Journal of IoT in Social, Mobile, Analytics, and Cloud (ISSN: 2582-1369)
www.irojournals.com/iroismac/

Preventing Road Crashes with IoT Monitoring of Driver Fatigue in Real-Time

Abhijan S. Kashyap[1], Sumit Singha Chowdhury[2], Ananya V. Hegde[3]

[1-3]Department of Master of Computer Application, Acharya Institute of Technology, Bengaluru, Karnataka, India

E-mail: [1]abhijanskashyap@gmail.com, [2]sumit2432@acharya.ac.in, [3]ananyavhegde2001@gmail.com

Abstract

Road safety is of utmost importance for national and regional connectivity and economic development; however, as more vehicles occupy our roads, the rise in road traffic accidents has led to reported fatalities (World Health Organization) of more than 1.3 million each year. Among the critical and commonly overlooked causal factors for road traffic accidents is driver fatigue, which detrimentally influences one's ability to react and maintain alertness. This paper presents a technically novel, non-intrusive, and low-cost Internet of Things (IoT)-based driver drowsiness detection system. While previous research has primarily utilized camera-based or wearable sensor solutions, this system utilizes an ESP32 microcontroller, equipped with an infrared (IR) eye-blink sensor and an MPU6050 Inertial Measurement Unit (IMU), to identify eye closure for extended durations and incorrect head movements. When drowsiness is identified for more than 5 seconds, the buzzer and LED provide real-time alerts to the driver, and the event is logged in the Firebase Real-time Database. Additionally, the system is accessible from a purpose-designated web dashboard, allowing the supervisor or authority to monitor the driver remotely. The system was tested in a simulated driving environment with human participants to evaluate persistent alertness and accuracy of detection. The results of this project revealed a detection accuracy of 90%, alerts issued in under one second, and anecdotal feedback from users confirmed that the interrupting mechanism of two alerts was successful in regaining the attention of the driver. The innovative element of this project is hybrid IR-IMU sensing, cloud integration, and a responsive feedback

DOI: https://doi.org/10.36548/jismac.2025.3.001
Received: 27.05.2025, received in revised form: 24.06.2025, accepted: 10.06.2025, published: 25.07.2025

loop, providing a scalable and low-cost solution for reducing road accidents or incidents related to driver fatigue.

Keywords: IoT, ESP32, Infrared Eye Blink Sensor, MPU6050, IMU, Head Movement Analysis, Fatigue Detection, Road Safety, Human Factors, Low-Cost Embedded System

1. Introduction

Road transport is entrenched in connecting people and products across India and facilitating the movement of millions of individuals and the burgeoning logistics ecosystem. However, the rise of vehicles on Indian roads has led to traffic-related accidents becoming a top public safety issue. The Ministry of Road Transport and Highways (MoRTH) reported more than 4.6 lakh road accidents in India last year, with around 1.68 lakh fatalities. A large number of these accidents result from human error, with two major aspects being driver drowsiness and fatigue. Drowsiness is defined as a state between wakefulness and sleep, where a person's awareness has declined. It is mainly associated with sleep deprivation, extended hours of driving, monotonous road conditions, or disturbances in the circadian rhythm, most often occurring during late-night/early-morning hours (usually between 12 AM and 6 AM). Research has shown that drivers are more likely to doze off during this time period since the body's natural sleep cycles are functioning. The later drowsiness initiates after detecting tiredness, the greater the risks involved in driving, including an increased probability of collision. Fatigue impairs driving by negatively affecting hazard perception, the ability to react in a timely manner, and decision-making abilities, while the driver may not even be aware that they are declining to a level of unsafe performance [4], [9].

While many traditional drowsiness detection systems (e.g., camera monitoring, Electroencephalography - EEG headbands, and worn sensors) can provide an accurate measure of drowsiness, they often come with high costs, require physical contact or presence during use, or are sensitive to environmental factors (e.g., lighting conditions, especially at night) [4], [9]. For example, while physical methods can provide accurate measurements, these methods require physiological sensors to come in contact with the driver, potentially creating discomfort [1]. Furthermore, camera systems can also be highly affected by lighting conditions or if the driver wears glasses or other accessories [9]. Due to such limitations, traditional drowsiness detection systems do not seem practical for larger vehicle applications [4]. This paper proposes a new approach to drowsiness detection by presenting a real-time driver drowsiness detection system based on the Internet of Things. The suggested system employs an ESP32 microcontroller with an infrared (IR) sensor to measure eye blinks, as well as an inertial measurement unit (IMU) (MPU6050 accelerometer and gyroscope) to monitor abnormal head movements (e.g., tilts, nodding) that are indicative physiological measures for drowsiness. Moreover, unlike many camera-based systems, this non-intrusive system is ideal for low-light settings, such as night-time operation. The system alerts the driver instantaneously through a buzzer and LED when these states of drowsiness are detected. Additionally, it provides real-time data to the Firebase Real-time Database, which can be visualized in a web dashboard. This enables transport authorities or their family members to track driver alertness remotely and take precautionary action. The proposed system aims to be low-cost, portable, and energy-efficient, allowing for the reduction of crashes due to drowsiness in India while increasing road safety through the enhanced use of IoT and edge computing technologies.

2. Background Study

Drowsy driving is a well-recognized cause of traffic accidents worldwide, and it poses threats to both the driver's own safety and public health. Impairment related to fatigue decreases a person's reaction time, situational awareness, and decision-making capacity. This occurs without the knowledge of the driver [4]. Because of this, researchers and developers have offered a range of technologies for detecting and warning drivers experiencing some level of drowsiness. One approach that has gained a lot of interest is the ability to apply the Internet of Things (IoT) to driver monitoring because IoT provides real-time, remote access, and scalability for implementation compared to other approaches [4], [9], [10]. Traditional approaches to detecting driver drowsiness can include physiological methods, as well as behavioral and in-vehicle kinematic approaches [4]. These systems have been developed using EOG, proximity sensors, cameras, and sound [4]. However, some of these systems are limited in terms of implementation because of cost, discomfort for the user (e.g., the electrodes for EEG/EOG), environmental sensitivity (e.g., camera lighting), or privacy concerns (e.g., sound or video) [4], [9]. In the last year or two, several studies have examined IoT models for driver drowsiness and reduced cost and discomfort by using various other types of sensors and microcontrollers to allow continuous monitoring of the driver's drowsiness and immediate feedback.

One significant area of research has been eye-blink detection, an early indication of fatigue [4], [7]. Vanitha and Narasimhayya [18] introduced a system that uses infrared (IR) sensors to investigate eye flickering patterns, claiming that eyelid activity changes dramatically before a crash. Manideep et al. [7] implemented an Internet of Things (IoT) based eye-blink detection system that uses abnormal blinking patterns to find early indicative signs of fatigue. Similarly, Inbamalar et al. [17] created anti-sleep goggles with IR sensors to determine the frequency of blinks. When drowsiness is suggested, an audible alarm is activated and, if unrecognized, can send serial data to the electronic control unit (ECU) of the vehicle via Bluetooth to slow it down independently. Other, more sophisticated non-intrusive systems involve BlinkRadar, presented by Hu et al. [2], which utilizes ultra-wideband (UWB) radar to detect eye blinks. This system avoids any physical contact with the driver and provides a high degree of accuracy, achieving 92.2% detection accuracy for drowsiness and 95.5% for blink identification. Such radar-based technologies provide a reasonable alternative to camera-based models and are likely ideal under variable light conditions.

