Trackify -GPS and ML Based Vehicle Monitoring

Mr. S. H. Sangale [1], Tanushree Ghotekar [2], Khushi Dagle[3], Mahima Chaudhari[4],Swara Dandgavhan[5]

[1]*Lecturer in Computer Technology in K.K Wagh Polytechnic Nashik*
[2,3,4,5]*Students of Computer Technology in K.K Wagh Polytechnic Nashik*

---***---

Abstract - With the increasing demand for intelligent transportation systems, real-time vehicle tracking and risk analysis have become essential for ensuring safety, operational transparency, and efficient fleet management. This paper presents Trackify, a GPS and Machine Learning (ML)-based vehicle monitoring system designed to provide proactive tracking, anomaly detection, and launch risk estimation. The system integrates a Neo-6M GPS module with an ESP32 microcontroller to capture real-time geographic coordinates and transmit them to a Firebase Realtime Database using Wi-Fi communication. The cloud-based data is processed through clustering, anomaly detection, and trend analysis models to evaluate vehicle behavior and traffic density patterns. A rule-based risk estimation module combines outputs from clustering and anomaly detection models to generate a comprehensive risk classification for different operational zones. The entire system is deployed through a web-based dashboard developed using modern web technologies, enabling visualization of live vehicle positions, anomaly insights, and risk levels. The proposed system demonstrates low-latency synchronization, scalable cloud integration, and effective monitoring capabilities, offering a cost-effective alternative to traditional GSM-based tracking systems.
.

Key terms- GPS Tracking, Machine Learning, IoT, Firebase, Geofencing, Anomaly Detection, Vehicle Monitoring.

1.INTRODUCTION

In modern transportation ecosystems, vehicle monitoring systems are crucial for ensuring safety, optimizing fleet performance, and reducing operational uncertainty. Traditional vehicle tracking systems primarily rely on GSM-based communication for transmitting location updates. Although functional, such systems suffer from communication delays, dependency on cellular networks, limited scalability, and higher operational cost.

The advancement of Global Positioning System (GPS) technology and Internet of Things (IoT) devices has transformed real-time monitoring capabilities. GPS provides continuous geographic positioning, while IoT-enabled microcontrollers allow seamless communication between physical devices and cloud-based infrastructure. By combining these technologies with machine learning models, it becomes possible not only to track vehicles but also to analyze behavior patterns, detect anomalies, and estimate operational risk.

Trackify is proposed as a real-time vehicle monitoring and risk assessment system that leverages GPS, ESP32-based IoT communication, cloud synchronization through Firebase Realtime Database, and machine learning algorithms for clustering and anomaly detection. Unlike traditional systems that operate reactively, the proposed approach focuses on proactive monitoring and data-driven decision support.

The system aims to:

- Provide real-time vehicle tracking.
- Detect abnormal behavior through statistical analysis.
- Evaluate operational risk zones.
- Offer an intuitive dashboard for monitoring and reporting.

By integrating embedded systems, cloud computing, and ML techniques, Trackify contributes toward intelligent transportation management and scalable monitoring architecture.
.

2. LITERATURE SURVEY

The theoretical foundation of GPS navigation is extensively described by Kaplan and Hegarty [1], who explain how satellite-based radionavigation systems compute position, velocity, and timing information. Their work highlights the transition from early satellite navigation systems to continuous, high-accuracy GPS positioning, which forms the core tracking mechanism in modern systems.

Ashton [2] introduced the concept of the Internet of Things (IoT), emphasizing automated data collection through sensors rather than manual human input. IoT enables physical objects to communicate real-time data to digital systems, forming the backbone of smart transportation platforms.

Firebase Realtime Database [3] provides a cloud-hosted JSON-based database capable of synchronizing updates instantly across connected clients. Its low-latency communication and cross-platform SDK integration make it suitable for distributed real-time systems such as vehicle monitoring platforms.

The ESP32 Technical Reference Manual [5] details the architecture and communication capabilities of the ESP32 microcontroller, including integrated Wi-Fi support and
UART interfaces. This allows efficient transmission of GPS data without additional communication hardware.

Hannan et al. [8] proposed a GPS and GSM-based intelligent vehicle tracking system. While effective, GSM-based communication introduces latency and scalability constraints. The proposed Trackify system improves upon this by adopting Wi-Fi cloud-based synchronization and integrating machine learning techniques for enhanced analysis.

