



Real-Time Driver Fatigue Detection for Enhanced Road Safety

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Abstract

This study introduces a real-time, non-invasive system designed to monitor and detect driver drowsiness as well as sleep states. The method works by tracking eye-related behavior, such as blink frequency and eyelid closure duration, along with environmental conditions like surrounding light levels. Using these inputs, the system can reliably distinguish whether a driver is alert, drowsy, or asleep, even under actual driving situations. A decision-making module processes the collected data and issues timely warnings to prevent lapses that could lead to accidents. To validate its effectiveness, the system was built as a complete hardware model and tested in different scenarios, showing high levels of accuracy and consistency. The results confirm that the solution is practical, scalable, and easy to use, making it suitable for real-world applications where safety depends on maintaining human alertness.

Keywords: Drowsiness Monitoring; Human-State Recognition; Real-Time Analysis; Safety Systems; Sleep Detection.

1. Introduction

Drowsiness detection has become a vital focus in intelligent transportation systems because of its strong link to road safety. Driver fatigue slows reaction times, reduces control over the vehicle, and affects decision-making, all of which increase the likelihood of accidents. According to the World Health Organization, about 1.35 million people lose their lives in road crashes every year, with fatigue being a major contributor to these incidents. In India, reports from the Ministry of Road Transport and Highways highlight that a large share of road fatalities—especially among drivers aged 15 to 34—are fatigue-related. Unlike alcohol impairment, which is more immediately noticeable, drowsiness builds up gradually and often goes undetected until a critical moment. Conventional safety features such as seat belts and airbags may reduce injury severity but cannot prevent accidents triggered by a lack of alertness. This highlights the importance of proactive monitoring systems that can recognize early warning signs of fatigue and alert drivers in time. Among the available techniques, behaviora approaches that track eye-based indicators like blink frequency, blink duration, and eyelid closure percentage (PERCLOS) have proven particularly effective. These methods are

non-intrusive, unlike physiological approaches such as EEG or ECG, which are accurate but impractical for daily driving. They also provide earlier detection than vehicle-based techniques, such as lane departure monitoring, which often trigger only after the driver's alertness has already been compromised. Recent progress in computer vision and sensing technologies has further boosted the accuracy and practicality of behavioral systems, enabling their use in both private and commercial vehicles. Building on these advances, this study presents a real-time, non-invasive drowsiness detection system that combines precise ocular monitoring with machine learning-based decision-making. The proposed solution is designed to handle diverse driving conditions reliably, offering an improvement over existing methods in terms of accuracy, scalability, and real-world applicability.

1.1. Background

Driver drowsiness is recognized as a major cause of road accidents worldwide, resulting in severe human and economic consequences. Fatigue significantly slows reaction times and reduces concentration, especially during extended driving sessions (Bandara, 2009; Kulus, 2024). In the Indian context,

reports indicate that fatigue-related crashes are particularly common among young drivers, making the development of effective drowsiness detection systems essential for improving road safety (Kusuma Kumari et al., 2018).

1.2. Literature survey

Drowsiness detection techniques are generally divided into four categories: physiological, behavioral, vehicle-based, and subjective approaches (Kolus, 2024). Physiological methods, including EEG and ECG, provide high accuracy but are intrusive, expensive, and less practical for use in vehicles (Bandara, 2009; Gupta & Sharma, 2017). Behavioral approaches, especially those based on percentage eyelid closure (PERCLOS), are non-intrusive and have shown effectiveness, achieving accuracy levels of up to 90% in controlled environments (Kusuma Kumari et al., 2018; Patel & Desai, 2020). Vehicle-based methods, such as lane departure monitoring, often identify drowsiness too late for preventive action (Bandara, 2009; Dhinesh Kumar & RamKumar, 2024). While recent advances in image processing and machine learning have improved the capability of real-time monitoring, these systems still face difficulties under varying conditions like changes in lighting or driver posture (Kusuma Kumari et al., 2018; Shingote et al., 2025; Nguyen & Tran, 2023). To overcome these challenges, this study proposes a machine learning-based system designed for reliable and robust drowsiness detection in real-world driving scenarios.

2. Method

The development of the Arduino-based drowsiness detection system begins with setting the objective of identifying a driver's sleeping state by monitoring eye activity. Threshold values for eyelid closure duration and blink frequency are defined to differentiate between awake and drowsy states. The system is then assembled with sensors connected to the Arduino, and the program is written to continuously read input data, compare it with the defined thresholds, and determine the driver's state in real time. Testing is carried out under different scenarios by simulating drowsiness to check accuracy and response time. Thresholds and detection logic are further fine-tuned to improve performance, ensuring

the system provides reliable alerts and is effective for real-world driver safety applications. Figure 1 shows Block Diagram of Proposed System