Multi-sensor and machine learning (ML)-based systems have also emerged in recent studies. For example, Naik and Machado [8] proposed a distributed IoT system that includes a number of sensors, such as blink detectors and steering wheel pressure sensors, to improve drowsiness detection for different vehicle types, including two-wheelers and commercial trucks. Similarly, in the context of safety management systems, Subhan et al. [14] proposed a system using sensors for eye blinks and hand positions on the steering wheel. Sudarshan et al. [15] proposed a webcam-based monitoring system using computer vision and ML to detect human facial features to compute Eye Aspect Ratio (EAR) and Mouth Aspect Ratio (MAR). These values, along with excessive yawning, served as indicators of fatigue. Their system relied on Mediapipe's face mesh and YOLO (You Only Look Once) to recognize human facial features, and the system displays an alert when EAR or MAR falls below a defined threshold [11], [16].

Recent developments in computer vision and deep learning have resulted in more accurate drowsiness detection systems. For example, Agarkar et al. [1] implemented a camera-based solution on a Raspberry Pi that accounted for monitoring lips, eye movement, and hand gestures (including hand movement to cover the mouth during yawning), and reached an accuracy rate of 92.5% for this action. Singhal et al. [13] also used computer vision with Python, OpenCV, and DLib, looking for head nodding with yawning, eye closure, and head movement. They calculated the EAR and used it along with MAR for multi-level alerts when certain amounts of movement are reached; with yawning and eye closure, they were able to analyze facial features. Shinny et al. [12] used OpenCV and Dlib to analyze and monitor, in real-time, facial features (e.g., eyes and mouth states) to detect operator drowsiness. Kumar et al. [5] presented an image processing-based system that can automatically analyze patterns of behavior related to facial characteristics and the frequency of blinking, citing PERCLOS (percentage eyelid closure) and observing ‘change’ in certain fEEG signal bands as key behaviors to detect/monitor drowsiness. Ojha et al. [9] conducted a systematic review of deep learning approaches to drowsiness detection. Although high accuracy (94-97.5%) was reported, they noted challenges such as environmental variability and lack of data standardization. The inclusion of different test subjects presents challenges with big data sets, and using emotions as criteria for classification is not adjustable to different contexts.

In addition, deep learning methods have provided excellent performance. Wunan et al. [19], looking at a side-by-side approach to eye state classification using MobileNetV2, EfficientNetB0, and NASNet Mobile models, found that EfficientNetB0 achieved an average accuracy of 98.5% with visual cues and PERCLOS. Osmani and Wawage [10] improved this by proposing a Real-Time Driver Drowsiness Monitoring system using a fine-tuned Vision Transformer (ViT) model, which achieved 98.8% accuracy on eye state, further highlighting ViT's ability to model complex, long-range dependencies in images. Lakhloufi and Mellouli [6] proposed a hybrid approach to combining Artificial Neural Networks (ANN) with Fuzzy Logic (FL) to enhance robustness against changes in brightness, noise, and blur, utilizing EAR and MAR, and reported 93.98% accuracy with FL. Commercial systems have also added the ability to detect drowsiness by using similar methods and incorporating steering angle sensors, front lane assist cameras, and vehicle speed to detect fatigue [5]. Kadam et al. [3] developed an Arduino-based system that featured an eye blink sensor, buzzer, GPS, GSM, and LCD display for local alerts and real-time tracking of location to tackle the problem of drowsiness. Sudharsan et al. [16] developed a smart safety system for both driver and passenger protection and incorporated multiple detection and alert mechanisms into one IoT system.

It is clear from the literature that despite the availability and development of many different systems in the area of driver drowsiness detection real-time, non-intrusive, sensor-based, etc. The majority continue to suffer from ongoing challenges. These include high implementation costs; sensitivity to environmental factors (e.g., lighting conditions for camera systems); discomfort from wearable sensors; heavy reliance on calibration; low scalability for real-world applications; and incompatibility for monitoring low-light/night driving scenarios. Many systems also lack dedicated cloud-based oversight or cannot be deployed as complete drowsiness detection packages. In addressing these shortcomings, the proposed system applies a low-cost, contactless, and low-hardware deployment method by using infrared (IR)-based eye-blink detection with MPU6050 inertial sensing (IMU) to detect drowsiness symptoms. The IR sensing method is a good alternative to camera systems because external lighting conditions can cause issues, and the system does not require contact with the driver for optimal functionality. The IR system will thus be user-friendly and provide comfort to the driver. Furthermore, the monitoring and processing of data during evaluation testing could impact the system's ability to operate on the ESP32 microcontroller, which is low-cost, readily accessible, and has modest hardware requirements. Hence, we have used basic, rule-based logic programming as a substitute for advanced machine learning models while considering the various scenarios for the attributes of drowsiness detection (sometimes the noise in a computer system can add additional lag and latency when using too many compute units).

Although much research has been done on driver drowsiness detection by camera-based vision systems, physiological sensors, and machine learning models, many existing solutions are limited due to high costs, lighting conditions, physical discomfort, and lack of cloud connectivity. Some literature explores IoT-based systems, but they often only rely on single-sensor modalities, don't offer real-time responses, or do not support remote oversight. Additionally, many studies are based on computationally intensive models that cannot be deployed on embedded hardware in resource-constrained vehicles. This study tackles these limitations and proposes building a hybrid, low-cost, non-intrusive driver drowsiness detection system based on both IR-based eye tracking and IMU head-movement monitoring, using an ESP32 microcontroller, with real-time transmission of data to Firebase and visualization on a remote dashboard. This multitasking approach between multimodal sensing, edge computing, and cloud monitoring in a single lightweight application represents the key research gap being tackled in this work.

Our system will also relay real-time data (databases and web dashboards) to supervisors, authorities, or institutional monitors, thereby permitting remote monitoring and interventions to be adopted in case drowsiness symptoms do arise.

3. System Architecture

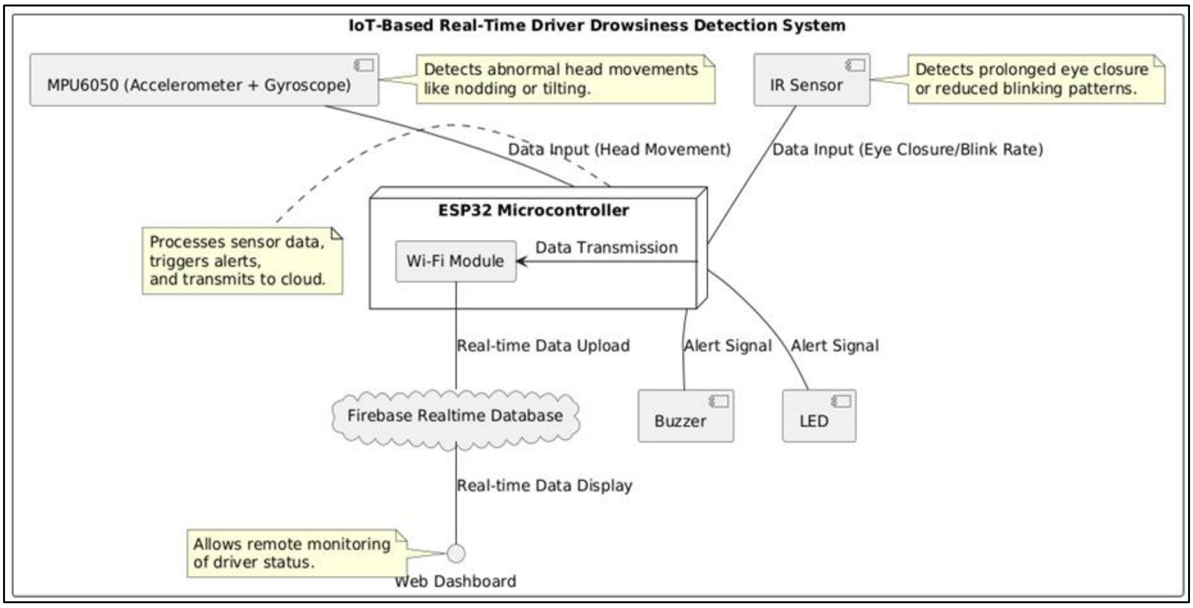

Figure 1. Architecture of the IoT-based Real-Time Driver Drowsiness Detection System

