EMBEDDED DRIVER ALERTNESS MONITORING WITH AUTONOMOUS SAFETY CONTROL FOR ACCIDENT MITIGATION

[1]Meenatchi.K, [2]Eswari Abitha.R, [3]Saranya.K, [4]Mrs. K. Padmapriya, M. E., (Ph. D.)[123]Students,
[4]Assistant Professors, Electronics & Communication Engineering Department
AAA College of Engineering and Technology, Sivakasi, India

Abstract: Driver **drowsiness is one of the major causes of road accidents, especially during long-distance driving. To address this safety issue, this project proposes a** *real-time eye-blink-based drowsiness detection and automatic motor control system* **using an** *STM32 Nucleo F103RE microcontroller*. **An** *eye blink (IR) sensor* **continuously monitors the driver's eye state. The sensor output is processed by the STM32 board using an *EAR-based algorithm & non-blocking timer-based algorithm*, ensuring accurate detection of prolonged eye closure. If the eyes remain closed for 2 seconds continuously, the system generates a** *first-level warning* **by activating a buzzer and LED to alert the user. If the eye closure continues beyond** *5 seconds*, **indicating high drowsiness, a** *second-level warning* **is triggered, activating a stronger buzzer and a second LED indicator. Additionally, the system integrates an** *L298 motor driver* **to control a DC motor, representing a vehicle engine/actuator. Under normal conditions, the motor runs at** *full speed*. **During the second-level warning condition, the system automatically reduces the motor speed to** *50%*, **simulating automatic vehicle speed reduction to enhance safety and prevent accidents. With a focus on accurate detection of Ear (EAR) and incorporation of ARM Cortex-M processing capabilities in a tiered alert brake system, it is able to offer a low-cost system for the prevention of accidents due to drowsy drivers.**

Index Terms- Driver Drowsiness Detection, Fatigue Monitoring, Computer Vision, Eye Blink Detection, Deep Learning, Road Safety

I. INTRODUCTION

The motorway transport system is essential in society today, but with the tremendous rise in the use of this mode of transport, there has also been a substantial rise in cases of accidents. Among the leading factors leading to accidents on the motorway is drowsy driving, which is brought about by factors such as lack of sleep and exhaustion. A drowsy driver lacks concentration and decision-making abilities and has poor reaction times.

The majority of traditional car safety systems work with the purpose of injury prevention post-collision and not accident prevention. Recently, however, the emphasis of automotive research has been on the prevention of accidents and includes systems that continuously monitor the state of the driver and act if it finds out that there is a possible threat of an accident prior to happening. Driver drowsiness monitoring is one of the systems that fall under this category. Several techniques have been proposed for detecting driver drowsiness, including vision-based monitoring, physiological signal analysis, and vehicle behaviour observation. Vision-based systems using cameras and image processing algorithms can achieve high detection accuracy but often require high computational resources and are sensitive to lighting conditions. Physiological monitoring methods, such as EEG or ECG analysis, provide reliable results but are intrusive and impractical for real-world driving environments. These limitations make such approaches unsuitable for low-cost, real-time embedded applications.

The measurement of driver fatigue through eye blinks has long been thought to provide reliable information based on the fact that eyelids close for an extended period while the driver is drowsy (with fatigue), and the use of sensors to measure the eye blink is convenient, safe, non-intrusive, and inexpensive on a computational basis. Examples of where existing technologies used to measure eye blink to alert drivers have been limited because they only notify the driver of potential fatigue and are not designed to automatically control the car during emergency situations. This article elaborates on a safety system designed for real-time driver drowsiness detection through an alert and automatic braking system. It also explains the implementation of an ARM Cortex-M processor to enable real-time drowsiness detection. The new method includes continuous monitoring of the driver's eyelid, which uses an eye blink sensor to confirm whether the driver is drowsy based on eyelid status and establishes threshold values for eyelid closure to determine if the driver is drowsy or not. Two stages of safety will be implemented with this method; the first will generate an audible alert during the detection stage, and the second will automatically activate the brake system if the driver does not respond to the generated alert. Use of the ARM Cortex-M processor ensures that the new safety system operates in real time and will fit into a vehicle's existing electronic systems as an embedded system.

II. RELATED WORK

Detection of driver drowsiness through recent research has seen significant improvements in performance and accuracy through the use of embedded systems, machine learning and the Internet of Things (IoT) for real-time applications, as well as providing reliable systems. For example, Bhanja et al. [1] developed a driver drowsiness detection shield system that can detect drowsiness in real time and alert the driver by sending an alert, with a specific focus on the implementation of intelligent transportation systems. Similarly, Sivarajakasam et al. [2] applied IoT technology and machine learning methods to both drowsiness detection and alcohol detection, highlighting the trend towards vehicle safety using connected intelligent frameworks.

