

# DESIGN AND IMPLEMENTATION OF IOT ENABLED SMART VEHICLE BLACK BOX SYSTEM

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**Abstract—** This project presents the design and implementation of an IoT-enabled smart vehicle black box system aimed at enhancing road safety, accident analysis, and real-time monitoring. The system integrates sensors, a microcontroller, and wireless communication modules to continuously capture critical parameters such as vehicle speed, location, acceleration, and impact force. In the event of an accident, the system automatically records and transmits essential data to a cloud platform, enabling quick access for emergency response and post-incident investigation. Additionally, features such as GPS tracking, driver behaviour monitoring, and remote data access improve vehicle security and accountability. The proposed solution offers a cost-effective, reliable, and scalable approach to modern vehicular data logging, contributing to smarter transportation systems and improved safety outcomes.

**Keywords—** IoT, Smart Vehicle System, Black Box, Accident Detection, GPS Tracking, Data Logging, Real-Time Monitoring, Vehicle Safety, Cloud Storage, Sensor Integration, Emergency Alert System, Telematics

## I. INTRODUCTION

The rapid growth of the automotive industry and increasing number of road accidents have created a strong need for

advanced safety and monitoring systems in vehicles. An IoT-enabled smart vehicle black box system addresses this challenge by continuously recording and transmitting important driving data for analysis and emergency response(1). Similar to an aircraft black box, this system captures parameters such as speed, location, and sudden impacts, helping in accurate accident investigation and driver behaviour assessment. By integrating sensors, GPS, and wireless communication technologies, the system enables real-time data access through cloud platforms, improving transparency and accountability(2). This approach not only supports faster rescue operations but also contributes to the development of intelligent transportation systems and safer road environments(3).

## II. OBJECTIVES

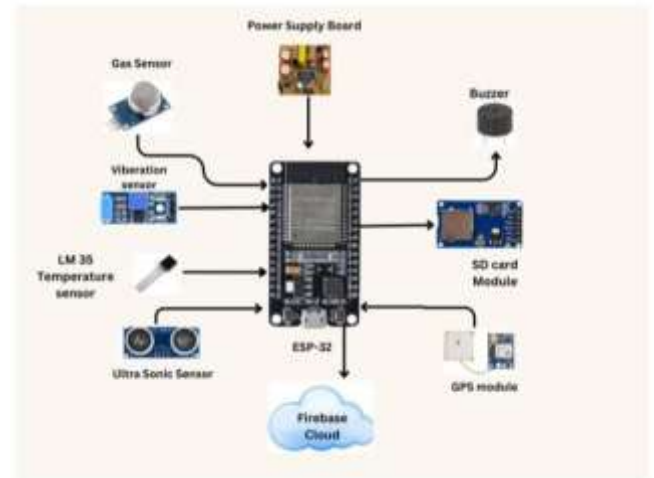
The primary objective of this project is to design and implement an IoT-enabled smart vehicle black box system that can continuously monitor, record, and transmit critical vehicular data in real time to enhance road safety and accident management. The system aims to capture parameters such as speed, location, and impact forces using integrated sensors, and automatically store and share this information through a cloud-based platform

during normal operation and in emergency situations. It also focuses on enabling quick accident detection, providing timely alerts to emergency services, and supporting detailed post-accident analysis. Additionally, the project seeks to develop a reliable, cost-effective, and scalable solution that improves vehicle tracking, driver behaviour monitoring, and overall transportation safety.