The system is developed as an IoT-based solution for detecting driver drowsiness in real time and acts to alert both the driver and a remote monitoring area. The system consists of several interrelated modules, which can be grouped into two main categories: continuously sensing, processing, alerting, and cloud communication/monitoring. Figure 1 illustrates the overall interaction between these modules and presents the architecture of the IoT-based real-time driver drowsiness detection system at a high level. It shows how the ESP32 processes the sensor data and ultimately enables local and remote alerts. The heart of the system is centered around the ESP32 microcontroller with processing and Wi-Fi signal capabilities, which integrates several components with sensors and communicates with the cloud called Space.

3.1 Component-wise Details

1. **Driver Unit (On-board Vehicle System):** This is the most important module and is located in the vehicle because it is responsible for real-time data collection and local alarms.

2. **IR Sensor:** This sensor is positioned in relation to the driver's eyes. The IR sensor analyzes the driver's eyes to detect every eye blink. Not blinking for prolonged periods raises the probability that the eye is closed due to drowsiness.

3. **MPU6050 (Accelerometer & Gyroscope):** The MPU6050 sensor tracks the head movements of the driver. The signature of abnormal patterns, like sudden nodding or prolonged tilting, shows preliminary signs of drowsiness.

4. **ESP32:** The ESP32 is the main processing unit because it receives data from the IR Sensor and MPU6050, along with GPS if needed. The ESP32 firmware performs its algorithms on the raw data from both sensors and produces a drowsiness classification. An Internet connection is also established through the built-in Wi-Fi module on the ESP32; therefore, any saved data is available anywhere with an internet connection.

5. **Buzzer:** The ESP32 has an acoustic alarm that will sound if the driver is detected to be drowsy or has transitioned to drowsy.

6. **LED:** The LED will turn on if drowsiness is detected, which is another local alarm indicating drowsiness.

7. **Battery:** The battery that is part of the driver unit provides power to all components, makes possible stand-alone local testing, and eliminates reliance on the vehicle's primary battery while initially setting up.

8. **Internet / Wi-Fi Module (Connectivity Layer):** The ESP32 uses its Wi-Fi capability to connect to the internet. This connection is vital for transmitting the driver's status data to the cloud platform and enabling remote monitoring.

9. **Cloud Database (Firebase Realtime Database):** The Firebase Realtime Database serves as the central cloud platform for storing the driver's drowsiness status data. The ESP32 constantly uploads real-time information, such as eye status, head movement status, alert status, and timestamps, to this database. Firebase's real-time nature ensures that updates are immediately available to connected applications.

10. **Web Dashboard (Monitoring Interface):** A web-based dashboard serves as a user interface for all authorized personnel to view the live data being generated about the driver(s). The dashboard pulls live data from the Firebase Realtime Database.

11. **Remote Monitoring:** This functionality allows real-time monitoring to be performed remotely by authorized users (e.g., transport authorities, fleet managers, family members) from any device that has an internet connection (e.g., PC, tablet, smartphone)

to view the current state of the driver(s) to eliminate the time delay of a driver being detected as drowsy and to take any necessary actions as soon as drowsiness occurs.

The dashboard can display several metrics such as driver ID, drowsiness status, time of drowsiness, and drowsiness history, which could provide data on the development or patterns of fatigue for specific drivers.

3.2 System Flow and Operation

1. **Sensors:** The IR sensor detects eye blinks, and the MPU6050 monitors head movements.
2. **Local Processing:** Once the ESP32 receives the raw data from the sensors, it processes the inputs and implements rules-based detection, which checks blink timing and head movements to determine drowsiness.
3. **Local Alert:** If drowsiness is detected on the ESP32, it triggers the buzzer for the audio alert and lights the LED for the visual alert to warn the driver.
4. **Database Communication:** At the same time as the local alert, the ESP32 will send the driver's status (drowsy/alert) and relevant timestamps to the Firebase Realtime Database over Wi-Fi.
5. **Remote Monitoring:** A web dashboard continuously pulls this live data from Firebase, allowing for live monitoring and intervention by a supervisor or family member.

This architecture provides layers of management and protection for driver safety by alerting the driver of drowsiness with a local alert and then enabling remote monitoring for safety management.

4. Hardware and Software Used

The development of the real-time driver drowsiness detection system relied on a specific set of hardware components and software tools. Figure 2 presents a physical implementation of the hardware components, integrated onto a breadboard, demonstrating the system prototype's compact and modular design.

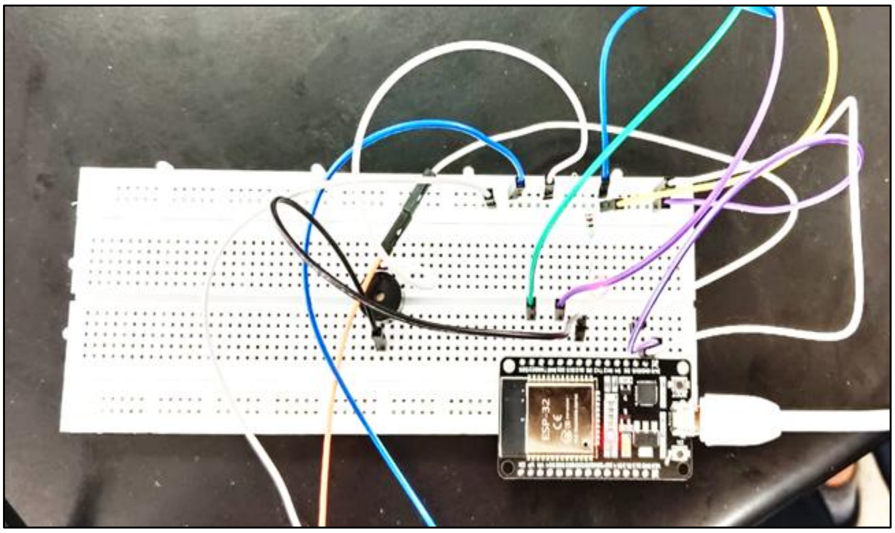

Figure 2. Prototype of the Drowsiness Detection Circuit Assembled on a Breadboard

The ESP32 Microcontroller serves as the central processing unit of the system. It is responsible for handling sensor data, applying threshold-based logic for drowsiness detection, and managing Wi-Fi communication with the Firebase Realtime Database. Its integrated Wi-Fi capability is particularly crucial for enabling real-time data transmission and remote monitoring. Figure 3 depicts the ESP32 development board utilized in the system, including onboard components, and the Wi-Fi module used to communicate with the cloud.

