Drowsiness Detection Using ESP32

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***Abstract*—Driver drowsiness is a critical safety issue globally, contributing significantly to road accidents and fatalities. Traditional detection systems often rely on expensive vehicle-based metrics or unreliable physiological signals. This paper presents a "Smart Drowsiness Detection System" utilizing the ESP32 microcontroller, which integrates both physiological and behavioral monitoring. The system combines an IR eye-blink sensor for real-time eye closure detection and an ESP32-CAM for visual behavioral analysis. Upon detecting fatigue, the system initiates a multi-stage alert mechanism involving an auditory buzzer, a tactile vibration motor, and a GSM-based emergency SMS with live GPS coordinates. This low-cost, wearable solution aims to provide a robust, real-time intervention to prevent accidents caused by driver fatigue.**

Keywords-Driver Drowsiness, ESP32, IoT, Road Safety, Wearable Technology, Real-time Monitoring, GSM/GPS.

I. INTRODUCTION

Road accidents represent one of the most severe safety challenges in the modern world. Globally, more than 1.3 million people lose their lives annually, and nearly 50 million suffer injuries due to traffic crashes. In addition to the loss of human life, these accidents impose a significant financial burden, costing nations approximately 3% of their GDP. In India alone, there are around 4.6 lakh accidents every year, resulting in 1.68 lakh deaths.

A primary factor contributing to these incidents is driver drowsiness, where drivers unknowingly lose focus or fall asleep. Studies have shown that in regions like Uttarakhand, 21% of road accidents were directly attributed to drivers dozing off. Similarly, in Andhra Pradesh, nearly 20% of accidents—accounting for 8,000 deaths annually—are linked to tired drivers. This highlights the urgent need for effective monitoring systems, especially for long-distance travelers and night-shift workers.

Existing solutions often suffer from high costs, bulkiness, or impracticality for daily use. Vehicle-based measures that monitor lane deviation or steering behavior can be unreliable due to external factors like road quality and weather. To address these limitations, this paper proposes a compact, affordable, and wearable drowsiness detection system. By leveraging the multitasking capabilities of the ESP32 microcontroller, the system integrates sensor-based accuracy with visual monitoring to ensure reliability across different driving conditions.

The recent proliferation of the Internet of Things (IoT) and embedded systems offers a transformative opportunity to address these limitations by enabling the creation of compact, affordable, and life-saving devices. This paper proposes a "Smart Drowsiness Detection System" that leverages the ESP32 microcontroller to integrate physiological and behavioral monitoring.

By combining an IR eye-blink sensor with an ESP32-CAM, the system ensures reliability by cross-referencing physiological signals (eye closure) with visual cues (yawning, head tilts).

The proposed solution employs a multi-stage alert mechanism—initiating with auditory warnings, escalating to physical vibration, and culminating in GSM-based emergency location sharing—to ensure immediate intervention and road safety.

II. LITERATURE SURVEY

Various methodologies have been explored to mitigate driver drowsiness, each with distinct advantages and limitations:

- ***Arduino-Based Systems:*** *Previous attempts utilized Arduino Nano with eye-blink sensors. While functional, the low processing power of the Arduino Nano limits its ability to multitask or integrate complex alert mechanisms effectively.*
- ***Heart Signal Processing:*** *Systems using the MAX30102 sensor monitor heart rate variability. However, physiological changes in heart rate are often slow to react, making them less suitable for immediate emergency intervention.*
- ***Vehicle Dynamics:*** *Methods monitoring steering wheel movement or lane deviation are heavily dependent on road infrastructure. Poor road markings or adverse weather can lead to false alarms or missed detection events.*
- ***Steering Wheel Grip Analysis:*** *A study by Li et al. (2020) proposed a method for fatigue detection by measuring the pressure applied to the steering wheel and analyzing it using SVM and CNN models. While innovative, this approach faces significant limitations because grip force varies widely depending on individual driver habits, stress levels, and vehicle ergonomics, often leading to inconsistent detection or false positives.*
- ***Camera-Only Systems:*** *While effective in controlled environments, camera-only solutions are vulnerable to poor lighting conditions, face angles, and obstructions.*

Our proposed system overcomes these issues by combining an IR blink sensor (for speed and night reliability) with an ESP32-CAM (for behavioral analysis), managed by a high-performance ESP32 board.

III. METHODOLOGY

The system is designed as a cohesive IoT solution that prioritizes local intervention before escalating to remote monitoring. The implementation is divided into Hardware Integration, Detection Algorithms, and Remote Communication Protocols.

