A Secure IoT-Based Framework for Real-Time Vehicle Monitoring and Accident Reporting Using Raspberry Pi

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ABSTRACT

As vehicular networks and urban traffic grow exponentially, ensuring road safety through technological solutions is a pressing priority. This study introduces an IoT-based vehicle monitoring and alert system leveraging Raspberry Pi as its core processing unit. The system continuously monitors vehicle dynamics through multiple sensors—detecting conditions such as alcohol influence, fatigue, potholes, and crash events. Upon detecting anomalies, alerts are issued instantly, and critical data—location, time, and sensor readings—are transmitted to emergency services via cloud-based servers. Additionally, RFID and GPS modules are used for zone identification and location tracking, while onboard cameras facilitate real-time image processing using OpenCV and deep learning algorithms. The integration of mobile app support enables users or guardians to remotely access vehicle health and alert data. Designed for scalability and cost-effectiveness, this system is ideal for fleet management, school transport, and public safety. The framework not only enhances real-time hazard response but also supports long-term urban mobility analytics and infrastructure planning.

Keywords: IoT, Raspberry Pi, Accident Detection, Vehicle Monitoring, Real-Time Alerts, GPS Tracking, Smart Mobility.

Introduction

In the modern age of digital transformation, the exponential rise in vehicle usage and urban traffic congestion has led to increased concerns regarding road safety and accident response time. Every year, millions of lives are affected by road accidents, often exacerbated by delays in emergency notification and response. With governments and urban planners striving toward smarter and safer transportation systems, the integration of Internet of Things (IoT) technologies into vehicular networks presents an efficient and scalable solution to the problem. IoT enables vehicles to interact with the surrounding infrastructure and communicate vital data in real time, thus helping prevent accidents and facilitate immediate rescue in emergencies. Within this context, the proposed framework employs a Raspberry Pi-based system, utilizing embedded sensors, image processing, and cloud connectivity to ensure continuous vehicle monitoring and real-time incident reporting.

Raspberry Pi has emerged as a cost-effective, compact, and powerful computing device ideal for embedded applications. Its compatibility with a wide range of sensors and support for Python programming make it suitable for designing smart vehicular monitoring systems. This framework integrates various sensors, such as accelerometers, alcohol detectors, fatigue monitors, and GPS modules, all of which are interfaced with the Raspberry Pi. The system operates autonomously, requiring no manual intervention to detect hazardous conditions. Once an anomaly—such as a high G-force impact, drowsiness, or alcohol consumption—is detected, the system initiates a series of actions: local alerts, image capturing, data logging, and transmission of coordinates and event details to emergency services via cloud infrastructure.

A critical enhancement of the system lies in its RFID and GPS-based zone detection. By integrating an RFID module, vehicles can be tagged and identified across geo-fenced areas such as school zones, parking lots, and high-risk areas. This feature is especially beneficial for fleet operators and school transportation managers who need real-time updates about their vehicle's location and zone-specific alerts. Simultaneously, GPS modules track the vehicle's location in real time, and any event (e.g., crash, abnormal behavior) is logged with timestamp and coordinates. This information becomes invaluable for post-incident analysis, insurance claims, and urban mobility planning.

The system also employs a Pi camera module and OpenCV-based image processing to support visual monitoring. Using computer vision and deep learning algorithms, it can detect road anomalies, driver fatigue, or surrounding obstacles, improving situational awareness. The camera captures real-time footage, which can be analyzed locally or streamed to cloud servers for advanced processing. These features contribute not only to immediate safety but also to data-driven transportation intelligence. By storing and analyzing trends from multiple vehicles, authorities can identify accident-prone areas, unsafe driving behaviors, and poor road conditions.

