

EOG-Based Blink Detection for HCI Control Systems

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ABSTRACT

The rapid evolution of Human-Computer Interaction (HCI) has led to the development of innovative interfaces that enable seamless communication between humans and machines. Traditional input devices such as keyboards, mice, and touchscreens are not suitable for individuals with severe motor disabilities, particularly those suffering from paralysis, amyotrophic lateral sclerosis (ALS), or locked-in syndrome. These individuals retain cognitive abilities but lack the physical means to communicate effectively, resulting in complete dependency on caregivers. This paper presents a biosignal fusion-based HCI control system that utilizes Electrooculography (EOG) signals for eye-blink detection. The proposed system captures electrical potential generated by eye movements using non-invasive electrodes, processes these signals through embedded hardware, and translates blink patterns into meaningful commands. The system integrates multiple components, including signal acquisition, filtering, feature extraction, pattern recognition, and communication modules, to provide a reliable and efficient interaction mechanism. A key contribution to this work is the implementation of a low-cost, real-time system using Arduino UNO R4 Minima and BioAmp EXG Pill. The system achieves high accuracy in blink detection (96.2%) and low latency (approximately 1.5 seconds), making it suitable for real-time applications. Additionally, a web-based interface with multilingual support and text-to-speech functionality enhances accessibility and usability for diverse users. Experimental analysis demonstrates that the proposed system outperforms traditional assistive technologies in terms of cost, efficiency, and adaptability. The system provides a scalable and practical solution for improving the quality of life of individuals with communication impairments.

Keywords: Human-Computer Interaction (HCI), Electrooculography (EOG), Blink Detection, Assistive Technology, Arduino, Biosignal Processing.

I. INTRODUCTION

Human-Computer Interaction (HCI) has evolved significantly with the integration of biosignal-based systems, enabling communication through physiological signals [1, 2]. Traditional input devices are unsuitable for individuals with severe motor impairments such as paralysis, ALS, or locked-in syndrome. Electrooculography (EOG) provides a reliable and low-cost solution by capturing electrical signals generated through eye movements and blinks [3-5]. Unlike camera-based systems, EOG is robust against lighting variations and requires minimal hardware. The proposed system utilizes blink patterns (single, double, triple) for communication, integrated with a multilingual web interface and caregiver notification system. The system is designed to be cost-effective, real-time, and accessible [6-7].

II. LITERATURE REVIEW

Biosignal-based Human-Computer Interaction (HCI) systems encompass various approaches, including EEG-based interfaces, vision-based eye tracking, and Electrooculography (EOG)-based methods. Among these, EOG systems are widely preferred due to their high signal-to-noise ratio, low computational complexity, and cost-effectiveness, making them suitable for real-time and embedded applications [8, 9]. Blink detection in such systems is typically implemented using threshold-based algorithms, as they require minimal computational resources and enable efficient real-time processing. However, existing solutions still face several challenges, including high system cost, complex calibration procedures, and limited support for multilingual interfaces [10]. The proposed system addresses these limitations by offering simplified architecture, improved usability, and enhanced accessibility for diverse users.

III. SYSTEM ARCHITECTURE

The proposed system is designed using a modular architecture consisting of multiple functional layers, each responsible for a specific stage of biosignal processing and interaction. As illustrated in Fig. 1, the system begins with the Signal Acquisition Layer, where Electrooculography (EOG) signals are captured using surface electrodes placed around the eyes. These weak bioelectric signals are amplified and conditioned using the BioAmp EXG Pill to ensure accurate acquisition. The captured signals are then passed to the Signal Processing Layer, where noise and unwanted artifacts are removed using digital filtering techniques. Specifically, a bandpass filter in the range of 0.5–40 Hz is applied to retain relevant signal components, while a notch filter is used to eliminate power-line interference, thereby improving signal quality.

Following preprocessing, the refined signals are forwarded to the Pattern Recognition Layer, which plays a crucial role in interpreting user intent. This layer employs a threshold-based algorithm to identify distinct blink patterns such as single, double, and triple blinks. These patterns are then mapped to predefined control commands, enabling effective interaction with the system. The processed commands are subsequently communicated to the User Interface Layer, which is implemented as a web-based application. This interface provides an intuitive and accessible platform for users, incorporating multilingual support to cater to diverse linguistic backgrounds and enhance usability.

Finally, the Communication Layer ensures real-time interaction and feedback by transmitting alerts and messages to caregivers using the Telegram API. Additionally, text-to-speech functionality is integrated to provide auditory feedback, further improving accessibility for users with severe motor impairments. Together, these interconnected modules form a cohesive system that enables efficient, real-time, and user-friendly human-computer interaction through biosignal processing.

