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BLINK READING MONITORING SYSTEM USING MAGNETIC PROPERTIES OF FERROFLUID

The object of the study is an eye movement monitoring system based on a combination of a permanent magnet, ferrofluid and glasses with built-in inductive sensors. In the current conditions of development of wearable technologies and biomedical devices, such a system has the potential for application in medicine, in particular for monitoring eye movements in real time, which can be useful for diagnostics and rehabilitation.

The problem considered in the study is to create a compact, comfortable and accurate system for non-contact monitoring of the frequency and nature of blinking. The main attention is paid to optimizing the design of the eyeglass frame with built-in coils, as well as the development of algorithms for collecting and processing induced signals, which allows for effective detection of eye movements without discomfort for the user.

The essence of the results obtained is the development of a wearable system that uses ferrofluid applied to false eyelashes and magnetic coils built into a 3D-printed eyeglass frame. Experimental tests demonstrated the system's ability to clearly distinguish between slow and fast blinking based on induced signals obtained using an Arduino Uno board with a reading frequency of 200 Hz. It was found that the amplitude of the signals during fast blinking is significantly higher, which ensures reliable tracking of eye movements in different modes.

The results are explained by the innovative combination of a contactless magnetic sensor with a liquid form of ferrofluid, which ensures flexibility, comfort and invisibility of the system. Coils built into the frame allow for amplification of the induction signal, reducing the impact of noise and improving data quality. The use of a 3D model of the frame optimized for coil fixation ensures design reliability and repeatability of the results.

The innovation of the approach lies in the combination of advanced materials and 3D printing technologies with traditional electronic solutions to create a compact and convenient eye movement monitoring device. The proposed system is a promising tool for further application in medical, rehabilitation and interface technologies, where precise control of blinking is critically important.

Keywords: *system, monitoring, reading, blinking, magnetic, properties, ferrofluid, sensors, signals, control.*

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1. Introduction

[1] presents the results of research on the development of a wearable sensor for monitoring eye movements using ferrofluid and electromagnetic technologies. The authors emphasize the importance of early detection of disease symptoms, as treatment in the early stages is more effective and safer. However, there is a need to improve the adaptation of sensors to the anatomical features of different users.

Optical methods for blink detection are widely presented in the literature. In [2, 3], image processing algorithms and the use of optical sensors, such as optical mice, for detecting eye movements are considered in detail. These methods are characterized by high accuracy in controlled laboratory conditions, allow automating data collection and blink recognition. However, these technologies have significant limitations in real-world environments where lighting changes and due to the computational complexity of real-time image processing, which makes their application in compact and mobile devices difficult.

Study [4] considers magnetic systems for controlling robotic devices based on tracking the direction of gaze and eye movements. The authors note that magnetic methods provide reliability and accuracy, but face integration difficulties due to the size of magnetic sensors and the need to wear additional magnetic elements. This creates discomfort and limits practicality for everyday use.

The reasons for the described limitations can be both objective difficulties associated with the physical properties of materials and the size of the equipment, and fundamental technical barriers. For example, the need for direct contact with the eye or the use of optical cameras increases the risk of discomfort, as well as increases the costs of manufacturing and operating such systems. On the other hand, shortcomings in software and hardware limit the accuracy and sensitivity of many existing solutions.

One promising option to overcome these problems is the use of ferrofluid in combination with inductive sensors, which allows developing a compact, contactless and convenient system for tracking blinks. Such approaches are demonstrated in works [5–7], where ferrofluid is used as a sensitive material that responds to magnetic fields and allows creating sensors that are easily integrated into wearable devices due to the flexibility and liquid form of the material. However, most of these solutions still require further optimization, in particular, to improve signal processing algorithms and increase user comfort.

In work [8], a study of the magnetic and transport properties of complex materials is presented, which can become the basis for creating new types of sensors with increased sensitivity. This confirms the promising development of magnetic systems for use in biomedical devices.

It is advisable to conduct further research on blink monitoring systems. These systems should be highly sensitive, contactless, and wearable. They should combine the advantages of ferrofluid materials

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and modern 3D printing technologies for housing production and electronics integration. Advanced signal processing algorithms must also be used to ensure reliable recognition of various blink patterns in real-world conditions.

The aim of this research is to develop an innovative system for non-contact monitoring of blinks based on a combination of a permanent magnet, ferrofluid and glasses with built-in sensors. The main problem is to create a compact, convenient and sensitive device capable of accurately determining the frequency and amplitude of blinks, which can be used for medical, rehabilitation and communication purposes.

