

Smart Driver Safety and Emergency Response System for Road Accident Prevention

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Abstract

The problem of road accidents resulting from fatigue and sudden health issues is a significant challenge for an intelligent transportation system. In traditional vehicle safety systems, airbags and seat belts are used for protection after an accident occurs. However, they do not help prevent accidents. In order to overcome the limitation of traditional safety systems, this paper proposes a " Smart Driver Safety and Emergency Response System for Road Accident Prevention " for detecting drivers' fatigue in real time and taking necessary actions for accident prevention. In the proposed system, computer vision technology based on OpenCV and facial landmark detection methods are used for calculating the Eye Aspect Ratio for real-time monitoring. When the EAR value is 0.29 below a threshold for a specific period of time, the system detects a "drowsy" condition and sends control signals automatically to a simulated embedded platform. The motor is stopped, and alert signals are shown. At the same time, rescue actions are initiated for safety purposes. The proposed architecture combines artificial intelligence and control of the embedded system. This is a cost-effective, non-intrusive, and real-time solution for accident prevention. Experimental validation of the proposed approach has confirmed the feasibility of deploying AI-driven proactive safety systems in the context of future smart vehicles.

Keywords: Driver Drowsiness Detection, Eye Aspect Ratio, Computer Vision, Embedded Systems, Vehicle Safety.

1. Introduction

Road traffic accidents are a major safety issue in the world, with a significant percentage of such accidents caused by human factors such as driver fatigue, drowsiness, distraction, and sudden medical emergencies. During road travel, especially at night or over long distances, reduced levels of alertness can significantly affect the driver's reaction time and decision-making capabilities, thus increasing the probability of major road accidents. Although today's vehicles are equipped with safety features such as airbags, anti-lock braking systems, and collision warning systems, most of these systems are passive in nature, meaning they can only react after a critical accident scenario has occurred. Thus, there exists a need for active intelligent systems that can continuously monitor the driver's state and react at an early stage to prevent accidents and enhance road safety.

Recent advances in Artificial Intelligence (AI), computer vision, and embedded technologies have now allowed for the development of 'smart' driver monitoring solutions that are both accurate and cost-effective. Techniques such as vision-based methods and the use of cameras, in addition to OpenCV, can now easily analyze facial features, eye-blink patterns, and head movements in real-time. These methods are relatively 'non-intrusive' compared to traditional methods of physiological monitoring. In addition, the availability of cost-effective and embedded technologies such as ESP32 and Raspberry Pi, in addition to wireless technologies such as GSM and GPS, allows for the development of smart driver monitoring solutions that not only detect unsafe conditions in a driver but also respond to them. These technological advancements are now slowly transforming conventional vehicles into 'Intelligent Transportation Systems' for the purpose of predictive and preventive safety.

Driver fatigue is highly hazardous while driving. Long periods of driving, not enough restful sleep, and medical problems, reduce how well a driver can stay focused. Many crashes are caused when a driver falls asleep or gets distracted for several seconds. Intelligent monitoring systems are needed to help reduce this issue. By using computer vision and artificial intelligence technologies, monitoring systems can monitor a driver's actions and determine if is fatigued. By advising the drivers before they become totally incapacitated, these devices can help prevent accidents by providing early warnings or activating safety devices.

2. Related Work

In recent years, road safety has become a major area of research due to the rapid increase in vehicle usage and the growing number of road accidents worldwide. To address these challenges, researchers have been focusing on integrating modern technologies such as the Internet of Things (IoT), artificial intelligence (AI), and real-time communication systems into accident detection and prevention frameworks. Kishore *et al.* [1] proposed a smart accident alert system that automatically detects accidents and sends immediate notifications to emergency services, thereby reducing response time and improving the chances of saving lives. Similarly, Kumar *et al.* [2] developed a system specifically designed for mountain roads, where accident risks are higher due to sharp curves, steep slopes, and low visibility conditions. Their approach emphasizes real-time monitoring and warning mechanisms to alert drivers in advance. Hariharan *et al.* [3] introduced an advanced system that combines IoT sensors with AI-based analysis to continuously monitor both vehicle conditions and driver behavior. Ravindran and Gurukarthik [4] further extended this concept by designing an IoT-driven safety solution for smart riders, focusing on enhancing awareness and minimizing risks during travel. Tao *et al.* [5] proposed an IoT-based early warning system that not only detects accidents but also predicts potential risks, enabling preventive action before critical situations arise.