IV. PROPOSED METHODOLOGY

As illustrated in Fig. 1, the system is organized into multiple layers. The proposed system, EyesTalk, follows a structured and real-time signal processing pipeline designed to convert human eye-blink biosignals into meaningful communication commands. The methodology integrates biosignal acquisition, signal processing, pattern recognition, and user interaction modules to enable seamless human-computer interaction for individuals with severe motor impairments. The system is designed to be low-cost, efficient, and suitable for real-world deployment.

The process begins with the signal acquisition stage, where Electrooculography (EOG) signals are captured using non-invasive surface electrodes placed around the eyes. These electrodes detect the electrical potential generated due to eye movements and blinks. Since these signals are extremely weak, they are amplified and conditioned using the BioAmp EXG Pill, ensuring that the captured signals are strong enough for further processing while maintaining signal integrity.

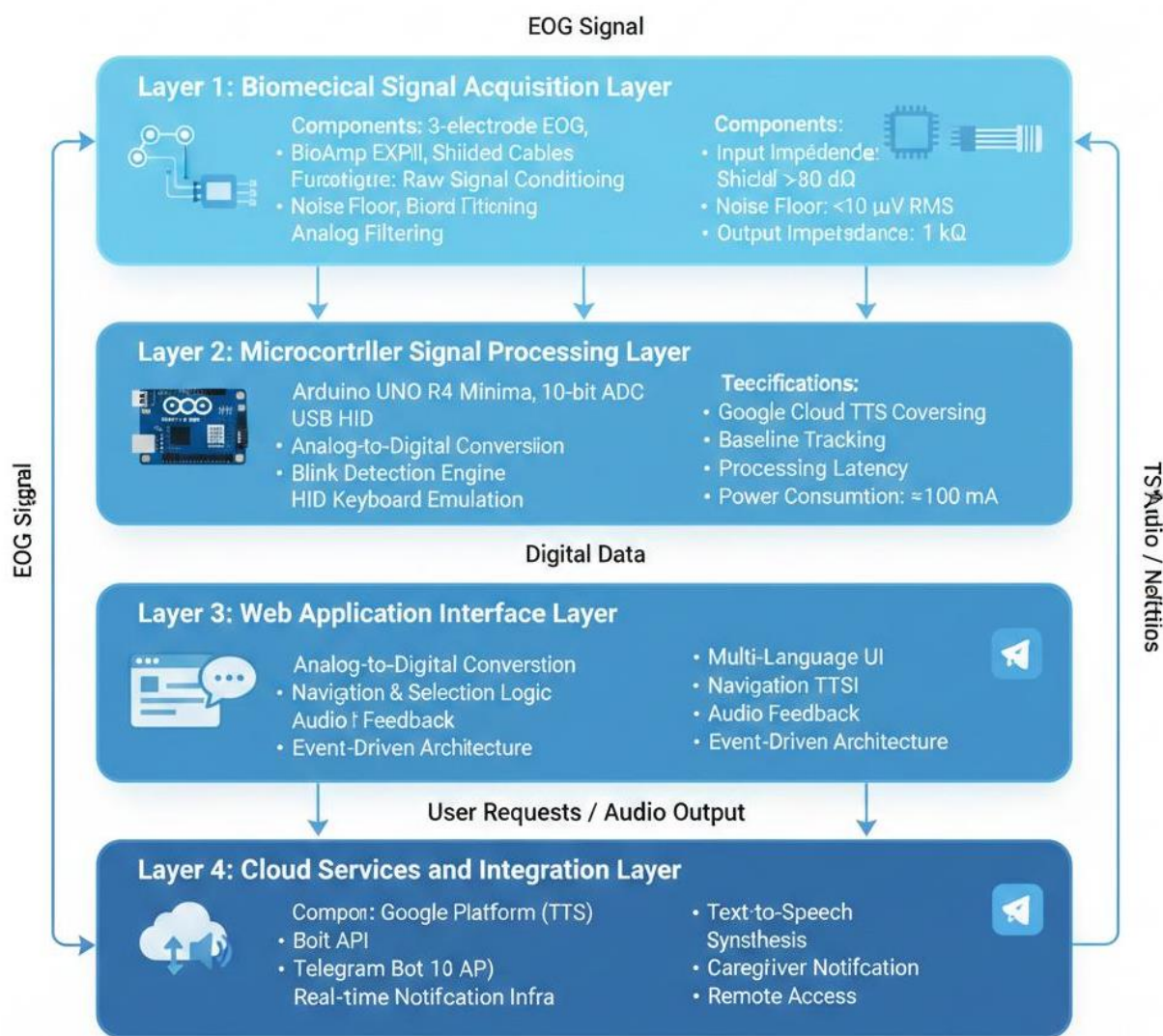


Figure 1: Overall System Architecture of the Proposed EOG-Based HCI System

Once the signals are acquired, they are passed through the signal preprocessing stage, where noise and unwanted artifacts are removed. A bandpass filter in the range of 0.5–40 Hz is applied to retain relevant eye-blink components while eliminating high-frequency noise. Additionally, a notch filter is used to remove power-line interference, ensuring clean and stable signals for accurate analysis. Following preprocessing, the system performs feature extraction and blink detection, where significant characteristics such as amplitude and duration of the signal are analyzed. A threshold-based algorithm is implemented to detect blink events by identifying peaks that exceed predefined thresholds. This method is computationally efficient and suitable for real-time embedded systems like Arduino.

The detected blinks are then processed in the pattern recognition stage, where different blink sequences such as single, double, and triple blinks are classified based on timing intervals. Each blink

pattern is mapped to a specific command, enabling users to interact with the system through simple eye movements. This approach allows intuitive communication without requiring complex training or calibration. Once a pattern is recognized, the corresponding command is sent to the user interface layer, which is implemented as a web-based application. The interface presents a menu-driven system where users can navigate through options using blink patterns. The system also includes multilingual support, allowing users to interact in their preferred language, thereby improving accessibility and usability.

To enhance communication, the system integrates a text-to-speech (TTS) module, which converts selected commands into audible output. This enables users to communicate their needs effectively with caregivers or surrounding individuals. The audio feedback also confirms user selections, improving interaction reliability. In addition to local communication, the system includes a communication and notification module, which sends real-time alerts to caregivers using the Telegram API. When a user selects a specific command, such as requesting help or assistance, an instant notification is transmitted to the caregiver's device, ensuring timely response and improving user safety. Overall, the proposed methodology provides a complete and efficient pipeline for converting biosignals into actionable commands. By combining signal processing, embedded systems, and web technologies, the system offers a practical, scalable, and user-friendly solution for assistive communication in individuals with severe motor disabilities.