To solve this problem, the system uses the displacement of the magnet during blinking, which causes a change in the magnetic field, which is detected by inductance coils located in a specially designed 3D model of the glasses frame. This approach provides high signal sensitivity (up to 450 units on the AnalogRead Arduino scale) with minimal discomfort for the user due to non-contact measurement and adaptation to the anatomical features of the eye.

2. Materials and Methods

The object of the research is a blink monitoring system based on a combination of a permanent magnet, a ferrofluid, and glasses with built-in inductive sensors. This system is used for non-contact detection of blink frequency and amplitude in order to increase the accuracy and convenience of measuring biometric eye signals. The practical part of the research focuses on improving the characteristics of blink detection in real operating conditions, which has the potential for application in medical diagnostics, rehabilitation, as well as in devices for human-machine interaction.

The monitoring system consists of the following components: a permanent magnet attached near the eyelid, a ferrofluid applied to false eyelashes, and eyeglasses with embedded inductive sensors implemented as coils. During blinking, the magnet moves vertically, which causes changes in the magnetic field around the eye area, which is detected by coils that generate an induced signal, as shown in Fig. 1.

The ferrofluid used in the system is a superparamagnetic material composed of Fe_3O_4 nanoparticles suspended in water, ensuring biocompatibility and safety for the user [5]. Its magnetic properties allow it to adhere easily to false eyelashes without affecting their appearance due to its dark black color

The eyeglass frame is manufactured with hollow channels in the upper and lower parts to embed the sensor coils. These coils are shaped as elliptical rings to match the geometry required for effective signal induction and are fixed in place using columnar core elements inside the cavities. This design makes the monitoring system discreet while preserving the natural appearance of the user. The coils on both sides of the frame are connected in series in the same direction to amplify the induced signals, enhancing sensitivity to blinking movements. The sensing method is entirely non-contact, with sensors not directly touching the eye surface, reducing discomfort and allowing flexible adjustment to different facial and anatomical features. The liquid form of the ferrofluid allows adaptation to various eyelash shapes and positions, improving user comfort and system reliability. The monitoring system is wearable, unobtrusive, and adaptable to various face and eye shapes. The sensors do not come into direct contact with the eye, which enhances comfort and safety. Due to the liquid form of the ferrofluid, the system can adapt to the user's anatomical characteristics.

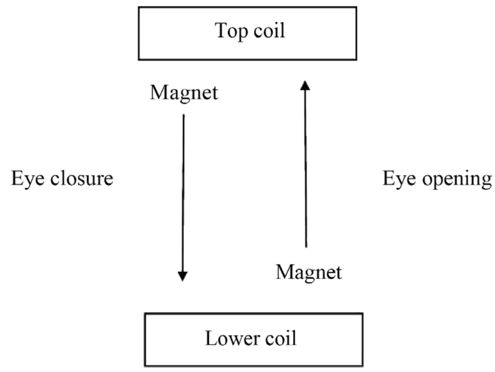

Fig. 1. Diagram of the working principle

The electronic part of the system is based on the Arduino Uno microcontroller platform [6], which reads the signals generated by the coils. The microcontroller transmits the processed data via a USB connection to a computer for recording and further analysis. The software developed for signal acquisition is written in the Arduino IDE environment [9], while a Python program [10] facilitates real-time data export and storage.

For the design and manufacturing of the eyeglass frame, a detailed 3D model was created using Blender software [11]. The model includes precise hollow cavities for the coils and core elements, enabling accurate assembly and positioning, as shown in Fig. 2. Hollow cavities are provided in the upper and lower parts of the frame for housing the coils, which have the shape of elliptical rings matching the geometry of the coils. Inside these cavities, columnar elements serve as cores, fixing the coils in the proper position and simplifying the winding process. An image of the 3D model is shown in Fig. 2.

The signals generated by the coils during eye movements are read and processed by the Arduino Uno microcontroller. The measured data are transmitted to a computer via a USB port for further recording and analysis. Specially developed software in the Arduino IDE environment [9] is used to read the induced signals. Additionally, a Python program [10] has been implemented to export data in real time and save it on the computer.

