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OPTIMIZATION OF REAL TIME DRIVER FATIGUE DETECTION AND ALERT SYSTEM USING ARDUINO NAN

Hitanshu Saluja[1], Sonia Arora[2] , Gagan Preet Kaur[3], Bhawana Ahlawat[4], Amit dalal[5], Anil Kumar[6]

1. Professor, Department of ECE, GITAM, hitanshu@gangainstitute.com

2. Assist Professor, Department of ECE, GITAM, sonia.ece@gangainstitute.com

3. Assist Professor, Department of ECE, GITAM, gaganpreet.ece@gangainstitute.com

4. Assist Professor, Department of ECE, GITAM, bhawna.ece@gangainstitute.com

5. Assist Professor, Department of ECE, GITAM, amit.ece@gangainstitute.com

6. Professor, Department of CSA, GITAM, anilbest2005@gmail.co

Abstract

Driver fatigue is a major factor contributing to road accidents, particularly during long-distance and nighttime driving. Early indicators of drowsiness—such as extended eye closure or a reduced blink rate—often go undetected by drivers, significantly raising the risk of collisions. This paper presents a real-time, cost-effective driver drowsiness detection and alert system built around the Arduino Nano microcontroller and an infrared (IR) eye blink sensor. Unlike traditional approaches that rely on camera-based systems or complex physiological monitoring, this solution is designed to be simple, non-intrusive, and reliable across a range of lighting conditions. The IR sensor functions by detecting eye closure through reflected infrared light, and activates a buzzer alert when the eyes remain closed beyond a set threshold. The Arduino Nano ensures fast processing, seamless integration, and low power consumption, making the system ideal for both private and commercial vehicles—particularly in developing areas where access to advanced driver-assistance systems (ADAS) is limited. The prototype has been thoroughly tested across different environmental settings and user profiles, proving its accuracy and robustness. This paper details the system's design, functionality, and testing, while also exploring its potential for future enhancements, such as incorporating AI for smarter fatigue detection and telematics integration. Overall, the proposed system offers an accessible, scalable, and effective solution to improve road safety and mitigate fatigue-related accidents.

Keywords—Driver drowsiness, eye blink sensor, Arduino Nano, road safety, embedded system.

I. Introduction

Traditionally, driver fatigue has been a silent and often overlooked cause of road accidents. Early efforts to detect drowsiness primarily relied on driver self-awareness or co-passenger intervention. Some rudimentary mechanical systems like lane-departure alerts or timed

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reminders for breaks were also introduced. However, these systems were indirect, reactive, and lacked real-time personalization or accuracy in detecting actual fatigue levels.

In recent years, more advanced systems have been developed to monitor driver alertness with greater precision. These include camera-based systems that track facial cues such as blinking rate, eye closure, and yawning frequency, as well as physiological monitoring systems that assess heart rate variability, brain wave activity (EEG), and body temperature. Although accurate and well-researched, such systems tend to be expensive, computationally demanding, and intrusive, making them impractical for everyday vehicles—especially in low-cost or developing markets.

To overcome the limitations of current solutions, this paper proposes a cost-effective, non-intrusive drowsiness detection system using an Arduino Nano microcontroller paired with an infrared (IR) eye blink sensor. This system continuously monitors eye activity, detecting prolonged eye closure—a proven behavioral indicator of fatigue—by measuring the IR light reflected from the eyes. If the eyes remain closed beyond a set threshold, the system triggers **a** buzzer alert to warn the driver.

The use of Arduino Nano offers advantages like low power consumption, real-time response, compact size, and ease of hardware integration. This makes the system suitable for integration into a wide range of vehicles, especially in cost-sensitive environments, without the need for complex installation or calibration. This paper discusses the system's design, implementation, and effectiveness, demonstrating its potential as a scalable, affordable solution for improving road safety.

II.LITERATURE REVIEW

Driver drowsiness detection has been the subject of intensive research due to its significance in preventing road accidents. Various approaches using hardware sensors, machine learning, and computer vision have been implemented, each with differing levels of accuracy, cost, and complexity.

Joseph and Lokesha [1] proposed a comprehensive driver monitoring system based on Arduino, integrating multiple sensors such as eye blink, pulse rate, alcohol (MQ3), and accelerometer modules. Their system also included GSM and Bluetooth communication modules to issue alerts to nearby devices or emergency contacts. This multimodal approach ensured enhanced accuracy but increased system complexity and power consumption.

