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Integrated Vehicle Monitoring System

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Abstract: The Integrated Vehicle Monitoring System (IVMS) is an advanced solution designed to enhance vehicle safety, performance, and management through real-time monitoring. The system integrates sensors, GPS, GSM, and microcontroller technologies to continuously track vehicle parameters such as location, speed, engine status, and fuel level. It enables remote data transmission to a centralized server or mobile application, allowing users or fleet managers to monitor vehicles efficiently. In case of abnormalities like accidents, theft, or engine failure, the system sends instant alerts via SMS or push notifications, promoting preventive maintenance and improving operational efficiency. The IVMS is suitable for both individual and commercial vehicles, offering benefits such as route optimization, driver behavior analysis, and fuel management. The system provides a reliable, cost-effective, and intelligent platform for ensuring vehicle security, enhancing transportation management, and supporting smart mobility solutions in modern automotive applications.
Keywords: IVMS, ESP32, GPS, GSM, IoT, Firebase, vehicle tracking, fleet management, real-time monitoring, mobile application

I. INTRODUCTION

In recent years, the demand for vehicle safety, efficiency, and real-time data acquisition has grown rapidly. Modern transportation systems increasingly rely on advanced electronics, sensors, and wireless communication to ensure driver safety and vehicle performance. The Integrated Vehicle Monitoring System (IVMS) is a technological advancement designed to continuously monitor key vehicle parameters, driver behavior, and environmental factors in real time. With the development of the Internet of Things (IoT), vehicles are no longer isolated mechanical machines but interconnected nodes capable of transmitting valuable information to remote servers and mobile applications. This connectivity provides a comprehensive view of vehicle operations, driver activities, and potential faults. However, the lack of integration between monitoring systems such as GPS tracking, fuel monitoring, engine diagnostics, and safety alert systems has created inefficiencies in data utilization and management. The motivation behind this project is to develop an integrated monitoring platform that merges GPS, GSM, and sensor networks into a unified system. This approach ensures improved safety, security, and operational control while providing users with instant data access and analytics. The system aims to bridge the gap between vehicle hardware and cloud-based data intelligence for enhanced transport management and accident prevention. The proposed IVMS utilizes GPS for real-time tracking, GSM for data transmission, and sensors for monitoring engine health, fuel levels, and environmental parameters. An ESP32 microcontroller serves as the central processing unit, collecting data from multiple sensors, processing it locally, and transmitting it to a Firebase cloud database for remote monitoring. A dedicated mobile application allows users to view live vehicle location, speed, and status, with automatic alerts generated for critical conditions.

II. LITERATURE SURVEY

An extensive literature survey was conducted covering IoT-based vehicle tracking, fleet management, safety systems, and cloud connectivity [1]–[20]. Kumar and Patel [1] introduced a GPS and GSM-based real-time vehicle tracking system that transmits location data via SMS, but lacked cloud integration and real-time visualization. Mehta and Roy[2] developed an IoT-based fleet monitoring solution using ESP32 and Firebase, demonstrating strong connectivity and scalability but without safety features such as accident alerts or driver monitoring. Sharma and Singh [3] proposed a combined vehicle tracking and safety alert system using GSM and GPS that automatically sent coordinates to emergency contacts during accidents.

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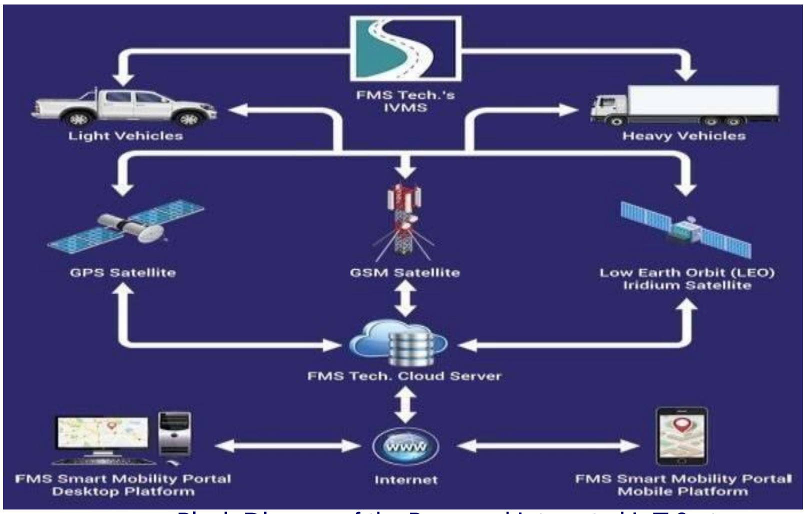
Fernandez and Krishnan [4] presented an OBD-II and IoT integration for vehicle health monitoring, accessing real-time engine data such as RPM, coolant temperature, and fault codes, though without tracking or emergency alerts. Das and Banerjee [5] designed a MEMS-based crash detection system with GPS tracking that reduced emergency response time but was limited to accident scenarios. Narayan and Gupta [6] developed a smart transportation platform integrating GPS data, traffic updates, and vehicle diagnostics, though it required high network bandwidth and suffered latency in low-signal areas. Khan and Alam [8] proposed an ESP32-powered vehicle surveillance system with motion detection, GPS tracking, and remote engine control via GSM. Thomas and Verma [9] introduced an IoT system measuring fuel levels, engine vibration, and temperature with SMS alerts, though lacking location tracking and data visualization. Iqbal and Hussain [10] integrated GPS, GSM, and IoT modules into a unified platform offering location tracking, accident alerts, and cloud-based monitoring. Selvam and Dinesh [11] demonstrated an ESP32-based IoT system collecting and visualizing live data via Firebase with mobile and web interfaces. The reviewed literature collectively motivates the comprehensive, multi-sensor, cloud-integrated approach adopted in this work.