In addition to accident detection, several studies have concentrated on improving post-accident management and emergency response systems. Jayashree *et al.* [6] developed an intelligent accident management system that integrates accident detection, alert generation, and communication with emergency services into a single platform, ensuring a faster and more coordinated response. Mateen *et al.* [7] explored the concept of smart roads, where embedded sensors and communication technologies enable automatic accident detection and real-time warning dissemination to nearby vehicles, which is particularly beneficial for autonomous and connected vehicle environments. Nair *et al.* [8] provided a comprehensive review of recent driver safety systems, highlighting key advancements such as fatigue detection, driver behavior analysis, and AI-based monitoring techniques. Furthermore, practical implementations by Sindhuja [9] and Oad *et al.* [10] demonstrated the feasibility of integrating sensors, microcontrollers, and communication modules to create cost-effective accident detection and alert systems. These studies collectively show that modern road safety solutions are becoming more intelligent, automated, and connected. However, despite

significant progress, challenges such as system reliability, real-time accuracy, scalability, and affordability still remain. Addressing these issues is essential for developing more robust and efficient road safety systems that can be widely adopted in real-world scenarios.

3. Proposed Work

The proposed system uses artificial intelligence, computer vision, and embedded systems technologies for detecting driver fatigue and responding appropriately. The proposed system architecture consists of three major components: image processing, fatigue detection, and response through an embedded system. The laptop camera captures images of the driver's face through a Python script developed using OpenCV and MediaPipe technologies. MediaPipe Face Mesh detects facial points around the eyes and calculates the Eye Aspect Ratio (EAR) for measuring eye openness.

If the driver is awake, then the EAR value will always be above a certain threshold. But if the driver is drowsy and their eyes are closed for a certain number of frames, then the EAR value will be below a certain threshold, and the driver will be classified as drowsy. Once the drowsiness of the driver is detected, the Python code will send a signal to an ESP32 microcontroller using serial communication. The microcontroller will activate a buzzer alarm and stop a servo motor used for simulating car motion. Moreover, it will display messages on an LCD screen to inform the driver of the condition. This will result in an intelligent safety system that will prevent road accidents caused by drowsy drivers.

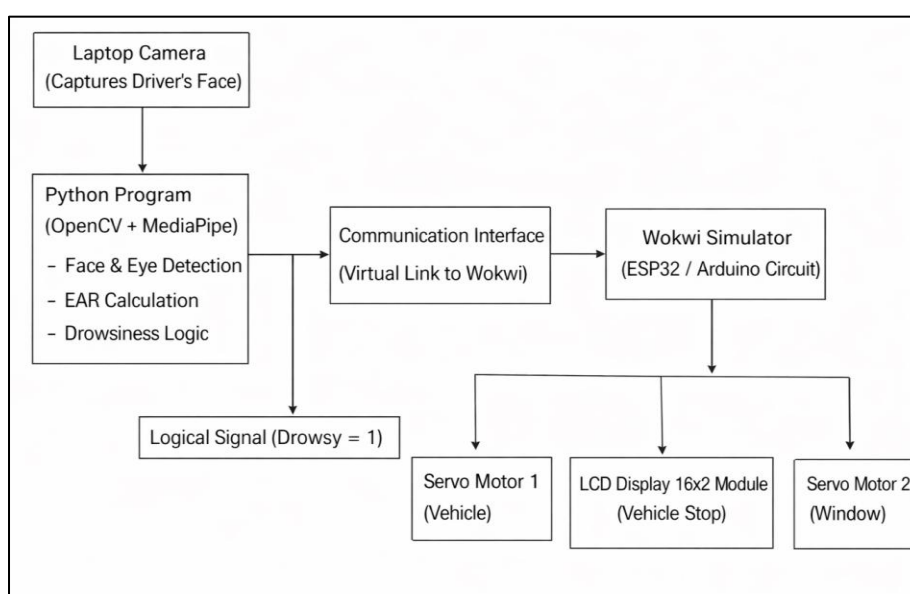


Figure 1. Block Diagram of the Driver Drowsiness Detection System

The proposed system (Fig. 1) consists of a laptop camera, which continuously captures the driver's face in real time. The video frames obtained from the camera are processed by a Python program, where face detection and eye detection are carried out using OpenCV and Media Pipe libraries, respectively. The Eye Aspect Ratio (EAR) is calculated using eye landmarks, and based on the calculated value, it is determined whether the driver's eyes are open or closed. The drowsiness detection logic is used to analyze the Eye Aspect Ratio, and once drowsiness is detected, a logical signal is generated using $Drowsy = 1$. This logical signal is sent using a communication interface, where the Python program is linked to the Wokwi simulator, which represents the ESP32/Arduino circuit. Once drowsiness is detected, several output actions are taken using the simulated microcontroller, such as controlling the Servo Motor 1 for vehicle movement, Servo Motor 2 for window opening, and LCD 16×2 for displaying warning messages such as Vehicle Stop. This proposed system is useful for improving driver safety by detecting drowsiness and thereby taking preventive actions.