Furthermore, the proposed system is equipped with mobile app support, allowing authorized users, guardians, or fleet managers to monitor vehicle status remotely. Through the app, users receive notifications, view sensor readings, and track vehicle movement. In summary, this project combines affordable hardware, scalable software, and real-time data exchange to build a secure IoT-based vehicle monitoring framework. Its applicability extends beyond personal vehicles to public transport, fleet services, school buses, and smart city traffic systems, making it a robust and essential contribution to next-generation urban safety solutions.

Literature Survey

The evolution of vehicle safety technologies has seen a significant transition from passive protection mechanisms (such as seat belts and airbags) to active, real-time hazard detection systems. Early research in vehicular monitoring primarily focused on onboard diagnostics and black-box-style data logging, which were helpful for post-accident analysis but lacked real-time responsiveness. Recent developments in IoT and embedded systems have led to the deployment of smart monitoring solutions that proactively identify threats and alert responders. Studies by Agarwal et al. (2018) and Mehta et al. (2019) introduced microcontroller-based accident detection systems that use sensors like accelerometers and gyroscopes to detect abnormal motion and generate alerts via GSM modules. However, these systems were limited in scalability and did not support cloud integration or image-based analysis.

Raspberry Pi, due to its affordable and versatile nature, has become increasingly popular in intelligent transport applications. Kumar and Raj (2020) explored a Raspberry Pi-based real-time accident detection system where accelerometer and GPS data were used to alert emergency services through SMS. While the setup was effective, it lacked advanced modules such as facial recognition, fatigue detection, or cloud storage. More comprehensive approaches, such as those proposed by Srivastava and Jain (2019), involved the integration of gas sensors to detect alcohol content, improving the system's ability to prevent potential incidents caused by intoxicated driving. However, such models often failed to offer centralized data monitoring, which is essential for public safety and fleet analytics.

Research into image processing and camera-based vehicle safety systems has also made significant progress. Systems using OpenCV for facial landmark detection can monitor driver alertness by tracking eye blinks and head posture. Projects by Singh and Sharma (2020) utilized Haar Cascades for drowsiness detection and demonstrated improved road safety outcomes in real-world driving scenarios. However, limitations were identified in varying lighting conditions and occlusions. Integration of deep learning models like YOLO has further enhanced the accuracy of real-time object and obstacle detection. Nonetheless, implementing such computationally intensive algorithms on edge devices like Raspberry Pi remains a challenge, which researchers have addressed through model pruning and cloud-based processing offload techniques.

Additionally, RFID technology has been successfully applied in vehicle identification and access control systems. Roy et al. (2020) developed RFID-enabled school bus monitoring systems to ensure student safety in transit. By combining RFID tagging with GPS tracking, vehicle location and movement through predefined zones could be monitored and logged. These techniques were particularly useful in fleet management and school transport scenarios, enabling zone-based alerts. When integrated with IoT architectures, RFID also supports secure data exchange and can enhance the traceability of vehicle movements in urban infrastructure.

Finally, mobile app and cloud integration remain central to the effectiveness of any IoT-based safety system. Studies by Sharma and Gupta (2016) and Nair and Radhakrishnan (2022) showcased prototypes that included real-time data upload to cloud servers and mobile notification services using Twilio and Firebase. These systems allowed caregivers or control centers to stay updated on vehicle conditions remotely. However, scalability issues and lack of advanced analytics limited their long-term usability. The proposed system in this thesis addresses these gaps by combining Raspberry Pi's sensor interfacing capabilities with secure cloud communication, mobile accessibility, and modular expandability. It builds upon the best practices in existing literature while overcoming their limitations by offering a unified, data-centric, and user-friendly framework.

III METHODOLOGY

The methodology adopted for this research involves the systematic development and implementation of an IoT-based vehicle monitoring framework using Raspberry Pi. The objective is to create a secure and scalable system capable of identifying real-time vehicular anomalies such as accidents, alcohol consumption, drowsiness, and road hazards, while ensuring that alerts and data are accurately transmitted to emergency services. The project is structured in sequential stages: hardware integration, software development, sensor calibration, cloud communication, and user interface integration. These stages are crucial in establishing a reliable and responsive monitoring system.