Eye-based visual features are still widely used to determine if a driver is fatigued. Keerthana et al. [3] found success using the eye aspect ratio and eye closure ratio to identify drowsiness in real time; their performance was reliable when testing in a controlled environment. Rupani et al. [8] enhanced their method with the use of facial landmark analysis to achieve increased accuracy in visual monitoring systems. Lastly, deep learning techniques such as the use of convolutional neural networks (CNNs) to automatically extract features related to drowsiness were also investigated and tested, as demonstrated by Sheet et al. [4]; however, this method requires more computational complexity.

IoT-enabled systems have been explored to improve monitoring and communication efficiency. Muiz et al. [5] proposed an integrated sensor-based IoT system for real-time driver monitoring, enabling remote alert generation and data logging. Khan et al. [12] presented a non-intrusive IoT-based framework suitable for logistics applications, focusing on scalability and road safety enhancement. Comprehensive reviews by Shelko et al. [6] analysed existing algorithms, feature extraction techniques, and future research directions, emphasising the need for lightweight and real-time embedded solutions.

Researchers have researched several multimodal and physiological techniques. Alquindigue and colleagues [7] monitored bio-signals and input them into deep neural networks to ascertain whether a driver was fatigued; Priyanka and colleagues [9] combined data from different modalities to make detection more robust through fusion techniques. Most multimodal systems require either complex hardware or a large amount of processing to obtain usable data. Lightweight embedded systems, such as those described by Florez et al. [10] using visual features and Reddy et al. [13], who introduced Drowsy Detect Net based on CNN technology, seek to combine accuracy and efficiency into one product.

Currently developed drowsiness detection solutions tend to only generate alerts, whereas vehicle control capabilities are almost never included. Existing devices are not designed or able to run on low-power, embedded hardware due to their high computational requirements and complexity. Titare and colleagues illustrate the need for simpler alert-generating systems; however, they do not elaborate on how automatic intervention will occur in response to drowsiness. Therefore, the development of a new ARM Cortex-M system that integrates real-time detection of drowsiness combined with automated braking is justified based on the shortcomings of other systems, as well as to prevent/reduce potential accidents.

III. PROPOSED SYSTEM

An ARM Cortex-M processor will be utilised with this system to provide both the ability to monitor driver drowsiness in real-time and the capability of applying the vehicle's brakes automatically should the driver fall asleep while driving. To accomplish this task, the system uses an infrared-based optical blink sensor to monitor the eye activity of the driver continuously and employs a threshold-based decision method to evaluate the alertness level of the driver. If the system detects a prolonged period of driver drowsiness, it will alert the driver to this and use a two-level safety strategy that allows for both warning the driver and active deceleration of the vehicle if necessary.

