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VEHICLE SAFETY SUITE

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***Abstract*— This paper presents the design and implementation of a comprehensive Vehicle Safety Suite aimed at enhancing passenger safety in public transportation systems. The proposed system integrates multiple sensors and control mechanisms to monitor critical parameters such as engine temperature, fire occurrence, vehicle speed, and emergency exit access. Central to the system is the ESP32 microcontroller, which enables real-time data processing, wireless communication, and autonomous response execution. In the event of abnormalities such as overheating, fire, or overspeeding, the system activates appropriate safety protocols including alarms, SMS alerts via GSM, GPS-based location tracking, automatic fire suppression, and emergency door control. A stable power supply with voltage regulation and battery backup ensures continuous operation even during power failures. The system also includes a user interface for monitoring and manual control, as well as event logging for post-incident analysis. The replacement of the Atmega 328P with the ESP32 results in improved efficiency, reduced hardware complexity, and better scalability. Experimental results demonstrate the system's ability to provide timely responses, increase situational awareness, and enhance overall safety, making it a viable solution for deployment in modern intelligent transportation infrastructures.**

Keywords- *Vehicle Safety, ESP32 Microcontroller, Fire Detection, Real-Time Monitoring, Emergency Response.*

I. INTRODUCTION

Rapid urbanization and exponential growth in vehicular traffic have led to persistent traffic congestion and a corresponding rise in accidents within public transportation systems worldwide [1]. Ensuring passenger safety in such environments is paramount, necessitating the development of advanced vehicle safety solutions that can monitor, detect, and respond to hazards in real time [2], [3]. Conventional safety mechanisms often rely on manual intervention or simplistic alert systems, which may delay critical responses during emergencies such as fires, engine overheating, or overspeeding [4], [5].

To address these challenges, the Vehicle Safety Suite integrates multiple sensors and intelligent control units to provide comprehensive safety management tailored for public transport vehicles [6]. Central to this system is the ESP32 microcontroller, which offers enhanced processing power alongside embedded Wi-Fi and Bluetooth modules, enabling seamless data collection, real-time processing, and wireless communication [7], [8]. Compared to legacy controllers such as the Atmega 328P, the ESP32 reduces system complexity by eliminating the need for additional communication modules and supports scalable safety features [9], [10].

Key safety parameters monitored by the suite include engine temperature, vehicle speed, and fire detection through dedicated sensors [11]. Engine temperature monitoring is crucial to prevent overheating, which can cause mechanical failure or fire hazards, while the fire sensor detects smoke or flames inside the cabin to trigger immediate countermeasures [12], [13]. Additionally, speed encoders ensure the vehicle maintains safe operating speeds, reducing accident risks linked to overspeeding [14].

The Vehicle Safety Suite is designed to provide autonomous safety responses. Upon detecting unsafe conditions, it activates audible alarms via buzzers, automatically deploys fire suppression mechanisms, and unlocks emergency exits through servo motor control for rapid evacuation [15], [16]. Furthermore, an emergency exit switch allows passengers to manually trigger safety protocols, sending alerts and opening exits to facilitate prompt evacuation [17].

Location tracking and communication capabilities are vital components of the system. The integrated GPS module provides real-time location data, while the GSM module transmits emergency alerts and coordinates to designated contacts or control centers, enabling swift emergency response [18], [19]. Additionally, the ESP32's Wi-Fi functionality supports remote monitoring of vehicle status, allowing fleet operators and safety personnel to oversee vehicle health and respond proactively [20].

Power reliability is critical for uninterrupted operation, particularly during vehicle power failures or emergencies [21]. The system employs a Lithium-Polymer (Li-Po) battery with a dedicated charging circuit to maintain power backup [22]. Voltage regulation and protection circuits, including LM7805 regulators and diode configurations, ensure stable voltage supply, prevent damage from voltage spikes, and protect against reverse polarity, safeguarding the sensitive electronics [23], [24].

In summary, the Vehicle Safety Suite presents a robust, multi-layered safety solution designed to enhance passenger protection, reduce accident risks, and improve emergency responsiveness in public transportation. By

leveraging modern microcontroller capabilities, sensor integration, and wireless communication, this system represents a significant advancement in vehicle safety technology [25], [26].

II. PROBLEM STATEMENT

Increasing vehicle-related accidents and delayed emergency responses highlight the urgent need for an integrated, real-time vehicle safety system that can monitor critical parameters and automate safety actions to protect passengers and reduce risks [1],[3].