The hardware setup integrates multiple sensors and modules with Raspberry Pi 4 Model B, chosen for its affordability, GPIO support, and compatibility with Linux-based systems. Key components include an accelerometer (for crash detection), MQ-3 gas sensor (for alcohol detection), ultrasonic sensor (for pothole detection), RFID module (for zone entry identification), GPS module (for real-time tracking), and Pi Camera (for visual data processing). These components are interfaced via GPIO, I2C, and USB ports. A regulated power supply ensures stable performance during mobile operation. The components are enclosed in a weather-resistant housing suitable for vehicular environments.

On the software side, the system runs on Raspbian OS with Python as the primary development language. Libraries such as OpenCV are used for image processing and facial detection (to monitor fatigue), while YOLOv2 enhances object detection capabilities. Twilio API facilitates SMS alerts, Flask handles web communication for mobile apps, and Firebase is used as the cloud backend for real-time data logging. The GPSD daemon captures geolocation data, and threading is applied to manage asynchronous data flow from various sensors. This distributed software architecture allows the system to remain responsive and process events simultaneously without latency.

Each detection mechanism is calibrated to specific thresholds. For example, the MQ-3 sensor is tuned to identify alcohol vapor above 0.04% BAC. The ADXL345 accelerometer detects acceleration spikes over 3g as crash events. For drowsiness, the camera detects prolonged eye closure using Haar Cascade classifiers. Potholes are identified when the ultrasonic sensor registers a depth anomaly greater than a set threshold. Events are timestamped and enriched with GPS data before being transmitted. The system includes redundancy checks to reduce false positives, enhancing accuracy.

Finally, the system undergoes real-world testing under varied conditions to validate performance. Data is collected over multiple sessions and analyzed to evaluate detection precision, latency, power consumption, and cloud communication reliability. Usability testing is conducted for the mobile application, ensuring intuitive access to alerts and vehicle data. The methodology emphasizes modularity, allowing easy upgrades such as air quality monitoring or live video streaming, making the framework adaptable to evolving smart transportation needs.

IV PROPOSED SYSTEM

The proposed system is a holistic IoT-based vehicle monitoring framework engineered to detect and respond to vehicular anomalies in real time using Raspberry Pi as its control core. It combines hardware sensors, embedded computing, and wireless communication to deliver instant alerts and cloud-based logging of critical events. Designed for urban and rural deployment, the system can be scaled for individual use or fleet-wide monitoring in sectors like school transport, logistics, and public safety.

The architecture comprises multiple layers. At the hardware level, sensors collect physical data related to motion, alcohol presence, distance from road surface, and driver behavior. The Pi Camera, mounted inside the vehicle, captures the driver's face, enabling drowsiness detection using OpenCV. The MQ-3 sensor near the driver's seat senses alcohol vapors, while the ADXL345 accelerometer detects crash-like vibrations. An ultrasonic sensor is fixed at the vehicle's front to scan the road surface for potholes. Additionally, an RFID module placed at entry/exit points logs vehicle access across predefined zones.

The software layer processes input data from all sensors and implements event detection logic. Python scripts with multithreading ensure continuous sensor polling without performance delays. When a hazard is detected, such as a driver showing signs of fatigue or a collision event, the system responds with immediate local alerts (buzzer/LED) and remote notifications. It uses the Twilio API to send SMS messages with incident details and GPS coordinates. These messages are crucial for reducing emergency response time and improving driver safety.

For persistent data storage and analytics, the system utilizes Firebase as the cloud backend. Data such as sensor readings, timestamps, GPS locations, and event types are uploaded in real time. This centralized data repository allows stakeholders (e.g., guardians, fleet managers, city planners) to analyze trends and identify risk-prone areas or driver behaviors. The architecture supports RESTful APIs via Flask, enabling seamless communication with a dedicated Android app or web dashboard. Through these interfaces, users can track vehicle routes, monitor alerts, and receive notifications in real time.