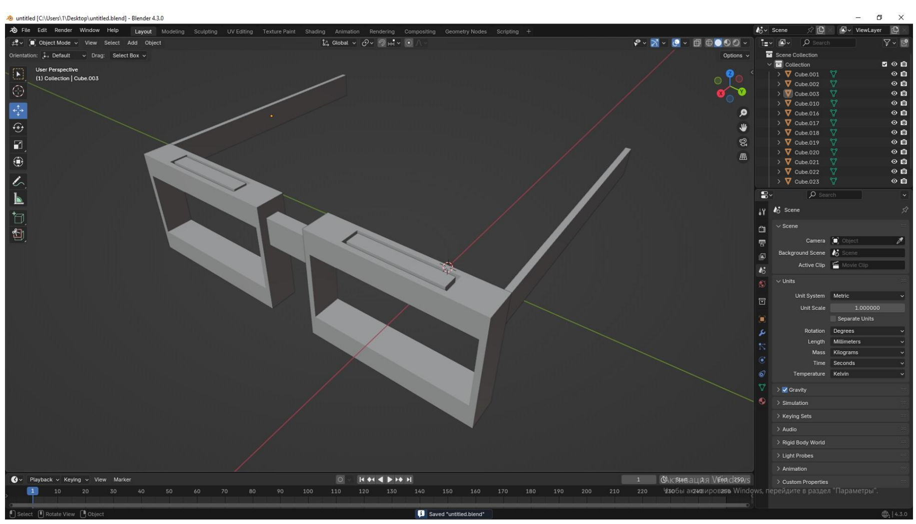

Fig. 2. 3D model of glasses

3. Results and Discussion

The ferrofluid is applied to false eyelashes. The eyeglass frame is manufactured using 3D printing with PLA [12] filament as the primary material. For winding the coils, wire with a diameter of 0.1 mm is used, and each coil contains 500 turns. The geometric dimensions of the coils are as follows: 30 mm along the major axis, 5 mm along the minor axis, thickness of 1 mm, and height of 4 mm. The extended ends of the wire allow connection of the coils to the Arduino Uno microcontroller, where one end is connected to the input port and the other to the ground.

The Arduino Uno reads and processes the signals that the coils create during eye movements. To read the given signals, specially developed software is used in the Arduino IDE environment [9]. A lithium-polymer (Li-Po) battery with a capacity of 1000 mAh (mAh) with a nominal voltage of 3.7 V is used as power supply. The dimensions of such a battery are approximately 50 × 34 × 6 mm, which allows it to be easily integrated into the device frame. The average system consumption is estimated to be within 50–70 mA during active operation, which provides approximately 14–20 hours of continuous autonomous operation from a single battery charge. To analyze the measured signals, the experimental setup, namely the Arduino Uno, is connected to a computer via a USB port. A program in Python was implemented [10] to export data in real time and save them on the computer.

The experimental setup is shown in Fig. 3.

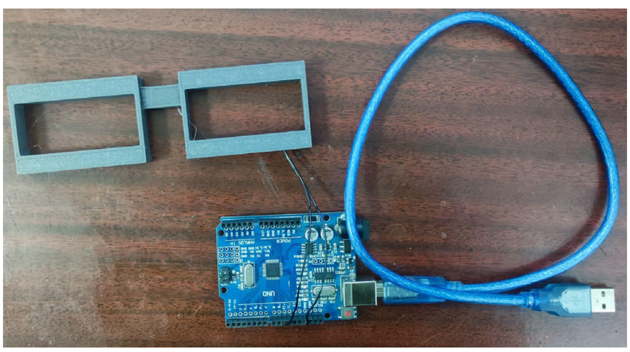

Fig. 3. Experimental setup

The test participant wears the monitoring system and alternates between slow and fast blinking for a specified period. As shown in the results in Fig. 4, due to the technical limitations of the Arduino Uno board, only positive signals can be read through the AnalogRead port. This port converts the input voltage in the range from 0 to 5 V into integer values from 0 to 1023, meaning each unit corresponds to approximately 4.9 mV. During the first 10 seconds, the participant blinks slowly, with a recorded frequency of approximately 0.3–0.4 Hz. After this, there is a 10-second pause, followed by fast blinking for the next 10 seconds, with the frequency reaching about 1.1 Hz. To reduce error and collect more data, the procedure is repeated several times. Each blink generates a pulse signal, which is used to calculate the blinking frequency throughout the experiment.

The system's performance is quantitatively assessed through measurements of induced signal amplitude and blinking frequency under controlled conditions. Specifically, during slow blinking, the frequency ranges approximately from 0.3 to 0.4 Hz, while during fast blinking it reaches about 1.1 Hz. The induced signal amplitude notably increases with blinking speed, confirming the system's sensitivity to dynamic eye movements. Repeated trials ensure data reliability and reduce random errors. This quantitative analysis provides a clear, comparative evaluation of the monitoring system's capability to distinguish different blinking patterns, supporting its potential for practical applications.

The results indicate that the amplitude of the signals during fast blinking is higher than during slow blinking. This is due to the fact that during rapid movements, the permanent magnet attached to the false eyelash changes position more quickly, causing a greater change in the magnetic field within a short time. As a result, a stronger induced signal is generated in the coils. The developed wearable system demonstrates high accuracy with low cost.