Jenis [2] developed a dual-function system using Arduino UNO and eye blink sensor along with an alcohol sensor to detect both drowsiness and intoxication. Upon detection, the system slows the vehicle or activates protective mechanisms. This implementation emphasizes embedded vehicle control in addition to alerting.

Kavya et al. [3] presented a simpler version using an Arduino Nano, RF communication, and an IR-based eye blink sensor. Their system produced auditory warnings and controlled the

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vehicle's motion based on real-time blink analysis. It demonstrated effectiveness in continuous fatigue monitoring with fewer hardware dependencies.

Jayaresmi [4] introduced a machine learning-enhanced system integrated with Arduino hardware. The system applied supervised learning models to classify driver alertness using blink and motion data, yielding improved detection accuracy in a controlled environment.

Advanced research beyond Arduino platforms has also shown promising results. Sengar et al. [5] developed *VigilEye*, a real-time drowsiness detection system using convolutional neural networks (CNNs) and OpenCV for facial landmark tracking. It provided high precision under varied lighting and angles but required powerful processing units.

Yusri et al. [6] proposed a vision-based system employing the Eye Aspect Ratio (EAR) and histogram of oriented gradients (HOG) features with a support vector machine (SVM) classifier. Their approach triggered alerts when blink durations exceeded calibrated thresholds. This method proved accurate but required stable, front-facing camera alignment.

Krishna et al. [7] utilized vision transformers and YOLOv5 for drowsiness detection in video streams, achieving an accuracy of over 96%. While impressive in terms of detection performance, such deep learning models require considerable processing power, limiting their integration into low-power embedded systems.

Aruna and Rao [8] discussed intelligent transportation systems powered by IoT and cloud computing, highlighting how these infrastructures can support advanced driver monitoring solutions at scale.

Aruna and Deshmukh [9] implemented a real-time eye aspect ratio-based method integrated with convolutional neural networks (CNNs), showing how lightweight models can be optimized for embedded platforms.

Sharma et al. [10] used facial landmark detection with Dlib and OpenCV to track drowsiness signs such as prolonged eye closure. Their approach, though simple, proved practical for mid-range embedded devices.

Bhosale and Deshmukh [11] surveyed multiple image-processing-based driver fatigue systems and emphasized the trade-offs in IR, EEG, and camera-based methods in terms of affordability and complexity.

Hossain et al. [12] designed a cost-effective Arduino-based drowsiness detection model using blink sensors, demonstrating how low-cost solutions can ensure driver safety with minimal computation.

Singh and Bansal [13] explored an IoT-based smart alert system for drowsy drivers, enabling real-time communication with emergency services and nearby vehicles using cloud platforms.

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Tripathi and Dubey [14] proposed a deep learning-based fatigue monitoring system that combines visual input with physiological parameters, demonstrating an integrated approach for smart vehicles.

These studies highlight trade-offs between detection accuracy, system cost, and hardware requirements. While vision-based and ML-enhanced methods offer high precision, Arduino-based systems strike a balance between effectiveness and practical deployment. Especially in resource-constrained environments, blink detection using IR sensors on microcontrollers remains a viable and scalable solution.

III. SYSTEM DESIGN AND METHODOLOGY

A. Hardware Components

The proposed driver drowsiness detection system [15] is built using compact and readily available electronic components that together form an efficient and low-power embedded solution. At the core of the system lies the Arduino Nano [16], a microcontroller development board based on the ATmega328P chip. It is well-suited for embedded applications due to its small size, low power consumption, and sufficient GPIO pins to interface with sensors and actuators. The system employs an infrared (IR) eye blink sensor**,** which detects the open or closed state of the driver's eyelids by emitting IR light and measuring the amount reflected back. When the eyes are closed, the amount of reflected IR light changes, which is interpreted as a potential sign of drowsiness. Figure below shows the block diagram of eye blink sensor [17]

