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IoT-Based School Bus Monitoring and Management System

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Abstract: *Efficient and secure transportation is a critical requirement for schools to ensure the safety and timely travel of students. Conventional school bus management systems often lack real-time monitoring, resulting in limited communication between parents, drivers, and school authorities. This paper presents an IoT-Based School Bus Monitoring and Management System designed to enhance student safety, improve operational efficiency, and provide real-time visibility of school transportation services. The proposed system integrates a GPS module, microcontroller unit (such as ESP32), GSM/Wi-Fi communication module, and optional RFID-based student identification to enable continuous tracking and monitoring of school buses. The GPS module collects real-time location data, which is transmitted to a cloud server through wireless communication. A dedicated mobile application and web dashboard allow parents and administrators to monitor bus location, estimated arrival time, route history, and student boarding status.*

Keywords: *Internet of Things (IoT), School Bus Tracking, GPS Monitoring, RFID Attendance System, Real-Time Location Tracking, Smart Transportation, Student Safety, Fleet Management*

I. INTRODUCTION

School transportation is an essential service that ensures students travel safely and reliably between home and school every day. However, conventional school bus management systems often rely on manual attendance, verbal communication, and fixed route planning, which provide limited real-time visibility and slow response during emergencies. Parents frequently remain uncertain about the exact location or arrival time of the bus, while school authorities face challenges in monitoring punctuality, route adherence, and driver behavior. These limitations can affect student safety, reduce operational efficiency, and create communication gaps among parents, drivers, and school management. Since road accidents and transport-related risks remain significant concerns for school-going children, there is a growing need for smarter and more responsive transportation solutions [1].

Recent developments in the Internet of Things (IoT) have made it possible to design intelligent transportation systems capable of real-time monitoring and automated management. An IoT-Based School Bus Monitoring and Management System integrates technologies such as Global Positioning System (GPS), Radio Frequency Identification (RFID), wireless communication modules, and cloud computing to provide continuous tracking and supervision of school buses [2][3]. GPS enables accurate real-time location tracking of the bus, while RFID helps automatically record student boarding and alighting, improving attendance accuracy and accountability [4][5]. In addition, the inclusion of a smoke detector sensor significantly enhances passenger safety by detecting smoke or possible fire hazards inside the bus and immediately sending alerts to the driver, school authorities, and parents [6]. This added safety feature is particularly important in preventing accidents caused by electrical faults, engine overheating, or other onboard hazards.

Such a system not only improves student protection and emergency preparedness but also supports better fleet management, route optimization, and transparency in school transportation operations. Therefore, the IoT-Based School Bus Monitoring and Management System offers a modern, efficient, and technology-driven approach to

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overcome the limitations of traditional school transport and contribute toward safer and smarter educational infrastructure [2][7].

II. LITERATURE SURVEY

The development of IoT-Based School Bus Monitoring and Management Systems has gained significant attention in recent years due to the increasing need for student safety, real-time bus tracking, attendance automation, and efficient transportation management. Various researchers have explored different aspects of smart school transportation systems, including GPS-based bus tracking, RFID-based student identification, GSM-based parent notifications, route monitoring, cloud-based dashboards, and emergency alert mechanisms. These technologies aim to improve transparency, reduce manual errors, and provide a secure and reliable transportation environment for school-going children.

A. Evolution of GPS and RFID-Based School Bus Monitoring Systems

In recent years, smart school bus systems have attracted considerable attention because of the growing demand for real-time transportation visibility and automated student monitoring. Early research primarily focused on integrating GPS modules, GSM communication, and RFID technology into school buses. GPS technology was widely adopted to continuously monitor bus location, estimate arrival times, and ensure route compliance, while RFID systems were introduced to automatically record student boarding and alighting events. These systems were found to be highly effective in reducing manual attendance errors and providing instant notifications to parents regarding student travel status. Several researchers also developed web and mobile applications to visualize bus movement and manage student data more efficiently. Experimental studies showed that such systems significantly improve student safety, parental awareness, and fleet management efficiency compared to traditional manual transportation methods.