In the Eye Aspect Ratio (EAR) equation, p_1 to p_6 are the landmark points identified in the eye region using various facial landmark detection techniques like OpenCV and Media Pipe. In the equation, p_1 to p_6 are the points identified in different positions in the eye region. p_1 and p_4 are the left and right eye corners, whereas p_2 and p_3 are the points identified in the upper eyelid region. Similarly, p_5 and p_6 are identified in the lower eyelid region. The EAR value can be calculated using the vertical distances between eyelid points and dividing it by the horizontal distance between eye corners. This can be used to identify whether the eye is open or closed. If the driver's eye remains closed for a longer time, the vertical distances are reduced, which in turn decreases the EAR value. This can be used to identify driver drowsiness.

$$EAR = \frac{|p_2 - p_6| + |p_3 - p_5|}{2|p_1 - p_4|}$$

- Eyes open → EAR value high ($\approx 0.25-0.30$)
- Eyes closed → EAR value low (≈ 0.15 or less)

If the EAR stays low for many frames, the system detects driver drowsiness.

3.1 Algorithm: Driver Drowsiness Detection Using EAR

Input: Real-time video stream of the driver

Output: Drowsiness detection signal

- Step - 1. Start the system
- Step - 2. Initialize the camera and required libraries (OpenCV, MediaPipe).
- Step - 3. Acquire real-time video frames from the camera.
- Step - 4. Detect the driver's face in each frame.
- Step - 5. Extract eye landmark points $p_1, p_2, p_3, p_4, p_5, p_6$.
- Step - 6. Compute the Eye Aspect Ratio (EAR) using the extracted landmarks.
- Step - 7. Compare the computed EAR value with a predefined threshold.
- Step - 8. If $EAR < \text{threshold}$ for a specified number of consecutive frames:
 - a. Set drowsiness state as TRUE (Drowsy = 1).
 - b. Generate a logical output signal indicating driver fatigue.
 - c. Transmit the signal to the ESP32/Arduino via the communication interface.
- Step - 9. Else:
 - a. Set drowsiness state as FALSE (Drowsy = 0).
- Step - 10. Perform decision-making based on threshold conditions.
- Step - 11. Repeat steps 3–10 for continuous monitoring.
- Step - 12. Stop the system.

3.1.1 Activate System Responses

1. Stop vehicle (Servo Motor 1).
2. Display warning on LCD.
3. Open window (Servo Motor 2).
4. Continue monitoring driver state.
5. Stop the system when program ends.

