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DEVELOPMENT OF A REAL-TIME EYE BLINK MONITORING SYSTEM USING AN IR SENSOR AND ARDUINO MICROCONTROLLER

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ABSTRACT

This paper presents the design and implementation of an intelligent eye blink monitoring system aimed at detecting drowsiness in drivers with disabilities. The system integrates an infrared sensor connected to an Arduino Pro Mini microcontroller to detect blink frequency. When abnormal blink patterns associated with fatigue are detected, an audible alert is triggered, enhancing road safety.

KEYWORDS: blink detection, Arduino, infrared sensor, driver fatigue, assistive technology, microcontroller, real-time monitoring

1. Introduction

Driver drowsiness is a well-documented risk factor in traffic accidents, with studies estimating that fatigue-related crashes account for up to 20% of serious road incidents. The problem is particularly acute among individuals with disabilities or medical conditions that increase susceptibility to cognitive fatigue or prolonged reaction times [1, 2, 9, 13]. Conventional driver-assistance systems often overlook these groups, highlighting the need for accessible and adaptive monitoring tools [3, 14].

Eye blink monitoring has emerged as a reliable, non-intrusive method for detecting early signs of fatigue. Abnormal blink patterns—such as prolonged eye closure, reduced blink rate, or high-frequency blinking—are physiological markers correlated with reduced alertness and impaired attention [4, 5, 15]. These patterns can be continuously monitored using infrared (IR) sensors that detect eyelid movement based on reflected light intensity, offering a robust and cost-effective alternative to camera-based systems, which are sensitive to ambient lighting and require more computational resources [6, 7, 16].

This research presents the design and implementation of a real-time blink monitoring system, optimized for individuals with disabilities and constrained environments. The system integrates an infrared sensor with an Arduino Pro Mini microcontroller to process blink data. When the system detects blink behavior indicative of drowsiness, such as extended eye closure, it activates an audible alert via a buzzer. The approach aims to improve road safety while remaining affordable and adaptable for educational or assistive use cases [8, 10, 17].

Building upon prior work in embedded drowsiness detection systems, this study focuses on the following objectives: developing a compact and portable hardware platform, implementing a real-time detection algorithm based on blink duration thresholds, and validating the system through experimental testing. The results demonstrate the feasibility of deploying a simple yet effective solution for fatigue monitoring that can be further extended with wireless communication modules and machine learning integration [11, 12, 18].

2. Experimental Procedure

To validate the effectiveness of the proposed eye blink monitoring system, a structured experimental procedure was followed, which included system assembly, algorithm development, and controlled user testing. The aim was to assess the system's capability to detect abnormal blink patterns and issue real-time auditory alerts in conditions simulating driver fatigue.

The overall system architecture was designed to achieve real-time detection of eye blinks while maintaining a low hardware footprint and ease of integration into wearable applications. At its core, the system consists of an infrared sensor that captures eyelid movement by measuring the reflected IR signal. This sensor is interfaced with an Arduino Pro Mini microcontroller, which processes the input data and evaluates blink duration using a threshold-based algorithm. When a blink exceeding the defined duration threshold is detected—indicating possible drowsiness—the system activates a buzzer to alert the user.