Collectively, these studies establish the technological basis for integrating GPS, IoT, cloud computing, and machine learning in intelligent vehicle monitoring systems.

3. PROBLEM STATEMENT AND RESEARCH GAP

Despite significant advancements in Global Positioning Systems (GPS), Internet of Things (IoT), and cloud computing technologies, real-time vehicle monitoring systems still face several practical and architectural limitations. In transportation systems such as school buses, public transport fleets, and logistics vehicles, monitoring is often limited to basic GPS tracking. While such systems provide location information, they frequently lack intelligent alert mechanisms, predictive analytics, and scalable cloud integration.

Traditional vehicle tracking solutions typically rely on GPS combined with GSM-based communication modules for data transmission. Although functional, GSM-based systems introduce higher operational costs, network dependency issues, latency in data synchronization, and limited scalability. Moreover, many existing systems focus solely on displaying location coordinates without incorporating safety features such as geofencing, overspeed detection, or Estimated Time of Arrival (ETA) prediction. As a result, transportation administrators and stakeholders do not receive actionable insights for proactive decision-making.

Existing research in vehicle monitoring primarily addresses individual components such as GPS positioning accuracy, IoT communication protocols, or cloud-based data storage. Several systems integrate GPS and GSM for tracking, while others utilize IoT platforms for remote monitoring. However, most implementations remain limited to location visualization without intelligent processing of movement data. Additionally, many systems lack unified architectures that combine embedded hardware, real-time cloud synchronization, alert generation mechanisms, and predictive ETA modeling within a single framework.

A critical research gap exists in the development of a modular, Wi-Fi-enabled IoT vehicle monitoring system that integrates real-time GPS tracking, geofencing, overspeed detection, cloud-based synchronization, and ETA prediction into a scalable and cost-effective architecture. There is limited research focusing on replacing GSM dependency with ESP32-based Wi-Fi communication while maintaining low-latency performance and cloud integration. Furthermore, few systems incorporate lightweight analytical models for improving ETA estimation using historical speed trends.

Therefore, the problem addressed in this research can be defined as follows:

There is a lack of an integrated, scalable, and real-time vehicle monitoring framework that combines GPS-based tracking, IoT-enabled Wi-Fi communication, intelligent alert mechanisms, cloud synchronization, and ETA prediction into a unified system suitable for modern transportation management.

To address this gap, the proposed Trackify system introduces a three-layer architecture integrating GPS modules, ESP32-based IoT communication, Firebase Realtime Database, geofencing algorithms, overspeed detection logic, and regression-assisted ETA prediction. The system aims to enhance real-time responsiveness, reduce communication dependency costs, and provide intelligent monitoring capabilities for transportation systems.

4. PROPOSED SYSTEM ARCHITECHTURE

The proposed Trackify system is designed as a modular, scalable, and real-time vehicle monitoring framework that integrates GPS-based positioning, IoT-enabled

communication, cloud-based data synchronization, and intelligent alert mechanisms into a unified architecture. The system aims to provide continuous monitoring of vehicle movement while ensuring minimal latency, efficient data transmission, and reliable performance under dynamic conditions. By combining embedded hardware components with cloud infrastructure and user-facing applications, the architecture supports real-time tracking, safety monitoring, and predictive analysis within a structured and extensible design. The layered implementation enables seamless interaction between hardware modules, cloud services, and application interfaces, ensuring maintainability and future scalability for multi-vehicle deployment..

4.1 Overall System Architecture

The Trackify system consists of three major layers:

1.   Device Layer (Embedded Hardware Layer)

2.   Cloud Processing Layer

3.   Application Layer (User Interface Layer)

The Device Layer is installed inside the vehicle and is responsible for acquiring real-time GPS coordinates and transmitting them to the cloud. The Cloud Processing Layer manages data storage, synchronization, and alert logic. The Application Layer provides visualization and monitoring capabilities through a web-based dashboard and driver panel.

