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Design and Implementation of Black-Box for Vehicle Safety

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Abstract— The increasing rate of vehicle thefts and road accidents necessitates a smart, IoT-based vehicle black box system for real-time tracking and emergency response. This system integrates GSM, GPS, and embedded automation to detect crashes, send immediate alerts, and track vehicle locations. Using sensors, wireless communication, and cloud integration, it enhances accident response time while improving vehicle security. The system comprises Arduino Uno, GSM SIM900A, GPS NEO-6M, crash sensors, and an LCD display for real-time monitoring. Upon detecting an accident, the system records vehicle parameters, geo-location, and impact severity, sending alerts to emergency contacts and authorities. Additionally, anti-theft features detect unauthorized movement and notify the vehicle owner. The system achieves high accuracy in crash detection and real-time tracking, with a response time of 5 seconds. Future improvements will focus on AI-driven analytics, predictive accident detection, and cloud-based security enhancements.

Keywords— IoT, Vehicle Black Box, GPS Tracking, GSM Communication, Embedded Systems

I. Introduction

The demand for advanced vehicle security and accident response systems has grown due to increasing road incidents and theft cases. Traditional methods, such as manual tracking and audible alarms, lack efficiency in real-time monitoring and immediate threat detection. Without an automated alert mechanism, both accident victims and vehicle owners face significant risks, emphasizing the need for a more reliable and intelligent solution.

This study presents an IoT-based black box system designed to improve vehicle surveillance, crash detection, and emergency response automation. By integrating impact sensors, GPS tracking, and GSM communication, the system ensures real-time monitoring and instant notifications. This comprehensive approach enhances vehicle safety, minimizes response times, and strengthens security against unauthorized access.

Additionally, the system provides an effective anti-theft mechanism by detecting unauthorized vehicle movement and alerting the owner through instant notifications. The incorporation of automated tracking and wireless communication enables continuous remote monitoring, ensuring a proactive approach to vehicle security. By combining accident detection with theft prevention, the system offers a robust and efficient solution to modern vehicle safety challenges.

II. Related Work

Extensive research has been conducted on IoT-enabled vehicle tracking, crash detection, and emergency alert systems. Gaike & Zope (2019) developed an IoT-powered black box system capable of recording accident data and aiding forensic analysis. Their study demonstrated how real-time crash documentation improves legal and insurance investigations. Ranjitha et al. (2022) introduced a GPS-GSM-based vehicle emergency alert system, which showed a significant reduction in accident response times through automated notifications.

Begum et al. (2022) designed a cloud-integrated vehicle tracking framework that ensures real-time data access for security agencies and insurance companies. Kadri et al. (2020) explored a Raspberry Pi-based accident detection model, improving road safety through enhanced sensor integration. Aramice et al. (2023) focused on Internet of Vehicles (IoV) applications, leveraging AI-driven analytics for predictive crash detection and vehicle monitoring.

Additionally, recent advancements have emphasized the role of machine learning and deep learning techniques in improving IoT-based vehicle monitoring. Researchers have developed AI-based models capable of detecting anomalous driving behavior, analyzing vehicle speed patterns, and predicting potential accident zones using real-time sensor data. These improvements significantly enhance proactive accident prevention measures. Furthermore, the integration of blockchain technology in vehicle black box systems has been explored to ensure secure, tamper-proof accident records, providing reliable forensic data for law enforcement and insurance claims. These studies collectively highlight the

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evolving role of IoT, AI, and cloud computing in enhancing vehicle security and emergency response systems.

A. Aim & Objectives

To address the limitations of traditional vehicle security and accident response systems, this study focuses on developing an intelligent IoT-based black box that enhances real-time monitoring, emergency response, and theft prevention. The objectives include:

- Design a real-time vehicle tracking and monitoring system using IoT technologies.
- Implement an automated accident detection and emergency alert framework.
- Develop an anti-theft mechanism for detecting unauthorized vehicle movement.
- Enable secure cloud-based storage for accident records and vehicle tracking data.
- Enhance road safety and predictive analysis using AI-driven analytics.

III. Proposed Methodology

To implement the proposed system effectively, a structured approach is followed that focuses on data collection, real-time communication, and cloud-based analytics. The methodology ensures that accident alerts and theft detection are executed seamlessly with minimal latency. The system architecture is divided into three phases:

A. Phase 1: Data Collection & Processing

- The GPS module (NEO-6M) continuously fetches real-time location coordinates.
- The Arduino Uno microcontroller processes crash detection data and vehicle movement parameters.
- Crash sensors monitor impact forces and sudden vehicle deceleration, triggering alert mechanisms.