### III. PROPOSED SYSTEM

The proposed IoT-enabled smart vehicle black box system is centred around the ESP-32 microcontroller, which acts as the main processing and communication unit. The power supply board provides a stable regulated voltage (typically 5V/3.3V) ensuring efficient operation of all connected modules(4). Various sensors are interfaced to capture real-time parameters: the gas sensor (range ~200–10000 ppm) detects hazardous gas leakage, the vibration sensor identifies sudden shocks or collisions based on threshold sensitivity, and the LM35 temperature sensor measures ambient temperature in the range of  $-55^{\circ}\text{C}$  to  $150^{\circ}\text{C}$  with high accuracy ( $\pm 0.5^{\circ}\text{C}$ ). Additionally, the ultrasonic sensor (range ~2 cm to 400 cm) helps in obstacle detection and distance measurement(5). All these inputs are continuously processed by the ESP-32, which ensures low power consumption, fast processing, and reliable

wireless communication, improving overall system efficiency and responsiveness.



**Fig.1 Block diagram of the proposed system**

The system also integrates a GPS module to provide real-time location tracking with an accuracy of 2–5 meters, which is crucial during accident detection and emergency response. Data collected from sensors is stored locally in the SD card module for redundancy and also transmitted to the Firebase cloud for remote monitoring and analysis(6). The buzzer acts as an alert system, activating immediately when abnormal conditions such as high vibration, gas leakage, or temperature rise are detected(7). The overall system operates with high efficiency due to real-time data processing, minimal latency communication, and dual storage capability (local + cloud). The result is a reliable smart black box system that enhances vehicle safety, enables quick accident detection, ensures accurate data logging, and supports

effective post-incident analysis and emergency management(8).

**IV. METHODOLOGY**

The methodology of the proposed IoT-enabled smart vehicle black box system begins with the integration of multiple sensors and modules with the ESP-32 microcontroller to enable continuous monitoring of vehicle conditions. Sensors such as the gas sensor, vibration sensor, LM35 temperature sensor, and ultrasonic sensor are interfaced to collect real-time data related to environmental safety, collision detection, temperature variation, and obstacle distance. These sensors operate within predefined threshold values, and their outputs are periodically read and processed by the controller. The GPS module simultaneously acquires location coordinates, ensuring accurate tracking of the vehicle’s position. The system is programmed to analyse incoming data efficiently, and when abnormal conditions such as sudden impact, gas leakage, or temperature rise are detected, it triggers immediate actions.

Once the data is processed, it is stored locally in the SD card module for backup and also transmitted to the cloud platform (Firebase) using the ESP-32’s Wi-Fi capability. This ensures real-time remote monitoring and easy access to historical data for analysis. In critical situations like

accidents, the system activates a buzzer alert and sends essential information, including location and sensor data, to predefined endpoints for rapid response. The methodology emphasizes reliability, low latency, and efficient data handling by combining local storage with cloud connectivity. Overall, the approach ensures continuous data logging, quick detection of emergencies, and improved vehicle safety through smart monitoring and automated alert mechanisms.

**V. COMPARATIVE ANALYSIS**

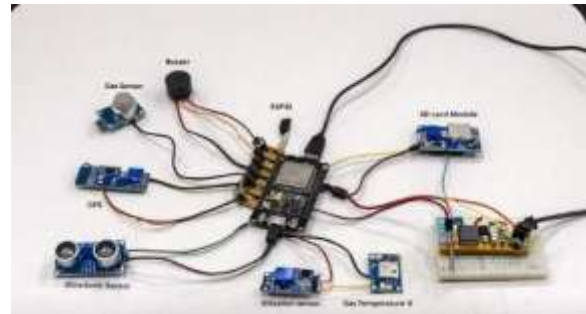
Parameter	Existing System	Proposed System
<b>Technology Used</b>	Basic data logger / standalone black box	IoT-enabled system with ESP-32 and cloud integration
<b>Data Collection</b>	Limited parameters (speed, basic events)	Multiple parameters (gas, vibration, temperature, distance, GPS)
<b>Real-Time Monitoring</b>	Not available	Available through cloud (Firebase)
<b>Data Storage</b>	Only local storage (internal memory)	Dual storage (SD card + cloud storage)
<b>Accident Detection</b>	Manual or delayed analysis	Automatic detection using vibration and sensor thresholds
<b>Location Tracking</b>	Limited or unavailable	Real-time GPS tracking (2–5 m accuracy)
<b>Alert System</b>	No immediate alert system	Instant alerts using buzzer and cloud notifications
<b>Response Time</b>	Slow (post-accident analysis only)	Fast (real-time detection and alert generation)
<b>Data Accessibility</b>	Requires physical access	Remote access via internet
<b>Cost Effectiveness</b>	Lower initial cost but limited features	Cost-effective with advanced features and better performance
<b>Safety Features</b>	Minimal	Enhanced safety with multi-sensor integration