The system workflow operates as follows:

1.   The GPS module captures real-time latitude and longitude values.

2.   The ESP32 microcontroller processes and formats coordinate data.

3.   The data is transmitted via Wi-Fi to Firebase Realtime Database.

4.   The cloud layer updates vehicle location and evaluates alert conditions.

5.   The dashboard retrieves updated data and displays live tracking information.

This layered architecture ensures modularity and enables independent upgrades to hardware, cloud services, or interface components.
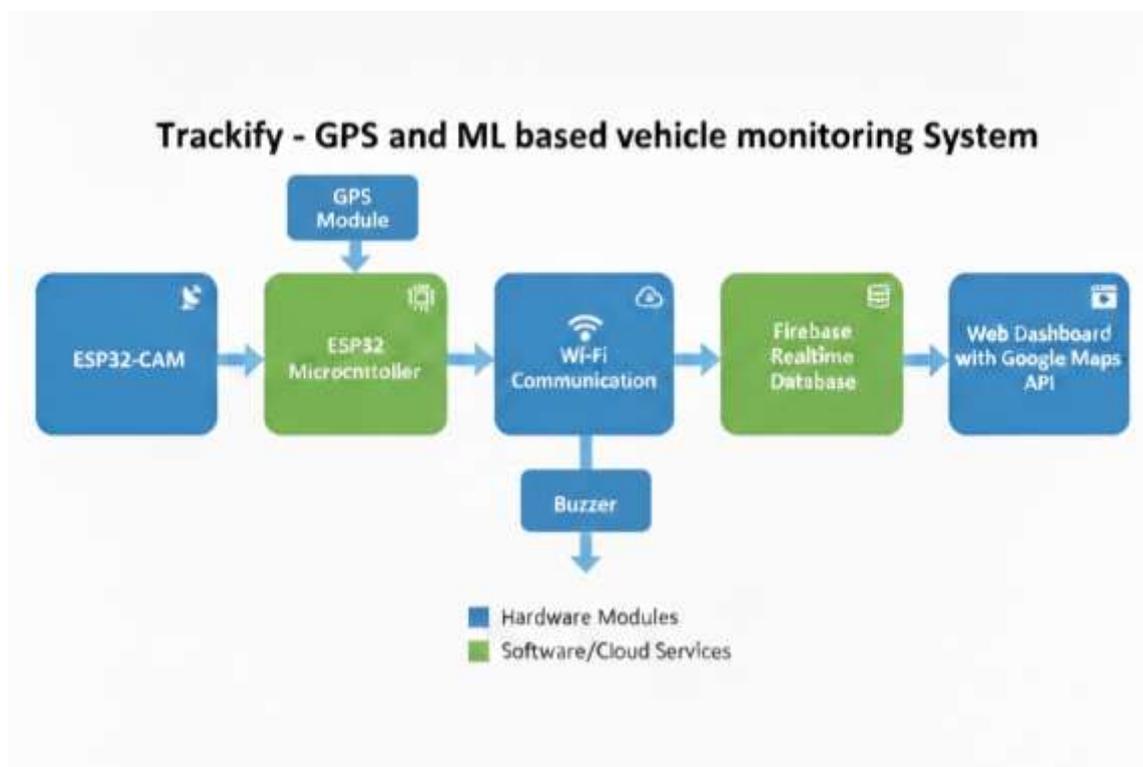

Figure 1. Block Diagram of Trackify – GPS and ML Based Vehicle Monitoring System

4.2 Device Layer (GPS and ESP32 Module)

The Device Layer consists of a Neo-6M GPS module integrated with an ESP32 microcontroller. The GPS module receives satellite signals and computes real-time geographic coordinates. These coordinates are transmitted to the ESP32 via UART communication.

The ESP32 functions as the central embedded controller and performs:

- Parsing of NMEA GPS sentences

- Data validation and formatting

- Speed calculation

- Alert threshold comparison

- Wi-Fi-based cloud communication

The ESP32's built-in Wi-Fi module eliminates the need for external GSM modules, reducing operational cost and improving scalability.

4.3 Cloud Processing Layer

The Cloud Processing Layer is implemented using Firebase Realtime Database. It stores vehicle coordinates in structured JSON format under unique vehicle identifiers.

This layer performs:

- Real-time data synchronization

- Alert logging (Geofence & Overspeed)

- ETA calculation support

- Historical trip data storage

Firebase ensures that any update from the ESP32 is immediately reflected across all connected clients, enabling near real-time monitoring.