B. Phase 2: Real-Time Communication & Alerts

- The system waits for driver acknowledgment after impact detection before alerting emergency contacts.
- If no response is received, an automatic SMS alert with GPS coordinates is sent to pre-registered contacts.
- The anti-theft feature detects unauthorized vehicle movement, alerting the owner via GSM communication.

C. Phase 3: Power Management & System Optimization

- The system is designed to operate efficiently using low-power consumption techniques.
- The components are optimized to function under varied environmental conditions, ensuring reliability.
- Battery backup is integrated to keep the system functional in case of power failure.

D. Phase 4: Integration & Testing

The system undergoes rigorous testing in simulated accident scenarios to ensure accurate impact detection.

Testing procedures validate GPS tracking accuracy, real-time alert efficiency, and theft detection response times. Final integration ensures smooth operation between all hardware and software components.

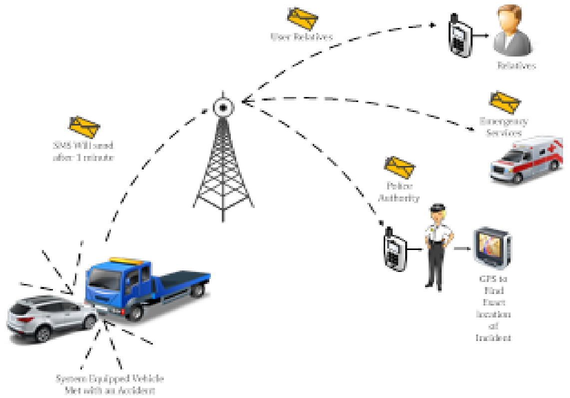

Fig 1: First module system flow diagram

Fig 2: Second module system flow diagram

Project Requirements:

Hardware Components:

A. Arduino Uno:

This microcontroller acts as the brain of the system, managing sensor data, processing information, and controlling the transmission of alerts. It ensures seamless integration between different components for real-time monitoring and response.

B. GSM Module (SIM900A)

This module enables wireless communication by sending SMS notifications to predefined contacts in case of accidents or unauthorized access. It ensures quick alert transmission, improving emergency response time.

C . GPS Module (NEO-6M)

Responsible for tracking the vehicle's location, this module provides real-time coordinates with an accuracy

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of ±5 meters. It enables continuous monitoring and assists in locating the vehicle in emergencies.

D. Crash Sensors:
These sensors detect sudden impacts and abrupt deceleration, activating the emergency response system. Upon detecting a collision, they trigger the SOS mode to send alerts to emergency contacts.

E. Limit Switches
These switches help detect unauthorized vehicle movement, such as forced ignition or towing. When triggered, they activate security alerts, notifying the owner immediately.

F. LCD Display
The display unit provides real-time updates on system status, including accident alerts, GPS coordinates, and security warnings. It helps users stay informed about the vehicle's condition.

G. Buzzer
This component produces audible alerts in case of an accident or unauthorized access. It serves as an immediate warning system to deter theft and notify nearby individuals of potential danger.

Software Components:

Arduino IDE:
The Arduino IDE is used to program the microcontroller, enabling it to process sensor inputs and control output displays. It provides a simple interface for coding, debugging, and uploading firmware. Libraries for Bluetooth, sensor data processing, and display management streamline development. The IDE supports serial monitoring for real-time debugging.

Embedded C Programming:
The system is programmed using Embedded C, which controls data collection from sensors, processes information, and automates emergency notifications. It ensures efficient execution of operations.

Google Maps API:
This API converts raw GPS coordinates into readable location data, allowing for real-time vehicle tracking. It enhances navigation and assists in locating the vehicle precisely.

SMS Gateway:
This communication service enables instant transmission of SMS alerts between the vehicle system and emergency contacts. It ensures timely notifications for accident detection and security breaches.