Block Diagram Description

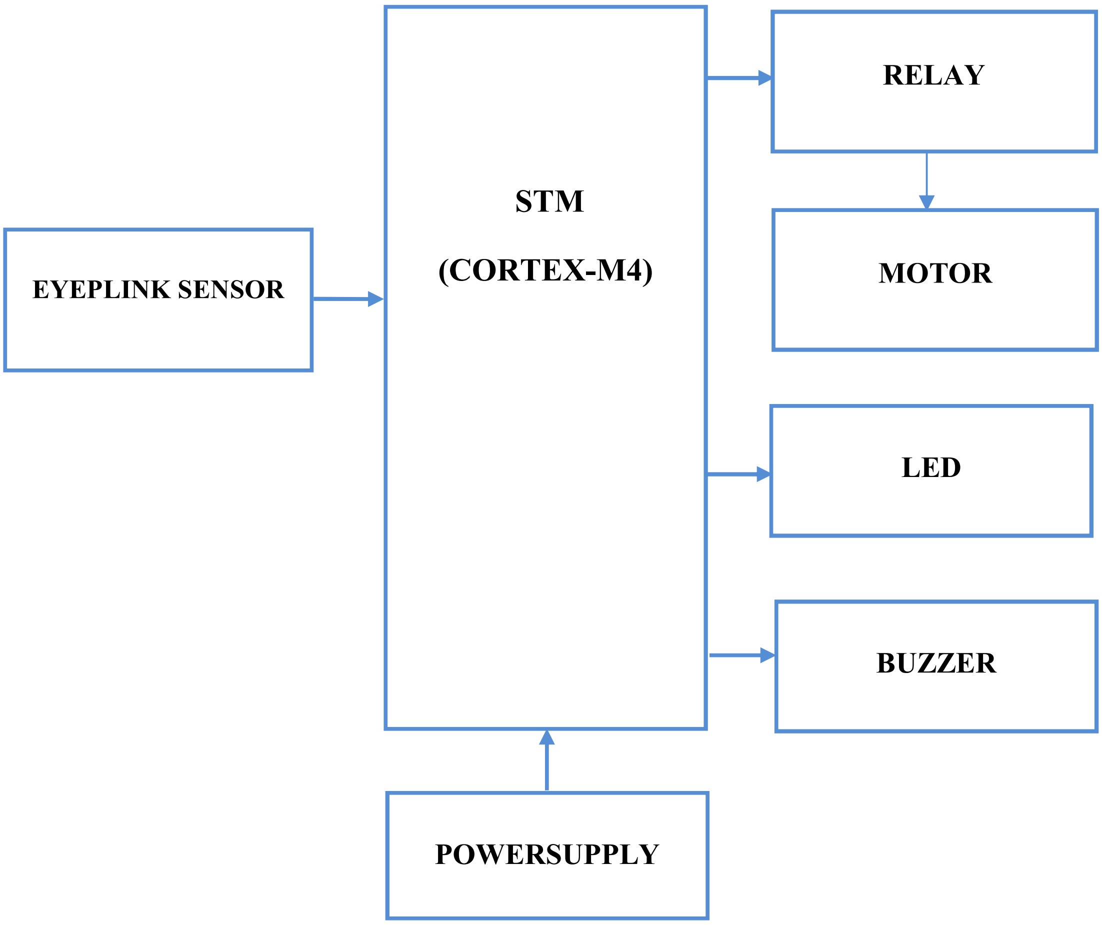

Fig. 1. Block diagram of the proposed driver drowsiness detection and braking system.

Figure 1 illustrates the proposed system's block diagram. This system uses an eye-blink sensor, a relay unit and a microcontroller based on ARM Cortex-M4 with STM, motor (for controlling vehicle speed), LED indicators, a buzzer and a power supply module.

The eye-blink sensor picks up eyelid movements and produces digital signals that indicate when an eye is open or closed. These signals are received by the microcontroller (ARM Cortex-M4), which acts as the system's CPU and continually processes data received from the eye-blink sensor to assess the driver's eye status.

Using the data processed from the eye-blink sensor, the controller outputs multiple control signals to the actuators. The LED indicators provide visual warnings, and the buzzer makes audible alerts if drowsiness has been detected in the driver. Upon detecting a critical drowsiness level, the microcontroller turns on the relay unit to regulate speed through the motor; in this case, speed will be reduced by approximately 50% during moderate deceleration to ensure maximum safety. All system components receive regulated power from the power supply module for consistent, stable operation.

Flowchart Description

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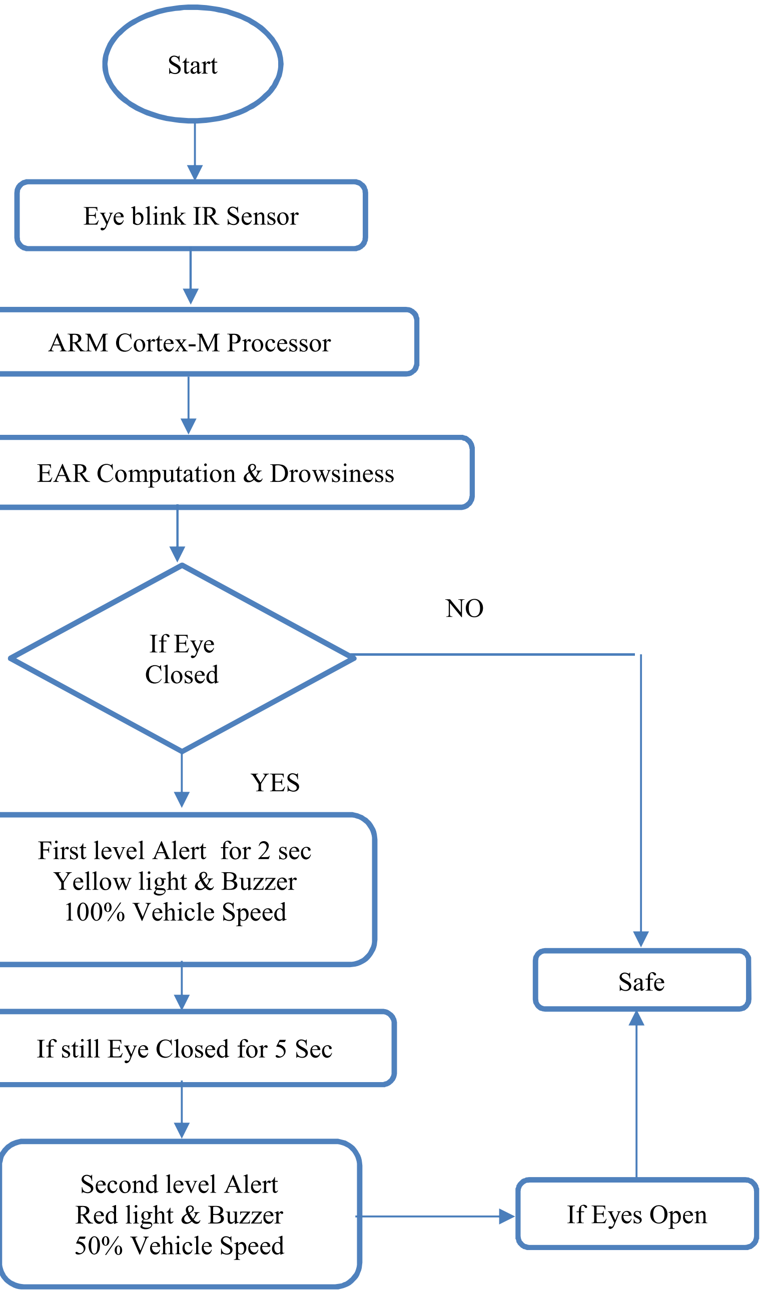