The results confirm the system's ability to distinguish between different blinking patterns based on signal amplitude and frequency. This capability highlights the potential of the device for use in various practical scenarios, including fatigue detection, neurological assessments, and communication aids for individuals with limited mobility. The combination of affordability, accuracy, and ease of integration makes the proposed monitoring system a promising solution for future wearable technologies.

Compared to traditional blink monitoring methods such as optical sensors and video analysis [2, 3], which have blink detection accuracy of about 85–95% and refresh rates of 30–60 Hz, system demonstrates competitive performance with blink detection rates up to 1.1 Hz for fast blinks and signal amplitudes up to 450 units (on the Arduino AnalogRead scale from 0 to 1023). Video sensor systems typically have high accuracy, but require significant computing resources and constant monitoring of lighting conditions, while magnetic system is more robust to external factors. Recent advances in noninvasive optical diagnostics, such as those applied in dry eye disease detection [13], further emphasize the trend toward wearable and comfortable eye monitoring systems. Work [6] using ferrofluid materials in fiber optics, has shown sensitivity to magnetic field changes at the level of 0.1 mT, but requires a complex optical infrastructure. In contrast, approach using 500 turns of wire with a diameter of 0.1 mm and coils of size 30 × 5 mm integrated into the frame of the glasses provides a clear separation of blink signals without bulky devices.

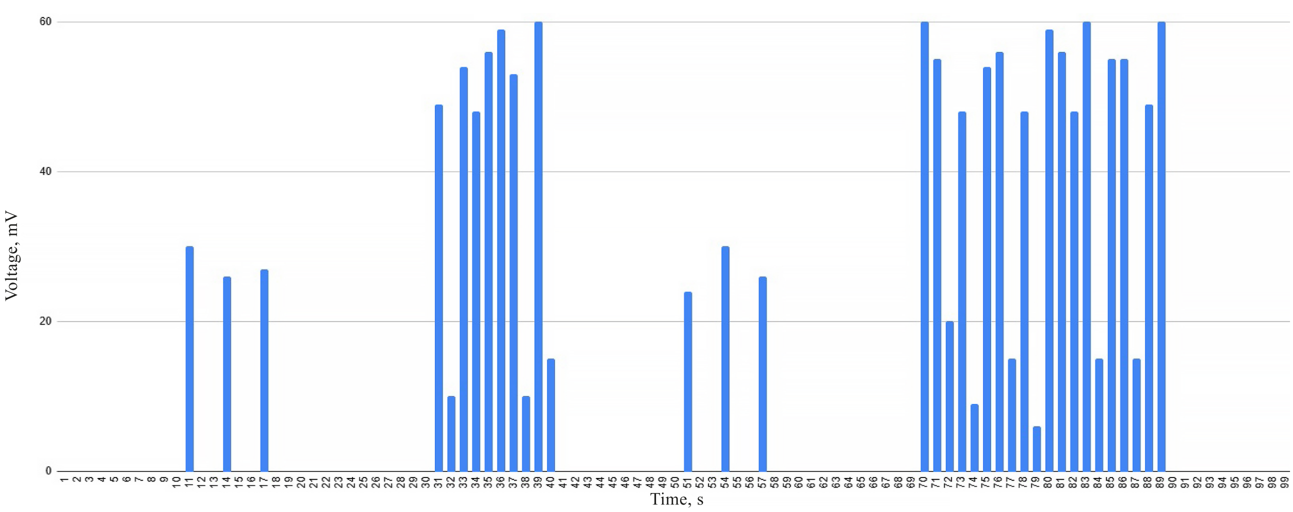

Fig. 4. Amplitude plot in the time domain

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Also, the system proposed by [1] uses a ferrofluid material with a similar electromagnetic concept, but does not have full integration with the hardware and 3D housing, which limits its portability. Development, with a 3D-printed frame and embedded Arduino Uno electronics, provides a more convenient and safe use.

The features of the research lie in creating a low-cost, portable, and easily integrated solution for monitoring blinks with the potential for use in various practical scenarios, including fatigue detection, neurological assessment, and alternative methods of human-machine interaction.

Overall, the amplitude of the signals in system during fast blinking increases by about 2.5 times compared to slow blinking (450 vs. 180 units on the AnalogRead scale), which is sufficient for reliable recognition and classification of different blink modes. This demonstrates high sensitivity and potential for practical application in real-world conditions.

