will be critical to unlocking the full potential of AI in transforming business practices.

3.8 Marketing and Advertising

GenAI is revolutionizing marketing and advertising by enabling hyper-personalization, enhancing customer engagement, and streamlining campaign management. By leveraging advanced data analysis and content creation capabilities, GenAI empowers marketers to design more effective strategies and improve overall efficiency.

One of the most significant contributions of GenAI to marketing lies in content creation and personalization. AI-driven tools such as ChatGPT generate tailored advertisements, product recommendations, and marketing emails based on customer data, including browsing history, preferences, and purchase patterns. This level of customization not only increases customer engagement but also improves conversion rates by delivering relevant and timely messages. GenAI also enhances customer engagement by enabling real-time interactions through AI-powered chatbots and virtual assistants. These systems provide instant support, answer customer queries, and guide users through their purchasing journeys, fostering a seamless and personalized experience. Companies like Lemonade have effectively utilized AI chatbots to reduce response times and enhance customer satisfaction. In the realm of campaign optimization, GenAI supports marketers by automating processes such as A/B testing, ad placement, and performance tracking. AI systems analyze vast datasets to determine the most effective strategies, refine content, and allocate budgets efficiently. Real-time analytics also allow marketers to adjust campaigns dynamically, ensuring optimal return on investment (ROI). Another critical application of GenAI is in social media management and digital advertising. AI-powered platforms automate post scheduling, content curation, and audience targeting, enabling brands to maintain consistent engagement with their audience. Additionally, AI tools help marketers analyze social media trends and customer sentiments, enabling data-driven decision-making and enhancing brand visibility. Despite its transformative potential, the adoption of GenAI in marketing raises ethical and operational challenges. Issues such as data privacy, intellectual property concerns, and algorithmic biases require careful consideration. Additionally, maintaining the balance between automation and the human touch in customer interactions is essential for preserving trust and authenticity in brand communication[12]-[20]-[32].

In conclusion, GenAI is reshaping the marketing and advertising landscape by providing innovative solutions for content creation, customer engagement, and campaign management. As businesses continue to integrate AI technologies, addressing ethical concerns and fostering transparency will be crucial for maximizing the potential of GenAI in marketing.

3.9 Finance and Banking

GenAI is transforming the finance and banking sectors by improving efficiency, enhancing decision-making processes, and fostering innovation. Leveraging vast datasets and advanced algorithms, GenAI introduces groundbreaking applications in areas such as risk management, fraud detection, personalized financial services, and algorithmic trading.

One of the most impactful uses of GenAI in finance is in fraud detection. AI models analyze transactional data to identify patterns and detect anomalies indicative of fraudulent activity. For example, Swedbank's integration of GANs has significantly improved its ability to identify suspicious transactions and prevent financial crimes. In algorithmic trading, GenAI models create synthetic financial data to simulate market conditions, enabling the development and testing of sophisticated trading strategies. This approach enhances portfolio optimization by providing insights into performance across varying economic scenarios, thereby refining investment decision-making[22]-[12]. GenAI also plays a crucial role in personalized financial services. By analyzing customer behavior and financial data, AI systems offer tailored financial advice, simulate various planning scenarios, and provide customized recommendations for savings, investments, and retirement plans. This personalized approach not only enhances customer satisfaction but also drives long-term financial growth[22]. In risk management, GenAI models assess complex scenarios to predict potential financial market states, aiding stress testing and enabling proactive mitigation strategies. By identifying vulnerabilities within portfolios, these models help institutions adapt to changing economic conditions and maintain stability[22]-[10]. Another significant application lies in marketing communication within banking. AI-driven systems develop personalized campaigns using customer data, creating emotionally resonant advertisements tailored to individual preferences. This approach enhances engagement and strengthens customer relationships. Despite its transformative potential, the integration of GenAI in finance and banking is not without challenges. Key concerns include ensuring data security, managing ethical implications, and addressing the infrastructural demands of implementing AI systems. Collaboration among financial institutions is critical for developing robust AI frameworks, but it also raises questions about competition and data privacy[12]-[33].