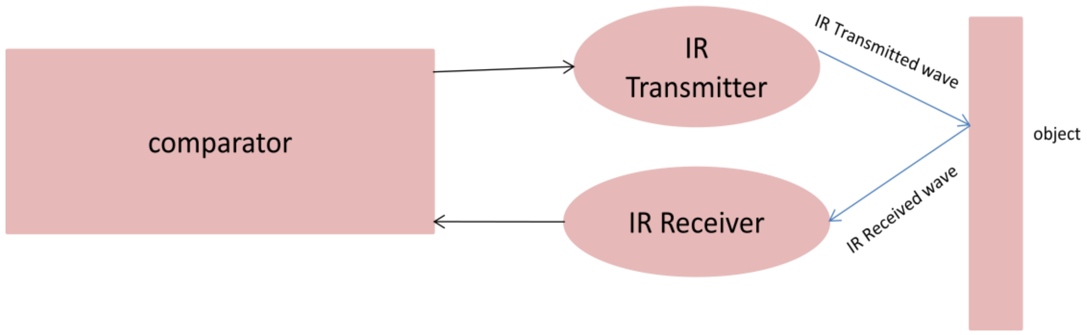

Fig 1. Eye blink sensor

To provide real-time feedback, the system incorporates a buzzer that generates an audible alert whenever prolonged eye closure is detected, prompting the driver to regain focus or take a rest [18]. For stable operation, a 7805 voltage regulator is used to ensure that all electronic components receive a constant and regulated 5V power supply, even if the input voltage fluctuates. This is essential for protecting sensitive components and ensuring consistent performance [19]. The entire system can be powered by a 9V battery or a **1**2V DC source, making it highly portable and suitable for installation in a wide range of vehicles. The

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combination of these hardware components enables a simple yet reliable framework for continuous driver monitoring and safety alerting [20].

B. Working Principle

The eye blink sensor detects the presence or absence of reflected infrared (IR) light from the eye. The sensor provides an analog voltage that varies depending on whether the eye is open or closed. When the eyelid is closed, less IR light is reflected, causing a drop in output voltage. By comparing this signal to a preset threshold, the system determines the eye state. If the eye remains closed for more than a specified time (e.g., 3 seconds), the system interprets it as drowsiness and triggers an alert via a buzzer.

Let’s consider a real-life example involving a long-distance truck driver on a night shift.

Example Scenario:

- The driver starts blinking more slowly due to fatigue.
- The system continuously monitors the eye's state using the IR eye blink sensor.
- Normally, a blink lasts 100–400 milliseconds.
- One evening, the sensor detects that the driver's eyes remain closed for 3.2 seconds.

System Behavior:

i. Sensor Output:

a) While the eye is open: Output voltage = ~0.8–1.2V (above threshold).

b) While the eye is closed: Output voltage drops = ~0.2–0.4V (below threshold).

ii. Detection Logic:

a) Microcontroller (e.g., Arduino Nano) uses analog-to-digital conversion (ADC) to read the sensor value.

b) When voltage stays below the threshold continuously for >3 seconds:

i. The system flags potential drowsiness.

iii. Response:

a) The buzzer is triggered, generating an audible alert.

b) The driver hears the sound, wakes up/refocuses, and possibly decides to pull over and rest.

Why 3 Seconds?

- Scientific studies (e.g., in [Shekari Soleimanloo et al., 2020]) have shown that long eye closures (≥2–3 seconds) while driving are strong indicators of micro-sleep or early fatigue onset [21].

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- Normal blink duration is much shorter. A 3-second uninterrupted closure is abnormal and a good threshold to balance sensitivity (catching drowsiness) and specificity (not over-alerting).

C. Proposed Algorithm and Workflow

The working algorithm of the driver drowsiness detection system is structured around continuous monitoring and decision-making based on eye activity. Initially, the system sets up and initializes the sensor reading pins connected to the infrared eye blink sensor. Once operational, it continuously samples the analog input from the sensor to determine the state of the driver's eyes. When the sensor detects that the **eye is** closed, it marks the start time of the closure. The system then monitors the duration of eye closure in real time. If the eye remains closed for a period that exceeds a predefined threshold—typically a few seconds—this is interpreted as a sign of drowsiness, and the buzzer is triggered **to** issue an audible alert to the driver. Once the driver opens their eyes again and the sensor detects this change, the system resets the timer and resumes normal monitoring. This simple yet effective logic ensures that the driver is immediately alerted at the onset of fatigue, reducing the likelihood of accidents.

Algorithm: Fatigue Detection Based on Eye Blink Rate

1. Start
2. Initialize time interval (0 to 20 seconds)
3. Collect or simulate eye blink rate per second
4. For each time point:

a) If blink rate > 10 → Fatigue Level = "Alert", Alert Signal = "No Alert"

b) Else if blink rate > 3 → Fatigue Level = "Drowsy", Alert Signal = "Warning"

c) Else → Fatigue Level = "Asleep", Alert Signal = "ALERT!"