III. PROPOSED SYSTEM



Block Diagram of the Proposed Integrated IoT System

A. System Architecture and Block Diagram

The proposed IVMS is designed around the ESP32 microcontroller placed at the center of the system architecture. All peripherals are connected to it as follows: the GPS Module(NEO-6M) provides continuous location tracking data (latitude, longitude, and speed); the GSM Module (SIM800L) sends SMS alerts and uploads data to the cloud when Wi-Fi is unavailable; and the built- in Wi-Fi of the ESP32 is used to communicate with the Firebase cloud server. Sensors for temperature, fuel level, and vibration connect via I2C, analog, and UART interfaces respectively.

B. Overcoming Drawbacks of Existing Methods

The proposed IVMS directly addresses shortcomings identified in existing systems. Table I presents a comparison of existing limitations and the corresponding IVMS solutions.

C. Detailed Working Principle

The operation of the IVMS is based on continuous data acquisition and condition-based responses. The working sequence is divided into four operational modes handled by the ESP32 microcontroller.

Mode 1: Power ON/Initialization

When power is supplied, the ESP32 initializes all sensors and modules including GPS, GSM, and Wi-Fi. The LCD displays a "System Ready" message and a green LED indicates normal operation. The microcontroller verifies cloud (Firebase) connectivity and loads pre-stored emergency contact numbers from non-volatile memory (EEPROM).

Mode 2: Normal Monitoring Mode

In this mode, the system continuously collects multi- sensor data: the MQ-3 sensor's analog reading is sampled and converted for alcohol detection; the IR sensor checks for driver eye blinks; the MPU6050 provides accelerometer and gyroscope data to calculate head tilt angle; the GPS module continuously streams NMEA data parsed for current coordinates; and the OBD-II module is polled periodically for vehicle speed and engine RPM. All live readings are displayed on the LCD screen.

Mode 3: GPS and GSM-Based Tracking

The GPS module continuously sends NMEA data to the ESP32,which parses latitude, longitude, and speed. When Wi-Fi is connected, data is logged in Firebase for continuous cloud tracking and visualized on Google Maps in the mobile app. If cloud connectivity is lost, the GSM module transmits coordinates via SMS to registered contacts as a reliable fallback.

Mode 4: Mobile Application and Cloud Integration

The mobile application (developed in Flutter or React Native) connects directly to the Firebase Real time Data base, displaying live vehicle location, speed, fuel level, and temperature. It receives instant push notifications via Firebase Cloud Messaging (FCM) for abnormal events.

Cloud Firestore maintains historical logs, enabling analysis of past alerts and route history.

D. Software Specifications

Embedded Firmware (ESP32): developed in C++ using Arduino IDE or Platform IO, with the Free RTOS operating system for multitasking. Key libraries include Tiny GPS++ for GPS parsing, FirebaseESP32 for cloud data exchange, Wire.h for I2C communication, Software Serial.h for GSM/GPS UART ports, and EEPROM.h for persistent storage of contacts and settings. Mobile Application: Flutter (Dart) for cross-platform Android/iOS compatibility, integrating Google Maps API for real-time map visualization and Firebase API for data and push notifications. Features include a real-time map, alert dashboard, control panel, and performance graphs. Cloud Backend: Google Firebase, providing Realtime Database for live data sync, Cloud Firestore for historical logs, and Firebase Cloud Messaging (FCM) for instant push notifications. Data is stored in JSON format with each vehicle assigned a unique identifier (UUID).