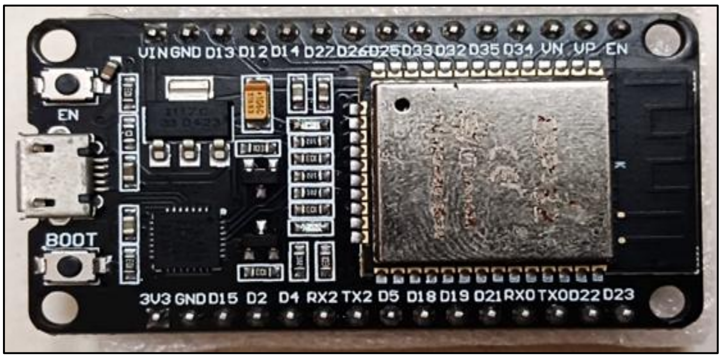

Figure 3. ESP32 Development Board

The Infrared (IR) Eye Blink Sensor is a key input device for the system. Its primary function is to continuously monitor the driver's eye blinks, detecting eye closure as a significant indicator of fatigue. This non-intrusive method helps identify drowsiness without causing discomfort to the driver. Figure 4 shows the IR sensor module used to detect eye blinks, where it is located to monitor the driver's eye status without distracting the driver's focus.

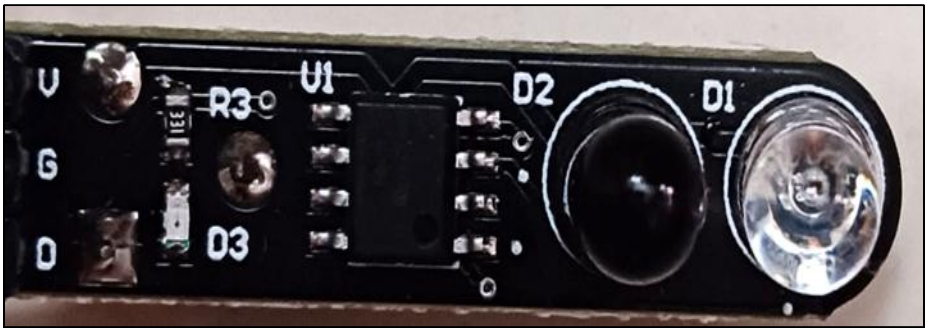

Figure 4. Infrared (IR) Sensor Module

The MPU6050 (Accelerometer and Gyroscope) is another vital sensor used in the system. It is responsible for detecting abnormal head movements, specifically tilting and nodding, which are recognized symptoms of drowsiness. The data from this sensor reinforces the drowsiness prediction alongside the eye blink information. Figure 5 shows the MPU6050 module, which provides accelerometer and gyroscope data in real-time to detect abnormal head movements, including nodding and tilting.

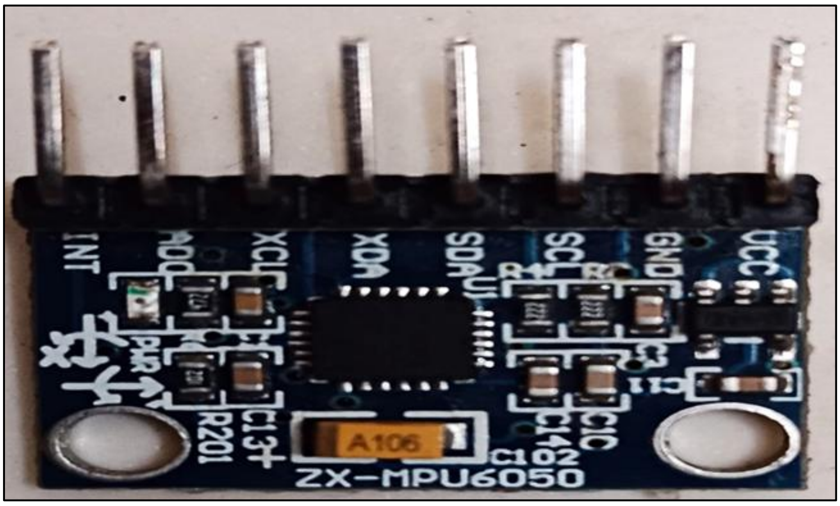

Figure 5. MPU6050 Accelerometer and Gyroscope Module

The Buzzer provides an auditory warning. The ESP32 will signal the buzzer as an immediate warning once drowsiness is detected. This auditory warning will be heard by the driver in the vehicle. The LED provides a visual warning to match the buzzer. The LED lights up when the ESP32 detects drowsiness, providing another form of immediate, local feedback to the driver. The Rechargeable Battery powers the entire drowsiness detection system. It provides the system with portability and the ability to be installed in nearly any type of vehicle without directly connecting to the electrical system of the vehicle.

On the software side, the Arduino IDE was the primary tool for developing the firmware for the project and allowed for uploading code onto the ESP32 microcontroller. The Firebase Realtime Database was used to back up the collected data with real-time synchronization. This cloud-based database helped transmit the driver's status so that it could be stored remotely. A web-based dashboard, developed in HTML, CSS, and JavaScript, was created to show the driver a visual representation of the driver status collected using Firebase, allowing transport authorities or family members to monitor driver status remotely.

5. Methodology

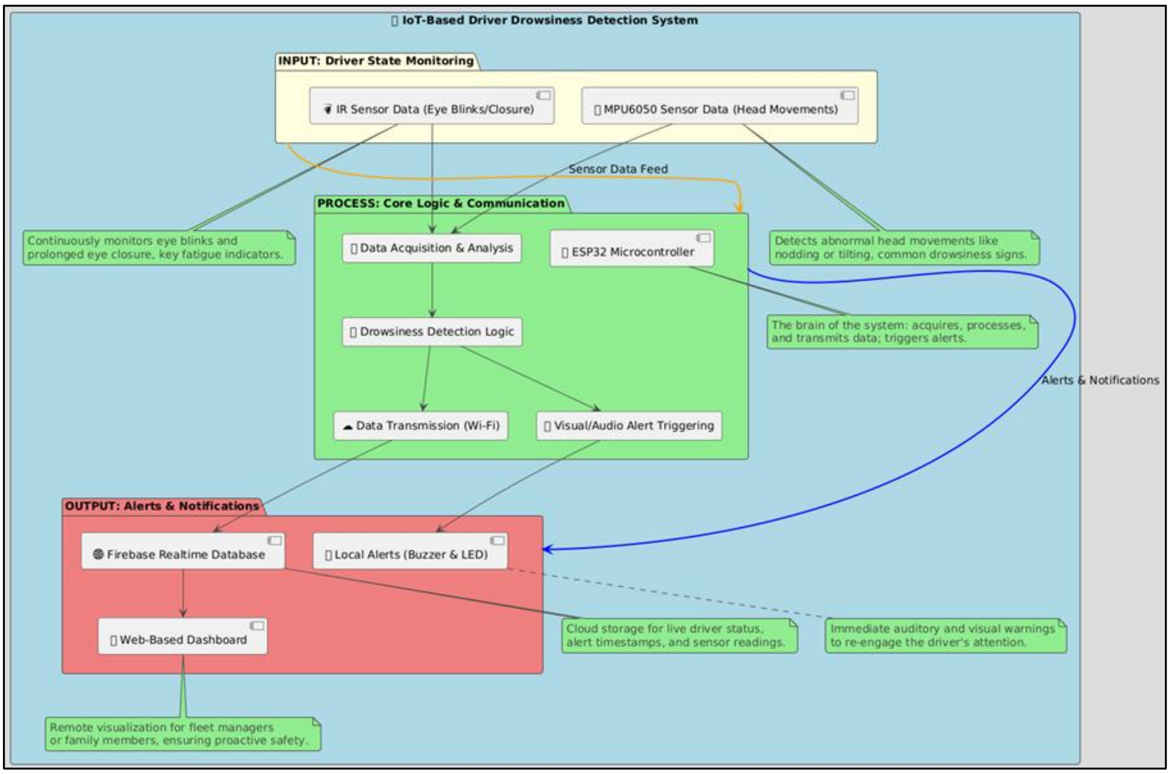

Figure 6. High-Level Architectural Overview of the IoT-based Driver Drowsiness Detection System

A high-level architectural diagram of the suggested system is presented in Figure 6, which also depicts the operational pipeline as its sensors and actuators work together to simultaneously ascertain a driver's status in real time. This section describes the methodical approach used in the real-time driver drowsiness detection system's design, development, and deployment. The operational flow of the system, the reasoning behind drowsiness detection, and the systems for cloud communication and local alerts are all covered.