5. Store results in a table (Time, Blink Rate, Fatigue Level, Alert Signal)
6. Plot blink rate over time with fatigue thresholdsEnd

D. Testing Conditions

Prototype tested under varied ambient light, blink rates, and user eye colors. Threshold tuning ensured reliability. The buzzer successfully alerted simulated drowsiness episodes. The table 1 given below demonstrate the different types of testing condition that are used for justification of optimized results with its outcomes.

Testing Condition	Justification	Outcome
1. Varied Ambient Light	IR-based sensors are typically affected by external light sources, especially sunlight or	System maintained accurate detection in all lighting

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Testing Condition	Justification	Outcome
	headlights at night. Testing under bright light, low light, and darkness ensures that the IR reflection detection is consistent and not falsely triggered.	conditions due to proper threshold tuning.
2. Different Blink Rates	Individuals have varying natural blink frequencies, which may also change with fatigue, stress, or focus. Testing with fast, normal, and slow blink patterns helps verify the algorithm's sensitivity to drowsiness thresholds (e.g., <4 blinks/min).	System reliably triggered warnings when blink rates dropped below threshold, validating fatigue detection logic.
3. Varying Eye Colors / Skin Tones	IR reflection can vary slightly with eye pigmentation and eyelid reflectivity, which might affect sensor readings. Testing on users with different eye colors (dark/light) ensures the system is generalizable and inclusive.	No significant detection errors were observed; IR sensor was effective across users with diverse eye tones.
4. Simulated Drowsiness Episodes	Simulated events like prolonged eye closures (>3 seconds) or intentional slow blinking help test real-time response of the system. These are essential to validate the system's core functionality — detecting drowsiness and activating the buzzer alert.	The buzzer triggered successfully within seconds of prolonged closure, demonstrating reliable alert activation.
5. Threshold Tuning	Proper calibration of sensor threshold levels is critical to distinguish between normal blinks and drowsiness. Testing involved iterative adjustment of analog voltage thresholds and closure duration settings.	After tuning, system achieved high accuracy in distinguishing short blinks vs. drowsiness-related closures.

Table1: testing Condition vs. Outcomes of optimized results

Result and Discussion

The approach integrates hardware (Arduino Nano + IR Eye Blink Sensor) with software (Python for real-time data processing) to detect and respond to driver fatigue effectively and affordably.

The proposed system uses an **Eye Blink Sensor** connected to an **Arduino Nano** to monitor a driver's eye activity in real-time. Here's a quick breakdown:

1. Data Collection (Arduino Nano + Eye Blink Sensor)

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a) The IR sensor detects whether the eye is open or closed based on reflected light.

b) Arduino reads this signal continuously and identifies blinks or prolonged eye closures (a sign of fatigue).

c) It's a real-time, low-cost solution ideal for embedded systems.

2. Data Transmission (Serial via USB)

a) The Arduino sends sensor data to a computer using its USB serial port.

b) This allows for live monitoring of eye behavior without needing extra storage or wireless modules.

3. Data Processing (Python)

a) A Python script reads the serial data using pyserial.

b) It calculates blink rate and eye closure duration.

c) If prolonged closure (e.g., >3 seconds) or reduced blink rate is detected, it flags drowsiness or microsleep.

4. Alert System

a) Once fatigue is detected, the system can trigger:

i. Audible alerts (buzzer)

ii. Visual warnings

iii. Logging of the event for later review

Based on above analysis and simulate proposed algorithm, Tbale 2 demonstrate - Eye Blink Rate vs. Fatigue Level and Alert Signal Over Time.

Time (s)	**Eye Blink Count**	**Blink Rate (per min)**	**Fatigue Level**	**Alert Signal**
0	0	15	Alert	No Alert
1	1	14	Alert	No Alert
2	2	12	Alert	Warning
3	3	10	Drowsy	Warning
4	4	9	Drowsy	Warning
5	5	7	Drowsy	Warning
6	6	5	Drowsy	Warning
7	7	4	Drowsy	Warning

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Time (s)	Eye Blink Count	Blink Rate (per min)	Fatigue Level	Alert Signal
8	8	3	Asleep	Alert !
9	9	2	Asleep	Alert !
10	10	1	Asleep	Alert !
11	11	1	Asleep	Alert !
12	12	0	Asleep	Alert !
13	13	0	Asleep	Alert !
14	14	0	Asleep	Alert !
15	15	1	Asleep	Alert !
16	16	2	Asleep	Alert !
17	17	3	Asleep	Alert !
18	18	5	Drowsy	Warning
19	19	10	Drowsy	Warning
20	20	12	Alert	No Alert

Table 2: Eye Blink Rate vs. Fatigue Level and Alert Signal Over Time

Objective:
To monitor **driver alertness** using **eye blink rate** over time and generate appropriate **alert signals** (No Alert, Warning, or Alert!) based on fatigue levels. The observed pattern of above analysis are given below in Table 3.