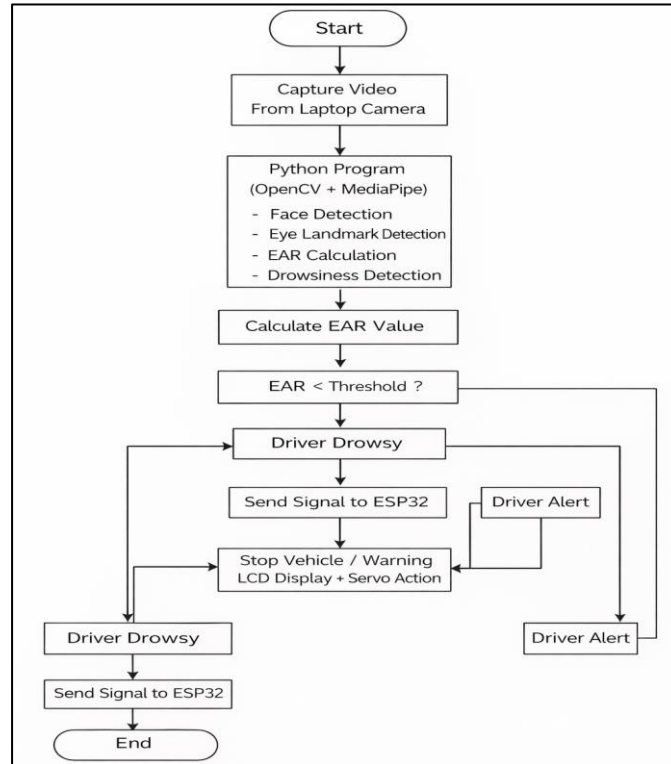


Figure 2. Flowchart for Eye Aspect Ratio (EAR) Based Drowsiness Detection

The following flowchart (Fig. 2) represents a real-time driver drowsiness detection system using computer vision techniques. In the initial state, a video stream is received from a laptop camera using a Python script that runs computer vision algorithms using OpenCV and MediaPipe libraries to detect faces and eye landmarks. The system calculates the Eye Aspect Ratio (EAR) to monitor eye closure levels in real-time. If the EAR value goes below a certain threshold level, it indicates that the driver is drowsy. In response to a drowsy state, a message is sent to an ESP32 microcontroller to trigger alerts or safety measures. If the driver is alert, no response is generated.

4. Results and Discussion

4.1 Experimental Results

The proposed AI-based driver monitoring system was tested under various test scenarios to check the efficiency of the system in recognizing drowsiness and responding accordingly. In normal conditions of driving, the monitoring system was able to correctly recognize the driver as alert and did not send any signals of warning. When the driver closed his eyes for a prolonged time beyond the predetermined time, the system was correctly able

to recognize the driver's fatigue by utilizing the Eye Aspect Ratio (EAR) method. In Fig. 4, the detection of drowsiness by the system can be seen by analyzing the eye behavior of the driver under unsafe conditions of driving.

Once this was done, the system produced a logical control signal, which was then sent to the simulated ESP32 Arduino control module using Wokwi-simulated code. The hardware response is shown in where Servo Motor 1 was used for simulating control of vehicles, Servo Motor 2 was used for simulating window control, and the LCD was used for displaying messages such as Vehicle Stop. The system responded instantly without any delay.

4.2 Simulation Using Python with OPENCV

4.2.1 Normal State

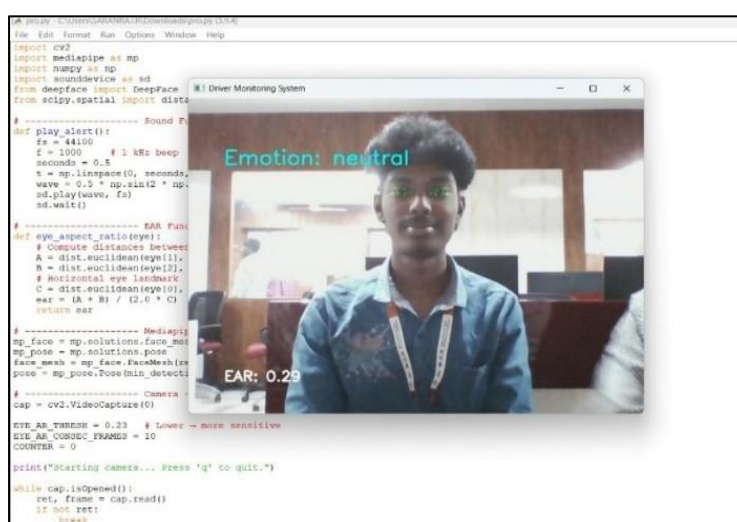


Figure 3. Driver Monitoring System – Normal State

Simulation using Python with OpenCV is defined as the utilization of the Python programming language coupled with the OpenCV library for simulating the image processing and computer vision functions. It allows the real-time processing of images or videos for the detection of objects, monitoring of the driver's behavior, and the road conditions. It is mostly useful for the development of driver monitoring systems, where the facial features of the driver are tracked. In the driver monitoring system, the Eye Aspect Ratio (EAR) is utilized for the detection of drowsiness. When the EAR value is less than 0.29, it indicates that the driver is closing his/her eyes due to drowsiness (Fig. 3). It is useful for the validation of the system without the utilization of physical devices. It is also useful for the improvement of the accuracy of the safety algorithms.