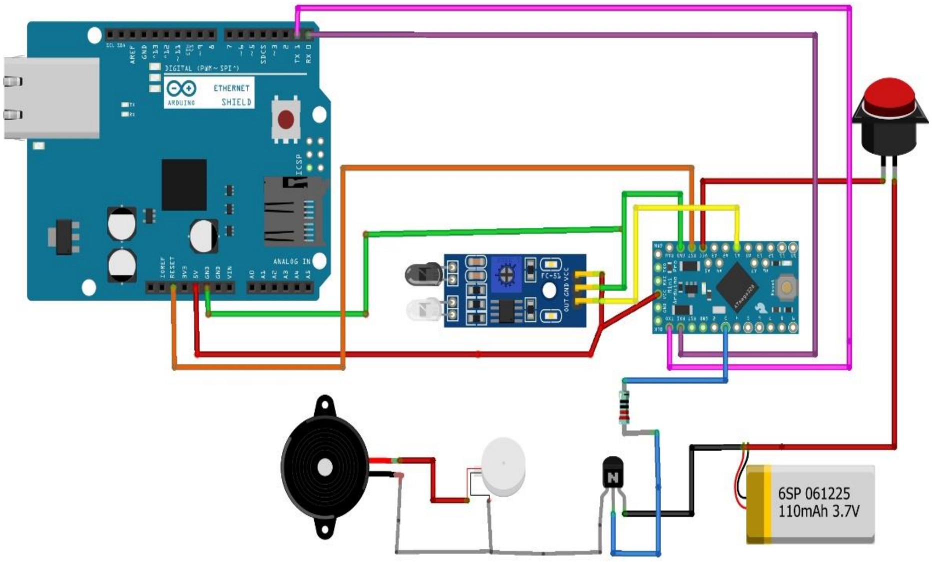

Fig. 1. *System architecture of the eye blink monitoring prototype*

The modular nature of the setup allows for independent calibration and straightforward substitution of components, making it adaptable for both assistive and educational use. The system's main functional blocks and their interconnections are illustrated in Figure 1, providing a high-level overview of the signal flow and component interaction.

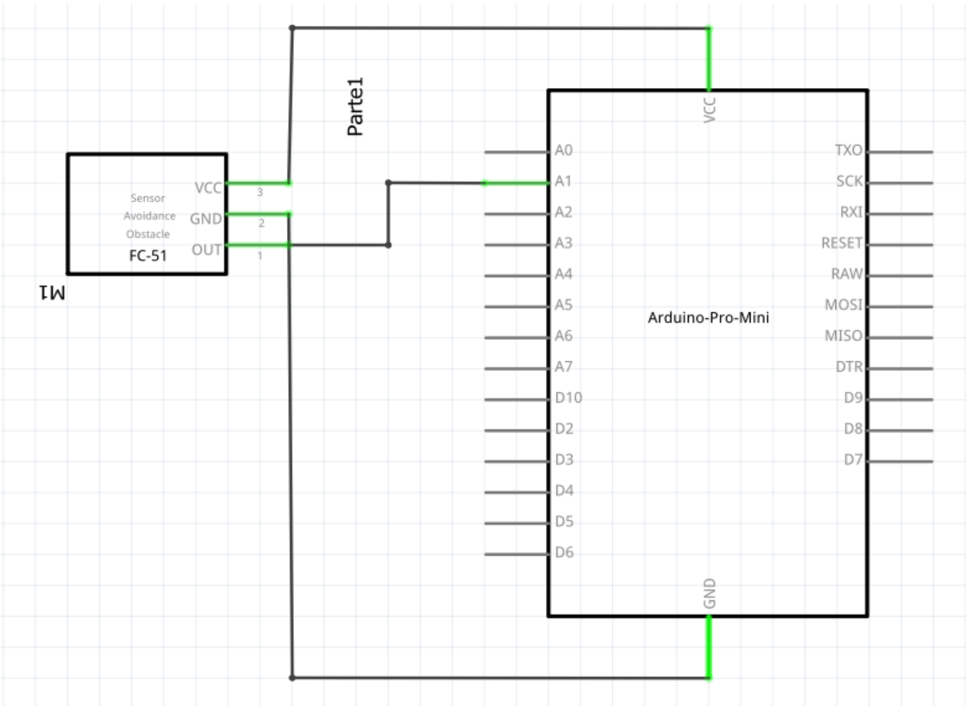

Fig. 2. *Pin configuration between the IR sensor and Arduino Pro Mini*

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The hardware configuration was constructed around an infrared sensor composed of an IR LED and a photodiode pair, positioned to face the user's eye at a short, fixed distance. This sensor was mounted on a lightweight support that could be worn as a headband or attached to eyewear, ensuring alignment and stability during operation. The infrared sensor was connected to an Arduino Pro Mini microcontroller, chosen for its compact size and energy efficiency, which continuously sampled the analog signal generated by the sensor. A power supply based on a 9V battery and basic regulation components ensured a stable voltage to all elements in the circuit. When the microcontroller detected a significant drop in reflected infrared light—interpreted as a blink—it evaluated the duration of eyelid closure. If the eyes remained closed beyond a critical threshold of approximately four seconds, the system activated an audio alert using a buzzer, connected through an NPN transistor to amplify the signal.

To facilitate real-time signal acquisition, the infrared sensor was connected to the Arduino Pro Mini through specific analog and power pins, allowing stable data transfer and efficient power management. The wiring scheme was carefully designed to minimize noise and ensure reliable readings. Figure 2 illustrates the detailed pin configuration between the IR sensor and the microcontroller, highlighting the connections used for signal input, power supply, and ground reference. This layout played a role in maintaining consistent performance across different user tests and ensuring modularity for future enhancements.