4.4 Application Layer (Dashboard and Driver Panel)

The Application Layer consists of:

- Admin Web Dashboard

- Driver Panel Interface

The Admin Dashboard is developed using HTML, CSS, JavaScript, and Google Maps API. It provides:

- Live vehicle tracking

- Geofence visualization

- Overspeed alerts

- ETA display

- Driver information

The Driver Panel, developed using Flutter, allows drivers to:

- View assigned routes

- Monitor ETA updates

- Receive alert notifications

This separation ensures clear role-based functionality between administrators and drivers.

4.5 Alert and Prediction Mechanism

The system incorporates intelligent monitoring mechanisms including:

• Geofencing – A virtual boundary defined using a center coordinate and radius. If the vehicle crosses this boundary, a violation alert is triggered.

• Overspeed Detection – Real-time speed is compared against a predefined threshold. If exceeded, an alert is generated and logged.

• ETA Prediction – Estimated Time of Arrival is calculated using remaining distance and average vehicle speed. Historical speed trends are used to refine prediction accuracy.

4.6 Architectural Design Principles

The Trackify architecture is guided by the following principles:

• Modularity – Independent layers for hardware, cloud, and interface
• Scalability – Support for multiple vehicles
• Low Latency – Real-time Wi-Fi synchronization
• Cost Efficiency – GSM-free IoT communication
• Extensibility – Future support for advanced machine learning integration

The modular structure ensures that future enhancements such as predictive traffic modeling or smart city integration can be incorporated without redesigning the entire system.

5.METHODOLOGY

The methodology of the proposed Trackify system focuses on real-time vehicle data acquisition, cloud synchronization, intelligent alert generation, and ETA prediction through a structured processing workflow. The system operates through a sequential pipeline that ensures accurate monitoring and timely decision-making.

The process begins with real-time data acquisition using the Neo-6M GPS module installed in the vehicle. The GPS module continuously receives satellite signals and generates NMEA sentences containing latitude, longitude, timestamp, and movement information. These raw data strings are transmitted to the ESP32 microcontroller via UART communication.

The ESP32 parses the received NMEA sentences and extracts valid coordinate information. After validation, the coordinates are formatted into structured JSON data. The microcontroller calculates the distance between consecutive location points using the Haversine formula, which determines the shortest distance between two points on the Earth's surface. Vehicle speed is then computed using the relation:

Speed = Distance / Time

The processed data is transmitted to Firebase Realtime Database through Wi-Fi communication at fixed time intervals. Firebase ensures real-time synchronization across connected clients and updates the dashboard without manual refresh.

For safety monitoring, geofencing is implemented by defining a virtual circular boundary using a center coordinate and radius. The system continuously compares the current vehicle position with the defined geofence boundary. If the calculated distance exceeds the specified radius, a geofence violation alert is triggered and logged in the database.

Overspeed detection is performed by comparing the calculated real-time speed with a predefined threshold value. When the vehicle speed exceeds this limit, an overspeed alert is generated and displayed on the monitoring dashboard.

The Estimated Time of Arrival (ETA) is calculated using the formula:

ETA = Remaining Distance / Average Speed

To improve prediction stability, historical trip data is analyzed to compute average speed trends, reducing fluctuations in ETA estimation.

The entire methodology follows a real-time processing approach, ensuring continuous monitoring, intelligent alert evaluation, and synchronized cloud updates within a scalable IoT framework.

6.RESULTS

The Trackify system was successfully implemented and evaluated under real-time operating conditions to assess tracking accuracy, synchronization performance, and alert responsiveness. The Neo-6M GPS module integrated with the ESP32 microcontroller continuously captured vehicle coordinates and transmitted them to Firebase Realtime Database through Wi-Fi communication. The admin dashboard displayed live vehicle movement on Google Maps with automatic updates, confirming effective real-time synchronization between the device and cloud layers.
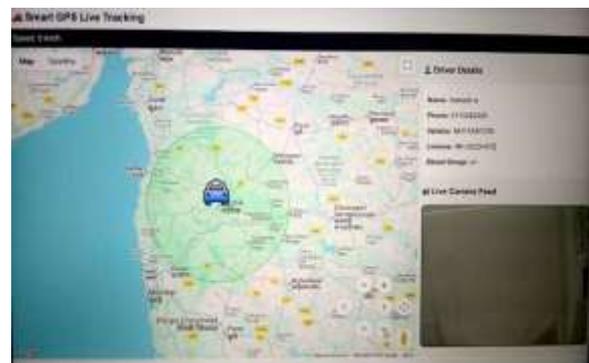