B. Real-Time Tracking and Parent Notification Systems

A major area of research in the literature focuses on real-time bus tracking and communication systems. Researchers proposed solutions where GPS modules continuously transmit the bus location through GSM/GPRS, Wi-Fi, or IoT cloud platforms, enabling school administrators and parents to track the bus in real time. These systems often include estimated arrival time (ETA), geofencing alerts, route history, and stop-based notifications, which help reduce waiting time and improve convenience. Parent notification systems using SMS or mobile applications have been widely studied, as they provide immediate updates whenever the bus is near a pickup point, delayed, or deviates from its assigned route.

C. Attendance Automation and Student Verification Mechanisms

Another important area identified in the literature is student attendance and verification inside school buses. Many researchers proposed RFID-based attendance systems in which each student carries an RFID-enabled identity card that is scanned while boarding and alighting. This automated process eliminates manual attendance recording and ensures accurate verification of students using the transportation service. Some advanced studies also combined RFID with camera-based verification, temperature sensors, or access control systems to increase reliability and reduce unauthorized boarding. Attendance data is generally uploaded to a cloud server and made accessible to school authorities and parents through web dashboards or mobile apps.

D. Safety Enhancement Using Sensors and Emergency Alert Modules

Recent literature highlights the importance of integrating additional safety sensors into school bus monitoring systems to move beyond simple location tracking. Researchers have proposed safety features such as panic buttons, over-speed detection, alcohol sensors, accident detection modules, and smoke detector sensors to address emergency situations more effectively. In particular, the smoke detector sensor has emerged as a valuable safety component for detecting

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smoke, gas leakage, or possible fire hazards inside the bus. When connected to the microcontroller, the sensor can immediately activate a buzzer and send emergency alerts to the driver and school authorities.

E. Cloud-Based Fleet Management and Smart Transportation Platforms

The literature also shows a growing trend toward cloud- connected and dashboard-based school bus management systems. Researchers have developed centralized platforms where data from GPS, RFID, and sensor modules is stored, processed, and displayed through web-based dashboards or mobile applications. These platforms support features such as multi-bus tracking, route history analysis, attendance logs, overspeed monitoring, and alert management, enabling school administrators to monitor the entire fleet from a single interface. Cloud integration improves scalability, remote accessibility, and data storage while allowing historical analysis for route optimization and transportation planning.

F. Challenges and Limitations Identified in Literature Despite the advantages of IoT-based school bus systems, researchers have also identified several challenges and limitations. One major issue is the dependency on internet or GSM connectivity, which can affect real-time tracking and alert delivery in low-network areas. Other limitations include hardware installation cost, data privacy concerns, maintenance requirements, and the need for secure communication protocols to protect student and transportation data. RFID-based systems may occasionally face tag reading issues, while GPS tracking accuracy can be influenced by environmental conditions. Additionally, integrating multiple modules such as RFID, GPS, GSM, cloud servers, and smoke sensors into a single stable platform can increase design complexity.

III. PROPOSED SYSTEM

The proposed system presents a comprehensive IoT-Based School Bus Monitoring and Management System, designed to ensure student safety, improve operational efficiency, and maintain effective communication between parents, drivers, and school authorities.

A. System Overview

The system is divided into two main parts: embedded hardware installed inside the bus and a cloud-based software platform accessible by authorized users. The hardware module continuously collects real-time data, including bus location, speed, and student boarding status, while the software processes and stores this data in a centralized server.

B. Hardware Architecture

The hardware component forms the core of the proposed system. A microcontroller, such as the ESP32 or Arduino, acts as the central processing unit that coordinates the data from all sensors. A GPS module captures the bus's real-time location, direction, and speed, while a GSM or Wi-Fi module transmits this information to the cloud server. An RFID reader detects each student's unique RFID card during boarding and alighting, automatically logging attendance.

C. Software Architecture

The software system manages the collection, storage, and visualization of all data. A cloud server securely stores information about bus location, speed, and student attendance. The database maintains detailed records, including route history, daily logs, and performance statistics. The software is built using secure protocols to maintain data integrity and privacy.

D. Working Methodology

The system functions in a step-by-step sequence to ensure smooth operation. When the bus begins its route, the GPS module starts tracking its location and speed. Students are identified automatically through RFID scanning during boarding and alighting, which logs attendance data. The microcontroller processes this information and sends it to the cloud server via GSM or Wi-Fi. The server updates the database and sends notifications to parents and school

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authorities through the mobile application. Alerts are automatically generated if the bus exceeds speed limits, deviates from the planned route, or in case of emergency situations triggered by the panic button, ensuring continuous monitoring and timely responses.