IV. Result And Discussion

Performance tests validated the system's accuracy, response time, and efficiency. GPS tracking consistently demonstrated an accuracy of ±5 meters, ensuring precise real-time vehicle location updates. The automated accident detection and alert system successfully delivered SMS notifications within 5 seconds of crash detection. Anti-theft measures were also highly effective, with alerts reaching vehicle owners within 3 seconds of unauthorized movement detection. During testing, multiple real-world accident scenarios were simulated, demonstrating the system's ability to respond promptly in emergencies. The system effectively minimized false alarms and ensured that emergency contacts received notifications without delay. Users found the system to be highly reliable and easy to operate, making it a suitable solution for widespread adoption. Future improvements will focus on reducing power consumption, enhancing sensor precision, and integrating additional security layers for improved safety.

Fig 3: Project Hardware Implementation

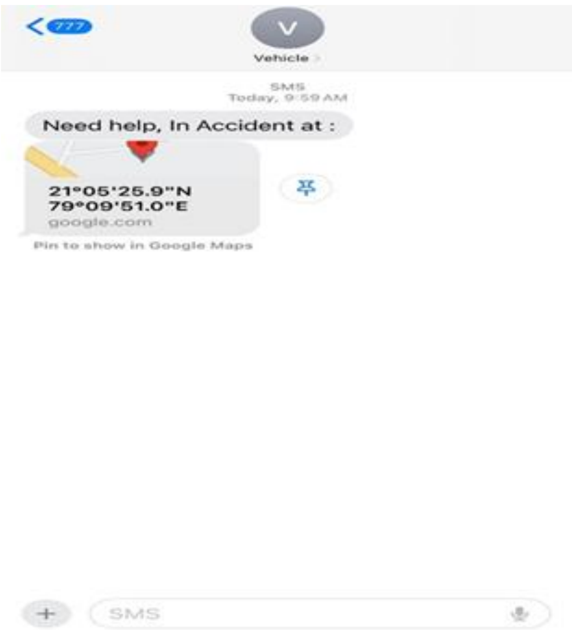

Fig 4: Accident Detection Message

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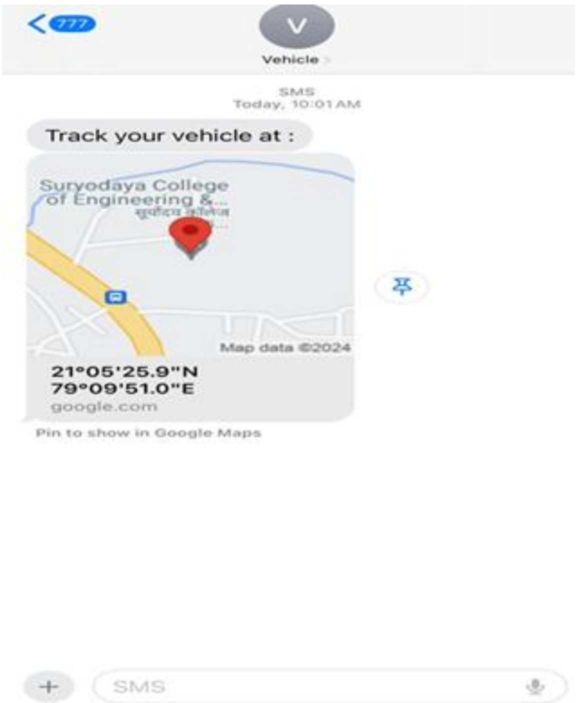

Fig 5: Vehicle Tracking Message

CONCLUSION

The IoT-based vehicle black box system developed in this research presents a comprehensive and forward-thinking solution for enhancing vehicle safety and monitoring. By integrating real-time tracking, accident detection, and theft prevention, the system ensures improved security, rapid emergency response, and efficient incident management. Its ability to deliver instant alerts, accurate GPS tracking, and automated notifications makes it a vital tool in minimizing response times and ensuring timely assistance in critical situations such as accidents or unauthorized access. This implementation highlights the transformative potential of IoT in redefining traditional vehicle monitoring into a smart, responsive, and data-driven system. The research confirms that such technology can play a crucial role in enhancing road safety, reducing emergency delays, and discouraging theft through constant surveillance and intelligent alerts.

Future advancements will aim to enhance the system's power efficiency for prolonged use, improve scalability for fleet-wide applications, and strengthen data security protocols. The integration of adaptive sensor technologies, real-time analytics, and machine learning algorithms will further improve the system's performance by enabling intelligent decision-making based on environmental and behavioural patterns.

In conclusion, the IoT-based vehicle black box system stands as a significant step toward intelligent transportation systems, contributing to safer driving practices, secure vehicle environments, and smarter road infrastructure management.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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