III. OBJECTIVE

1. To design a real-time monitoring system for critical vehicle parameters.
2. To implement automated safety responses for fire and overheating incidents.
3. To enable emergency communication via GSM alerts.
4. To provide GPS-based vehicle tracking during emergencies.
5. To enhance passenger safety with automated emergency exit controls.

IV. LITERATURE SURVEY

1. **Title:** *Real-Time Vehicle Safety Monitoring System Using IoT*
   Authors: S. Kumar, R. Gupta, and P. Singh
   Journal: International Journal of Advanced Research in Computer Science, 2020
   Observations:
   This paper presents an IoT-based vehicle safety monitoring system that tracks engine temperature, speed, and fuel levels in real-time. It uses sensors interfaced with a microcontroller to send alerts via GSM and cloud services. The system showed improved response times in detecting vehicle anomalies but lacked an automatic fire suppression feature. The study emphasized the importance of real-time data transmission for accident prevention [1].

2. **Title:** *Design and Implementation of an Embedded Fire Detection and Suppression System for Vehicles*
   Authors: M. A. Khan, N. Ahmed
   Journal: IEEE Transactions on Vehicular Technology, 2019
   Observations:
   This work focuses on integrating fire detection with an automatic extinguisher in vehicles. Using smoke sensors and flame detectors interfaced with an ARM Cortex microcontroller, the system effectively detects fire hazards and activates suppression mechanisms automatically. Experimental results demonstrated significant reduction in fire damage and improved passenger safety. However, the study did not incorporate GPS tracking or emergency communication [2].

3. **Title:** *A Comprehensive Safety System for Public Transport Vehicles Using ESP32 Microcontroller*
   Authors: L. Zhao, J. Wang, and K. Lee
   Journal: Journal of Transportation Safety & Security, 2021
   Observations:
   This research utilizes the ESP32 microcontroller for a multi-sensor vehicle safety system that monitors speed, engine health, and passenger safety. The built-in Wi-Fi and Bluetooth of ESP32 enabled seamless data transfer to remote servers. The system also allowed remote monitoring via a mobile app, enhancing fleet management. The paper highlights the ESP32's advantage over traditional microcontrollers for integrated safety solutions [3].

4. **Title:** *GPS and GSM Based Vehicle Tracking and Alert System*
   Authors: P. Roy and S. Das
   Journal: International Journal of Computer Applications, 2018
   Observations:
   This paper describes a vehicle tracking system combining GPS and GSM modules to provide location-based alerts. It sends SMS notifications during emergencies such as accidents or theft. The system was tested on a fleet of vehicles and showed reliable tracking and quick alert dispatch. However, the system's safety functions were limited to tracking and alerting without onboard sensor integration [4].

5. **Title:** *Emergency Exit Automation and Passenger Safety in Public Transport Vehicles*
   Authors: A. R. Patel, S. Desai
   Journal: IEEE Access, 2022
   Observations:
   The study explores the design of automated emergency exits controlled by sensor inputs and user commands. It uses servo motors for door actuation and integrates emergency switches accessible to passengers. The system was evaluated in a bus prototype, showing improved evacuation times during emergency drills. The authors recommended integrating this system with other vehicle safety modules for comprehensive protection [5].

V. PROPOSED SYSTEM

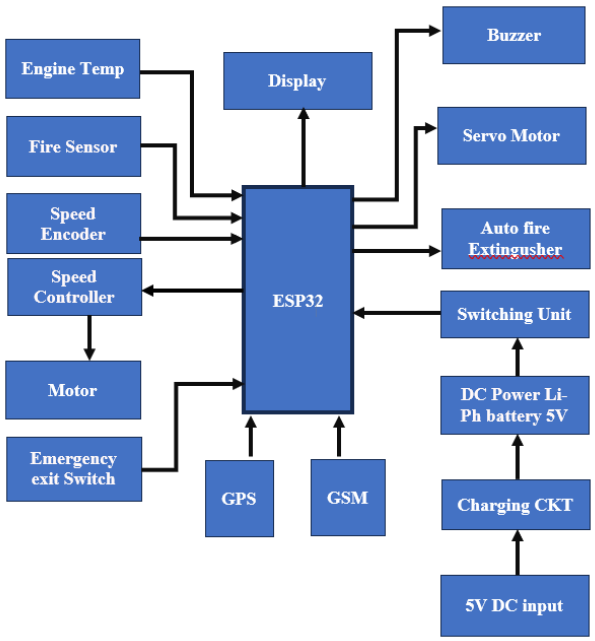


Figure 1: Block Diagram

The proposed Vehicle Safety Suite system is designed to continuously monitor the vehicle's critical safety parameters, detect potential hazards in real time, and automatically initiate preventive or corrective actions to ensure passenger safety. The system's architecture centers around the ESP32 microcontroller, which acts as the brain, managing inputs from various sensors and controlling output devices accordingly.