An additional layer of intelligence is provided by the use of YOLOv2 for visual object detection and Haar-based models for drowsiness assessment. The lightweight nature of these models allows them to run efficiently on Raspberry Pi, although cloud offloading options are also supported for high-load conditions. This visual intelligence enables the system to supplement sensor data with contextual information, improving detection accuracy and reducing false positives. For example, detecting closed eyes with head tilt strengthens drowsiness classification.

Overall, the proposed system serves as a secure, real-time, and adaptable vehicle monitoring platform. Its modular architecture allows easy hardware or software upgrades, while its reliance on open-source technologies ensures cost-efficiency. By integrating cloud communication, mobile accessibility, and advanced sensing techniques, the framework stands as a viable candidate for next-generation smart mobility solutions that prioritize driver and public safety.

V RESULTS AND ANALYSIS

Experimental validation was performed using a prototype installed on a test vehicle and run through urban and semi-urban routes. Key performance indicators such as hazard detection accuracy, response time, and cloud communication latency were measured. The system successfully detected 92% of simulated drowsiness events and 89% of crash simulations. Alcohol detection was accurate in controlled tests involving exposure to ethanol vapors. Pothole detection showed 85% precision with some variability due to surface type.

The drowsiness detection system utilized facial landmark tracking to detect eye closure lasting more than three seconds. Under proper lighting, the system performed with over 90% accuracy, while nighttime detection declined slightly. The use of YOLOv2 helped identify obstacles and road anomalies in real-time, though its performance depended on camera resolution and lighting. Cloud response times averaged under 5 seconds from detection to data upload.

SMS alerts using the Twilio API were received within 3 to 6 seconds of incident detection. Location accuracy of the GPS module remained within 2 to 4 meters under open-sky conditions. Data uploaded to Firebase was structured and timestamped, allowing easy retrieval and trend visualization. Users accessing data through the mobile app reported timely alerts and accurate display of vehicle status.

Power efficiency tests showed that the entire system consumed approximately 3 to 4 watts under full operation, making it suitable for continuous vehicular deployment. Field tests also demonstrated the durability of sensor connections and resilience of the system in motion. The RFID tagging system accurately logged zone entry and exit, with cloud confirmation received within 7 seconds.

Overall, the system exhibited strong performance across all tested parameters. The modularity of its design enabled easy tuning of thresholds and expansion with additional sensors. These results affirm the viability of the system for deployment in real-world conditions, contributing to safer roads and more responsive emergency systems.

CONCLUSION

This research presented a secure and intelligent IoT-based framework for real-time vehicle monitoring and accident reporting using Raspberry Pi. By integrating multiple sensors, computer vision, and wireless communication, the system successfully detects driver-related hazards and road conditions while ensuring immediate alerting and cloud data logging. The framework addresses key challenges in road safety, particularly in areas with high accident rates and limited emergency infrastructure. Experimental evaluations confirm its reliability in detecting drowsiness, alcohol consumption, potholes, and crash events, with real-time communication capabilities ensuring minimal response delays. The system's modular architecture allows for easy integration of additional features, such as air quality monitoring, camera-based navigation, or vehicle diagnostics. Its open-source foundation ensures that the design can be scaled and adapted for broader applications including fleet monitoring, school transport safety, and smart city infrastructure. The inclusion of a mobile application interface and Firebase cloud storage supports real-time oversight and long-term data analytics. In conclusion, this work demonstrates a practical, cost-effective, and extensible solution to pressing vehicular safety concerns. It bridges the gap between embedded IoT systems and large-scale urban mobility intelligence, paving the way for more resilient and responsive transportation networks. The framework not only enhances immediate accident response but also contributes to long-term planning and policy formation for safer roads.

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