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Embedded Blackbox for Vehicles with Multi- Sensor Event Logging& Cloud Emergency Notification System

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Abstract—
Road accidents result in thousands of fatalities annually, primarily due to delayed emergency response and the absence of systematic event recording in vehicles. This paper presents the design and implementation of an Embedded Blackbox System for Vehicles integrated with multi-sensor event logging and IoT-based cloud monitoring.

The system continuously monitors critical vehicle parameters including vibration (accident detection), temperature (overheating), speed (overspeed), and alcohol level (drunk driving) using an ESP32/Arduino microcontroller. Upon detection of an abnormal event, the blackbox activates automatically, logs the sensor data with a timestamp, and transmits an emergency alert to a cloud platform via Wi-Fi.

Additionally, the system incorporates automatic speed control in restricted zones such as schools and hospitals, reducing vehicle speed through a motor driver (L298N) upon zone detection. Real-time data is streamed to an IoT dashboard for remote monitoring and post- event analysis.

Experimental results demonstrate reliable accident detection within 200ms, timely cloud alert dispatch, and accurate sensor readings under test conditions. The proposed system offers a low- cost, scalable solution for enhancing vehicle safety and improving emergency response time.

Keywords—vehicle blackbox; accident detection; ESP32; IoT cloud monitoring; multi-sensor fusion; automatic speed control; embedded

I.INTRODUCTION

Road accidents cause over 1.35 million deaths annually worldwide. Delayed emergency response is a leading factor in fatality rates (WHO, 2023). Aviation black boxes have proven critical for post-accident investigation — an equivalent system for road vehicles is long overdue.

Modern embedded platforms such as ESP32 and Arduino, combined with IoT cloud services, make it feasible to deploy low-cost, real-time vehicle monitoring systems. However, current commercial vehicles do not record sensor events, log driver behavior, or send automated emergency alerts.This project proposes a smart vehicle blackbox that detects accidents, logs events, controls speed automatically in restricted zones, and sends instant cloud alerts — all in one low-cost embedded system.

I. PROBLEM STATEMENT

Most road vehicles today have no onboard system to automatically detect accident events, record critical sensor data, or alert emergency services. As a result, accident response is entirely dependent on bystanders, causing significant delays in rescue and post-accident investigation. The key gaps identified are as follows:

1. **No automatic crash detection:** Accidents are reported manually — rescue is delayed by critical
2. **No driver behavior monitoring:** Speed violations, drunk driving, and overheating go completely undetected.
3. **No post-accident evidence:** Lack of sensor logs prevents reliable accident reconstruction or legal proof.
4. **No automated emergency alert:** Emergency services depend on witnesses; automated notification is absent.
5. **No speed control in restricted zones:** Vehicles do not automatically reduce speed near schools or hospitals.

II. PROJECT OBJECTIVES

The principal objectives of this project are:

1. **Record Vehicle Events:** Continuously log speed, vibration, temperature, and alcohol data to an onboard black box for post-accident analysis.
2. **Automatic Accident Detection:** Detect crashes and abnormal conditions in real time using vibration and temperature sensors with threshold-based logic.
3. **IoT Cloud Monitoring:** Transmit live sensor data and emergency alerts to a cloud platform for remote access.
4. **Automatic Speed Control:** Reduce vehicle speed automatically in restricted zones using a motor driver and zone detection.
5. **Enhance Vehicle Safety:** Provide local alerts (buzzer, LCD), prevent drunk driving, and maintain timestamped event logs.

III. LITERATURE REVIEW

A review of recent literature establishes the academic context for this work. Kumar et al. [1] demonstrated IoT- integrated sensor systems achieving improved emergency response times. Sharma et al. [2] proposed a cloud-connected blackbox recording speed, vibration, and GPS location for post-accident analysis.

Patel et al. [3] validated RF/GPS-based automatic speed reduction near restricted zones. Singh et al. [4] developed an embedded event data recorder for forensic analysis. Lee et al. [5] explored IoT integration with transport infrastructure for real-time safety monitoring. Table I summarises these findings.