5.1 System Operation Flow

To guarantee prompt identification and reaction to driver fatigue, the suggested system runs on a continuous monitoring cycle. Continuous data collection from the onboard sensors starts the operational flow, which is then followed by real-time processing, local alerting, and concurrent cloud communication. From data collection to warning the driver and logging to a database, Figure 7 provides a detailed flowchart that explains how the suggested system works. It also depicts its real-time operational state machines for the ESP32 microcontroller's decision-making. The following are the sequential steps:

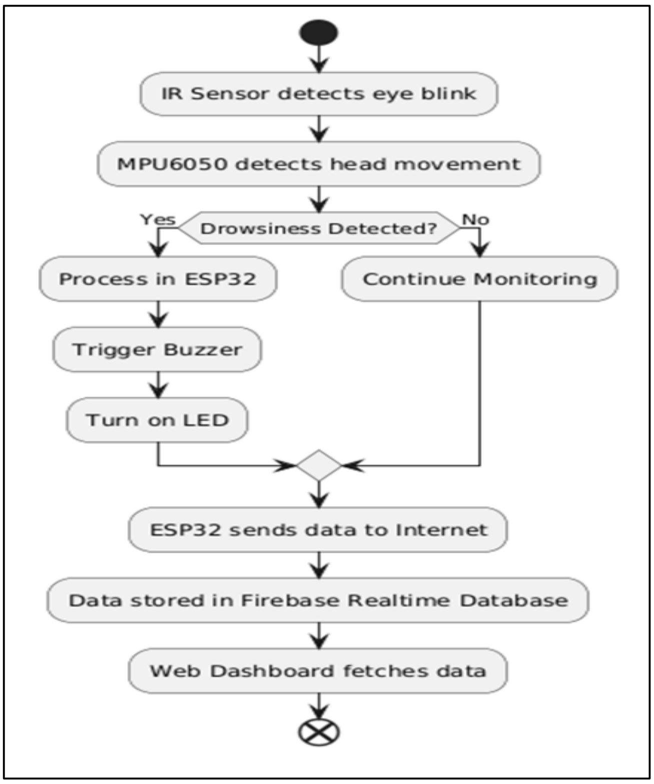

Figure 7. Flowchart of the IoT-based Driver Drowsiness Detection System

1. **Sensor Data Acquisition:** The ESP32 continuously reads data from the Infrared (IR) sensor, which monitors eye blink patterns, and the MPU6050 (accelerometer and gyroscope), which tracks head movements.

2. **Data Pre-processing:** Raw sensor data is received by the ESP32. For the IR sensor, this involves detecting changes in infrared light reflection corresponding to eye closure. For the MPU6050, it involves capturing acceleration and angular velocity data along X, Y, and Z axes.

3. **Drowsiness Detection Logic:** The pre-processed sensor data is fed into a rule-based algorithm implemented on the ESP32. This algorithm analyzes the patterns from both sensors to determine the driver's drowsiness status.

4. **Local Alert Triggering:** If the detection logic identifies signs of drowsiness, the ESP32 immediately activates the onboard buzzer for an audible alert and illuminates the LED for a visual alert, directly warning the driver.

5. **Cloud Data Transmission:** Simultaneously, the ESP32 utilizes its integrated Wi-Fi module to transmit the driver's current status, along with a timestamp, to the Firebase Realtime Database.

6. **Remote Monitoring and Visualization:** The data stored in Firebase is then accessed and visualized on a web-based dashboard, enabling remote monitoring by authorized personnel.

5.2 Drowsiness Detection Logic

The system employs a rule-based detection algorithm for identifying drowsiness, prioritizing low-latency responses over complex machine learning models. This logic is derived from recognized physiological and behavioral indicators of fatigue.

5.2.1 Eye Blink Monitoring (IR Sensor)

The system uses an infrared (IR) sensor to detect the yawning eye state of the driver in real time. The sensor supplies an output value of either HIGH or LOW depending on whether the eyes are open or closed. The principal function of the system is to capture the period during which the eyes are kept closed, and the system will categorize this as a key indicator of drowsiness when the user keeps the eyes closed longer than a predetermined amount of time, typically about five seconds. The amount of time is determined experimentally so that it distinguishes normal eye blinks from the sustained closed state of the eyes, which is a well-established physiological measure of fatigue. The non-intrusive nature of the infrared sensing provides a reliable way to detect the state of the eyes with guaranteed comfort to the driver.

5.2.2 Head Movement Detection (MPU6050)

To supplement eye tracking, the system also taps into the MPU6050 sensor module (combining an accelerometer and a gyroscope) for recording head movements by the driver. The MPU6050 accelerometer measures tilt, and the gyroscope determines angular velocity on the X, Y, and Z axes. The ESP32 controller identifies patterns of unnatural head movements, primarily repetitive nodding (which is defined as valence angle pitch motion of sufficient rapidity) or long head tilting from the neutral driving posture, which lasts much longer than just a few seconds and has much larger deviations from the neutral position. For nodding, the pattern is based on trends of rapid incremental motion along the pitch axis with deviations greater than ±15 degrees over a few cycles or at least driver evaluation actions in a short period of time. Long tilting head movements are defined as the driver's head remaining at an angle greater than 20 degrees for more than three seconds indicating loss of postural control (due to either fatigue or microsleep episodes).

5.2.3 Incorporated Logic and Detection Mechanism

The system combines the outputs of the IR sensor and the MPU6050 module within a multimodal, rule-based logic model, allowing it to utilize all the outputs of the systems simultaneously to provide greater accuracy and reduce false positives. This combined logic approach also ensures that even minor indicators of fatigue are detected. A single significant indicator, such as excessive eyelid closures, will initiate an alert, while the system can also determine the level of drowsiness using small combinations of less significant indicators, such as minor but consistent head nodding in combination with eyelid closure for a short duration of time. By combining two complementary physiological markers, the system is robust in detecting fatigue in a wide variety of conditions and maintains low latency and computational efficiency on embedded hardware.

5.3 Local Alerting and Cloud Communication

Upon detection of drowsiness, the system performs two critical actions simultaneously:

5.3.1 Immediate Local Alerts

The system provides local alerts as soon as signs of drowsiness are detected to ensure a timely alert to the driver. First, the system sounds an audible alarm, which is a high-frequency buzzer that should quickly grab the driver's attention and mitigate any period of inattention. The LED indicator lights up, predominantly red, which is also visually obvious to the driver. The audible and LED indicators are specified to be immediate and evident to increase the likelihood of the driver taking corrective action, such as pulling off the road or stopping for a rest; thus helping in real-time to enhance road safety. The data structure saved and represented in Firebase Realtime Database is shown in Figure 8, containing various fields including driver ID, eye/head status, timestamp, and overall drowsiness status, among others.