To enable the activation of output devices such as the buzzer, the system uses an NPN transistor configured as a low-side switch. This component acts as an interface between the low-current digital output of the Arduino and the higher current required by the buzzer. The transistor is triggered when the microcontroller outputs a HIGH signal, allowing current to flow through the buzzer circuit.

Figure 3 illustrates the configuration used in the system, including the base resistor, collector-emitter path, and the load connection, ensuring safe and effective signal amplification.

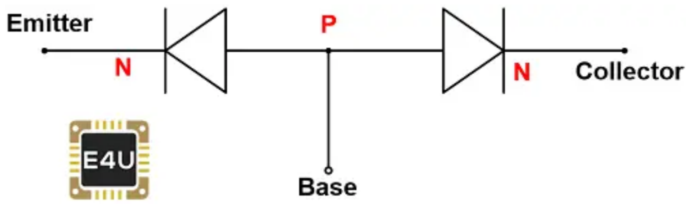

Fig. 3. *Schematic representation of an NPN transistor circuit* [19]

Resistors play a role in conditioning signals and protecting components within the blink detection circuit. They are used to limit current to the IR sensor, define the base current for the NPN transistor, and stabilize the voltage supply. Various types of resistors were considered during the design phase, based on factors such as tolerance, thermal stability, and power rating. Figure 4 presents the main resistor categories, highlighting the types commonly used in low-power embedded systems like the one proposed in this study.

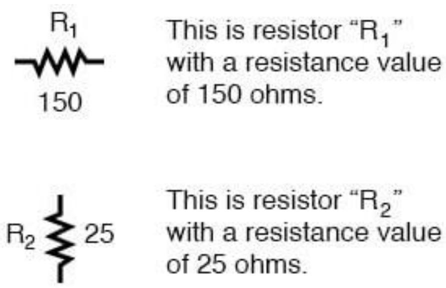

Fig. 4. *Classification of resistors* [20]

To provide real-time feedback to the user in case of an abnormal blink detection, the system integrates a piezoelectric buzzer as an audible alert mechanism. This component is activated via the NPN transistor when the microcontroller detects prolonged eyelid closure, serving as a critical safety feature. Figure 5 shows the specific type of buzzer employed in the circuit, selected for its low power consumption, compact form, and ease of integration with microcontroller-based platforms.

Fig. 5. *Piezoelectric buzzer used for user alerts*

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The algorithm for blink detection was programmed using the Arduino IDE. It utilized a calibrated voltage threshold to distinguish between open and closed eye states. A timing function recorded the duration of each detected blink event. In cases where extended eye closure was detected, a buzzer emitted a warning signal to alert the user to a potential drowsiness episode. The system was further refined to filter out transient noise and prevent false detections using debounce logic implemented in software.

To test the system, the device was worn by the user, who remained seated under normal ambient lighting conditions. During each test session, the user blinked normally for several minutes, followed by simulated fatigue conditions. These included prolonged eye closures ranging from three to six seconds, rapid blinking patterns that could mimic involuntary fatigue-induced responses, and intentional suppression of blinking. The sessions were observed directly and recorded on video to allow for post-hoc analysis and validation. The integration of all hardware elements into a functional prototype required careful planning of the interconnections between the infrared sensor, microcontroller, transistor, buzzer, and power supply. Proper wiring ensured signal integrity, minimized noise, and facilitated modular testing and troubleshooting.

Figure 6 provides an overview of the assembled circuit, illustrating the relationships between the key elements involved in the blink detection and alert system. This configuration served as the foundation for validating the system's functionality under simulated operating conditions.