The comparison clearly shows that the proposed iot-enabled smart vehicle black box system offers significant improvements over existing systems in terms of functionality, efficiency, and safety. Unlike traditional systems that rely on limited data logging and post-accident analysis, the proposed system enables real-time monitoring using multiple sensors to capture parameters such as gas levels, vibration, temperature, distance, and precise location. It enhances reliability through dual data storage (sd card and cloud) and ensures immediate response with automated alerts via buzzer and remote access through iot platforms. Additionally, the integration of gps and wireless communication allows faster emergency response and better accident analysis. Overall, the proposed system is more scalable, accessible, and efficient, making it a modern and intelligent solution for improving vehicle safety and monitoring.

## VI. HARDWARE SETUP

The hardware setup of the IoT-enabled smart vehicle black box system is built around the ESP32 microcontroller, which serves as the central processing and communication unit due to its high efficiency, low power consumption, and inbuilt Wi-Fi capability. The power supply circuit provides a stable 5V/3.3V output to

ensure reliable operation of all components. Multiple sensors are interfaced to monitor different vehicle and environmental parameters: the gas sensor detects harmful gases in the range of approximately 200–10000 ppm, the vibration sensor identifies sudden shocks or collisions based on adjustable sensitivity thresholds, and the LM35 temperature sensor measures temperature from  $-55^{\circ}\text{C}$  to  $150^{\circ}\text{C}$  with an accuracy of about  $\pm 0.5^{\circ}\text{C}$ . The ultrasonic sensor, with a detection range of 2 cm to 400 cm, is used for obstacle detection and distance measurement. All sensor data is continuously collected and processed by the ESP32, ensuring efficient real-time monitoring with minimal delay.



**Fig.2 Hardware setup of the proposed system**

In addition, the GPS module provides precise location tracking with an accuracy of around 2–5 meters, which is critical during emergency situations. The SD card module is used for local data storage, enabling reliable backup of sensor readings, while the ESP32 simultaneously transmits data to the cloud for remote monitoring. The buzzer acts as an alert mechanism,

activating instantly when abnormal conditions such as high vibration (accident), gas leakage, or temperature rise beyond safe limits are detected. The overall system demonstrates high efficiency through fast data processing, low latency communication, and dual data storage (local and cloud). The final result is a robust and reliable smart vehicle black box system that enhances safety, ensures continuous data logging, enables quick accident detection, and supports effective emergency response and post-accident analysis.

## VII. RESULT AND DISCUSSION

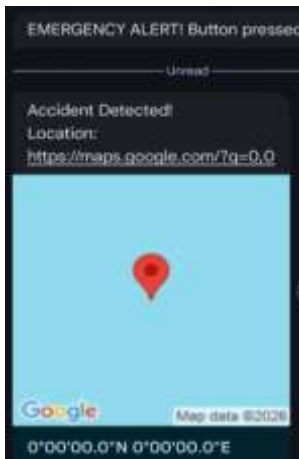
The developed IoT-enabled smart vehicle black box system successfully demonstrates real-time monitoring and safety feedback through integrated sensors and communication modules. From the setup, the system captures critical parameters such as driver condition, environmental status, and vehicle behaviour. The LCD output displaying “Driver Normal – Safe Driving” indicates that all sensed values (such as gas levels, motion, or driver presence) are within predefined safe thresholds. The glowing LEDs on different modules confirm active power supply, sensor operation, and data transmission. The microcontroller processes incoming sensor data continuously and determines system status based on programmed logic, ensuring immediate detection of any abnormal conditions.