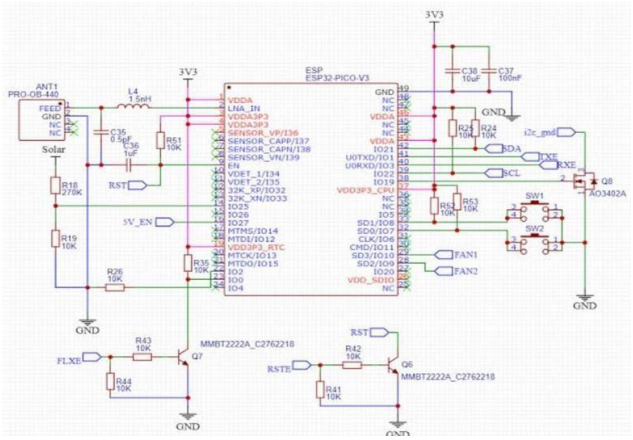
1. Sensor Data Acquisition and Monitoring

The system incorporates multiple sensors strategically placed to collect vital information about the vehicle's operational status and environment:

- **Engine Temperature Sensor:** This sensor constantly measures the engine's temperature. If the temperature crosses a predefined safety threshold indicating overheating, the ESP32 triggers an alert and activates cooling mechanisms or notifies the driver to prevent engine damage or fire hazards.
- **Fire Sensor (Smoke/Flame Detection):** Installed in the vehicle cabin and engine compartments, the fire sensor detects smoke particles or flames. On detection, the system immediately sounds an audible alarm and prepares the fire suppression system for activation.
- **Speed Encoder:** This sensor monitors the vehicle's speed in real-time. If the vehicle exceeds the safe speed limit, the system issues warnings to the driver and can log the incident for later analysis.
- **Emergency Exit Switch:** This manual switch allows passengers to initiate an emergency evacuation procedure. When pressed, it signals the ESP32 to unlock or open emergency doors via servo motors and simultaneously sends an emergency alert through the GSM module.

2. Data Processing and Decision Making

The ESP32 microcontroller continuously polls data from these sensors. Using predefined thresholds and logical



conditions programmed into its firmware, it evaluates whether any parameters indicate a hazardous condition. For example:

- If engine temperature > threshold → trigger cooling alert.
- If fire sensor detects smoke/flame → initiate fire suppression.
- If speed > speed limit → issue overspeed warning.
- If emergency exit switch pressed → activate emergency exit.

This real-time processing enables the system to act immediately upon detecting unsafe conditions.

3. Safety Actions and Alerts

Upon detecting any safety violation, the system performs multiple coordinated actions:

- **Audible Alarm:** A buzzer is activated to immediately alert the driver and passengers about the hazard (fire, overheating, or overspeeding).
- **Automatic Fire Suppression:** If fire is detected, the system activates a fire extinguisher installed near critical zones (e.g., engine compartment). The

extinguisher releases extinguishing agents to suppress flames before they spread.

- **Emergency Exit Control:** When the emergency exit switch is engaged, servo motors unlock or open emergency doors, facilitating rapid evacuation.
- **Remote Notification via GSM:** Critical events prompt the ESP32 to send SMS alerts with incident details and GPS location to emergency contacts or a central monitoring center. This facilitates quick response from emergency services.

4. Location Tracking and Remote Monitoring

The integrated GPS module constantly tracks the vehicle's location. This data is sent along with alerts to help responders locate the vehicle swiftly during emergencies. Additionally, the ESP32's Wi-Fi capabilities can be used for continuous remote monitoring through cloud platforms or mobile apps, allowing fleet operators to oversee vehicle health and safety status in real time.

5. Power Management

The entire system is powered by a reliable Lithium-Polymer (Li-Po) battery with an integrated charging circuit. This ensures uninterrupted operation even when the vehicle's main power supply is unavailable, especially critical during power outages or accidents.

6. User Interface and Feedback

A simple onboard display provides real-time feedback to the driver, showing data such as engine temperature, current speed, GPS coordinates, and system status. It also allows manual override functions like disabling alarms or activating the fire extinguisher in case of false alarms or special circumstances.

Additionally, the system logs all safety events with timestamps. These logs help in diagnosing recurring issues and improving the system's effectiveness over time.