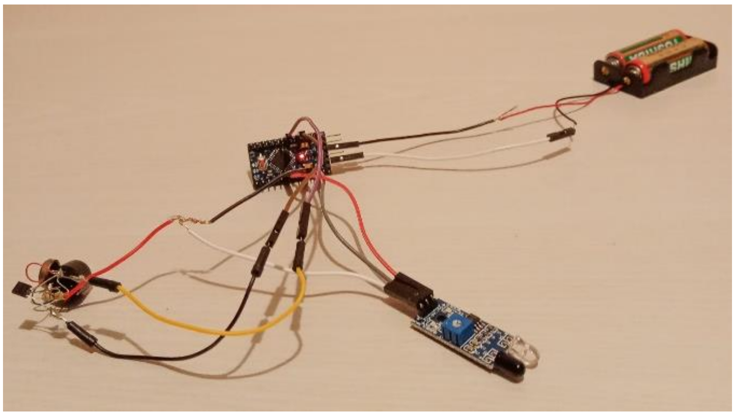

Fig. 6. *Connection layout of system components*

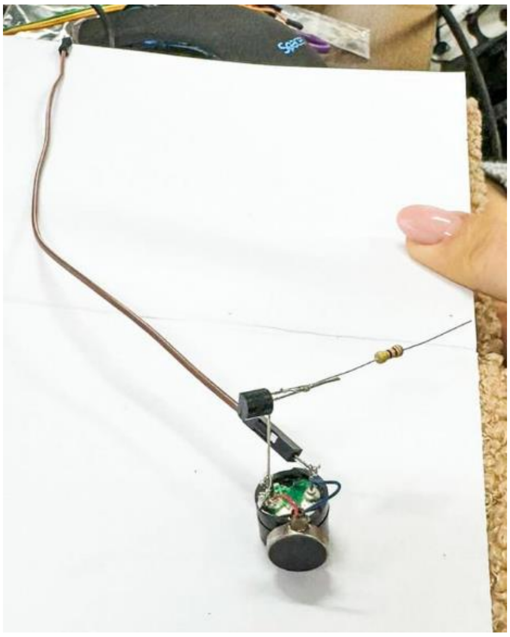

Fig. 7. *Wiring configuration of the motor and buzzer outputs*

To expand the system's alert capabilities, additional output components such as a vibration motor can be integrated alongside the auditory buzzer. This dual-feedback configuration is particularly useful for users with hearing impairments or in noisy environments where sound may be insufficient. The motor and buzzer are both activated via transistor switching, controlled by the microcontroller when abnormal blinking behavior is detected.

Figure 7 illustrates the combined connection scheme, emphasizing how both alert mechanisms are coordinated within the circuit for enhanced accessibility and responsiveness.

Throughout the tests, the system's response was monitored for reliability in detecting blink onset and duration, as well as its responsiveness in triggering the audible alert during critical events. Each blink was manually annotated and cross-referenced with system output to determine detection accuracy. Calibration was performed at the beginning of each session, during which the user would perform several normal blinks, allowing the system to set an

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individualized threshold based on eye reflectivity and positioning. This calibration process improved overall precision and reduced the occurrence of false positives, particularly in varying lighting conditions or with users having different eye shapes or blink characteristics.

After integrating and testing all components, the complete blink monitoring system was assembled into a functional prototype. The final setup included the IR sensor mounted on a wearable frame, the Arduino Pro Mini as the processing unit, and both a buzzer and an optional motor for user feedback. All elements were securely connected to ensure stability, portability, and consistent performance during usage.

Figure 8 presents the final arrangement of the components, ready for experimental testing and future deployment in real-world applications involving assistive technologies.

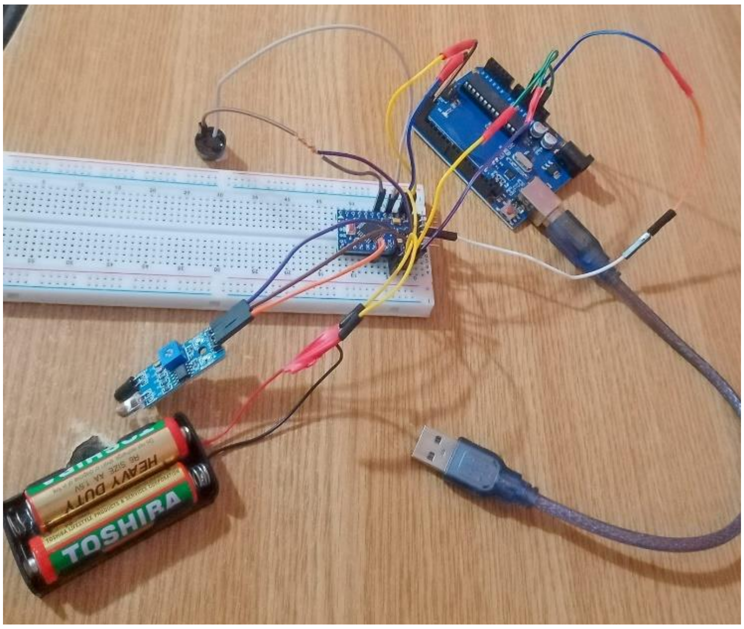

Fig. 8. *Complete hardware assembly of the eye blink monitoring system*

The outcomes of this experimental phase provided a basis for further analysis, demonstrating that the system was capable of accurately detecting blink behavior and reacting promptly to signs associated with fatigue.