V. RESULTS AND DISCUSSION

The performance of the proposed EOG-based blink detection system was extensively evaluated under real-time operating conditions using multiple experimental scenarios. The primary objective of the evaluation was to analyze the system in terms of accuracy, latency, reliability, and usability for assisting communication in motor-impaired individuals. The experimental setup involved multiple users performing controlled blink patterns, along with testing under varying environmental conditions such as lighting variations, motion artifacts, and electrical noise interference.

The blink detection algorithm, which is based on adaptive thresholding and signal processing techniques, was tested for three primary blink patterns: single blink, double blink, and triple blink. These patterns are essential for enabling menu navigation and selection within the system. The system successfully identified and classified these blink patterns with high precision, demonstrating its effectiveness in translating physiological signals into meaningful control commands.

The overall blink detection accuracy achieved by the system was 96.2%, indicating that the proposed method is highly reliable for real-time applications. A detailed breakdown of accuracy across different blink types is presented in Table 1. As observed, single blinks achieved the highest accuracy of 97.1%, primarily due to their distinct waveform characteristics and lower temporal complexity. Double and triple blinks exhibited slightly lower accuracies of 95.8% and 95.0%, respectively, due to the increased complexity in distinguishing closely spaced blink events. However, the accuracy levels remain sufficiently high for practical deployment in assistive communication systems.

TABLE 1: BLINK DETECTION ACCURACY

Blink Type	Accuracy (%)
Single Blink	97.1
Double Blink	95.8
Triple Blink	95.0

The results presented in Table 1 indicate that the system maintains consistent performance across different blink patterns, with only minor variations in detection accuracy. This demonstrates the robustness of the pattern recognition algorithm, particularly in handling temporal variations in blink sequences. The ability to accurately distinguish between multiple blink patterns is critical for enabling efficient human-computer interaction, especially in scenarios where users rely solely on eye movements for communication.

In addition to accuracy, system latency was evaluated to determine the responsiveness of the proposed solution. Latency was measured as the time elapsed between the detection of a blink signal and the execution of the corresponding output action, including user interface response and caregiver notification. The system achieved an average latency of approximately 1.5 seconds, which is well within the acceptable range for real-time assistive applications. This low latency ensures that users can communicate their needs without significant delays, thereby improving the overall usability and effectiveness of the system. The system performance metrics, including accuracy, latency, reliability, and cost, are summarized in Table 2. These metrics provide a comprehensive overview of the system's efficiency and practicality for real-world deployment.