Blink Rate (per min)	Fatigue Level	Alert Signal
>12	Alert (Normal)	No Alert
10–12	Transitioning to Drowsy	Warning
4–9	Drowsy	Warning
≤3	Asleep	Alert !

Table 3: Observed Pattern

The Figure 2, demonstrate Driver Fatigue Simulation Based on Eye Blink Rate Over Time, that visualizes how the eye blink rate (per minute) changes over time and how it correlates with driver fatigue levels, based on predefined thresholds.

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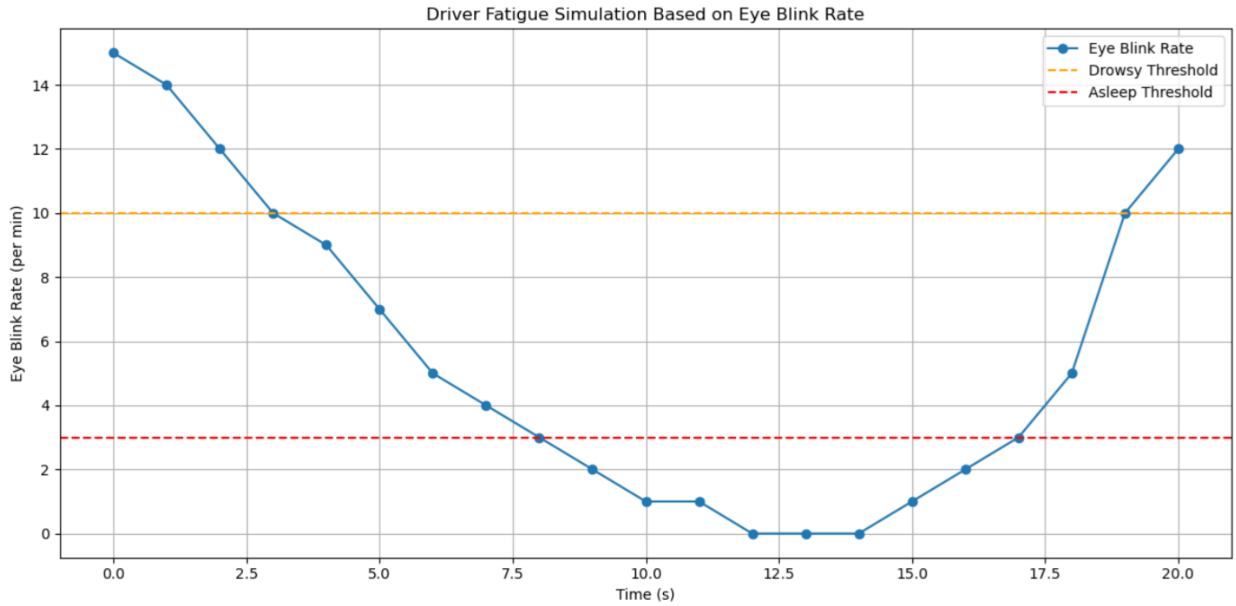

Figure 2. Demonstrate Driver Fatigue Simulation Based on Eye Blink Rate Over Time

The above figure shows a gradual decline in eye blink rate, which is commonly associated with fatigue or sleep onset in drivers:

i. Eye Blink Rate > 10/min: Classified as "Alert", normal state — blue line starts high.

ii. Between 3 and 10/min: Indicates "Drowsy", requiring attention — shown in orange threshold zone.

iii. Below 3/min: Indicates "Asleep", critical danger — indicated by red zone in the graph.

Based on above observation, overall conclusion is: ·

I. Initial Phase (0–5 seconds):

a) Eye blink rate decreases from 15 to 7 blinks/min.

b) This range lies above the drowsy threshold (orange line at ~10).

c) The driver is alert but showing early signs of reduced attentiveness.

II. Drowsy Phase (6–8 seconds):

a) Blink rate falls below the drowsy threshold but remains above the asleep threshold (red line at ~3).

b) Indicates drowsiness — driver may lose focus, and system should trigger warning alerts.