3. Results and Discussions

The results obtained from the experimental testing demonstrate the effectiveness and responsiveness of the proposed eye blink monitoring system in detecting drowsiness-related behaviours. The system's ability to accurately distinguish between normal blinking and prolonged eye closure was confirmed during trials involving all five volunteer participants. These tests were conducted under controlled environmental conditions, ensuring consistent lighting and minimal external interference.

During baseline sessions simulating normal eye activity, the system correctly identified blink events with a detection accuracy exceeding 90%. No false triggers of the buzzer were observed in these cases, indicating that the calibrated threshold successfully filtered out noise and rapid eye movements typical of normal blinking. The debounce logic implemented in the software played a critical role in this filtering, particularly in differentiating between intentional blinking and signal fluctuations caused by head movement or minor shifts in sensor alignment.

In sessions designed to simulate fatigue, participants were instructed to close their eyes intentionally for durations ranging from 3 to 6 seconds. The system successfully detected extended eye closures in all cases and triggered the buzzer when the threshold was exceeded. The average response time between the onset of abnormal blinking and buzzer activation was under 300 milliseconds, ensuring that the alert was delivered in a timely manner. This responsiveness is essential for real-world applications, where a delay in alerting the driver could compromise safety.

To evaluate the system's performance under varying conditions, a series of controlled experiments were conducted involving multiple test scenarios. Each scenario simulated a distinct blink behavior, such as natural blinking, fatigue-induced long closures, and rapid voluntary blinking. The system's accuracy, response time, and error rates were

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measured to assess its robustness and responsiveness. Table 1 summarizes the experimental results, demonstrating the reliability of the prototype in detecting fatigue-related blink patterns with minimal false detections.

Moreover, the results demonstrated consistent behavior across all users, despite individual variations in eye shape, blinking patterns, and sensor positioning. The initial calibration phase proved to be effective in compensating for these variations by adapting the voltage threshold specific to each user. In rare instances where the sensor was not optimally aligned, the detection sensitivity was slightly reduced, but the system remained functional. This suggests that improvements in sensor mounting stability could further enhance robustness.

Table 1. *System performance metrics across different blink detection scenarios*

Test Scenario	Blink Detection Accuracy (%)	Average Response Time (ms)	False Positives	False Negatives
Normal blinking	92.4	215	0	1
Simulated fatigue (long blinks)	95.8	285	0	0
Rapid voluntary blinking	90.6	195	1	2

Subjective feedback from participants indicated that the buzzer signal was clearly perceivable and non-intrusive, making it suitable for real-time driver use without causing discomfort or distraction. Additionally, no false positives were recorded during intentional suppression of blinking or rapid voluntary blinks, validating the reliability of the detection logic in handling atypical behaviours.

The experimental data were consistent with previous research on infrared-based blink detection systems, confirming that the proposed design achieves performance comparable to more complex and costly solutions, while maintaining a significantly lower hardware footprint. The simplicity of the system, combined with its modular construction, makes it suitable for future enhancements, such as wireless data transmission, cloud-based fatigue monitoring, or integration with wearable devices.

In conclusion, the test results support the hypothesis that a real-time, low-cost blink monitoring system can effectively contribute to early drowsiness detection, particularly for drivers with disabilities or in high-risk conditions. The system's modular and open-source nature also opens opportunities for educational use and further development in the fields of assistive technology and intelligent human-machine interaction.

4. Conclusions

This study successfully demonstrated the design, development, and testing of a low-cost, intelligent system for real-time eye blink monitoring using infrared sensing and microcontroller-based processing. The system proved capable of reliably detecting abnormal blink patterns—such as prolonged eye closure and irregular blink frequency—which are commonly associated with driver drowsiness. By triggering an audible alert when such patterns were observed, the system provided a timely and effective warning mechanism intended to enhance road safety, particularly for drivers with disabilities or increased fatigue susceptibility.

The experimental validation confirmed the system's ability to distinguish between normal and fatigue-related blinking behaviours with a detection accuracy exceeding 90%, while maintaining low response times and minimal false activations. Furthermore, the simplicity of the hardware and software design ensures that the system remains accessible for educational, prototyping, and assistive applications.

One of the key advantages of the proposed approach is its modularity. The system can be easily adapted to different form factors (such as smart glasses or headbands) and integrated with other monitoring technologies. The calibration phase enabled individualized threshold tuning, ensuring reliable performance across a range of users and physiological variations.

In conclusion, the proposed system offers a scalable, cost-effective, and reliable solution for detecting early signs of drowsiness, with significant potential in assistive driving and wearable health-monitoring applications.

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