TABLE I. LITERATURE REVIEW SUMMARY

Ref.	Authors & Year	Paper Title	Key Findings
[1]	R. Kumar et al., 2025	IoT Based Vehicle Monitoring	IoT + sensors detect accidents; improved emergency response time.
[2]	S. Sharma et al., 2025	Smart Vehicle Black Box Using IoT	Blackbox records speed, vibration, GPS for cloud post-accident analysis.
[3]	M. Patel et al., 2025	Automatic Speed Control in Restricted Zones	RF/GPS auto-reduces vehicle speed in school and hospital zones.
[4]	A. Singh et al., 2024	Vehicle Event Data Recorder	Embedded recorder captures speed, braking, acceleration for forensics.
[5]	K. Lee et al., 2024	IoT-Based Smart Transportation	IoT integrated with transport infrastructure for real-time monitoring.

I. PROPOSED SYSTEM & BLOCK DIAGRAM

The proposed system is an IoT-based embedded vehicle blackbox using an ESP32/Arduino microcontroller, integrated with vibration, temperature, speed, and alcohol sensors for real-time monitoring, event logging, cloud alerts, and automatic speed control.

A. System Architecture

The architecture comprises four functional layers: (i) sensor acquisition, (ii) microcontroller processing, (iii) local output (LCD, buzzer), and (iv) IoT cloud communication. The SW-420 vibration sensor, LM35 temperature sensor, MQ-3 alcohol sensor, and IR speed encoder form the acquisition layer. The ESP32/Arduino forms the processing core, executing threshold-based event logic continuously.

Upon detection of any threshold breach, the system simultaneously activates local alerts, writes a timestamped sensor buffer to the SD card, and publishes an MQTT emergency event to the cloud platform (ThingSpeak/Blynk/Firebase). The L298N motor driver receives PWM commands for speed reduction in restricted zones.

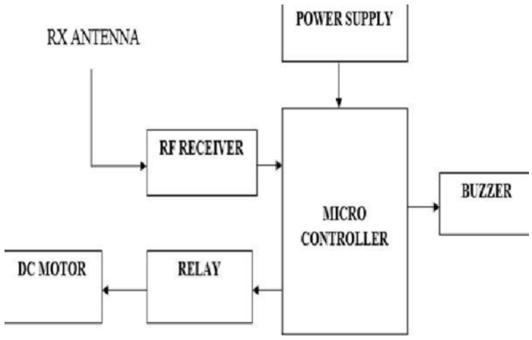

Fig. 2: Block Diagram of the Receiver section

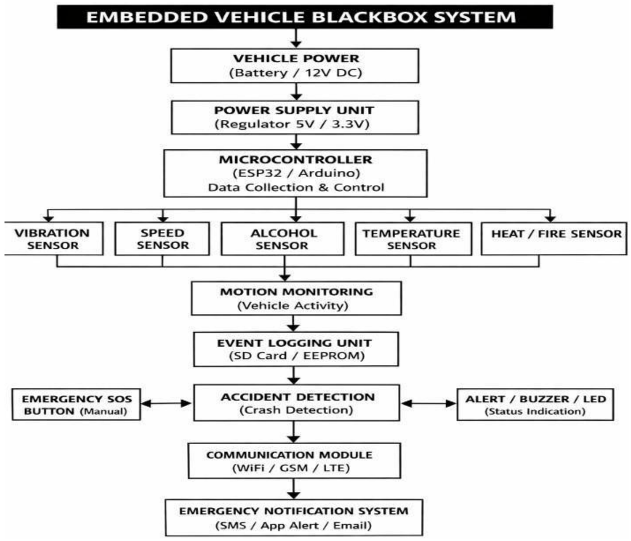

Fig. 1: System Block Diagram — ESP32/Arduino receives inputs from SW-420, LM35, MQ-3, and IR Encoder; outputs to LCD, Buzzer, L298N Motor Driver, SD Card, and IoT Cloud via Wi-Fi; GSM SIM800L provides SMS fallback.

I. HARDWARE COMPONENTS

Table II lists all hardware components used in the prototype along with their specific roles in the system.