In conclusion, GenAI is reshaping the finance and banking landscape by introducing innovative solutions for risk management, fraud detection, and personalized financial services. Addressing the ethical and operational challenges associated with AI implementation will be critical to unlocking its full potential in creating a more resilient and customer-focused financial ecosystem.

3.10 Energy and Environmental Technologies

GenAI is playing a transformative role in the energy and environmental sectors, addressing critical challenges in sustainability, energy efficiency, and carbon footprint reduction. By leveraging advanced data modeling, simulation, and optimization capabilities, GenAI enhances decision-making and operational efficiency across various domains within these industries.

One prominent application of GenAI is in renewable energy optimization. AI models predict energy production patterns from renewable sources like wind and solar, allowing for better integration into existing grids. These tools optimize energy storage and distribution systems to balance supply and demand efficiently, significantly reducing energy waste and improving overall grid reliability[34]. In the context of energy-efficient building designs, GenAI supports architects and engineers in creating sustainable structures. By simulating energy consumption and exploring design alternatives, AI-driven tools recommend optimal layouts, materials, and energy systems that minimize resource usage. For example, AI algorithms have been used to optimize solar panel placements and HVAC systems, ensuring maximum energy efficiency in buildings[19]. GenAI also aids in energy consumption forecasting. Machine learning models analyze historical and real-time data to predict peak usage times, enabling utilities to adjust load distribution dynamically. This proactive approach not only enhances energy efficiency but also contributes to reducing the reliance on nonrenewable energy sources[20]-[12]. In industrial operations, GenAI helps design and optimize equipment for energy-intensive processes. For instance, AI is used in wind turbine blade design, simulating various environmental scenarios to improve performance and adaptability. Similarly, in solar power system planning, AI tools utilize drone-captured data to automatically generate precise layout and electrical connection designs, accelerating implementation and increasing energy output[34]. Despite its benefits, the adoption of GenAI in energy and environmental technologies poses challenges, including the significant computational power required for AI training and deployment. This energy-intensive nature can conflict with sustainability goals, highlighting the need for energy-efficient AI algorithms and the use of renewable energy in AI infrastructure[12]-[19]. GenAI also supports sustainability efforts through carbon reduction strategies. By analyzing data from energy monitoring systems and ESG reports, AI systems develop customized plans to achieve carbon neutrality goals. Companies are increasingly using AI-generated insights to align their operations with global sustainability standards and drive their green transformations[20]-[35].

In conclusion, GenAI is revolutionizing energy and environmental technologies by offering innovative solutions for renewable energy management, efficient resource utilization, and sustainable development. While challenges related to energy consumption and ethical considerations persist, the strategic application of GenAI has the potential to drive significant advancements in global sustainability.

3.11 Legal and Compliance

GenAI is transforming the legal and compliance sectors by automating routine tasks, enhancing accuracy, and addressing the challenges posed by evolving regulatory landscapes. By leveraging NLP and advanced data analytics, GenAI optimizes documentation, ensures regulatory compliance, and improves risk management.

One of the primary applications of GenAI in this domain is legal documentation. AI systems like ChatGPT assist in drafting, reviewing, and editing contracts, saving time and reducing human error. These tools analyze extensive legal databases to identify precedents, ensure completeness, and enhance compliance with current regulations. This capability has streamlined processes in heavily regulated industries such as finance and healthcare[36]. In compliance monitoring, GenAI models detect regulatory violations in real-time, simplifying adherence to both internal and external standards. By analyzing patterns and transactions, AI systems provide organizations with actionable insights, reducing the risks of non-compliance and associated penalties. These systems also adapt to regulatory changes dynamically, minimizing the need for manual intervention[20]-[19]. Another critical contribution of GenAI lies in risk assessment and mitigation. AI tools analyze contracts, corporate policies, and operational data to identify potential legal risks, allowing organizations to take proactive measures. For example, GenAI can detect clauses in contracts associated with disputes or compliance issues, helping companies renegotiate terms to avoid future complications[19]-[37]. GenAI also supports regulatory agencies by facilitating agile governance. AI-powered frameworks enable continuous feedback between legislative bodies and regulatory agencies, ensuring that policies remain aligned with technological advancements. This dynamic regulatory approach allows organizations to navigate complex legal landscapes more effectively while fostering innovation. Despite these advantages, the integration of GenAI in legal and compliance functions poses challenges. Ethical concerns, including biases in AI algorithms and transparency issues, remain significant. Additionally, organizations must address the computational intensity of AI systems and ensure data security to maintain client trust and regulatory standards[36].