E. Advantages and Applications

Advantages of the proposed IVMS include: integrated operation combining tracking, monitoring, and safety in one system; real-time alerts for immediate notification of abnormal conditions; dual communication (Wi-Fi and GSM) for reliable data transmission; remote access and control from anywhere via the mobile app; scalable and modular architecture for easy extension; cost-effective use of affordable IoT components; and enhanced safety through proactive fault prevention. Applications include: personal vehicles for real-time monitoring and theft prevention; fleet management for centralized tracking of commercial transport; rental and logistics companies for driver accountability; and public transport monitoring of buses and taxis for route and safety compliance.

2. SOFTWARE REQUIREMENTS

A. Embedded Software (ESP32Firmware)

The embedded firmware forms the core of the IVMS, handling sensor data acquisition, real-time processing, decision-making, and communication with cloud and GSM networks. The development environment uses Arduino IDE or Platform IO with C++ programming, the ESP32 board package by Espressif Systems, FreeRTOS for multitasking support, and USB-to-Serial upload via CP2102 or CH340 driver.

B. Core Algorithms and Logic

The main program uses a continuous sensor data acquisition loop that reads all sensors (GPS, fuel, temperature, accelerometer) asynchronously to prevent data blocking. Moving averages filter sensor values to reduce noise. Key event detection algorithms include: Fuel Theft Detection (sudden voltage drop in fuel sensor triggers an alert); Overheating Detection (engine temperature exceeding 90°C triggers buzzer and cloud alert); Accident Detection (high G-force from MPU6050 triggers an emergency message); and Engine Health Monitoring (OBD-II checks for Diagnostic Trouble Codes). On detecting an event, the system executes in order: (1) activates buzzer and LED indication; (2) sends an SMS through the GSM module; and (3) uploads event data to Firebase with timestamp and GPS coordinates. The firmware supports remote engine lock/unlock commands from the mobile app parsed from Firebase in real time, with safe shutdown and auto-restart recovery on power loss.

C. Cloud Backend (Firebase)

Google Firebase acts as the central data management platform for IVMS. Data is stored in JSON format with each vehicle assigned a unique UUID. The bidirectional data flow operates as follows: (1)the ESP32 continuously sends live data packets to Firebase via HTTPS; (2) Firebase updates the live Data node in real time; (3) the mobile app receives instant updates via Web Socket event listeners; (4) when the user sends a command (e.g.,Engine Lock),Firebase updates the command node; and (5) the ESP32 listens for command changes and executes them immediately.

D. Mobile Application Software

The mobile application is developed in Flutter (Dart) or React Native (JavaScript), interfacing with Firebase SDK and Google Maps API for visualization. Key features include: a real-time map showing live vehicle location; live data display for speed, fuel, and temperature; push notification alerts via FCM; and a control panel for remote engine lock/unlock and SOS commands. Table III summarizes the communication protocols used across the system.

3. HARDWARE IMPLEMENTATION

ESP32 Microcontroller

The ESP32 (Qty: 1) serves as the main control unit of the entire IVMS. It is based on the Xtensa LX6 dual-core processor with built-in Wi-Fi and Bluetooth (Classic + BLE). Key features include multiple GPIO pins, low power consumption, ADC/DAC support, and Free RTOS multitasking. The ESP32 collects data from all sensors, processes it locally, transmits to Firebase via Wi-Fi, and triggers GSM alerts during network failures.

ESP32Microcontroller

GPS Module (NEO-6M)

The NEO-6M GPS module (Qty: 1) provides high-accuracy real-time location tracking. Features include 50- channel receiver with -161 dBm tracking sensitivity, UART communication, built-in EEPROM for configuration storage, and ceramic antenna for improved reception. In the IVMS, it continuously parses NMEA sentences to extract latitude, longitude, speed, and time, which are transmitted to Firebase for cloud-based livemap tracking.

GPS Module (NEO-6M)

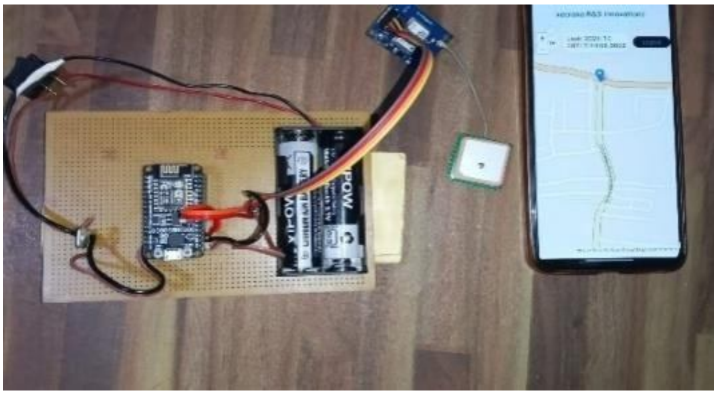
5.3.Power Supply Unit

The power supply unit (Qty: 1) provides a stable 5V regulated output to power the ESP32, GPS module, and other peripherals. It uses a bridge rectifier with an RC filter and a 7805 linear voltage regulator to ensure consistent output regardless of input voltage variations, protecting sensitive electronic components from power fluctuations.