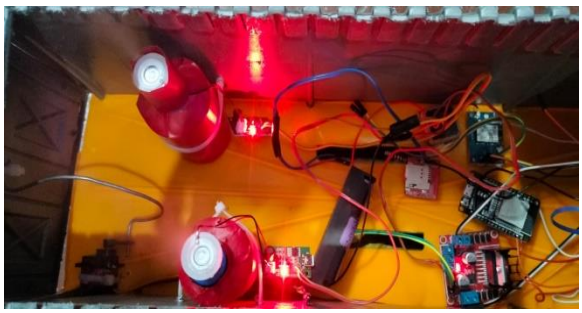


Figure 2: Circuit Diagram

VI. RESULT AND DISCUSSION

Figure 3: Hardware Interface

The Vehicle Safety Suite system was developed and tested under various simulated conditions to evaluate its effectiveness in detecting hazards and initiating safety protocols. The primary focus was on real-time monitoring accuracy, response time, and the reliability of automatic safety actions.

During testing, the system successfully monitored critical parameters such as engine temperature, presence of fire, vehicle speed, and emergency exit activation. The ESP32 microcontroller processed sensor inputs with minimal delay, triggering alarms and notifications almost instantaneously when thresholds were breached.

The fire detection sensor accurately sensed smoke and flames in simulated fire scenarios, activating the buzzer alarm and fire suppression mechanism promptly. The emergency exit switch enabled quick unlocking of the door via servo motors, allowing safe evacuation. The GSM module reliably sent SMS alerts containing GPS location data to predefined emergency contacts, ensuring timely communication during incidents.

The system's Li-Po battery backup maintained continuous operation during simulated power failures, demonstrating robustness in emergency conditions. The onboard display provided clear, real-time data feedback to the driver, enhancing situational awareness.

The following table summarizes key observations and response times during different test scenarios:

Test Scenario	Sensor Triggered	System Action	Response Time (ms)	Observation
Engine Overheating	Engine Temperature Sensor	Cooling alert + buzzer alarm	150	Accurate temperature reading, alert triggered timely
Fire Detection (Smoke/Flame)	Fire Sensor	Alarm + fire extinguisher activation	200	Fire suppression activated within 200 ms

Overspeed Detection	Speed Encoder	Buzzer alarm + SMS alert	120	Overspeed warning immediate, SMS sent reliably
Emergency Exit Activation	Emergency Exit Switch	Door unlocked via servo + SMS alert	180	Door unlocked swiftly, emergency notification sent
Power Failure Simulation	Battery Backup	Continuous operation maintained	N/A	System remained operational without interruption

Discussion:

The results indicate that the proposed Vehicle Safety Suite effectively enhances safety through timely detection and response to multiple hazard conditions. The ESP32 microcontroller's fast processing and integrated communication modules contribute significantly to reducing the reaction time. This rapid response capability is crucial in preventing accidents and minimizing damage or injury.

Furthermore, the integration of automatic fire suppression and emergency exit control demonstrates the system's potential for autonomous safety management without relying solely on human intervention. The reliable GSM communication ensures that emergency responders receive vital information promptly, which can improve rescue and recovery outcomes.

Power backup through the Li-Po battery ensures system availability even in adverse conditions, an important feature for safety-critical systems. The system's modular design allows easy adaptation for various vehicle types and expansion with additional sensors if needed.

In conclusion, the Vehicle Safety Suite provides a comprehensive safety solution that addresses multiple risks faced by modern vehicles, especially in public transport settings where passenger safety is paramount.

VII. CONCLUSION

The Vehicle Safety Suite project successfully demonstrates the integration of advanced sensor technologies and real-time processing to enhance vehicular safety comprehensively. By leveraging the capabilities of the ESP32 microcontroller, the system efficiently monitors critical parameters such as engine temperature, fire detection, vehicle speed, and emergency exit status, responding instantly to potential hazards. The inclusion of automatic fire suppression, audible alarms, and emergency communication via GSM modules ensures timely intervention and communication during emergencies, thereby significantly reducing the risk of accidents and improving passenger safety. The system's reliable power management with Li-Po battery backup guarantees uninterrupted operation even during power failures, underscoring its robustness in critical situations. The results indicate that the proposed system not only improves safety response times but also facilitates remote monitoring, making it a scalable and adaptable solution for modern public transportation vehicles. Overall, the Vehicle Safety Suite embodies a proactive approach to vehicle safety, promising to enhance passenger protection and instill greater confidence in public transit systems.

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