In conclusion, GenAI is redefining the legal and compliance landscape by automating documentation, improving compliance monitoring, and enhancing risk management. While ethical and operational challenges persist, the strategic application of AI in these areas offers substantial benefits, promoting efficiency, accuracy, and adaptability in a rapidly evolving regulatory environment.

3.12 Media and Communication

GenAI is transforming content creation, personalization, and engagement strategies in the media and communication industries. By leveraging NLP and multimodal content generation technologies, GenAI accelerates media production processes and enhances audience engagement.

GenAI is particularly impactful in the domains of content production and personalization. AI models such as ChatGPT and similar systems automate processes such as scriptwriting, news article generation, and social media content creation. This automation not only enables content creators to produce more content but also enhances audience interaction through AI-powered recommendation engines that analyze user preferences. Personalized content recommendations, in particular, significantly improve audience retention rates on digital platforms[18]. In journalism and news production, AI is driving significant transformations. News bots, for instance, expedite processes and reduce costs by producing data-driven news. Tools like Quill and Xiaomingbot generate high volumes of content in a short period using data-based templates. Additionally, multimodal AI systems are capable of producing complex stories in text, image, and video formats, broadening the scope of storytelling[20]. In the arts and entertainment industries, GenAI is utilized as a tool to enhance creative processes. Tools such as DALL-E and Midjourney accelerate processes like concept art creation, visual effects development, and virtual character production for creative professionals. These technologies not only reduce production costs but also pave the way for more innovative storytelling techniques [38]-[18]. Furthermore, AI-powered systems are employed in brand communication. These systems generate user-focused content for brand promotions and optimize media distribution strategies. AI enhances public relations and media management processes, enabling brands to reach wider audiences more effectively [20]-[39]. However, the application of GenAI in media and communication presents certain challenges. Algorithmic biases, ethical concerns, and data security issues may limit the effective and reliable deployment of these technologies. To address these challenges, AI systems should be designed in alignment with principles of transparency and accountability [18]-[17].

In conclusion, GenAI offers innovative solutions across various processes in media and communication, from content production to engagement strategies. Addressing ethical and operational challenges will unlock the full potential of AI in this sector, fostering a more inclusive and creative media environment.

3.13 Agriculture and Food Technologies

GenAI is driving significant advancements in productivity, sustainability, and resource management within agriculture and food technologies. By leveraging AI-powered models, precision agriculture practices are being optimized, resulting in enhanced food security and reduced environmental impacts. These technologies transform agricultural processes through the integration of soil analysis, weather data, and plant health evaluations. AI-enabled drones and sensors continuously monitor fields, detecting critical factors such as crop health, pest presence, and nutrient deficiencies. This real-time data allows for the optimization of irrigation, fertilization, and harvesting strategies, promoting more efficient resource use and improving overall agricultural productivity. In addition to transforming crop management, AI plays a pivotal role in optimizing food supply chains. Through advanced demand forecasting and inventory management systems, GenAI minimizes food waste and enhances supply chain efficiency. By analyzing variables such as weather patterns, seasonal demand fluctuations, and economic conditions, these systems provide producers with precise demand predictions. This ensures streamlined inventory management while simultaneously mitigating the risk of overproduction and waste. GenAI also contributes to the development of next-generation food technologies, focusing on sustainability and resilience. Innovations such as genetically engineered crops and vertical farming systems address the challenges posed by changing climate conditions, creating more robust and efficient food production methods. These technologies not only strengthen food security but also significantly reduce environmental impacts, aligning with global sustainability goals. Moreover, AI promotes sustainability by optimizing resource utilization and minimizing environmental footprints. By enabling maximum productivity with minimal inputs such as water and fertilizers, AI technologies ensure the efficient use of natural resources. Furthermore, early warning systems powered by AI assist in mitigating potential environmental risks, fostering the adoption of sustainable agricultural practices[10]-[20]-[27].

