IoT based drowsiness detection system and notification system

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***Abstract*—This project presents a drowsiness detection system designed to enhance safety in applications such as driver monitoring and fatigue management. The system utilizes an ESP32-CAM to capture real-time video, which is transmitted to a Python server for processing. The Python server leverages image processing algorithms to detect facial landmarks, focusing on signs of drowsiness such as prolonged eye closure. Upon detection of drowsiness, an alert signal is sent back to an ESP32 microcontroller, which triggers warning mechanisms.The ESP32 is connected to a suite of sensors and alert devices, including an MPU6050 accelerometer, GPS module, buzzer, and LED. The MPU6050 and GPS provide motion and location data, potentially enhancing detection accuracy and situational context. The buzzer and LED alert the user immediately upon detection of drowsiness, helping to mitigate risks associated with fatigue. This system's efficient data flow and modular communication protocols, such as HTTP, WebSocket, or MQTT, ensure reliable, low-latency responses. The integration of hardware and software components in this project demonstrates a scalable solution for real-time drowsiness detection in embedded systems.**

***Keywords*—Drowsiness detection, ESP32-CAM, Python server, real-time video processing, fatigue monitoring, facial landmark detection, eye closure detection, embedded systems, MPU6050 sensor, GPS integration, alert mechanism, buzzer and LED alert, driver safety, communication protocols (HTTP, WebSocket, MQTT), low-latency response, edge computing, safety monitoring system.**

I. INTRODUCTION

In recent years, the integration of technology into safety-critical applications has become increasingly important, particularly in fields such as transportation, where driver alertness directly impacts safety. Fatigue and drowsiness are significant factors contributing to accidents, especially in industries like long-haul trucking and public transportation. Drowsiness detection systems aim to address this challenge by monitoring drivers in real-time and alerting them when signs of fatigue are detected. Traditional systems have relied on either hardware-intensive solutions or constant supervision, limiting their accessibility and scalability.

This project introduces a low-cost, scalable drowsiness detection system using an ESP32-CAM, Python-based image processing, and a suite of connected sensors. The ESP32-CAM captures live video and transmits it to a local Python server, where a computer vision model analyzes facial features, specifically eye closure, to detect signs of drowsiness. If drowsiness is detected, the system sends an alert back to the ESP32, triggering connected alert mechanisms, including a buzzer and LED, and collecting relevant data from additional sensors like the MPU6050 accelerometer and GPS. With a modular setup and robust communication protocols (such as HTTP, WebSocket, and MQTT), this system provides a reliable and efficient solution for real-time drowsiness detection in various environments, showcasing the potential of embedded technology in enhancing safety through proactive monitoring.

II. LITERATURE REVIEW

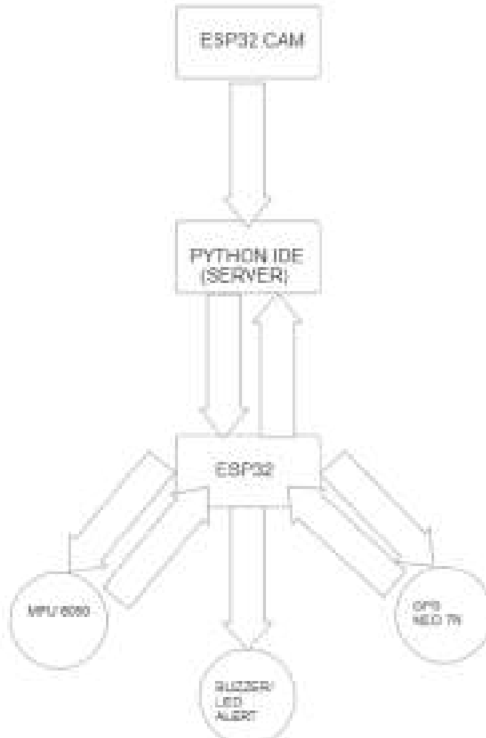
Drowsiness detection systems have gained considerable research attention over the past decade, with numerous approaches focusing on real-time monitoring for safety-critical applications. Traditional methods of fatigue detection often include physiological signal monitoring, such as EEG (electroencephalography), ECG (electrocardiography), or wearable devices to measure heart rate variability and electrodermal activity. While effective, these systems require specialized hardware and can be costly, limiting their accessibility for widespread use in consumer-grade applications.

