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DEVELOPMENT OF AN EYE-CONTROLLED MOBILE ROBOT SYSTEM USING EOG SIGNALS

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Abstract
The development of an eye-controlled mobile robot system using Electrooculography (EOG) signals is presented in this study. The proposed system enables robot motion control through eye movement detection, providing an alternative interaction method for individuals with limited physical mobility. The EOG sensor captures eye movement potentials, which are processed by a microcontroller to generate motion commands. A threshold-based detection algorithm was implemented to classify eye movements into four directional commands: left, right, forward, and backward. The system was tested to evaluate movement accuracy and response time. Experimental results show that the proposed system achieved an average directional detection accuracy of 88.3% and an average response time of 218 milliseconds, indicating reliable and real-time performance. The findings demonstrate that EOG-based control provides a feasible and responsive approach for human–robot interaction. Future improvements may involve noise filtering techniques and machine learning models to enhance signal stability and classification precision.

1.0 INTRODUCTION

The advancement of robotics technology and human–machine interface (HMI) systems has progressed rapidly, particularly in bio-signal-based control systems [1]. One of the most widely studied biological signals is Electrooculography (EOG), which measures the electrical potential generated by eye movement activity [2]. This signal has great potential for controlling electronic and robotic systems without the need for conventional physical inputs such as buttons or joysticks. The use of EOG signals as a control medium is relevant due to their natural, intuitive, and easily measurable characteristics, which can be achieved using surface electrodes [3]. This technology is especially beneficial for individuals with physical disabilities who cannot operate mechanical devices directly but retain control over their eye movements [4]. Thus, eye-movement-based control systems can serve as innovative solutions in both assistive technology and intelligent robotics applications.

In practice, EOG-based robot control faces several challenges, primarily related to signal quality and the stability of eye movement detection [5]. EOG signals are often contaminated by noise originating from blinking, facial muscle contractions, or external electrical interference [6]. Several previous studies have utilized EOG signals to control various robotic systems, most of them offering an alternative means of interaction for individuals with disabilities. Early studies by [7] combined a wheelchair and an intelligent robotic arm, based on an electrooculogram

(EOG) signal, to help patients with spinal cord injuries (SCIs) accomplish a self-feeding task. Other studies present a novel single-channel Electrooculography (EOG)-based efficient Human–Machine Interface (HMI) for helping individuals suffering from severe paralysis or motor degenerative diseases regain mobility [8], and eye movement detection using a wearable HCI system [9]. In recent years, research on sensors and electronics has enabled the development of electrooculogram (EOG) detection systems for recording eye movements [10][11][12]. However, when EOG signals are processed without any control mechanism to recalibrate or compensate for baseline drift, the accuracy of eye-movement recognition deteriorates substantially.

Therefore, it is essential to design a system capable of acquiring and processing EOG signals in real-time, while maintaining a stable and responsive control algorithm to interpret user commands accurately. One approach to address these challenges involves applying pattern recognition algorithms to detect eye movement directions (right, left, up, and down). The detected movement patterns are then used as input commands to control a mobile robot according to the user's line of sight. This approach enables a more natural human–machine interaction and supports the development of adaptive robotics based on bio-signals. By designing a mobile robot control system based on eye movement using EOG signals, this research aims to contribute to the development of non-conventional robot control technology that is efficient, responsive, and inclusive. Moreover, the proposed system can serve as an initial prototype for assistive applications for individuals with disabilities and as a foundation for future research in neuro-robotics and biomedical engineering.

2.0 RESEARCH METHOD

2.1. Integration Design of the EOG Sensor, Microcontroller, and Mobile Robot

The proposed system consists of three main components that work together to enable eye-movement-based control of a mobile robot. Each component plays a critical role in acquiring, processing, and executing control commands derived from Electrooculography (EOG) signals. The EOG sensor serves as the primary input device, responsible for capturing electrical potentials generated by horizontal and vertical eye movements. These signals represent changes in corneal-retinal potential and are detected through surface electrodes placed around the eyes. The raw analog signals obtained from the EOG sensor contain directional information that must be processed before being translated into robot motion commands.

The microcontroller, an Arduino Uno, functions as the central processing unit of the system. It receives the analog EOG signals through its analog-to-digital converter (ADC), processes the data in real-time, and applies a direction detection algorithm to classify eye movements into specific control commands. The microcontroller then generates appropriate output signals based on the detected direction and transmits them to the robot's motor controller. The mobile robot, typically designed as a two-wheel differential drive platform, executes the motion commands received from the microcontroller. The robot can move forward, backward, turn left, or turn right depending on the interpreted eye movement. The motor driver regulates the speed and direction of the DC motors according to the control signals, enabling the robot to respond accurately to user intentions conveyed through eye movements.

Together, these components form an integrated system that allows intuitive, non-contact control of a mobile robot using bioelectrical signals generated by eye movements. Figure 1 shows the functional relationship among the EOG sensor, the microcontroller, and the mobile robot platform. In Figure 1, the EOG sensor captures changes in electrical potential generated by eye movements. The resulting analog signals are then transmitted to the microcontroller's ADC for digitization. The microcontroller processes these signals and detects directional movements to the left, right, upward, and downward. The corresponding control commands are subsequently sent to the motor driver (L298N) to move the robot in the appropriate direction.