5.3.2 Real-time Cloud Communication

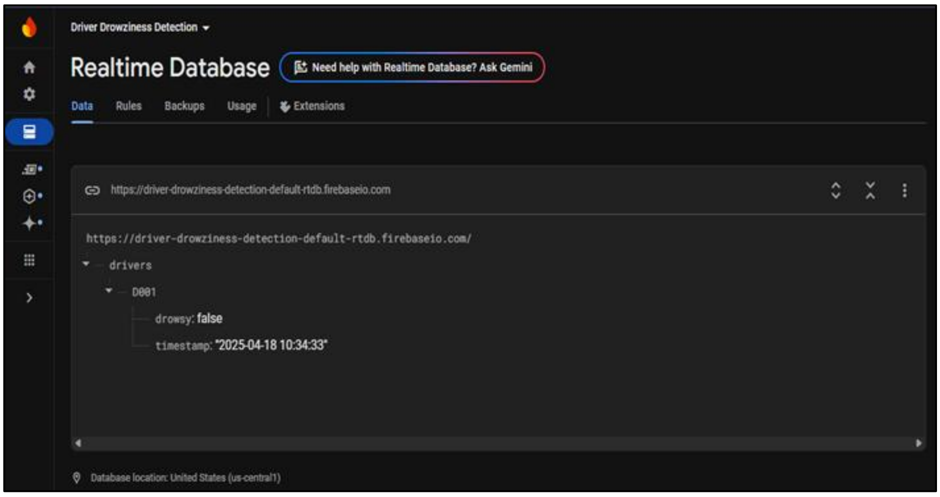

Figure 8. Firebase Realtime Database Interface Showing Driver Status

In the proposed system, the ESP32 microcontroller establishes a Wi-Fi connection, allowing for real-time detection of the driver's status and sending that information to the Firebase Realtime Database. The data is formatted as JSON and contains a few important parameters from the sample, including a driver identifier (driverID), the timestamp of the drowsiness detection, the eye closure status (eyeStatus), the head movement status (headStatus), and an overall summary of the driver status as either drowsy or alert (overallStatus). This constant stream of data allows remote stakeholders, such as transport supervisors depending on the driver, fleet managers, or family members, to closely monitor the driver's level of alertness in near real time through a single web dashboard. Due to the low latency of the Firebase process and this system, changes in the driver status should be reflected in a very short amount of time, allowing remote workers to intervene if fatigue is detected. The custom-made web dashboard implemented for monitoring drivers in real time is shown in

Figure 9, displaying the driver status, the time of driving detection, and historical logs for remote monitoring.

Figure 9. Web Dashboard for Driver Drowsiness Monitoring

6. Implementation

The implementation phase involved the systematic integration of hardware and software components to realize the real-time driver drowsiness detection system. This included interfacing various components, programming the ESP32 microcontroller, configuring the Firebase Realtime Database, and developing a web-based dashboard for remote monitoring.

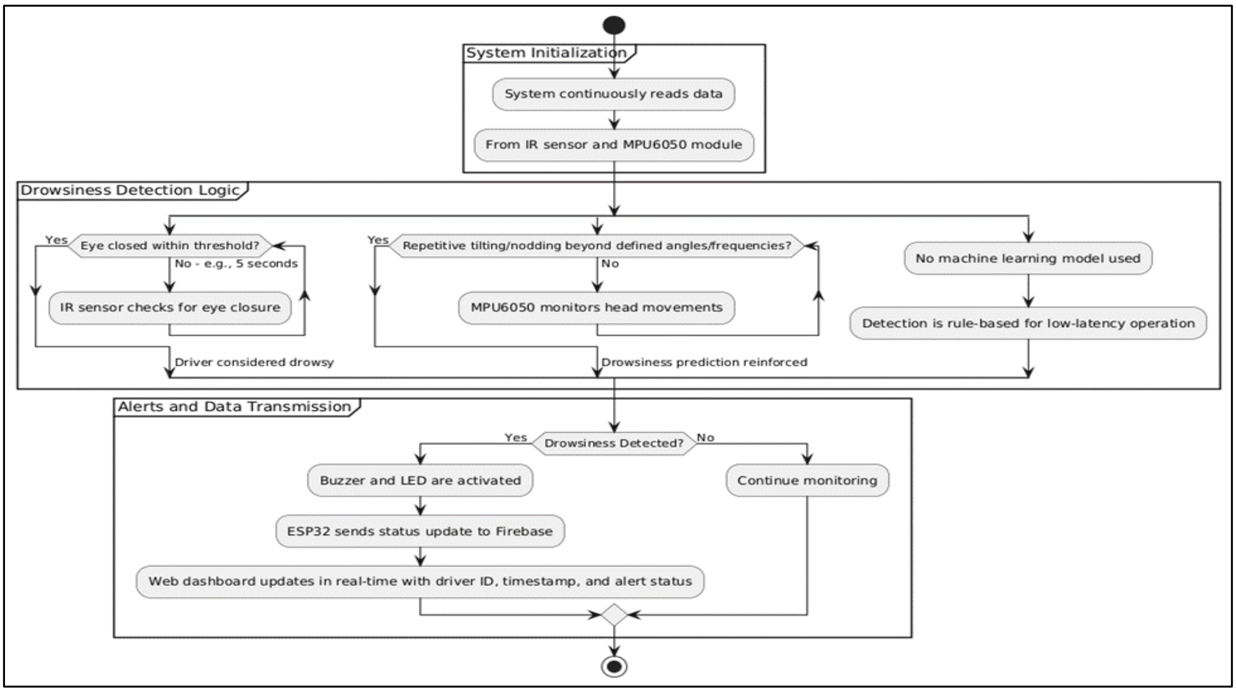

Figure 10. Detailed Activity Diagram of the Drowsiness Detection System

Figure 10 contains a detailed activity diagram documenting the complete system process from system sensor initialization, data collection and acquisition, to alert generation and synchronized data on the cloud.

6.1 Hardware Setup

The ESP32 Microcontroller is the main controller and uses its integrated Wi-Fi resources for IoT solutions to access sensor data and send alert responses using Firebase. An IR Sensor is used to measure eye blink rates and the decimal representations of eye closure time. The IR Sensor sends digital outputs based on eye blink rates and eye closure response times, with blink rates above a certain threshold indicating potential drowsiness levels. The second sensor used is the MPU6050 Sensor, usually deployed as a head motion sensor. The MPU6050 Sensor provides accelerometer and gyroscope readings to indicate head nods or tilt angles based on threshold levels indicative of drowsiness. To provide immediate awareness to the driver, a Buzzer and an LED are connected to the GPIO pins of the ESP32. Both the Buzzer and LED will activate when drowsiness is detected.

6.2 Circuit Connections

The components are wired to the corresponding ESP32 pinout. The VCC and GND of the IR Sensor are wired to 3.3V and GND, and the OUT of the IR sensor is wired to GPIO 32. The VCC and GND of the MPU6050 are also wired to 3.3V and GND. The SCL and SDA of the MPU6050 are wired to GPIO 22 and GPIO 21 (SCL/SDA) on the ESP32 board, respectively. Finally, the Buzzer and LED are wired to GPIO 25 and GPIO 26, respectively.

6.3 Software and Firmware Development

The firmware was developed using the Arduino IDE, where the ESP32 board support package and libraries (Wire.h, MPU6050.h, FirebaseESP32.h, WiFi.h) were installed. Sensors need to be calibrated first; the MPU6050 will be calibrated to detect nodding by differentiating between pitch angle ranges, while the IR sensor will be coded to detect eye closure timings above 2 seconds. Firebase integration includes setting up a Firebase real-time database project and securely saving API Keys, database URLs, and authentication credentials. The ESP32 returns data in a JSON format, indicating eye_status (open/closed), head_status (normal/nodding), alert_status (active/inactive), and timestamp. The alert mechanism is activated when prolonged eye closure and head nodding are detected, which will activate the local alerts (buzzer and LED) and push the drowsiness status data for remote monitoring.