PowerSupply Unit

5.4. Additional Components

The system includes a manual ON/OFF switch for system control (5VDC compatible, compact and durable design), an LCD display for real-time parameter visualization, LED indicators (green for normal, red for alert conditions), and a buzzer for audible fault alerts. GPS tracking is further supported through mobile applications such as Google Maps and platform-native tracking apps, which interface with the Firebase backend for real-time location visualization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5.5 Top GPS Tracking Apps

4. RESULTS AND DISCUSSION

A. Sensor Calibration and System Testing

The IVMS prototype was designed and simulated using Arduino IDE and tested under various operating conditions. Each sensor module GPS, temperature, fuel, and vibration was calibrated to ensure accuracy and reliability before integration into the complete IoT framework.

GPS Module Performance

The NEO-6M GPS module was tested for location accuracy, signal stability, and data refresh rate. GPS coordinates were compared against GoogleMaps readings for verification. The average positional error was less than 12meters,acceptablefor vehicle-level tracking.The1Hz GPS update rate ensured smooth real-time location monitoring through Firebase. Table IV summarizes GPS accuracy test results.

B. Cloud and Mobile Application Testing

The system was linked to Google Firebase Real time Database, with data visualization achieved through a custom mobile application.

The app displayed real-time parameters including speed, fuel, temperature, and location, along with system alerts. Two operational modes were validated: Normal Mode (displaying real-time data with green indicators) and Alert Mode (changing interface to red with alert type, timestamp, and location when faults such as "Fuel Drop" or "Overheat Detected" occur). The mobile interface successfully received push notifications and displayed live map tracking through Google Maps API with negligible delay.

C. System Integration and End-to-End Testing

The complete hardware setup was tested for end-to-end performance with all modules connected simultaneously (ESP32, GPS, GSM, temperature, and fuel sensors). Results confirmed: stable and continuous data flow from sensors to microcontroller to Firebase to mobile app; no interference between simultaneous GPS and GSM module operation; automatic fallback to GSM SMS alerts when Wi-Fi connectivity was lost; and successful retrieval of cloud-stored historical logs for past alert event analysis. The system exhibited consistent communication with minimal packet loss, validating the reliability of the proposed architecture for real-world deployment.

D. Comparative Analysis

Table V presents a comparative analysis of the proposed IVMS against existing vehicle monitoring systems. The proposed IVMS clearly outperforms existing systems in terms of integration, connectivity, automation, and user accessibility.

E. Overall System Performance Discussion

The experimental and simulation results confirm that the IVMS achieves its design objectives effectively. The GPS module provided accurate, stable tracking data with average error below 12 meters. Sensors demonstrated reliable measurement and detection capabilities across all tested conditions. The ESP32 firmware efficiently handled simultaneous tasks including data acquisition, cloud communication, and event control. The Firebase backend ensured fast and secure data synchronization. The mobile application successfully visualized and controlled vehicle operations in real time. The total system response time remained below 3seconds, suitable for critical vehicle monitoring scenarios. The IVMS prototype proved efficient, cost-effective, and scalable, making it adaptable for both personal and commercial vehicle applications.

5. CONCLUSION

The Integrated Vehicle Monitoring System (IVMS) was successfully designed, implemented, and simulated to demonstrate the effectiveness of IoT-based monitoring in vehicular applications. The system integrates multiple hardware and software components including ESP32,GPS (NEO-6M), GSM (SIM800L), multi-parameter sensors, Firebase cloud backend, and a Flutter-based mobile application to provide a comprehensive real-time monitoring solution. Key achievements include continuous vehicle tracking and parameter monitoring through GPS and sensors; dual communication support (Wi-Fi and GSM) ensuring uninterrupted connectivity even in low-network areas; automatic event detection and alert transmission with response times within 3 seconds; and bidirectional control through the mobile application for remote engine lock/unlock and SOS commands. The prototype was thoroughly tested and validated through simulation and experimental trials, with results confirming high system accuracy, reliability, and quick response time. The proposed IVMS provides a unified, cost-effective, and scalable solution for modern transportation systems. By combining IoT connectivity, automation, and cloud intelligence, it bridges the technological gap between traditional vehicle systems and emerging smart mobility frame works, opening the path toward intelligent transport management and enhanced road safety.

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