Figure 1. Integration Design of the EOG Sensor, Microcontroller, and Mobile Robot

2.2. Algorithm/Pseudocode for Mobile Robot Control Based on EOG

The system algorithm is used to detect eye movement directions based on EOG signals and translate them into motion commands for the robot. The detection process employs a threshold-based detection approach. The following is a pseudocode that was implemented on Arduino:

```
Initialize ADC_pins for EOG_input
Initialize MotorDriver_pins for left and right motors

Set threshold_left = -200
Set threshold_right = 200
Set threshold_up = 150
Set threshold_down = -150

Loop:
  Read horizontal_signal from ADC1
  Read vertical_signal from ADC2

  # Direction detection based on signal threshold values
  If horizontal_signal > threshold_right:
    direction = "RIGHT"
    Move robot to the right
  Else if horizontal_signal < threshold_left:
    direction = "LEFT"
    Move robot to the left
  Else if vertical_signal > threshold_up:
    direction = "FORWARD"
    Move robot forward
  Else if vertical_signal < threshold_down:
    direction = "BACKWARD"
    Move robot backward
  Else:
    direction = "STOP"
    Stop robot

  Display direction on serial monitor
  Delay(50 ms)
End Loop
```

3.0 RESULT

3.1. System Performance Measurement

The system testing phase was conducted to evaluate the accuracy and responsiveness of the eye-movement-based robot control mechanism. A total of 30 trials were performed for each eye movement direction, which included right, left, upward, and downward movements. During each trial, the system detected the user's eye movement and generated a corresponding motion command for the mobile robot.

Each successful detection resulted in the robot moving in the intended direction, allowing the performance of the detection algorithm and the overall control system to be assessed comprehensively. This testing procedure ensured that the system's behavior could be measured under repeated conditions, providing reliable data regarding consistency, accuracy, and operational stability.

The results of the directional detection tests are summarized in Table 1. Table 1 presents the number of trials conducted for each eye movement direction, the number of correctly detected movements, and the corresponding accuracy percentages. These measurements provide an overview of the system's ability to correctly interpret eye movements and translate them into the appropriate robot motion commands.

Table 1. Results of Robot Direction Detection Measurements

Eye Movement Direction	**Number of Trials**	**Correct Detections**	**Accuracy (%)**
Right	30	27	90.0
Left	30	26	86.7
Upward	30	28	93.3
Downward	30	25	83.3
Average Accuracy			88.3%

Besides that, the response time of the system was also measured to evaluate how quickly the robot reacts to the detected eye movement signals. Table 2 summarizes the average response time for each directional command, along with explanatory notes regarding the system's performance. These measurements provide insight into the system's real-time capabilities and its consistency in translating eye movements into robot actions.

Table 2. Response Time Measurement

Movement Direction	**Average Response Time (ms)**	**Description**
Right	210 ms	Fast Response
Left	230 ms	Stable
Upward	190 ms	Fastest Response
Downward	240 ms	Slightly Slower
Average	218 ms	Real-time Responsive System

3.2. Analysis

The system achieved an average directional detection accuracy of 88.3%, which demonstrates that the threshold-based algorithm is sufficiently robust for recognizing consistent horizontal and vertical eye movement patterns. This level of accuracy indicates that the signal amplitudes generated by eye movements are distinguishable enough from noise when processed through the selected threshold values. It also suggests that the algorithm can maintain performance across repeated trials, reflecting its stability and reliability under controlled testing conditions.

The measured response time, which remained below 250 ms, confirms that the system operates within the real-time range required for simple robotic control applications. A response time in this range ensures that users perceive the robot's movement as immediate and responsive, which is crucial for maintaining natural interaction flow between human intention and robot action. This performance level is particularly important in assistive or interactive systems where delayed responses may lead to user discomfort or reduced usability.

However, some variability in response time was observed across different directional commands. This variation can be attributed to several factors, including signal processing latency, inherent fluctuations in EOG signal amplitude, and noise artifacts caused by involuntary eye blinks or facial muscle activity. These noise sources can momentarily reduce the signal-to-noise ratio, requiring additional processing time for direction classification.

Overall, the results indicate that the system provides a reliable foundation for real-time eye-controlled robot navigation. Yet, the presence of noise-related fluctuations also highlights the opportunity for improvement through the integration of more advanced filtering techniques to enhance the precision and stability of the detection process.

5.0 CONCLUSION

The development of the eye-movement-based control system demonstrates the feasibility of utilizing EOG signals as an intuitive and non-physical interaction method for mobile robot navigation. The system architecture successfully integrates biosignal acquisition, real-time processing, and directional robot control within a compact and low-cost platform. The experimental evaluation confirms that the approach supports natural human intention mapping, enabling users to guide a robot solely through eye movements without requiring conventional manual interfaces. These findings highlight the potential of EOG-driven interaction as a promising alternative for applications involving users with limited motor abilities or in scenarios where hands-free control is advantageous. Future studies may explore several directions to further enhance system performance and robustness, such as implementing advanced filtering techniques using Kalman filtering, adaptive noise suppression, or wavelet-based denoising could reduce signal artifacts and improve detection consistency. Furthermore, testing the system with a broader and more diverse group of users, including individuals with motor impairments, would provide better insight into usability, ergonomics, and long-term reliability for assistive technology applications.

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