6.4 Dashboard Development

We built the web dashboard with HTML, CSS, and JavaScript using the web version of the Firebase SDK. The dashboard provides a real-time view of the driver's state (Awake/Drowsy), a timestamp of the last 'alert', recorded drowsiness incidents, and a responsive web design optimizing the view for both mobile or tablet and desktop uses.

6.5 Testing and Optimization

Testing consisted of multiple iterations, including normal eye blinking (no alert), heavy and prolonged eye closure (to trigger alert), nodding of the head only (to trigger alert), and mixed symptoms, resulting in a significant alert and update to Firebase. Local alerts and indications of drowsiness were also possible with no available Wi-Fi signal. Some of the challenges addressed during optimization included variations in lighting situations for sensor calibration, maintaining stable Wi-Fi connectivity with the ESP32, and managing rate-limiting and potential delays with the Firebase service.

7. Results and Discussion

The proposed real-time driver drowsiness detection system underwent extensive evaluation in a laboratory environment designed to simulate driving conditions. Specific behaviors, including prolonged eye closure, head-nodding, and typical driving behavior, were tested in the driving simulation. Our testing showed the system had a fast and reliable response time, indicating an alert would be triggered in less than 1 second from the point the drowsiness symptom was detected. The quick responsiveness of the drowsiness detection system is particularly important in aiding the immediate attention of the driver, also allowing the opportunity for immediate corrective action. In terms of detection accuracy, the system was accurate approximately 90% of the time, meaning that we are confident in the reliability and accuracy of our fatigue-related driving behavior identification. Additionally, the system was able to distinguish normal driving behavior from drowsy behavior, thereby reducing the likelihood of false alarms under normal driving conditions, particularly for drowsiness-related driving behaviors. In terms of power usage, the current consumption for the alert states was pale in comparison to the maximum draw of 150mA, indicating that this driver drowsiness detection system would be well-suited for long-term applications in vehicles utilizing rechargeable battery modules. An important feature of the driver drowsiness detection system is the embedded cloud integration via the Firebase Realtime Database. The overall latency from event detection via the sensor to the availability of data visualization displayed on the web dashboard was well under 2 seconds, thus allowing for near real-time remote monitoring of the system by transport operators or family members. The following table summarizes the system's performance under different conditions:

Table 1. Drowsiness Detection Performance

Test Condition	Detection Time	Alert Triggered
Eye closed > 5 seconds	1.2 seconds	Yes
Nodding (head tilt)	1.5 seconds	Yes
Normal driving behavior	–	No

As far as usability is concerned, the system has several key strengths. It utilizes non-intrusive motion detectors and IR, ensuring driver comfort without depending on vision or touch systems. Vision-based systems are susceptible to glare and illumination issues, detracting from the ability of the system. The system's performance for varying tests was equivalent to long eye closure, head nodding, and normal driving, illustrated in Table 1. The table illustrates fast detection time and efficient generation of alert for the simulated fatigue states. Buzzer and LED symbolize immediate on-board alerts that notify the viewer of the driver's fitness to drive. The dashboard is also connected to Firebase and remote-accessible, in a way that real-time status reports are achievable, towards making the system scalable and feasible. The portability, low cost, and simplicity in design render it feasible to be easily integrated into many cars, including commercial fleet and public transport vehicles. Even though the system has many advantages, there are disadvantages. There are some conditions that may cause false positives, such as traveling over bump roads that cause the driver to naturally move his/her head. Sensor alignments play a crucial role in detection; if not aligned, they might miss signals occasionally or obtain an erroneous measurement of the location of the head. The hybrid system employs current rule-based reasoning but does not involve any machine learning programming or adaptable calibration procedures for the management of false alarms and improving accuracy in changing or more challenging conditions. In summary, the outcomes confirm the feasibility and effectiveness of the suggested driver drowsiness detection IoT-based system. With further innovations, such as the inclusion of learning-based detection models and environmental adaptability, the system can ultimately provide a tremendous potential for road safety improvement through effective monitoring of the driver.

7.1 Comparative Evaluation of Proposed System with Existing Methods

The purpose of this section was to compare the effectiveness of the proposed system to the selected existing methods according to several performance criteria which include detection accuracy, response time, intrusiveness, cost, light dependency and cloud integration capabilities. A summary of the comparative evaluation is presented in Table 2.

Table 2. Comparison of Proposed System with Existing Approaches

Method	Accuracy	Avg. Response Time	Intrusiveness	Lighting Sensitivity	Cloud Support	Cost
Camera-based with OpenCV (Singhal et al. [13])	92%	1.5–2 sec	Medium (camera focus)	High	No	Medium
EEG-based Wearable (Kumar et al. [5])	95%	1.2 sec	High (head contact)	Low	No	High
Radar-based BlinkRadar (Hu et al. [2])	92.2%	1–1.5 sec	Low	Low	No	High
ML-based EAR/MAR + Dlib (Sudarshan et al. [15])	94%	1.3 sec	Medium	Medium	Partial	Medium
Proposed IR + IMU IoT System	90%	<1 sec	Low (non-contact)	Low	Yes (Firebase + Dashboard)	Low

This comparison indicates that while some existing methods may show marginally higher accuracy (e.g., EEG or deep learning) it also has very prohibitive costs, physical intrusiveness, or environmental issues. For example, EEG headsets require direct skin contact and require constant recalibration, not practical for in-vehicle continuous use while camera-based sensing suffers with irrelevant and varying lighting especially in night-time driving.

The proposed system, although simple and rule-based logic, demonstrates similar accuracy (90%) with significantly quicker response time (average < 1 second), which allows real-time response. In addition, it can sense non-contact, provides dual alerts (audio and visual). Provides monitoring with Firebase in real-time thus is far more practical for deployment commercially in low-resource and night-time environments. It employs low-cost sensors, ESP32, IR sensors, MPU6050 modules, which is more affordable and accessible than high-tech machine learning or vision-based systems.

7.2 Human Factors Testing: Alert Effectiveness Evaluation

To assess the effectiveness of buzzer and LED alerts in regaining driver attention (an important human factor in drowsiness detection research), a small user testing study was implemented in a simulated driving environment. The study engaged 10 voluntary participants (22-40 years old, mixed genders) to take part in a monotonous driving simulation on a screen for approximately 30 minutes. During the 30 minutes of simulation, simulated fatigue was introduced either by asking users to minimize their head and eye movement or by inducing a dull environment.

The research team programmed the system to detect drowsiness factors (such as prolonged eye closure and uncharacteristic head nods). Once drowsiness was detected, the system initiated both the audible buzzer and visual LED alerts via the computer interface. The research team utilized a data collection technique by recording response times while participants completed their driver’s test and employed a post-test questionnaire to solicit participant subjective feedback. From the results, 9 out of 10 drivers responded to the alerts within 2-3 seconds by either changing their posture, blinking rapidly, or pausing the simulation. All participants reported that they immediately noticed the buzzer and felt they needed to take action. The LED alert alone was less effective in bright ambient light but was found to be informative during low light conditions, providing a secondary confirmation of the alert. None of the participants reported disorientation, discomfort, or distraction from the alerts.