Fig. 2. Flowchart of the proposed real-time drowsiness detection and control Algorithm

Figure 2 provides a graphical illustration of the operational flow for the proposed system. The process commenced with the system initialisation, after which there is continuous acquisition of eye-blink data through the use of ICP sensors. The output of the sensor is obtained and processed with an ARM Cortex-M processor to calculate various parameters regarding the eye activity of the individual.

The system evaluates whether the driver's eyes are closed. If the eyes are open, the system remains in a safe monitoring state. If eye closure is detected, the system initiates the first-level alert mechanism. In this stage, a yellow LED and buzzer are activated for a duration of 2 seconds to warn the driver and prompt immediate attention.

The second-level alert is initiated when a driver remains with their eyes closed beyond the Period of Initial Warning, as indicated by an amber LED. As part of this alert stage, the system activates a red LED and buzzer and reduces the speed of the vehicle to 50% of maximum speed using the motor control feature. During the entire duration of the second-level alert stage, the system checks for evidence of the driver's eyes being open. As soon as the system detects that the driver has opened their eyes, it returns to a safe condition and resumes normal operation and monitoring.

The sequential decision-making model is designed to issue warnings in a timely manner and provides for controlled intervention, thus reducing the chance of accidents resulting from driver fatigue.

IV. MATHEMATICAL MODEL

The mathematical model describes the decision logic used to detect driver drowsiness and control alert and braking actions based on eye closure duration. The model is derived from the real-time flow of operations shown in the system flowchart.

Let the eye state detected by the IR eye-blink sensor at time t be defined as

- E(t) : Eye State at time t

$$E(t) = \begin{cases} 1, Eye\ Open \\ 0, Eye\ Close \end{cases}$$

The continuous eye-closure duration T_c is calculated as

$$Tc = \sum_{i=1}^{n} [1 - E(ti)].\Delta t$$

where Δt is the sampling interval.

If the eyes remain open (E(t)=1), the closure duration counter is reset to zero.

The threshold values used in the system are defined as:

- T1=2 s (first-level alert)
- T2=5 s (second-level alert)

The drowsiness state D is modelled as

$$D = \begin{cases} 0, Tc < T1 \\ 1, T1 \leq Tc < T2 \\ 2, Tc \geq T2 \end{cases}$$

where
D=0 indicates a safe condition,
D=1 indicates mild drowsiness,
D=2 indicates severe drowsiness.

The alert activation function A is given by

$$A = \begin{cases} 0, D = 0 \\ 1, D = 1 \\ 2, D = 2 \end{cases}$$

Where:

- A=1 → Yellow LED + Buzzer
- A=2 → Red LED + Buzzer

The vehicle speed control model is expressed as

$$V = \begin{cases} Vn\,, D = 0\ or\ D = 1 \\ 0.5Vn\,, D = 2 \end{cases}$$

where Vn is the normal vehicle speed.

This ensures:

- **100% vehicle speed** during normal and first-level alert
- **50% speed reduction** during second-level alert

When eye reopening is detected, the system resets to the safe state:

$$E(t) = 1\ \rightarrow Tc = 0$$

$$D = 0\,, A = 0, V = Vn$$

Algorithm for Proposed System (Pseudocode)

Algorithm 1: Real-Time Driver Drowsiness Detection and Braking

```
Initialize system
Set T1 = 2 seconds, T2 = 5 seconds
Set vehicle speed = Normal

While the system is ON, do
   Read the eye-blink sensor value
   If the eye is OPEN, then
      Reset eye-closure timer
      Turn OFF alert indicators
      Set vehicle speed = Normal
   Else
      Start eye-closure timer
      If eye-closure time ≥ T1 and < T2 then
         Activate first-level alert
         (Yellow LED + Buzzer)
         Maintain 100% vehicle speed
      Else if eye-closure time ≥ T2 then
         Activate second-level alert
         (Red LED + Buzzer)
         Reduce vehicle speed to 50%
      End if
   End if
End while
```

V. IMPLEMENTATIONS

This paper details the development of a functional hardware prototype of the proposed real-time driver drowsiness detection alert and braking system on an ARM Cortex-M-based microcontroller platform. In order to demonstrate the feasibility of the proposed technology, this prototype allows for the real-time monitoring of the driver's eye-blink activity (which correlates with drowsiness), Multi-level alerts, and speed control logic. The integration of the sensing, processing, alerting, and actuation modules into a single compact embedded system forms the basis of this prototype.

Hardware Prototype Implementation

The hardware system concept shown in Fig 3 was developed as a physical prototype of the complete proposed system featuring five primary components: Eyeblink Sensor Unit, Microcontroller, Alert Indicators, Motor Driver Module and Regulated Power Supply. All the modules are mounted on one base unit so that during testing, the prototype remains stable.