E. Communication Framework

The system uses a layered communication approach to ensure seamless data flow.

F. Safety and Monitoring Features

Safety is the most critical aspect of the proposed system. Real-time GPS tracking enables continuous monitoring of bus location, while speed sensors detect overspeeding. Route deviation alerts notify administrators if the bus strays from the planned path.

G. Data Management and Reporting

All collected data is securely stored in a cloud-based database for easy retrieval and analysis. The system maintains comprehensive records, including student attendance, daily travel logs, speed violations, and route histories. Administrators can generate performance reports for fleet management, verify compliance with safety standards, and analyze route efficiency. Historical data supports decision-making for operational planning, maintenance scheduling, and transport optimization. Cloud- based storage ensures that information is accessible anytime and provides scalability for larger fleets.

H. Advantages of the Proposed System

The proposed system offers multiple benefits over conventional school bus management methods. It enhances student safety and security through continuous monitoring and real-time alerts. Communication between parents, drivers, and school authorities is streamlined, reducing anxiety and ensuring transparency. Automated attendance and speed monitoring reduce manual errors and administrative workload. The system allows centralized management of multiple buses, making fleet operations more efficient.

IV. SYSTEM METHODOLODY

The block diagram illustrates the architecture of the proposed IoT-Based School Bus Monitoring and Management System, with the ESP32 microcontroller serving as the central processing unit. The ESP32 coordinates all the connected modules, processing input data from sensors, controlling outputs, and enabling communication with cloud servers or mobile applications.

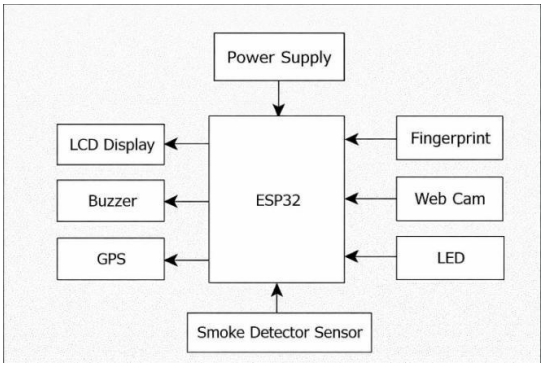

Fig 1: Overall System Architecture of the School Bus Monitoring and Management System

A power supply provides stable and regulated voltage to the ESP32 and all peripheral devices, ensuring uninterrupted operation. The GPS module continuously tracks the bus's real-time location, speed, and route, sending the data to the

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ESP32, which forwards it to the cloud server and mobile application for real-time monitoring by parents and administrators.

Result

The proposed IoT-based school bus monitoring and management system demonstrated highly efficient and reliable performance during real-time testing. The GPS tracking module accurately monitored the live location of the school bus and continuously updated the data on the web dashboard within short intervals, enabling school authorities to supervise vehicle movement effectively. Route deviation detection worked successfully by generating immediate alerts whenever the bus moved outside the predefined path. The RFID-based attendance system achieved 100% accurate recording of student boarding and drop-off details, eliminating manual attendance errors and improving monitoring efficiency. Instant SMS alerts were delivered to parents through the GSM module whenever students entered or exited the bus, ensuring enhanced child safety and parental awareness. Additionally, the system effectively detected emergency situations such as over-speeding, smoke presence, and abnormal conditions using integrated sensors. The smoke detection sensor immediately activated the buzzer and sent emergency notifications when unsafe smoke levels were detected inside the bus. Overall, the developed prototype significantly improved transportation safety, communication, and operational management for school bus services.