The tests provide preliminary evidence that a buzzer and LED visor alarm system is effective and safe in regaining attention and, when implemented, may be an immediate countermeasure to mild-to-moderate levels of driver drowsiness. Future work could include testing in actual vehicular environments and possibly further enhancing the alert system by incorporating adaptive alert intensity and temporal components based on the time of day, ambient light conditions, etc. The system identifies head nods that are caused by fatigue versus head nods initiated by normal, controlled motions. It does this by using timing to assess the mobility pattern of the head nod captured through the MPU6050 sensor. For drowsiness-related head nods, they tend to be repetitive, unregulated, and have pitch angle deviations that individually exceed ±15 degrees every few cycles in a short amount of time. In contrast, voluntary movements typically occur quickly, on one occasion, and are followed by the head remaining still shortly afterward. To address false positives, the system also monitors the duration of eye closure using the IR sensor. The detection of fatigue occurs only when abnormal movement occurs in conjunction with eye closure. In this way, the fatigue detection system can make accurate detections of fatigue while avoiding detections of the execution of intentional head motion.

8. Conclusion and Future Work

In this paper, we have explored the concept of an IoT-based real-time driver drowsiness sensing system. We used an ESP32 as our microcontroller system, an IR sensor to measure eye blinks, and an MPU6050 to measure head movements to evaluate tiredness. A two-level warning system has been developed, including radio and visual alarms, as well as uploading to a Firebase database to measure data outside the car in real time. We hope to make driving on our roads safer. The design created in this paper is a non-intrusive, low-cost, and compact system to maintain driver awareness and has around 90% accuracy levels with response times of less than 1 second while using low power. In future phases of this work, we could perhaps include camera-based machine learning object detection to perform advanced facial measurements EAR, MAR to reduce false positives; include GPS location data to record when drowsy incidents occur; and expand on the web dashboard to include limited analytics from Firebase and allow users to view their data history. We could also incorporate physiological sensors (heart or pulse monitors, etc.) so that we can implement multimodal detection for safety. Ultimately, this shows a practical implementation of an intelligent IoT-based drowsiness system that may provide both benefit and utility for road safety.

References

[1] Agarkar, Arpit S., R. Gandhiraj, and Manoj Kumar Panda. "Driver drowsiness detection and warning using facial features and hand gestures." In 2023 2nd International Conference on Vision Towards Emerging Trends in Communication and Networking Technologies (ViTECoN), IEEE, (2023): 1-6.

[2] Hu, Jingyang, Hongbo Jiang, Daibo Liu, Zhu Xiao, Schahram Dustdar, Jiangchuan Liu, and Geyong Min. "BlinkRadar: non-intrusive driver eye-blink detection with UWB radar." In 2022 IEEE 42nd International Conference on Distributed Computing Systems (ICDCS), IEEE, (2022): 1040-1050.

[3] Kadam, Anuradha, Kaustubh Gaikwad, Joel Jose, Gayatri Khairnar, and Seema U. Deoghare. "Drowsiness Detection and Alert System." In 2022 6th International Conference On Computing, Communication, Control And Automation (ICCUBEA, IEEE, (2022): 1-4.

[4] Kalisetti, Vinay, Vamsi Sai Chandra Vasarla, Sujeeth Babu Kolli, Rakesh Varaparla, Vamsidhar Enireddy, and Moulana Mohammed. "Analysis of driver drowsiness detection methods." In 2023 Second International Conference on Electronics and Renewable Systems (ICEARS), IEEE, (2023): 1481-1485.

[5] Kumar, Rishabh, Mayank Pratyush, Om Gupta, Utkarsh Tiwari, and Shweta Chauhan. "Driver drowsiness detection system using image processing." In 2023 12th International Conference on System Modeling & Advancement in Research Trends (SMART), IEEE, (2023): 19-22.

[6] MLakhloufi, Mouhcine, and El Mehdi Mellouli. "New Method of Driver Drowsiness Detection System Based on Fuzzy Logic and Artificial Neural Networks." In 2024 4th International Conference on Innovative Research in Applied Science, Engineering and Technology (IRASET), IEEE, (2024): 1-5.

[7] Manideep, Tungali, Isha Upadhyay, Nikhil Aggarwal, P. Govardhan Reddy, and Deepak Das. "IOT based Eye blink detection system." In 2022 2nd International Conference on

Advance Computing and Innovative Technologies in Engineering (ICACITE), IEEE, (2022): 491-494.

[8] Naik, Bhushan Suresh, Tanish Vijay Khot, Bliss Dexter Machado, and Ronak Bhushan Raut. "IoT-Enabled Drowsiness Detection Systems for Enhanced Road Safety Across Diverse Vehicle Types." In 2025 Fourth International Conference on Power, Control and Computing Technologies (ICPC2T), IEEE, (2025): 293-298.

[9] Ojha, Dhiren, Amit Pawar, Gaurav Kasliwal, Roshani Raut, and Anita Devkar. "Driver drowsiness detection using deep learning." In 2023 4th International Conference for Emerging Technology (INCET), IEEE, (2023): 1-4.

[10] Osmani, Fariya, and Pawan Wawage. "Real-Time Driver Drowsiness Detection System using Vision Transformer for Accurate Eye State Analysis." In 2024 International Conference on Intelligent Systems and Advanced Applications (ICISAA), IEEE, (2024): 1-5.

[11] Rathod, Siddharajsinh, Trushil Mali, Yash Jogani, Nil Faldu, Vidit Odedra, and Pradip Kumar Barik. "RealD3: A Real-time Driver Drowsiness Detection Scheme Using Machine Learning." In 2023 IEEE Wireless Antenna and Microwave Symposium (WAMS), IEEE, (2023): 1-5.

[12] Shiney, S. Arumai, R. Seetharaman, N. Mageshwari, S. Saikiran, B. K. Sulaksha, S. Sai Pravin, and P. L. M. Dheepak. "A Methodology for Driver Drowsiness Detection based on OpenCV and Dlib Libraries." In 2024 5th International Conference on Smart Electronics and Communication (ICOSEC), IEEE, (2024): 2047-2051.

[13] Singhal, Vidushi, Nitasha Soni, Kanika Khatri, Bhavesh Kumar Chokkar, and Krishan Kumar. "Drowsiness detection and alert system using dlib." In 2023 International Conference on Advances in Computation, Communication and Information Technology (ICAICCIT), IEEE, (2023): 242-246.

[14] Subhan, S. Jayesh, T. Avinash, and S. Thirumal. "Driver's safety management system for commercial purposes using IoT." In 2022 7th International Conference on Communication and Electronics Systems (ICCES), IEEE, (2022): 334-339.

[15] Sudarshan, Pragathi, and Vivek Bhardwaj. "Real-time driver drowsiness detection and assistance system using machine learning and IoT." In 2023 8th International Conference on Communication and Electronics Systems (ICCES), IEEE, (2023): 1128-1132.

[16] Sudharsan, S., S. Rajesh, N. Selvam, P. S. Sangeeth Raj, R. Babu Prasad, and A. Duraimurugan. "Smart Safety System for Driver and Passenger Protection." In 2025 International Conference on Data Science, Agents & Artificial Intelligence (ICDSAAI), IEEE, (2025): 1-6.

[17] Inbamalar, T. M., and Chettiyar Vani Vivekanand. "Design and Development of Anti-Sleep Goggles for Drowsiness Detection while Driving to Avoid Accidents." In 2023 International Conference on Innovations in Engineering and Technology (ICIET), IEEE, (2023): 1-6.

[18] Vanitha, K., and B. E. Narasimhayya. "Blinking Detection Utilizing Internet of Things." In 2022 11th International Conference on System Modeling & Advancement in Research Trends (SMART), IEEE, (2022): 361-365.

[19] Wunan, Thomas Dante, Pretty Calista Jappy, Stephanie Aurelia, Ivan Sebastian Edbert, and Derwin Suhartono. "Driver drowsiness detection using nasnet mobile, mobilenetv2, and efficientnetb0." In 2024 IEEE International Conference on Artificial Intelligence and Mechatronics Systems (AIMS), IEEE, (2024): 1-4.