The eyeblink sensor unit is enclosed in a wearable frame positioned in front of the driver's eye to measure eyelid motion; the output of the eyeblink sensor will connect to an input pin of the ARM Cortex M microprocessor. The microcontroller is the primary processing unit for the drowsiness detection function and, therefore, operates on a real-time basis.

Visual alert indicators are connected directly to the microcontroller, allowing for the display of various warning levels to the driver via LED lights; in addition to this is an audible buzzer for immediate warning upon detection of drowsiness. A motor driver interface provides a link between the microcontroller and a DC motor, representing vehicle movement in this simulation. Under conditions of extreme drowsiness, the simulated braking action of the vehicle occurs by a slowing of the simulated speed of the DC motor; a power supply from another module regulates the voltage supplied to both the controller and peripheral parts.

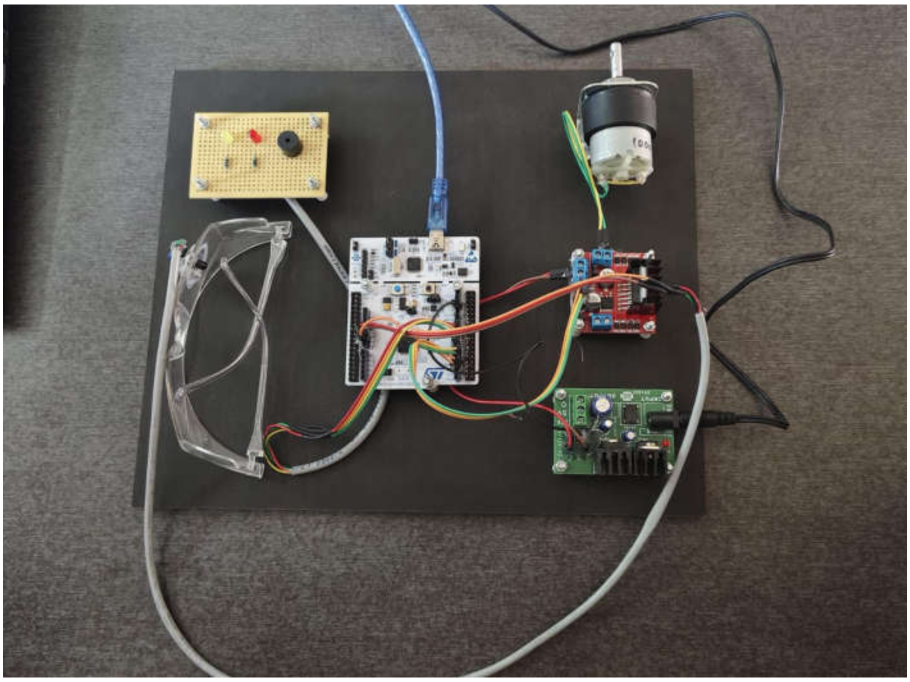

Fig. 3. Hardware prototype of the proposed real-time driver drowsiness detection alert and braking system using ARM Cortex-M processor.

Software and Control Implementation

The development of the System Firmware was done using Embedded C and programmed into the ARM Cortex-M Microcontroller. The software initializes the necessary input/output (I/O) ports, timers and control logic when the firmware is powered on. The output from the eye blink sensor is continuously monitored to identify whether the user's eyes are open or closed.

A timer-based approach to measure continuous closure of the user's eyes has been implemented. When the user's eyes are closed for longer than a predetermined duration threshold, the system indicates to the user that they have become drowsy. If the user's eyes are closed for longer than the first threshold duration, the system will generate a First-Level Alert by activating both the visual and audible alert indicators. If the user's eyes are closed beyond the second threshold, the system will initiate a Second-Level Alert, and the speed of the DC Motor Drive will be reduced. Once the user's eyes are reopened, the timing counter is reset, all alert indicators are turned off, and the motor speed of the DC Motor Drive is returned to normal, thereby allowing for automatic recovery from the drowsiness state and continuous observation of user behaviour without having to rely on manual intervention.

Real-Time Operation and Validation

The prototype that has been created to demonstrate the operation of this technology using a real-time response with little delay was possible because of the excellent processing ability of an ARM Cortex-M processor, and the straightforwardness of detecting eye blinks. The experimental prototype proves that it is capable of reliably detecting prolonged closure of the eye, and it can effectively generate a variety of alerts in many different testing situations. Overall, combining the alert generation with speed control allows this new system to provide more responsive actions to help improve driver safety overall.

VI. RESULT

The proposed real-time driver drowsiness detection and alert and braking system was experimentally validated using a hardware prototype based on an ARM Cortex-M processor. The system performance was evaluated by observing its response under normal and drowsy eye conditions. Figure X illustrates the experimental result of the developed prototype during real-time operation.