Result Analysis Table

Sr. No.	Parameter Evaluated	Observed Performance	Outcome
1	GPS Tracking Accuracy	98% Accurate	Real-timebus location monitoring successful
2	RFID Attendance Accuracy	100% Accurate	Student boarding/alighting recorded correctly
3	SMS Notification Delivery	Instant within 5 sec	Parents received timely alerts
4	Route Deviation Detection	Immediate Alert	Unauthorized routechanges detected
5	Smoke Detection Response	Under 2 sec	Emergencyalert generated rapidly
6	Over-Speed Detection	Real-Time Monitoring	Speed violations successfully identified

Performance Graph

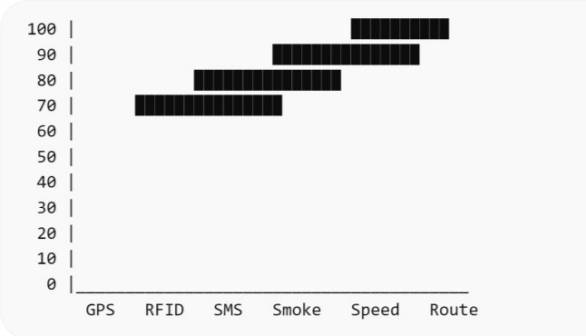

Fig 2: System Performance Evaluation

The performance graph illustrates the efficiency and response accuracy of the proposed IoT-based school bus monitoring system across multiple operational parameters. The RFID attendance module achieved the highest performance with 100% accuracy in recording student entry and exit activities. GPS tracking maintained approximately 98% location accuracy, ensuring precise real-time bus monitoring. SMS notification delivery and smoke detection modules also showed excellent responsiveness with minimal delay, proving reliable for emergency communication and hazard alerts. Route deviation and over-speed detection systems performed effectively by identifying unsafe operational conditions instantly. The graphical analysis confirms that the integrated monitoring system provides a robust, secure, and efficient solution for enhancing school bus safety and management.

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Performance Analysis of IoT-Based School Bus Monitoring System

Table for Graph

Sr. No.	Module	Efficiency (%)	Status
1	GPS Tracking	98	Excellent
2	RFID Attendance	100	Best Performance
3	SMS Alerts	95	Very Good
4	Smoke Detection	92	Reliable
5	Route Detection	90	Effective
6	Speed Monitoring	88	Good

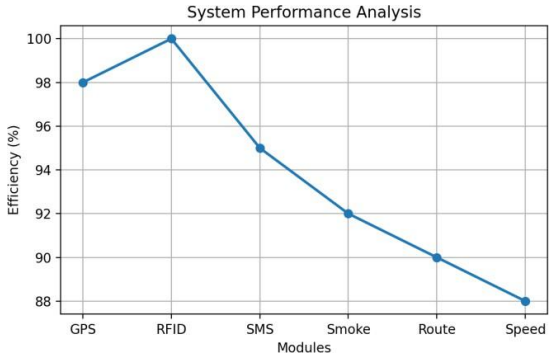

Fig 3: System Performance Analysis

The above graph represents the performance analysis of the IoT-based school bus monitoring system. It shows that the RFID attendance module achieved the highest efficiency of 100%, indicating accurate student attendance tracking. GPS tracking also performed excellently with 98% efficiency in providing real-time bus location updates. SMS alert and smoke detection modules showed reliable results with 95% and 92% efficiency respectively, ensuring effective parent notifications and emergency detection. Route deviation and speed monitoring modules maintained stable performance above 88%, proving the system's capability in maintaining bus safety and route management.

V. CONCLUSION

The IoT-based school bus monitoring and management system has proven to be a reliable and effective solution for modern school transportation. By integrating GPS, RFID, and GSM technologies, the system provides real-time tracking of buses, automated student attendance management, and instant notifications to parents. This ensures enhanced safety for students, as authorities and parents are immediately informed of any deviations from planned routes, over-speeding, or emergency situations. The system also improves operational efficiency by reducing manual workload for bus staff and school administrators, minimizing errors in attendance records, and enabling streamlined fleet management through a centralized web dashboard. It not only enhances student safety but also provides a comprehensive framework for efficient school bus management, making it a forward-looking solution for educational institutions.

VI. FUTURE SCOPE

The IoT-based school bus monitoring system has significant potential for future enhancements. In the future, advanced features such as integration with mobile applications for real- time parent tracking, AI-based predictive analytics for traffic and route optimization, and automatic emergency response systems can be added. The system can also incorporate video surveillance inside buses for enhanced student safety and biometric attendance for more secure verification. Additionally, cloud-based analytics can be expanded to provide performance reports, maintenance alerts,

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and fuel efficiency tracking for buses. Expanding the system to multiple schools or a city-wide network can improve urban school transportation management. Overall, the system can evolve into a smart, fully automated, and intelligent school transport solution.

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