A. Hardware Integration & Wearable Design

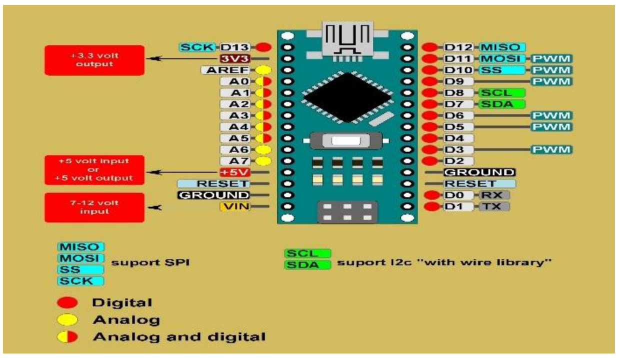
The core control unit is the **ESP32**, selected for its high processing speed (240 MHz dual-core) and built-in Wi-Fi/Bluetooth stack, which is essential for the "Live View" feature.

1. **Wearable Sensing Unit:**
    - The **IR Eye Blink Sensor** is mounted on the frame of the goggles, positioned 15-20mm from the driver's eyelid. It operates on a digital logic level: outputting HIGH when the signal reflects off the closed eyelid and LOW when the eye is open (cornea absorbs IR).
    - The **Vibration Motor** is a coin-type ERM (Eccentric Rotating Mass) motor integrated into the temple of the goggles or a wristband. It is driven via a transistor (NPN 2N2222) switching circuit connected to a GPIO pin on the ESP32.
2. **Central Processing & Monitoring Unit:**
    - **GPS Interface:** The **GPS Neo 6M module** communicates with the ESP32 via UART (Universal Asynchronous Receiver-Transmitter) protocol using a baud rate of 9600. It continually parses NMEA sentences (specifically $GPGGA and $GPRMC) to extract latitude, longitude, and ground speed.
    - **Visual Interface:** The **ESP32-CAM** is utilized specifically for the emergency phase. It is connected in a "Deep Sleep" or standby mode to conserve power until the critical alert threshold is reached.

B. Detection Algorithm and Escalation Logic

The detection logic is implemented using a Finite State Machine (FSM) approach in the Arduino IDE. The system transitions between states based on driver responsiveness.

- **State 1: Continuous Monitoring (Normal Operation)**
    - The system continually polls the IR sensor state every 100ms.
    - An internal timer T_closure starts counting whenever the sensor reads CLOSED.
    - If the eye opens before T_closure > 2000ms, the timer resets, and the system remains in the



Normal state.

- **State 2: Auditory Warning (Level 1 Alert)**
    - **Trigger:** If T_closure > 2000ms (2 seconds).
    - **Action:** The Active Buzzer is toggled at a frequency of 10Hz to create a jarring alarm.
    - **Exit Condition:** If the driver opens their eyes immediately, the buzzer stops, and the system resets to State 1.
- **State 3: Haptic Feedback (Level 2 Alert)**
    - **Trigger:** If the driver remains unresponsive (eyes closed) for T_closure > 4000ms (4 seconds) despite the buzzer.
    - **Action:** The Vibration Motor is activated in a pulsing pattern (500ms ON, 500ms OFF). This physical stimulus addresses cases where the driver is auditory-desensitized or wearing noise-canceling headphones.
- **State 4: Critical Emergency (Remote Live View)**
    - **Trigger:** If T_closure > 7000ms (7 seconds).
    - **Action:** The system assumes the driver is incapacitated.

1. **GPS Lock:** The last valid NMEA string is captured to fix the vehicle's location.
2. **Web Server Initiation:** The ESP32-CAM initializes a local Web Server on port 80.
3. **Streaming:** It begins capturing MJPEG video frames and serving them to a static IP address.
4. **Notification:** The system logs the event and makes the IP address available for remote access by fleet managers.

C. Software Implementation & Optimization

To ensure real-time performance, the software utilizes **FreeRTOS** (Real-Time Operating System) capabilities inherent to the ESP32.

- **Task 1 (Core 0):** Dedicated to heavy network tasks, such as maintaining the Wi-Fi connection and handling the HTTP video stream server.
- **Task 2 (Core 1):** Dedicated to time-sensitive sensor polling (IR sensor) and managing the alert IO (Buzzer/Motor). This separation ensures that the video streaming lag does not delay the critical eye-blink detection logic.

D. Remote Live Monitoring Interface

The "Live View" is accessed via a simple HTML interface hosted on the ESP32. When the emergency state is triggered:

1. The authorized external user enters the ESP32's IP address into a browser.
2. The dashboard displays the **Live Video Feed** on the left.
3. On the right, it displays a **Google Maps embedded link** generated using the coordinates from the GPS Neo 6M (e.g., maps.google.com/?q=LAT,LON).

IV. SYSTEM ARCHITECTURE

The proposed system architecture is centered around the **ESP32 microcontroller**, selected due to its integrated Wi-Fi connectivity, dual-core processing capability, low power consumption, and compatibility with multiple peripheral interfaces. The system is divided into **three major subsystems**, each functioning collaboratively to detect drowsiness, generate alerts, and provide remote monitoring for safety management.

A. Wearable Detection Unit

This subsystem incorporates an **Infrared (IR) Eye Blink Sensor**, which is integrated into a lightweight pair of goggles worn by the user. The sensor continuously monitors eyelid movement by detecting eye blink durations. When the eyelid remains closed beyond a predefined threshold, the system interprets it as a sign of drowsiness. The processed sensor data is transmitted to the ESP32 for real-time analysis. The wearable design ensures constant monitoring without obstructing the user's field of view, enabling comfortable long-duration usage.