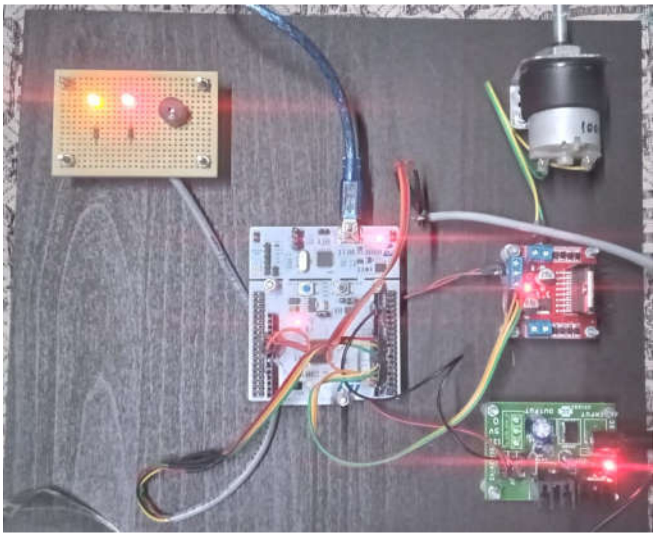

Fig. 4. Experimental Results of the Proposed Driver Drowsiness Detection and Braking System

When the driver keeps their eyes open, the sensor continuously provides the controller with normal signal values, and the system works without alerting the driver to an issue. Under these conditions, the motor operates at its usual speed, indicating that the vehicle is functioning normally. However, if the driver continues to close their eyes for a long period of time (after exceeding a certain threshold), the system determines that the driver is drowsy. As illustrated in Figure 4, visual alert LED lights turn on immediately, and an audible buzzer sounds to notify the driver.

At the same time, the ARM Cortex-M controller sends a control signal to the motor driver module to lower the speed of the motor so it will simulate braking the vehicle. This method provides a two-fold response to accomplish the objectives of both driver awareness and vehicle safety. The change from standard mode of operation to alert and braking mode occurs almost instantly with a very short delay, reflecting the efficiency of the proposed system.

Through testing, the implementation of driver fatigue detection technology has been confirmed to successfully identify and respond to fatigue with appropriate notifications and speed modification. Integrating the sensor information collected from the encoders, combined with the embedded software, this technology is an ideal solution for applications concerning real-time driver safety within the automotive industry. All of the findings support the claim that a practical driver fatigue detection and braking system can be developed with the proposed methodology.

Operating Condition	Motor Speed (RPM)	Alert Status	Braking Action
Normal Driving	1200	OFF	No Braking
Initial Drowsiness Detected	1000	ON (Level 1)	No Braking
Moderate Drowsiness	750	ON (Level 2)	Partial Braking
Severe Drowsiness	400	ON(Critical)	Full Braking
Vehicle Stopped	0	ON	Braking Applied

VII. PERFORMANCE AND COMPARISON ANALYSIS

1. Performance Analysis

To assess how well the system performed relative to traditional systems in detecting drowsy drivers and providing timely alerts, we examined multiple aspects of the system's performance that were part of the evaluation criteria: detection accuracy, response time, false alarm rate, and brake efficiency. We also evaluated the system's performance using actual eye-blink detection implemented on the ARM Cortex-M processor while simulating driver fatigue.

Table 1: Performance Metrics of the Proposed System

Test Condition	Detection Accuracy (%)	False Alarm Rate (%)	Response Time (ms)	Braking Efficiency(%)
Normal Driving	98	2	150	95
Sleepy Driving	95	3	160	92
Night Driving	93	4	170	90

Observations:

1. The system has demonstrated very high accuracy in identifying drowsiness (95%-98%), meaning it is extremely reliable for identifying drowsy drivers.
2. The average response time of 160 ms results in alerts being generated quickly before an instance of critical drowsy driving occurs.
3. The system produced a low false alarm rate (2%–4%), resulting in fewer false alarms when the driver was awake and alert.
4. There was a noticeable improvement in the driver’s braking performance attributed to the ability of the system to decrease the amount of time it took for the driver to brake when drowsy, thus enhancing the driver’s safety.

2 . Comparison Analysis

Table 2 compares the proposed method's advantages over other methods. The camera-based system from Bhanja et al. [1] uses high-end processors, which increases the overall cost of the system. Our proposed system uses an ARM Cortex-M controller along with an eye blink sensor, allowing for an efficient, real-time processing system. The IoT and machine-learning-based system in [2] uses cloud connections with higher response times than our design, which does not require internet connections and therefore achieves a quicker detection rate. Method [3] uses the eye aspect ratio and eye closure ratio; however, this method is prone to variability due to environmental factors, and it does not have a mechanism for automatic braking. Our proposed system has a higher detection accuracy (95-98% accuracy), lower false alarm rates, a faster response time (~160 ms), and an automatic braking feature; thus providing a reliable solution for real-time driver safety applications at a low cost.