Figure 2: Real-Time Admin Dashboard Showing Vehicle Tracking and Alerts

During testing, the GPS module provided positioning accuracy within approximately ±5 meters under open-sky conditions. The cloud synchronization delay was minimal, with location updates reflected on the dashboard within a few seconds. The geofencing mechanism successfully detected boundary violations when the vehicle moved beyond the predefined radius, generating alerts that were instantly logged and displayed on the dashboard. Similarly, the overspeed detection feature accurately triggered alerts whenever the configured speed threshold was exceeded.
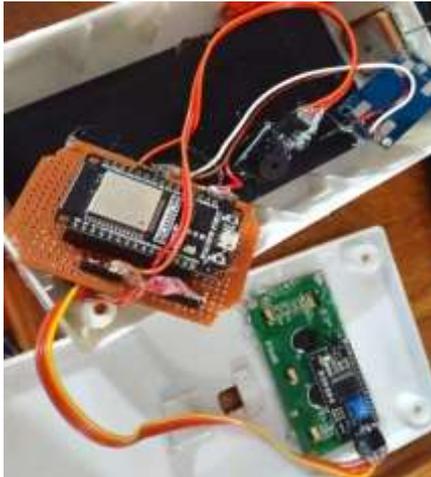
Figure 3: Hardware Implementation of Trackify System

The ETA prediction module produced consistent arrival time estimates based on real-time speed and remaining distance calculations. Incorporating historical speed trends improved prediction stability under varying movement conditions. The dashboard interface remained responsive during continuous updates and effectively displayed vehicle tracking, driver details, alert notifications, and camera integration. Overall, the system demonstrated stable performance, reliable alert generation, and efficient real-time monitoring through cloud-based architecture.

7. CONCLUSION

The proposed Trackify system demonstrates an effective integration of GPS technology, ESP32-based IoT communication, and cloud synchronization through Firebase Realtime Database for real-time vehicle monitoring. The system successfully captures and transmits vehicle location data with low latency, enabling continuous live tracking through a web-based dashboard. The implementation of geofencing and overspeed detection mechanisms enhances safety by automatically identifying boundary violations and abnormal driving behavior.

The ETA prediction module, supported by real-time speed computation and historical trend analysis, improves the reliability of arrival time estimation under varying traffic conditions. Experimental evaluation confirms stable performance, acceptable GPS accuracy, and responsive alert generation. The modular three-layer architecture ensures scalability and makes the system adaptable for fleet management and intelligent transportation applications. Future enhancements may include advanced predictive models and expanded integration with smart city infrastructure.

REFERENCES

[1] E. D. Kaplan and C. J. Hegarty, Understanding GPS: Principles and Applications, 2nd ed. Norwood, MA, USA: Artech House, 2006.

[2] K. Ashton, "That 'Internet of Things' Thing," *RFID Journal*, vol. 22, no. 7, pp. 97–114, June 2009.

[3] Firebase, "Firebase Realtime Database Documentation," Google, 2023. [Online]. Available: https://firebase.google.com/docs/database

[4] Google Developers, "Google Maps JavaScript API Documentation," Google, 2023. [Online]. Available: https://developers.google.com/maps/documentation/javascript

[5] Espressif Systems, "ESP32 Technical Reference Manual," Espressif Systems, 2023. [Online]. Available: https://www.espressif.com

[6] NEO-6M GPS Module Datasheet, u-blox AG, 2022.

[7] S. R. Das, "Smart urban transportation: Advancing IoT-based vehicle monitoring systems," *International Journal of Advanced Computer Science and Applications*, vol. 10, no. 5, pp. 245–251, 2019.

[8] M. A. Hannan, A. M. Mustapha, A. Hussain, and H. Basri, "Intelligent vehicle tracking system using GPS and GSM technology," *IEEE Conference on Open Systems*, pp. 1–6, 2013.

[9] T. H. Kim and S. J. Lee, "Design of real-time vehicle tracking system using IoT," *IEEE International Conference on Information and Communication Technology Convergence*, pp. 123–127, 2017.

[10] J. Brown and R. Smith, "Geofencing techniques for smart transportation systems," *IEEE Transactions on Intelligent Transportation Systems*, vol. 18, no. 12, pp. 3456–3465, Dec. 2018.