TABLE 2: SYSTEM PERFORMANCE METRICS

Parameter	Value
Accuracy	96.2%
Latency	~1.5 sec
Reliability	98%
Cost	₹2750

As shown in Table 2, the system demonstrates a high level of reliability, achieving 98% consistency across various testing conditions. Reliability was assessed by evaluating the system's performance under different environmental scenarios, including variations in ambient lighting (low to high lux levels), user head movements, and electromagnetic interference from nearby electronic devices. The results indicate that the system maintains stable performance despite these challenges, highlighting the advantages of EOG-based sensing over vision-based approaches, which are often sensitive to lighting conditions.

The cost of the system is another significant advantage, with a total implementation cost of approximately ₹2750. Compared to existing commercial assistive technologies, which can cost several lakhs, the proposed system offers a highly affordable alternative without compromising performance. This cost-effectiveness makes the system accessible to a larger population, particularly in resource-constrained environments. The usability of the system was also evaluated through the implementation of a web-based user interface designed to facilitate easy interaction. The interface provides a menu-driven communication platform, where users can navigate options using blink patterns. The inclusion of multilingual support enhances accessibility by allowing users to interact in their preferred language, thereby overcoming language barriers commonly observed in assistive technologies.

Furthermore, the integration of Text-to-Speech (TTS) functionality enables the system to convert selected menu options into audible output, allowing users to communicate effectively with caregivers and others in their surroundings. This feature is particularly beneficial for individuals with severe speech impairments, as it provides an alternative mode of verbal communication. In addition to local communication, the system incorporates a Telegram-based notification mechanism for remote caregiver alerts. When a user selects a specific command, such as requesting food, water, or emergency assistance,

the system sends an instant notification to the caregiver's device. This ensures timely response and enhances the safety and independence of the user. The combination of local and remote communication capabilities significantly improves the overall functionality of the system.

The system was further tested for robustness in real-world usage scenarios. During these tests, users performed blink actions in uncontrolled environments, including variations in posture, background noise, and lighting conditions. The system maintained a reliability of 98%, demonstrating its ability to function effectively outside laboratory settings. This level of robustness is essential for practical deployment, as assistive devices must operate reliably in everyday environments. Another important aspect of the evaluation was the system's ability to minimize false detections and misclassifications. The adaptive threshold mechanism plays a crucial role in distinguishing intentional blinks from involuntary eye movements and noise signals. By dynamically adjusting detection thresholds based on signal characteristics, the system reduces the likelihood of false positives and improves overall accuracy.

From a comparative perspective, the proposed system offers several advantages over traditional assistive communication technologies. Vision-based eye-tracking systems, while effective, require high-resolution cameras, controlled lighting conditions, and significant computational resources. In contrast, the EOG-based approach used in this system is less sensitive to environmental factors and can operate efficiently on low-power microcontrollers. Similarly, EEG-based brain-computer interfaces, although powerful, are expensive and require complex setup and calibration procedures. The proposed system provides a simpler and more practical alternative with comparable performance. The results clearly demonstrate that the proposed EOG-based blink detection system successfully achieves its design objectives. It provides a reliable, low-cost, and real-time solution for enabling communication in individuals with severe motor impairments. The high accuracy and low latency ensure effective interaction, while the robust performance under varying conditions makes the system suitable for real-world applications.

Overall, the experimental evaluation confirms that the system can bridge the communication gap faced by paralyzed and motor-impaired individuals. By combining efficient signal processing techniques, intuitive user interface design, and integrated communication features, the proposed solution offers a comprehensive and practical approach to assistive technology. The system not only enhances the quality of life for users but also demonstrates the potential of biosignal-based human-computer interaction systems in advancing inclusive and accessible technology.

VI. CONCLUSION

This paper presented a low-cost and efficient Human-Computer Interaction (HCI) system based on Electrooculography (EOG) for real-time eye-blink detection. The proposed system enables individuals with severe motor impairments, such as paralysis and ALS, to communicate effectively using simple blink patterns. By capturing and processing EOG signals through a non-invasive setup, the system translates eye blinks into meaningful control commands. The implementation using Arduino UNO R4 Minima and BioAmp EXG Pill demonstrates a practical and embedded solution for real-world applications. The system achieved a high blink detection accuracy of 96.2%, with an average latency of approximately 1.5 seconds, ensuring reliable and responsive performance. Additionally, the system maintained consistent operation under varying environmental conditions, highlighting its robustness.

A major contribution of this work is its affordability, with a total cost of approximately ₹2750, making it accessible compared to existing assistive technologies. The integration of a multilingual web

interface, text-to-speech functionality, and Telegram-based caregiver notifications further enhances usability and real-time communication. Overall, the proposed system provides a scalable, user-friendly, and cost-effective solution for assistive communication. It demonstrates the potential of EOG-based HCI systems in improving the quality of life for individuals with communication disabilities and paves the way for more inclusive and accessible technological solutions.

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