B. Alert Unit

The alert subsystem is responsible for providing immediate corrective feedback to the user upon detection of drowsiness. It consists of a **5V Active Buzzer** and a **miniature vibration motor** mounted near the ear or embedded in the wearable frame. When abnormal blinking patterns are detected, the subsystem is activated to generate an audible alarm and a tactile vibration stimulus. This dual-mode feedback mechanism increases the probability of user response even in noisy environments or during high fatigue, thereby preventing potential hazards.

C. Remote Monitoring Unit

The remote monitoring subsystem enhances safety by enabling real-time location and visual supervision. It integrates a **GPS Neo-6M module**, which continuously tracks the geographical coordinates of the user and transmits the data via Wi-Fi to a cloud dashboard or a remote mobile application. Additionally, an **ESP32-CAM module** is deployed for live video streaming to enable remote observation or recording of the user's condition. The combination of location tracking and video feedback allows supervisors or emergency response teams to monitor driver status and take timely action in case of critical events.

IV. CHALLENGES AND FUTURE DIRECTIONS

While the proposed "Smart Anti-Drowsiness System" demonstrates a functional and effective prototype for accident prevention, several challenges remain for large-scale deployment. Addressing these will be the focus of future research and development.

A. Technical and Operational Challenges

- **Ergonomics and User Compliance:** The current design requires the driver to wear specific goggles equipped with sensors. Long-duration usage may cause discomfort or fatigue around the eyes and nose bridge. Furthermore, drivers who already wear prescription glasses may find it difficult to wear the device simultaneously.
- **Ambient Light Interference:** Although the IR sensor is shielded by the goggle frame, extreme lighting conditions—such as direct sunlight hitting the sensor at specific angles—can potentially saturate the IR receiver, leading to false negatives (failing to detect eye closure).
- **Connectivity Dependencies:** The "Remote Live View" feature using the ESP32-CAM relies on a Wi-Fi connection. In a real-world driving scenario, the system depends on an in-vehicle mobile hotspot. If the vehicle travels through areas with poor cellular network coverage, the live video stream may suffer from high latency or connection loss, delaying the remote monitoring capability.

B. Future Scope

To overcome these limitations and enhance system capabilities, future iterations of the project will focus on the following areas:

- **Integration of Edge AI (TinyML):** Implementing lightweight machine learning models (using TensorFlow Lite for Microcontrollers) directly on the ESP32. This would allow the system to analyze complex facial expressions—such as micro-expressions of pain or stress—rather than relying solely on simple eye-closure timing.
- **Vehicle Interface (OBD-II Integration):** Future designs aim to interface the system with the vehicle's On-Board Diagnostics (OBD-II) port. This would allow the system to actively intervene by gradually reducing the vehicle's speed or activating the hazard lights automatically when the "Critical Emergency" state is confirmed.
- **Vital Sign Monitoring:** Integrating Pulse Oximetry (MAX30100 sensor) into the goggle frame to monitor Heart Rate and SpO2 levels. Sudden drops in heart rate variability (HRV) can serve as a precursor to drowsiness, allowing for predictive alerts before the driver actually closes their eyes.
- **Standalone Connectivity:** Replacing the Wi-Fi dependency with a 4G/LTE IoT module (such as the SIM7600). This would allow the device to transmit video and GPS data independently of a mobile hotspot, ensuring wider coverage and reliability on highways.

V. EXPECTED OUTPUT

The system is designed to function as a reliable "life-saving companion" for drivers.

- **Real-Time Detection:** The integration of IR and camera inputs allows for accurate detection of drowsiness even in low-light conditions (e.g., night driving).
- **Alert Efficacy:** The combination of loud sound and strong vibration makes it difficult for a driver to ignore the warning.
- **Emergency Response:** The automated SMS feature ensures that family members or fleet managers can immediately locate the vehicle via Google Maps if the driver is incapacitated.

VI. CONCLUSION

The Smart Drowsiness Detection System with ESP32 successfully addresses the growing need for an affordable, accurate, and real-time driver safety solution. By combining physiological monitoring through an IR eye-blink sensor with behavioral analysis using the ESP32-CAM, the system overcomes the limitations of single-sensor approaches. This multimodal strategy significantly enhances detection reliability across different environments and user conditions. The ESP32 microcontroller efficiently manages sensor data, decision-making, and alert mechanisms, ensuring fast and consistent performance during continuous monitoring.

The incorporation of a multi-stage alert system—buzzer, vibration motor, and with GPS location—adds an essential layer of safety by escalating responses based on driver inactivity. This not only helps prevent accidents but also enables external assistance during critical situations. Compact, wearable, and cost-effective, the system demonstrates the practical application of IoT and embedded design principles in improving road safety. Overall, the project highlights a promising direction for future intelligent transportation and driver-assistance technologies.

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