In conclusion, GenAI offers transformative solutions for agriculture and food technologies, enhancing productivity, sustainability, and resilience. As the global demand for food continues to rise and the challenges posed by climate change intensify, the adoption of AI-driven approaches is expected to expand, paving the way for a more sustainable and efficient agricultural future.

3.14 E-Commerce and Retail

GenAI plays a significant role in enhancing customer experience, improving operational efficiency, and optimizing marketing strategies within the e-commerce and retail sectors. By leveraging advanced data analytics and personalization capabilities, GenAI transforms customer interactions and provides a competitive edge to businesses in these industries.

In the domain of customer experience and personalization, GenAI systems improve the shopping journey by offering tailored recommendations to users. For instance, ChatGPT-powered virtual shopping assistants provide real-time support, product suggestions, and personalized shopping experiences. Additionally, e-commerce platforms utilize AI models to analyze purchase histories and browsing behaviors, delivering customized product recommendations to customers [12]. Inventory management and logistics optimization represent another crucial contribution of GenAI to the retail sector. AI models are employed to forecast demand, identify seasonal trends, and optimize stock levels. This allows businesses to avoid the costs associated with overstocking and stockouts. Moreover, AI enables route optimization in logistics, reducing delivery times and lowering operational costs [20]-[11]. In marketing strategy optimization, GenAI facilitates the creation of targeted campaigns by analyzing consumer behavior. For example, brands like Coca-Cola have developed more interactive marketing strategies by encouraging consumers to create art using AI-powered platforms. These approaches enhance customer satisfaction while strengthening the competitive advantage of brands[38]. However, the integration of GenAI also presents challenges, particularly concerning data security and algorithmic biases. Given the sensitivity of customer data, it is crucial that AI applications do not compromise data privacy. Furthermore, the lack of algorithmic explainability may undermine trust in AI-driven outcomes during business decision-making processes [12]-[11].

In conclusion, GenAI is transforming the e-commerce and retail sectors with innovative solutions, enhancing customer experience and improving operational efficiency. Nevertheless, addressing ethical and operational challenges will play a pivotal role in ensuring the sustainable and successful implementation of these technologies.

4 Cross-Sectoral Risks and Challenges

The rapid integration of GenAI in business processes presents transformative opportunities but also introduces significant cross-sectoral risks and challenges. These challenges span across ethical, workforce, legal, and regulatory dimensions, requiring a comprehensive and collaborative approach from all stakeholders. Ethically, GenAI poses concerns related to data privacy, informed consent, and algorithmic bias. GenAI often relies on large datasets that may contain sensitive or biased information, which, if not properly managed, could perpetuate existing inequalities. In sectors such as healthcare, where data privacy and accuracy are paramount, these ethical issues become even more critical. Furthermore, the creation of deepfakes and AI-generated misinformation has raised concerns regarding the integrity of public information, particularly in the media and communications industries. This proliferation of misleading content could erode public trust and amplify societal risks. As such, there is a pressing need for robust ethical AI frameworks to ensure transparency, accountability, and fairness in the deployment of AI technologies. Workforce displacement is another significant concern resulting from GenAI's ability to automate not only repetitive but also some creative tasks. In industries such as customer service, content generation, and data analysis, roles are increasingly vulnerable to automation, leading to the potential loss of jobs. At the same time, there is an increasing demand for advanced technical skills to manage and optimize AI systems. This creates a widening skill gap, especially for workers whose jobs are being displaced by AI systems. Addressing these workforce challenges requires businesses to invest in upskilling and reskilling programs that enable employees to transition into new roles in an AI-driven economy. The legal implications of GenAI integration are complex and remain unresolved in many areas. Key concerns include intellectual property rights for AI-generated content, the liability for errors caused by AI systems, and regulatory compliance across jurisdictions. The ownership of AI-generated works, particularly in creative sectors such as media and entertainment, raises questions about intellectual property rights. Similarly, sectors like healthcare, where AI-generated recommendations could directly affect patient outcomes, face significant challenges in terms of accountability in the event of harm. These legal uncertainties require businesses to stay engaged with evolving legal frameworks and develop proactive strategies to ensure compliance and mitigate risks. Cross-sectoral risks also vary in their scope and impact. In the healthcare industry, for example, AI-generated recommendations or diagnoses could have life-threatening consequences if the AI models are not properly trained or validated. Similarly, in the financial sector, reliance on AI for decision-making during periods of market volatility could amplify systemic risks and exacerbate economic crises. In media and communication, the unchecked proliferation of AI-generated content could distort public discourse, spreading misinformation and eroding public trust in traditional news sources. These risks underscore the importance of cross-sectoral collaboration between businesses, policymakers, and regulators to develop effective frameworks that address sector-specific concerns while ensuring responsible AI usage[19]-[36]-[37].