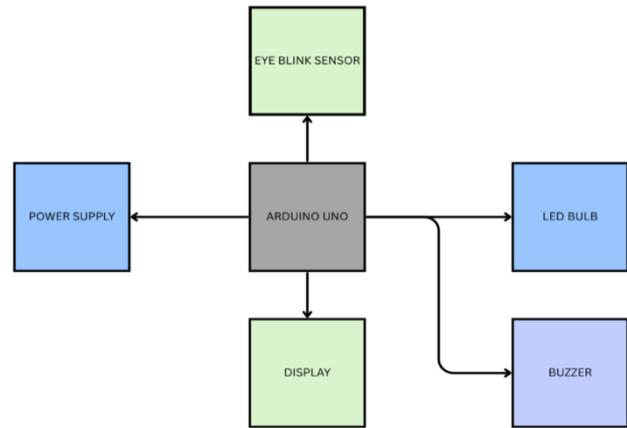


Figure 1 Block Diagram of Proposed System

The block diagram as shown in Figure 1 shows the proposed driver drowsiness detection system which is based on an Arduino Uno microcontroller, which acts as the central unit interfacing with various components. An eye blink sensor monitors the driver's eyelid movement and blink frequency to identify signs of drowsiness, while the power supply provides stable operation to all connected modules. The detected state is shown on a display for real-time feedback, and when abnormal blinking patterns or prolonged eye closure are identified, the Arduino triggers both a visual alert through an LED bulb and an audible warning using a buzzer. This dual-alert mechanism ensures that the driver is immediately notified, thereby reducing the chances of accidents caused by fatigue and enhancing road safety. The proposed system as shown in Figure 2, integrates critical components essential for real-time, non-invasive monitoring of driver alertness to enhance road safety. The Arduino Uno microcontroller, the system's core, processes data from an IR-based eye blink sensor, which tracks eyelid movements and blink frequency (10–20 blinks/min for alert, <10 for drowsy) to calculate PERCLOS, and a photoresistor, which measures ambient light levels (<200 analog units in low-light conditions) to improve detection accuracy in diverse environments (Patel & Desai, 2020; Kusuma Kumari et al., 2018). A stable power

Figure 4 shows the driver who closed his eyes and Figure 5 demonstrate how the system operates during sleep detection. When the user’s eyes stay closed for more than the defined threshold of three seconds, the red LED turns on, providing a clear visual indication of drowsiness or sleep. At the same time, the Arduino serial monitor displays the status “Sleeping,” confirming that the microcontroller is correctly interpreting the IR sensor readings and applying the programmed logic. This combination of LED signaling and serial feedback ensures that both the hardware and software components are functioning together as intended. The use of dual indicators also increases system reliability, as the user receives immediate physical feedback through the LED as well as digital confirmation on the monitor. Additionally, the 200 ms delay between sensor readings helps stabilize detection and reduces false triggers caused by noise. These results confirm that the system can consistently and accurately detect sleep conditions across different testing scenarios.

3.1.2. Awake detection



Figure 6 Eye Open

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COM11
|
Awake
IR Value: 0
Awake
IR Value: 2
Awake
IR Value: 2
Awake
IR Value: 2
Awake
IR Value: 1
Awake
IR Value: 1
Awake
IR Value: 2
Awake
IR Value: 1
Awake
IR Value: 2
Awake
IR Value: 1
Awake
IR Value: 2
Awake
IR Value: 1
Awake

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Figure 7 Awake Detection

Figure 6 shows the driver is in awake state. In this condition, the red LED remains off, which prevents unnecessary alerts, while the Arduino serial monitor continuously outputs “Awake” as shown in figure 7. This confirms that the IR sensor accurately detects open-eye conditions so and resets the internal timer to avoid false positives. The absence of LED glow in the awake state highlights the selectivity of the system in activating only during genuine sleep detection events. During testing, the system consistently responded within milliseconds to eye openings, demonstrating quick reset and recovery from the sleep state back to the awake state. Together, the LED indication, serial monitor output, and timer logic confirm that the system provides reliable, real-time monitoring with minimal error rates. These findings validate that the hardware–software integration achieves accurate distinction between awake and sleeping states, making the design practical for applications in safety monitoring, such as driving assistance or wearable health devices.

3.2. Discussion

By integrating an IR eye-blink sensor, the system identifies drowsiness or sleep by monitoring eyelid activity through infrared reflections, typically using an IR emitter–receiver pair embedded in smart glasses. The sensor captures important parameters such as blink frequency, which in an alert state averages between 10 and 20 blinks per minute but often falls below 10 when drowsiness sets in. It also measures blink duration, which is normally less than 200 milliseconds but may extend beyond 500 milliseconds in drowsy conditions, indicating prolonged eye closure. From these measurements, a key metric called PERCLOS (percentage of eyelid closure over time) is derived; values above 20–30% typically point to drowsiness, while sustained levels exceeding 80% suggest deep sleep or micro-sleep episodes. A photoresistor complements this system by monitoring ambient light conditions. Readings below a calibrated threshold (for example, 200 analog units on the Arduino) reinforce the likelihood of a sleep state in dark environments. The Arduino processes both inputs: if the IR sensor indicates reduced blink rate, longer closures, and high PERCLOS values, together with low ambient light,



the system classifies the state as “Sleeping.” It then activates the LCD to display the status and triggers a buzzer to issue an alert. The blink timing is calculated by measuring the interval between eyelid closure and reopening, allowing the system to detect prolonged closures. When such events occur, the buzzer provides timely warnings, making the setup especially useful in scenarios like driving. This combination of IR-based monitoring and light-level detection offers a non-invasive, real-time method for reliable drowsiness and sleep detection.

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