III. Critical Phase / Microsleep (9–15 seconds):

a) Blink rate drops to ≤3 blinks/min, reaching as low as 0.

b) Falls below the asleep threshold.his is a high-risk phase indicating possible microsleep or unconsciousness, where immediate alerting (e.g., buzzer) is essential.

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IV. Recovery Phase (16–20 seconds):

a) Eye blink rate gradually increases back to alert levels.

b) Suggests the driver may have responded to alerts or regained attention.

The Table 3, demonstrate - System Response Based on Eye Blink Rate Thresholds that defines the **threshold-based logic** used by the driver drowsiness detection system to classify the driver's state and issue appropriate alerts. It is based on widely accepted physiological benchmarks related to eye blink frequency:

Eye Blink Rate	Interpretation	System Response
> 10	Driver is alert	No alert issued
3–10	Driver is drowsy	Warning signal (buzzer, LED)
< 3	Driver is asleep	Critical alert (e.g., loud buzzer, vibration)

Table 3: System Response Based on Eye Blink Rate Thresholds

This logic is easily implementable in Arduino using sensors like IR Eye blink sensor or camera-based system and output modules like buzzers or GSM modules for alerts.

justification by Stages:

Stage 1: Normal Alertness (Time 0–2 sec)

i. Blink Rate: Starts at 15 → gradually decreases to 12

ii. Interpretation: Within normal physiological range. A healthy, awake person blinks ~15–20 times per minute.

iii. System Response: No alert initially; as blink rate dips toward 12, a warning is initiated anticipating fatigue onset.

Stage 2: Drowsy Phase (Time 3–7 sec)

i. Blink Rate: Drops from 10 to 4

ii. Interpretation: Reduced blinking indicates cognitive slowdown. Research (e.g., Shekari Soleimanloo et al., 2019) shows prolonged closures and lower blink frequency as strong fatigue indicators.

iii. System Response: Issues continuous Warning signals to suggest caution or rest break.

Stage 3: Micro-sleep / Asleep (Time 8–17 sec)

i. Blink Rate: Falls to critical levels (≤3 blinks/min); even zero at times

ii. Interpretation: These values suggest micro-sleep or near sleep state. At 0–1 blinks per minute, the driver is likely unconscious of surroundings.

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iii. System Response: Activates Alert! buzzer immediately — to wake the driver and prevent accidents.

Stage 4: Recovery Phase (Time 18–20 sec)

i. Blink Rate: Begins to increase again (5 → 12)

ii. Interpretation: Driver may have responded to alerts (e.g., buzzer), showing signs of regained focus

iii. System Response: Alert level downgrades from Alert! → Warning → No Alert

The results justify the system's design logic: as blink rate drops, fatigue level increases, and the system responds with appropriate escalation of alerts — from No Alert → Warning → Alert!

This threshold-based, real-time monitoring approach ensures early detection of drowsiness, enhancing road safety effectively with a simple, low-cost setup.

IV. Conclusion

The Arduino-based driver drowsiness detection and alert system developed in this study offers a practical, affordable, and dependable solution to combat one of the major causes of road accidents: driver fatigue. Utilizing an infrared (IR) eye blink sensor integrated with an Arduino Nano microcontroller, the system provides real-time monitoring of the driver’s eye activity in a non-intrusive manner.

Unlike camera-based or physiological monitoring approaches that require complex hardware, high computational resources, or invasive procedures, this system is lightweight, power-efficient, and easy to implement—making it highly suitable for both personal and commercial vehicles. Its core functionality relies on detecting prolonged eye closure, a key indicator of drowsiness, and issuing timely alerts via a buzzer to refocus the driver’s attention.

The system's effectiveness is further supported by the accompanying analysis, which shows that monitoring blink rate trends is a reliable method to identify drowsiness and trigger graduated alert levels. This real-time response to fatigue symptoms enhances driver safety by reducing the likelihood of fatigue-induced incidents.

Additionally, the system’s modular design allows for future scalability, including the integration of additional sensors or communication modules to expand its capabilities. This research establishes a solid foundation for the development of low-cost embedded safety solutions, particularly for regions lacking access to advanced driver assistance systems (ADAS). Future improvements, such as AI-based decision-making and multi-sensor data fusion, could further elevate its performance and pave the way for its inclusion as a standard vehicle safety feature.

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