4.2.2 Drowsiness Detected

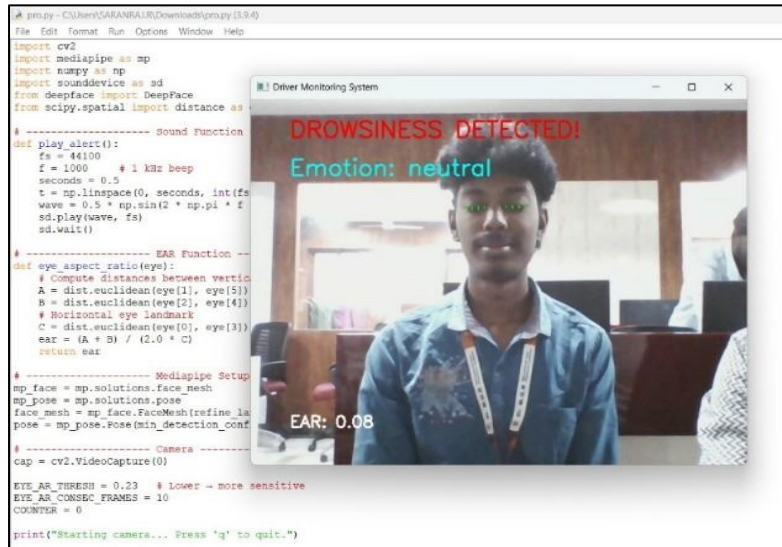


Figure 4. Driver Monitoring System – Drowsiness Detected

The drowsiness detected is a safety feature that monitors the behavior of the driver at all times to detect any signs of drowsiness, as depicted in (Fig. 4.) This feature uses cameras and sensors to monitor the behavior of the driver by detecting eye closure, blinking, and head movement. Once drowsiness is detected, the system alerts the driver through alarm sounds and vibrations to wake them up and prevent any accident caused by drowsiness.

4.2.3 Simulation Using WOKWI

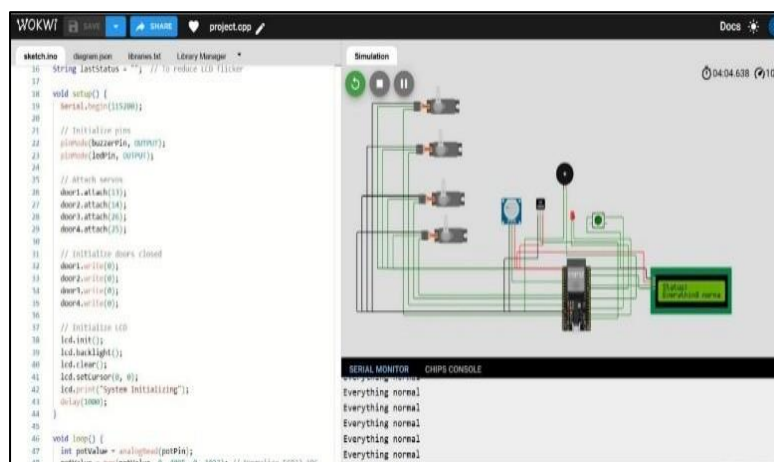


Figure 5. Wokwi Hardware Simulation Output

The above Fig. 5 refers to the outcome of virtual prototyping in the Wokwi environment. This output indicates how the designed components of the embedded system, such as the sensors, microcontrollers, and alerts, interact in real time under virtual conditions.

This simulation validates the functionality of the system in terms of signal processing, response, and communication. This simulation enables designers to identify potential system errors and guarantee reliable system performance before the actual implementation of the system.

4.3 Discussion

The experimental results verify that the proposed system can effectively differentiate between normal and fatigued states of a driver through non-intrusive vision-based detection. The proposed EAR-based detection method has been found to be efficient in detecting eye closure states effectively while avoiding false detection due to natural eye blinks. The smooth interaction between the AI module for monitoring and embedded simulation for control illustrates the potential of the proposed system in performing automatic safety controls. The activation of servo motors and a warning display illustrates the potential of performing preventive controls. Thus, it is possible for the proposed system to be incorporated into future autonomous or semi-autonomous driving systems for continuous driver monitoring in mixed control environments.

5. Conclusion

The proposed AI-based driver health monitoring and emergency response system is effective in tackling the important problem of road accidents caused by driver fatigue and sudden health conditions. By using computer vision techniques and Eye Aspect Ratio (EAR) analysis, it is possible for the system to detect drowsiness in real time, and if the EAR is less than 0.29 for a certain time, it will send preventive measures through its embedded control mechanism in a timely manner. The results of the experiments conducted on this system prove its reliability and accuracy in minimizing road accident risks by taking proactive measures. It is also cost-effective and non-intrusive, making it suitable for integration into smart transportation systems. In future, this system will be made more robust by incorporating more physiological factors like heart rates and head movements, improving its accuracy using more advanced deep learning techniques, and implementing it in real-world vehicular environments using IoT and cloud-based technologies.

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