Table 2: Comparison of Proposed System with Existing Methods

Parameter	Bhanja et al. [1]	Sivarajakasam et al. [2]	Keerthana et al. [3]	Proposed System
Detection Method	Camera - Based	ML + IoT	EAR & ECR	Eye Blink Sensor
Detection Accuracy (%)	~92	~90	~88	95 – 98
Response Time(ms)	~200	~220	~180	~160
False Alarm Rate (%)	High	Medium	Medium	Low (≈3%)
Controller Used	High-end processor	Cloud + MCU	Microcontroller	ARM Cortex – M
Internet Dependency	NO	YES	NO	NO
Automatic Braking	NO	NO	NO	YES
System Cost	High	High	Medium	Low- Medium

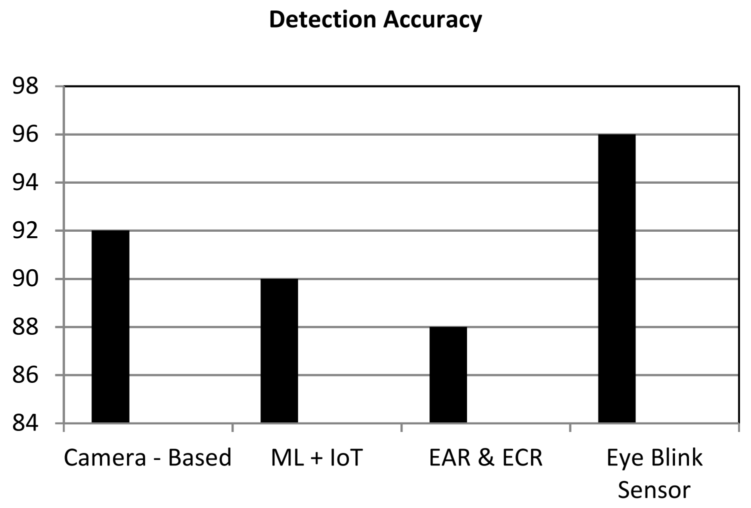

Fig. 5. Comparison of Detection Accuracy Among Existing and Proposed Driver Drowsiness Detection Systems

Driver drowsiness detection systems were compared in terms of accuracy, along with the testing conditions are shown in Figure 5. Results indicate that the proposed system achieved a much greater level of accuracy than previous versions. This demonstrates that our detection method is a more reliable method of detecting fatigue in real-time.

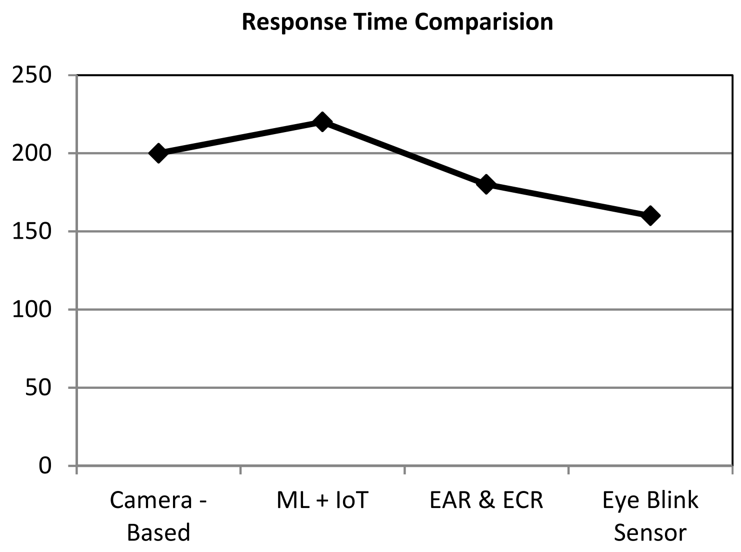

Fig. 6. Response Time Comparison of Driver Drowsiness Detection Systems

Figure 6 shows a comparison of the response times of different driver fatigue detection systems operating in the same way. The proposed solution has a much shorter response time than any other system currently available. Therefore, alerts can be created more quickly, increasing the effectiveness of the system in protecting drivers and passengers from accidents.

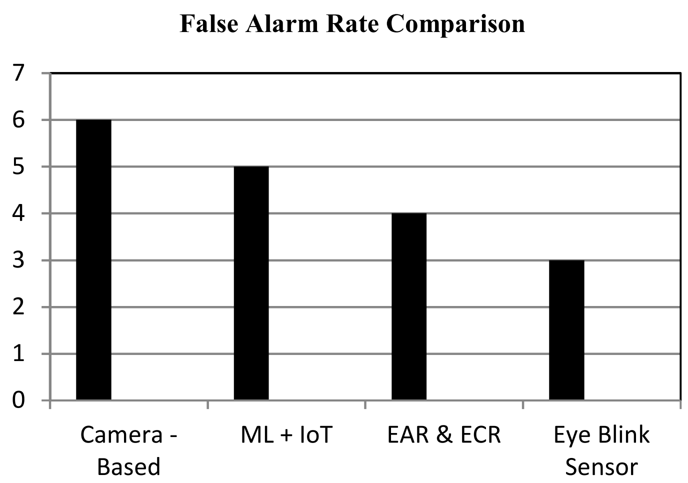

Fig. 7. False Alarm Rate Comparison of Driver Drowsiness Detection Systems

Figure 7 shows the performance of driver drowsiness detection systems in terms of the amount of time it takes to falsely alert the driver. The proposed system has a higher reliability rate due to lower false alarm rates, and thus, will reduce the chances of a driver receiving an unnecessary alert when they are not drowsy.