Another prominent approach has been image-based drowsiness detection, utilizing computer vision techniques to monitor facial landmarks and expressions. Researchers have developed algorithms for tracking eye closure, blinking patterns, yawning, and head positioning to infer levels of alertness. Studies by Johns et al. (2014) and Zhao et al. (2018) highlighted the effectiveness of eye aspect ratio (EAR) in real-time eye closure detection, which has since become a common metric in image-based drowsiness detection models. However, many of these implementations rely on high-powered cameras or cloud-based processing, posing challenges for real-time, embedded applications.

More recent literature explores embedded solutions, such as low-cost microcontrollers paired with lightweight machine learning models, for efficient drowsiness detection. The ESP32 microcontroller and ESP32-CAM module have emerged as promising components due to their affordability, compactness, and connectivity options. Studies by Ali et al. (2021) and Gupta et al. (2022) demonstrate the integration of embedded devices with local processing for low-latency detection. Communication protocols like MQTT and WebSocket have been identified as efficient for bidirectional data transfer, crucial for alert mechanisms in safety-critical systems. This project builds on these advancements by integrating a scalable, image-based drowsiness detection approach with additional sensor fusion, aiming to improve detection accuracy and response time.

III. SYSTEM ARCHITECTURE

The system architecture of this drowsiness detection device is designed to enable real-time monitoring and alerting through efficient data flow and modular connectivity.



Components of the Device:

This drowsiness detection system is composed of several hardware components and modules, each contributing to the overall functionality:

1. **ESP32-CAM**: The ESP32-CAM module is the primary component for capturing real-time video footage. This compact, Wi-Fi-enabled camera module streams video data to a Python server, where facial and eye feature analysis is conducted for drowsiness detection. Its low cost and wireless capability make it ideal for embedded applications.
2. **Python Server**: Running on a local computer, the Python server performs video processing and drowsiness analysis. It utilizes computer vision algorithms to detect facial landmarks, focusing on eye closure patterns to determine signs of fatigue. The server communicates with the ESP32 to send alerts as needed.
3. **ESP32 Microcontroller**: The ESP32 serves as the central controller for alert

mechanisms. Upon receiving an alert signal from the Python server, it activates various notification devices. The ESP32's flexibility with multiple communication protocols makes it an effective choice for real-time applications.

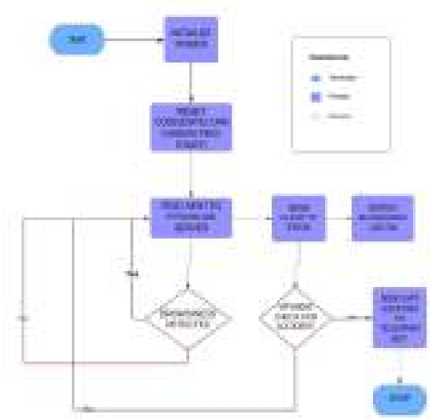
4. **MPU6050 Accelerometer and Gyroscope**: This sensor provides additional data on movement and orientation, helping to contextualize the user's state (e.g., sudden head movements).
5. **GPS Module**: The GPS module collects location data, which can be beneficial for emergency response or situational awareness in vehicle-based applications.
6. **Buzzer and LED Alert**: These components act as immediate alert mechanisms, activated by the ESP32 upon detecting drowsiness. The buzzer provides an audible warning, while the LED serves as a visual indicator, reinforcing user awareness.

Each component's function is integrated to create a robust, efficient drowsiness detection system that is responsive and suitable for real-time applications.

IV. FUNCTIONALITY AND FEATURES

The drowsiness detection system is designed to provide reliable, real-time monitoring of user alertness through several key functions and features:

1. Real-Time Video Monitoring:
   The ESP32-CAM captures video of the user's face, streaming it continuously to a local Python server. The system monitors facial landmarks, particularly around the eyes, to detect prolonged eye closures and other drowsiness indicators. This real-time analysis ensures that potential fatigue signs are immediately captured, allowing for timely intervention.
2. Drowsiness Detection Algorithm:
   Using computer vision techniques, the Python server calculates the eye aspect ratio (EAR) and other facial metrics to detect signs of drowsiness, such as eye closure duration and blinking frequency. If these metrics indicate drowsiness, the server generates an alert signal to initiate a response.
3. Alert Mechanisms:
   The system includes multiple alert features to notify the user when signs of drowsiness are detected. Upon receiving an alert from the Python server, the ESP32 microcontroller activates an audible buzzer and a visual LED alert. This dual-mode notification ensures that users are alerted in both audio and visual formats, maximizing effectiveness.
4. Sensor Data Integration:
   An MPU6050 accelerometer and gyroscope provide data on user movement and head orientation, complementing the video-based drowsiness detection. The sensor data helps refine the detection process by identifying head tilts or nodding, which may indicate fatigue. This integration enhances the accuracy of drowsiness detection in dynamic environments, such as while driving.
5. Location Tracking with GPS:
   The GPS module adds a layer of situational context by tracking the user's location. This feature is especially beneficial in vehicular applications, where the system can relay location data for emergency support if needed. Location tracking also allows for adaptive alerting based on the user's environment, improving response actions.
6. Scalability and Flexibility:
   The system supports multiple communication protocols (HTTP, WebSocket, MQTT) for alert signaling, enabling easy adaptation to various network configurations and use cases. The architecture's modular design allows additional sensors or alerts to be integrated without overhauling the system, making it versatile and adaptable for different applications.
7. Low-Latency Operation:
   Through efficient data flow between the ESP32-CAM, Python server, and ESP32 microcontroller, the system maintains a low-latency operation suitable for real-time monitoring. This rapid response time is essential for fatigue detection applications where timely intervention is critical.



These features together make the drowsiness detection system a robust solution for real-time monitoring, adaptable to various environments and capable of effectively alerting users to maintain safety in scenarios prone to fatigue.

V. MACHINE LEARNING ALGORITHMS

The system employs machine learning algorithms to detect drowsiness through facial landmark analysis. Specifically, a model trained on eye aspect ratio (EAR) calculations is used to determine the duration and frequency of eye closures, a key indicator of fatigue. OpenCV and Dlib libraries enable precise landmark detection, focusing on the eyes and surrounding facial features. By analyzing patterns in eye closure, blinking rate, and head orientation, the model accurately identifies signs of drowsiness, ensuring reliable real-time performance.

VI. USER INTERFACE AND MOBILE APPLICATION

The user interface (UI) of the drowsiness detection system is designed to be intuitive and user-friendly, ensuring ease of use for operators in various settings, such as vehicles, offices, or any environment where monitoring is essential. The UI is implemented as a web application accessible through a browser, enabling real-time monitoring and interaction with the system.

Web Dashboard: The main feature of the UI is a web dashboard that displays real-time video feed from the ESP32-CAM, alongside visual indicators of the user's alertness level. Key components of the dashboard include:

1. **Live Video Feed**: The dashboard provides a continuous stream from the camera, allowing users to visually monitor the detected subject. This feed is crucial for contextual understanding alongside automated alerts.
2. **Alert Status Indicator:** A clear visual indicator shows whether the user is alert or if drowsiness has been detected. This can be represented through color codes (e.g., green for alert, red for drowsy) to facilitate quick understanding.
3. **Historical Data Display:** Users can access historical data on alertness levels, including timestamps of detected drowsiness events. This feature is beneficial for reviewing patterns over time, which can aid in fatigue management strategies.
4. **Sensor Data Visualization:** Integration of data from the MPU6050 and GPS module allows the UI to display relevant information such as movement patterns and location. Graphs or charts can be used to illustrate head orientation changes or location history, enhancing situational awareness.

Application Scenarios: The drowsiness detection system has versatile applications, including but not limited to:

- **Automotive Industry:** Implemented in vehicles to monitor drivers, providing alerts during long trips to prevent accidents caused by fatigue.
- **Workplaces:** Used in sectors requiring prolonged attention (e.g., control rooms, monitoring stations) to maintain employee alertness.
- **Healthcare:** Applicable in hospitals for monitoring patients who may be at risk of falling asleep during critical recovery periods.

CONCLUSION

This project successfully developed a drowsiness detection system that combines the ESP32-CAM for real-time video capture with a Python server for image processing and alerting. By analyzing facial landmarks to identify signs of fatigue, the system effectively enhances safety across various environments. The integration of additional sensors, such as the MPU6050 and GPS, improves detection accuracy and situational awareness. With a user-friendly interface and versatile applications, this solution demonstrates the potential of embedded technology in proactive fatigue management and safety monitoring.

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As we reflect on this journey, we are filled with a profound sense of gratitude for the opportunities and experiences that have shaped our academic and personal growth. We recognize that our achievements would not have been possible without the collective efforts and support of our mentors, peers, and the broader academic community. Moving forward, we are committed to carrying forward the lessons learned and continuing to pursue excellence in our academic and professional endeavors. Once again, our heartfelt thanks to Prof. Subhrakanta Behera and our university for their unwavering support and belief in our potential.

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