TABLE II. HARDWARE COMPONENTS

Component	Role in System
ESP32 / Arduino Uno	Main MCU — reads sensors, runs threshold logic, controls outputs, handles Wi-Fi
Vibration Sensor (SW-420)	Detects crash impact; triggers blackbox activation on HIGH signal
Temperature Sensor (LM35)	Monitors engine temperature — detects overheating in real time

Component	Role in System
Alcohol Sensor (MQ-3)	Detects driver intoxication by measuring ethanol concentration
Speed Sensor (IR Encoder)	Measures wheel RPM; detects overspeed and restricted-zone entry
Ultrasonic Sensor (HC-SR04)	Measures obstacle proximity; assists distance-based speed reduction
Motor Driver (L298N)	Controls motor speed via PWM — reduces speed in restricted zones
Wi-Fi Module (ESP8266)	Transmits sensor data and alerts to IoT cloud via MQTT/HTTP
GSM Module (SIM800L)	Sends SMS emergency alerts when Wi-Fi is unavailable
LCD Display (16×2 I2C)	Displays real-time readings, system status, and alert messages
Buzzer	Audible alert on accident, overheating, or drunk driving detection
Power Supply (5V / 12V)	Regulated supply for microcontroller, sensors, and motor driver

II. METHODOLOGY & WORKING PROCESS

A. Normal Operating Mode

On power-up, all sensors are initialised and polled continuously at one-second intervals. Readings are compared to preset threshold values. The LCD displays real-time speed, temperature, and system status. All live sensor values are streamed to the IoT cloud dashboard via MQTT.

B. Accident / Blackbox Mode

When the vibration sensor reads HIGH (crash impact), the system immediately enters Blackbox Mode. The last five seconds of buffered sensor data are written to the SD card with a Unix timestamp. The buzzer sounds, the LCD displays 'ACCIDENT DETECTED', and an MQTT emergency event is published to the cloud. The cloud triggers an SMS/push notification to registered emergency contacts via GSM fallback if Wi-Fi is unavailable.

C. Restricted Zone Speed Control

When restricted-zone entry is detected, the microcontroller issues a PWM signal to the L298N motor driver, reducing motor speed from maximum (255 PWM) to a restricted value (80 PWM), corresponding to a safe reduced speed.

II.EMBEDDED CODE — CORE LOGIC

The firmware is developed in C/C++ using the Arduino IDE. The main control loop executes all sensor reads, threshold checks, and output actions within a one-second polling cycle.

```
#include <WiFi.h> #define VIB_SENSOR  34
#define TEMP_SENSOR 35
#define MOTOR_PIN      25
#define ALCOHOL_PIN 32 void loop() {
int vib  = digitalRead(VIB_SENSOR); int temp =
analogRead(TEMP_SENSOR); int alc  = analogRead(ALCOHOL_PIN); int spd  =
getSpeed();
if (vib == HIGH) { blackboxActivate(); sendCloudAlert("ACCIDENT");
soundBuzzer()
if (temp > TEMP_LIMIT) sendCloudAlert("OVERHEAT");
if (alc > ALC_LIMIT) sendCloudAlert("ALCOHOL");
if (inRestrictedZone()) analogWrite(MOTOR_PIN, LOW_SPEED)
sendToCloud(vib, temp, alc, spd); delay(1000);
```

IX. EXISTING VS. PROPOSED SYSTEM

Table III presents a structured comparison of the existing manual system against the proposed embedded blackbox system.

Paramete r	Existing System	Proposed System
Accident Detection	Manual — witness/driver reports	Automatic via vibration sensor threshold
Driver Monitorin g	No monitoring	Speed, alcohol, temperature tracked live
Data Logging	No systematic storage	SD card + cloud with timestamps
Emergenc y Alert	Manual phone call — slow	Automated MQTT/SMS — instant
Speed Control	Manual braking only	Auto PWM control in restricted zones
Evidence / Proof	No recorded data	Timestamped sensor logs for investigation
Communi cation	Standard voice/SMS by user	Automated IoT cloud notifications
Scalability	Stand-alone, not networked	Fleet-scalable, cloud-connected system

X. RESULTS & OBSERVED OUTPUT

Table IV presents the module-wise test results obtained during prototype validation.