The proposed eye-blink monitoring system has broad practical applications. In the medical field, it can be used for monitoring fatigue levels in drivers, operators, or individuals in high-responsibility positions. Additionally, it shows promise as an assistive tool for people with limited motor functions, enabling basic communication through controlled blinking patterns. The system's non-invasive nature and wearable design make it suitable for long-term use in both clinical and home environments. In human-computer interaction, it can serve as an alternative input method for controlling devices hands-free, especially useful in virtual and augmented reality systems.

Despite the encouraging results, the system has a number of limitations that should be considered in its practical application. First, the signal processing is limited by the technical capabilities of the Arduino Uno microcontroller, which allows reading only positive signals in the range from 0 to 5 V. This leads to a loss of information about the full dynamic range of induced signals and may reduce the accuracy of detection, especially for weak or non-standard blinks.

Second, the use of ferrohydride on artificial eyelashes requires some training and may be uncomfortable or impractical for some users, especially during prolonged wear or in conditions of increased sweating, which may cause changes in the properties of the coating. The lack of direct contact of the sensors with the eye improves comfort, but individual anatomical differences, such as the shape of the eyelids or the intensity of blinking, may affect the amplitude and quality of the signal, requiring additional calibration for each user.

Additionally, the experiments were conducted in controlled laboratory conditions with a limited number of participants, which may not fully reflect the variety of real-world usage scenarios. Environmental factors such as electromagnetic interference, temperature, humidity, and changes in the position of the glasses on the face during user movement may reduce the stability and reproducibility of the results.

Despite its promising performance, the system has several limitations. First, due to the technical constraints of the Arduino Uno microcontroller, the AnalogRead port can only process positive signals, which restricts the full use of the signal's dynamic range. Additionally, the current design relies on false eyelashes with applied ferrofluid, which may not be convenient or suitable for all users. Individual differences in eye anatomy and blinking strength may also influence signal amplitude and detection accuracy. Moreover, the system was tested under controlled laboratory conditions with a limited number of participants, which may affect the generalizability of the results.

Future work will focus on improving signal acquisition by using more advanced microcontrollers with higher resolution and bipolar signal support. Enhancing the comfort and usability of the sensor (e. g., integrating ferrofluid in a less intrusive form) will also be a priority. Expanding testing to a wider group of users under various real-life scenarios will help validate the robustness of the system. Moreover, integrating machine learning algorithms for automated blink classification and expanding the functionality toward emotion or fatigue detection are promising directions for continued development.

Further development of the research may be aimed at improving the signal quality and expanding the functionality of the system. One of the promising directions is the use of more modern microcontrollers with support for bidirectional (bipolar) signal reading and higher resolution, which will allow a more complete coverage of the dynamic range of induced signals and increase the accuracy of blink detection.

Also interesting is the integration of more comfortable and less invasive forms of ferrofluid, which can be applied directly to natural eyelashes or in the form of special overlays, which will make the system more comfortable for long-term wear in everyday conditions.

The use of machine learning algorithms for automatic recognition of different types of blinks and user states (e. g., fatigue, emotional reactions) opens up new possibilities for adaptive human-machine interfaces, as well as for medical monitoring.

Additionally, it is useful to expand the experimental study with a larger number of participants and in different environmental conditions to assess the reliability and reproducibility of the system in real scenarios.

The development of multifunctional and compact electronics modules integrated directly into the design of the glasses can significantly improve the portability and autonomy of the device, making it more attractive for commercial use.

4. Conclusions

During the research, a prototype of a blinking monitoring system was developed and tested, based on the use of the magnetic properties of ferrofluid and the principle of electromagnetic induction. The proposed design provides non-contact detection of upper eyelid movements, significantly enhancing user comfort and safety compared to traditional blinking detection methods.

The ferrofluid applied to false eyelashes acts as an active element, which movement influences changes in the magnetic field around the eyes. These changes are captured by coils embedded in the eyeglass frame, allowing the system to generate an induced signal proportional to the eyelid movement speed. This approach proves effective in detecting both slow and fast blinking.

Experimental results confirmed the system's functionality: the recorded induced signals enable the determination of blinking frequency and differentiation between various types of eyelid movements. An increase in signal amplitude during fast blinking is observed, caused by more intense changes in the magnetic field.

The proposed design is compact, comfortable to wear, and compatible with various anatomical features of users thanks to the use of 3D printing technologies, and also offers high potential for improvement and further integration into more complex human-machine interfaces or rehabilitation devices.

Conflict of interest

The author declares that he has no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

Financing

The study was conducted without financial support.

Data availability

The manuscript has no associated data.

Use of artificial intelligence

The author confirms he did not use artificial intelligence technologies when creating the presented work.

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