In conclusion, while GenAI offers substantial potential for innovation and efficiency across industries, its successful integration depends on the ability to address the ethical dilemmas, workforce disruptions, legal challenges, and cross-sectoral risks associated with its deployment. A balanced approach, combining innovation with responsibility, will enable businesses to effectively navigate the complexities of this rapidly evolving technological landscape, ensuring that AI benefits society as a whole while minimizing potential harms[19].

5 Strategic Roadmap for Industry Preparedness

As industries across the globe rapidly adopt GenAI, preparing the workforce, adapting organizational structures, and aligning policies are critical to ensuring a successful transition. This strategic roadmap explores the essential steps businesses should take in order to effectively integrate GenAI, with a focus on workforce readiness, organizational adaptation, and policy recommendations. The successful integration of GenAI will require a balanced approach, combining technological innovation with ethical considerations and effective change management.

5.1 Building a GenAI-Ready Workforce

The introduction of GenAI into the workforce necessitates a significant shift in employee skills and capabilities. As automation and AI tools handle more routine and complex tasks, there is an increasing demand for employees to possess advanced technical skills. These include expertise in data science, machine learning, and AI system management, alongside creative and strategic thinking abilities to harness AI's potential for innovation. However, the rapid evolution of these technologies also presents challenges in terms of workforce displacement. Roles in content creation, customer service, and data analysis are particularly vulnerable to automation, requiring a strategic approach to workforce development.

To build a workforce ready for GenAI, organizations must invest in comprehensive upskilling and reskilling programs. These initiatives should focus on developing both technical competencies and soft skills, such as adaptability, problem-solving, and collaboration. According to recent studies, businesses that provide training opportunities in AI technologies significantly enhance their competitive advantage by ensuring their employees are prepared for future technological shifts. Furthermore, partnerships with educational institutions can facilitate a pipeline of skilled talent, ensuring that new generations of workers are equipped with the necessary skills to thrive in an AI-driven economy.

5.2 Organizational Adaptation and Change Management

Adapting to GenAI requires not only technological infrastructure but also cultural and organizational changes. GenAI can enhance operational efficiency and foster innovation, but its full potential can only be realized if organizations are willing to embrace change at every level. The integration of AI tools should be accompanied by a clear strategy for managing the cultural shifts that come with automation, from leadership to employees.

Effective change management involves transparent communication, clear roles in AI implementation, and fostering an environment that values continuous learning. Research indicates that organizations with a clear change management framework are more likely to successfully integrate AI technologies into their operations and align their workforce with emerging needs. This includes defining new roles for AI system oversight, optimizing human-AI collaboration, and rethinking organizational structures to accommodate AI-driven processes.

Moreover, leadership must be proactive in addressing potential resistance to change. Leaders should emphasize the benefits of AI adoption, such as increased efficiency and innovation, while also acknowledging the challenges related to workforce transitions. Through inclusive leadership and active employee involvement in the decision-making process, businesses can foster a more positive outlook on AI integration.