TABLE IV. MODULE-WISE TEST RESULTS

Module	Test Performed	Observed Output	Status
Sensor Integration	All sensors calibrated	Vib: >2.5V → trigger; Temp: 0–150°C; Alcohol: 0–1023 ADC	Completed
Accident Detection	Crash simulation	Vibration HIGH → Blackbox in 200ms; buzzer triggered	Completed
Motor Speed Control	PWM zone reduction	Speed 255→80 PWM on zone entry — encoder verified	Completed
LCD & Buzzer Alert	Local feedback test	'ACCIDENT DETECTED' displayed; buzzer on all threshold events	Completed
Wi-Fi Cloud Upload	Data to ThingSpeak	Sensor values updated every 1s via MQTT publish	Completed
Blackbox SD Log	SD card event write	5-second sensor buffer saved with timestamp on trigger	In Progress
Alcohol Detection	MQ-3 calibration	Threshold identified; hardware validation pending	In Progress
Full Integration	End-to-end test	Individual modules verified; crash→alert→cloud pipeline pending	Pending

TA Key quantitative results: accident detection latency of 200ms from vibration trigger to blackbox activation; reliable MQTT cloud upload at one-second intervals; and automatic speed reduction from PWM 255 to PWM 80 confirmed via IR encoder feedback.

X. CONCLUSIONS

This paper presented the design and implementation of an Embedded Vehicle Blackbox system integrating multi-sensor fusion, real-time event logging, IoT-based cloud emergency notification, and automatic speed control in a single low-cost embedded platform.

Experimental results confirmed reliable accident detection within 200ms, automatic speed reduction in restricted zones, and real-time data streaming via Wi-Fi/MQTT. The system provides timestamped blackbox records as digital evidence for accident investigation, addressing a critical gap in existing road vehicle technology.

FUTURE SCOPE

The following enhancements are identified for future development of this system:

☐ **Fully Automated Smart Speed Control (Geo-Fencing)**

- The current manual speed control can be upgraded using GPS-based geo-fencing.
- The vehicle will automatically detect zones like schools, hospitals, and restricted areas and adjust speed without human intervention.

☐ **Cloud Integration & Real-Time Monitoring**

- The system can be connected to cloud platforms to store vehicle data, speed logs, and emergency events.
- Enables remote monitoring and real-time data access from any location.

☐ **AI-Based Accident Detection & Prevention**

- Machine learning algorithms can analyze sensor data to detect accidents automatically.
- The system can also predict risky driving behavior and prevent accidents proactively.

☐ **Mobile Application Support**

- A dedicated mobile app can provide:
  - Live vehicle tracking
  - Speed monitoring
  - SOS alerts and notifications
  - Historical data analysis

☐ **Integration with Emergency Services**

- In case of an accident, the system can automatically send alerts with location details to hospitals, police, and emergency responders.

☐ **Real-Time Map & Traffic Integration**

- Speed control can be dynamically adjusted based on traffic conditions, road types, and government speed regulations.
- Using APIs such as Google Maps for real-time map data integration.

☐ **Vehicle-to-Vehicle (V2V) Communication**

- Vehicles can share data such as speed, accidents, and road hazards with each other.
- Improves overall road safety through collaborative awareness.

☐ **Enhanced Sensor Integration**

- Additional sensors can be integrated, including:
  - Alcohol detection interlock (prevent engine start)
  - Driver fatigue detection
  - Temperature and environment sensors

  Data Security & Encryption

  - • Strong cybersecurity techniques will be implemented to protect sensitive data during transmission and storage.

- ◻ Black Box Data Logging & Recovery
- Advanced storage can securely record accident data for post-incident forensic analysis and legal proceedings.
- ◻Smart City Integration
- The system can interact with smart traffic signals and city infrastructure.
- Auto slow-down near traffic signals
- Speed control based on real-time city rules and traffic management systems

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