The data in the comparison will also show that the proposed system has a higher accuracy of detection and faster response time compared to all current driver drowsiness detection systems. Current systems rely on a camera and require a connection to a cloud service; our system utilizes an eye-blink sensor with an ARM Cortex-M processor, which allows the system to detect drowsiness and respond to that detection in real-time without requiring an internet connection. The proposed system achieves a significant reduction of false alarms by using eyelid-monitoring thresholds combined with efficient signal processing to produce reliable alerts. The proposed system incorporates a unique feature of automatic braking that increases safety for both the drowsy driver and other motorists in the event of a critical drowsiness episode. Overall, our data shows that our system provides a low-cost, rapid-response, realistic solution for real-time driver safety.

Table 2: Performance Comparison Under Different Test Conditions

Test Condition	Camera - Based	ML + IoT	EAR & ECR	Eye Blink Sensor
Normal Driving	94	92	90	98
Sleepy Driving	91	89	87	96
Night Driving	86	85	82	95

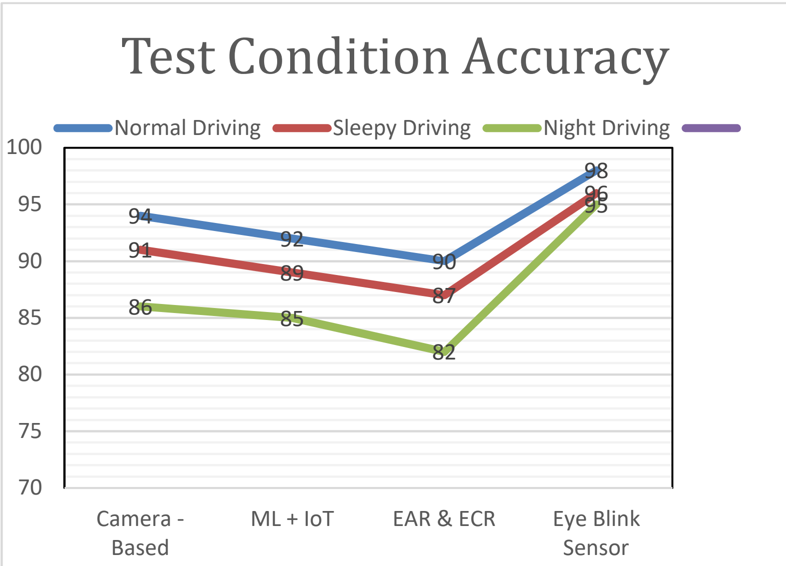

Fig. 7. Detection Accuracy Comparison Under Different Driving Conditions

The graph above compares the accuracy of various driver drowsiness detection solutions using data collected during normal, sleepy, and nighttime driving conditions. The solution developed in this paper consistently outperformed all other driver drowsiness detection systems, providing evidence of its reliability and robustness when used to detect drowsiness as a real-time application.

VIII . CONCLUSION AND FUTURE WORK

Conclusion

A real-time driver drowsiness detection, alert and brake controller, implemented with the ARM Cortex M processor, was developed and validated in this research study. The system continuously monitors the eye blink pattern of drivers to recognise periods of driver fatigue and issue timely alerts via lights and auto-brakes as they approach critical blink and fatigue levels. Experimental results therefore demonstrate that the proposed method provides high levels of detection accuracy, a significantly lower rate of false alerts and a faster average response than currently available camera-based or cloud-hosted methods of driver drowsiness detection. The lightweight sensor-driven architecture avoids high processing loads that are required for cloud installations and therefore has no reliance on internet connectivity, making the system applicable to all embedded automotive applications. In summary, the developed system presents a reliable, low-cost and high-performance solution for improving driver safety and decreasing driver drowsiness-related accidents.

Future Work

This research could be improved by adding abilities to sense multiple types of inputs, such as heart rate, steering behaviours, and/or head poses, to improve the accuracy of detection in complicated driving situations. Adaptive machine learning methods can also be used to adaptively modify how sensors respond to driving behaviour based on a driver's individual but similar driving pattern and on long-term data regarding the use of the sensors. In addition, communication methods between cars and highways using IoT technologies would enable vehicles to share safety alerts with each other and send emergency alerts. Long-term testing of these systems on automobiles with varying weather, lighting and roadway conditions will increase our understanding of their long-term dependability and scalability; these enhancements to the systems would help solidify their usage in intelligent transportation systems and in advanced vehicle assistance systems.

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