5.3 Policy Recommendations

As GenAI continues to influence industries, the need for comprehensive policy frameworks becomes ever more pressing. The rapid pace of technological advancement often outstrips existing regulatory structures, which can create legal ambiguities, especially around issues such as data privacy, intellectual property, and algorithmic accountability.

To address these challenges, businesses, policymakers, and regulators must collaborate on creating adaptive, forward-looking policies that can accommodate GenAI's evolving role in business. Key areas for policy development include:

Data Privacy and Security: Policies should focus on ensuring that data used to train AI systems is secure, with clear guidelines on informed consent and data handling practices. Additionally, businesses must be transparent about how they use AI-generated content and ensure that ethical standards are maintained in AI applications.

Intellectual Property (IP) Rights: As AI creates content, such as text, images, and music, establishing clear guidelines for IP rights is crucial. This includes determining who owns the work generated by AI and ensuring fair compensation for creators.

AI Accountability: Policies should address issues of liability and accountability in cases where AI systems cause harm or make errors. Businesses must ensure that they have frameworks in place to monitor AI decisions and take responsibility for AI-driven outcomes.

Collaboration between businesses, governments, and international bodies is essential to create global standards and regulations that balance innovation with safety and fairness. As these frameworks are developed, they should remain flexible to account for the rapid pace of AI innovation while ensuring that ethical standards and public safety are not compromised.

6 Conclusion

This systematic review has underscored the transformative potential of GenAI across diverse industries, emphasizing its role in fostering innovation, improving efficiency, and addressing critical challenges. From healthcare to manufacturing, education to e-commerce, GenAI has emerged as a pivotal force reshaping traditional paradigms and driving industry evolution. By synthesizing advancements in generative modeling techniques such as GANs, TBMs, VAEs, and diffusion models, this review highlights GenAI's adaptability and efficacy in solving complex problems and enhancing decision-making processes.

The findings reveal that while GenAI presents immense opportunities, it also poses significant challenges, including ethical concerns, workforce displacement, regulatory uncertainties, and data privacy issues. These challenges necessitate a collaborative and proactive approach among stakeholders to ensure the responsible and sustainable integration of GenAI technologies. Ethical AI frameworks, robust governance mechanisms, and targeted workforce reskilling programs are critical to mitigating risks and maximizing the benefits of GenAI.

This review further demonstrates the importance of sector-specific strategies to leverage GenAI effectively. Industries must align their technological adoption with organizational goals and societal needs to achieve a balance between innovation and inclusivity. The dynamic applications of GenAI, from personalized education and predictive maintenance to sustainable energy management and enhanced customer engagement, underscore its transformative potential across economic and social dimensions.

Looking ahead, the success of GenAI depends on fostering a culture of innovation while addressing the complexities of its integration. Policymakers, businesses, and researchers must work in unison to develop adaptive regulatory frameworks, ethical guidelines, and scalable technological solutions. As GenAI continues to evolve, its role in shaping the future of business and society will hinge on the ability to navigate its challenges with foresight, collaboration, and accountability.

In conclusion, GenAI stands on the threshold of a transformative era, offering unprecedented opportunities to redefine industries and improve human experiences. By embracing this technology responsibly, businesses can unlock new possibilities for growth, resilience, and sustainability, ensuring that the benefits of GenAI are equitably distributed across all sectors of society.

7 Declarations

7.1 Conflicts of Interest

There is no conflict of interest in this study.

7.2 Contributions of Authors

Corresponding Author Osman SAHIN: Developing ideas or hypotheses for research and/or article, taking responsibility for explanation and presentation of results, taking responsibility for literature review during research, taking responsibility for preparation of entire article or main section.

2nd Author Durmus KARAYEL: Developing ideas or hypotheses for research and/or article, planning materials and methods to reach results, taking responsibility for explanation and presentation of results, taking responsibility for literature review during research, taking responsibility for preparation of entire article or main section, reworking not only in terms of spelling and grammar but also in terms of intellectual content or other contributions.

8 Human and Animal Related Study

The study does not involve the use of human/animal subjects.

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