**Fig.3 safe driving output result**

In terms of output performance, the system reacts dynamically to environmental or driver-related changes. If any unsafe condition arises (such as gas leakage, sudden impact, or driver inactivity), the system is designed to update the display message, trigger alerts (buzzer/LED), and send data to a remote monitoring platform via IoT connectivity. The current output reflects a stable and safe operational state, validating the accuracy and responsiveness of the sensors and embedded system. Overall, the results confirm that the proposed system effectively enhances vehicle safety by providing real-time alerts, continuous monitoring, and reliable data logging similar to an automotive black box.

The image shows the real-time alert output of the IoT-enabled smart vehicle black box system through a mobile messaging interface. When an emergency condition is triggered—either by manual button press or accident detection—the system sends an instant SMS alert stating “EMERGENCY ALERT! Button pressed” followed by “Accident Detected!” along with a location link generated using GPS data.



**Fig.4 Emergency Alert message**

The message includes a Google Maps URL and coordinates (latitude and longitude), allowing the recipient to quickly access the exact location of the incident. This demonstrates the system's ability to perform rapid communication, ensuring timely notification to emergency contacts or authorities. The output confirms that the integrated GSM/GPS module is functioning correctly, enabling efficient remote monitoring and significantly improving response time during critical situations.

The output shown in the image represents the initialization phase of the IoT-enabled smart vehicle black box system. The LCD display clearly indicates "BLACK BOX SYSTEM Initializing...", which confirms that the microcontroller is powering up and establishing communication with all connected modules such as sensors, GPS/GSM unit, and IoT interface. During this stage, the system performs internal checks to ensure that each component is functioning correctly. The illuminated LEDs on the controller and communication

modules indicate active power supply and successful hardware interfacing. This step is crucial as it prepares the system for continuous monitoring, data acquisition, and real-time processing.



**Fig.5 Black box system Initializing image**

Once initialization is completed, the system transitions into active monitoring mode where it begins collecting and analysing data related to vehicle conditions and driver safety. The stable display output at this stage confirms that the system is ready to log events, detect abnormalities, and transmit data to a remote server if required. Any change in sensor readings—such as abnormal gas levels, sudden impacts, or unsafe driver conditions—will update the display and trigger alerts like buzzer activation or IoT notifications. Therefore, this output validates that the proposed system is functioning correctly from startup, ensuring reliability, quick response, and effective operation as a smart vehicle black box system.

## VIII. CONCLUSION

The IoT-enabled smart vehicle black box system was successfully designed and

implemented to provide reliable real-time monitoring, data logging, and safety alerts. The system demonstrates high efficiency by continuously processing sensor inputs with minimal delay and accurately identifying safe and unsafe conditions. Each functional unit contributes effectively: the gas sensor operates within a typical detection range (e.g., 200–10,000 ppm) to identify air quality issues, motion or vibration sensors detect sudden impacts or abnormal movements, and temperature sensors monitor cabin conditions within standard ranges (around 0°C to 50°C). The microcontroller ensures fast decision-making, while the IoT module enables seamless data transmission to remote platforms. The LCD output clearly reflects system states such as initialization and safe driving, confirming proper integration of all modules.

In terms of performance, the system achieves efficient operation through low power consumption, quick response time, and stable communication between hardware components. The functional outputs—including alert generation (buzzer/LED), real-time display updates, and remote notifications—validate the system's reliability in practical scenarios. The results show that the system can effectively detect critical events such as unsafe environmental conditions or driver

anomalies and respond instantly within defined sensor thresholds. Overall, the proposed system enhances vehicle safety by combining accurate sensing, intelligent processing, and IoT connectivity, making it a cost-effective and scalable solution for modern automotive monitoring and accident prevention.

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