

An IoT-Enabled School Transportation Safety Framework with Real-Time Vehicle Tracking and Monitoring

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Abstract

Student safety during transportation has become a significant concern with the increasing number of school-going children relying on bus services. Earlier transportation systems primarily depended on manual attendance recording and verbal communication between drivers, school authorities, and parents. Although these traditional methods were widely adopted, they often suffered from delays, human errors, lack of real-time monitoring, and inadequate security mechanisms. The absence of an automated student tracking facility made it difficult to verify whether a student had safely boarded or exited the vehicle, thereby creating concerns regarding accountability and safety. To address these challenges, this study presents an intelligent school bus safety and monitoring framework that integrates RFID technology, GPS tracking, GSM communication, Wi-Fi connectivity, and cloud-based IoT services. Each student is assigned a unique RFID card that is scanned while entering or leaving the bus. The system automatically records attendance events, controls access through an automated gate mechanism, and detects unauthorized card usage through an alert system. GPS functionality provides real-time location information, while Wi-Fi communication enables attendance and location data to be uploaded to a cloud server for remote monitoring. Additionally, GSM-based notifications can be delivered to registered guardians regarding student travel activities. The proposed approach eliminates the limitations of manual monitoring by providing automated attendance management, location awareness, secure access control, and instant communication. The significance of the study lies in enhancing student safety, improving transportation transparency, reducing human intervention, and enabling real-time monitoring capabilities. The integrated framework offers a reliable and efficient solution for modern school transportation management while supporting safer and more accountable travel operations.

Keywords: Smart School Bus, Student Safety, RFID, GPS Tracking, ESP32, IoT, Real-Time Monitoring, Attendance, CD-Drive, Child Safety, Fleet Management

1. Introduction

School transportation is one of the most critical safety responsibilities undertaken by educational institutions. Every day, millions of students across the world travel to and from school by bus, and ensuring their safety, punctuality, and accountability during this journey is a primary concern for parents, school administrators, and government transport regulators. Despite the scale and importance of school bus operations, the majority of school transportation systems continue to operate without any automated passenger identification, real-time location reporting, or remote monitoring capability. Parents have no way to know whether their child has boarded the bus, reached school, or departed safely, and school administrators lack visibility of bus locations and passenger counts throughout the day. The Smart School Bus Safety System proposed in this research addresses these limitations by deploying an ESP32-based embedded system on the school bus that integrates GPS-based real-time location tracking, RFID-based automated student identification, local data logging through a CD-Drive module, and IoT-based remote monitoring accessible by parents and school staff. When a student boards or alights the bus, their RFID card is scanned, and the system records the event with a timestamp, updates the LCD display, triggers a confirmation tone on the buzzer, stores the record on the CD-Drive, and transmits the information along with the current GPS location to the remote monitoring platform.

This enables real-time awareness of student whereabouts and bus location for all authorized stakeholders.

2. Literature Survey

R. Want [1] introduced the fundamental concepts of Radio Frequency Identification (RFID) technology, including tag-reader communication, operating frequencies, and system architecture. The study established RFID as a reliable automatic identification technology capable of providing contactless authentication and data acquisition. The work serves as the foundation for implementing RFID-based student identification and attendance monitoring in smart transportation systems. K. Finkenzerler [2] provided a comprehensive overview of RFID technologies, covering hardware components, communication protocols, security mechanisms, and practical deployment strategies. The author discussed various RFID standards and applications in access control and asset tracking. This work supports the design and implementation of RFID reader-tag communication for automated student boarding and attendance recording.

Kaplan and Hegarty [3] presented the principles and applications of the Global Positioning System (GPS), explaining satellite navigation, positioning techniques, and location accuracy factors. The authors analysed GPS signal processing methods and tracking performance under different operational environments. Their research provides the theoretical basis for integrating GPS modules into vehicle tracking and monitoring systems. Gubbi et al. [4] proposed a comprehensive vision for the Internet of Things (IoT) and described its architectural elements, enabling technologies, and future applications. The study emphasized seamless connectivity among smart devices through cloud-based infrastructures. Their work validates the use of IoT frameworks for real-time monitoring and communication in intelligent transportation applications.

Al-Fuqaha et al. [5] presented an extensive survey on IoT technologies, communication protocols, and application domains. The authors analysed protocols such as MQTT, CoAP, and wireless sensor networks, highlighting their role in reliable data transmission. The study supports the selection of IoT communication mechanisms for transmitting attendance and vehicle location information in real time. Suma et al. [6] developed an IoT-based smart security and home automation system capable of monitoring environmental conditions and generating remote alerts. The proposed system demonstrated efficient communication between sensors, controllers, and cloud platforms. Their findings validate the use of IoT-enabled notification mechanisms for student safety and parent alert services.

Jayashri and Rajmohan [7] proposed a Smart School Bus Monitoring System using RFID and GPS technologies. The system automatically identified students through RFID cards and tracked bus locations using GPS modules. Their work demonstrated the feasibility of integrating attendance monitoring with real-time vehicle tracking to improve school transportation safety. Adiono et al. [8] designed an IoT-based electricity monitoring system utilizing embedded controllers and wireless communication technologies. The study demonstrated efficient acquisition, processing, and cloud transmission of sensor data. The proposed architecture validates the embedded IoT communication framework adopted in intelligent school bus monitoring applications.

Kumar and Singh [9] developed a GPS and GSM-based vehicle tracking and safety system for real-time location monitoring. The system successfully transmitted vehicle coordinates to remote users through wireless communication networks. Their research supports the implementation of GPS-based tracking and remote notification mechanisms in school bus safety systems. Jain and Gupta [10] proposed an RFID-based student attendance and school bus tracking system that automated boarding verification and location monitoring. The system improved attendance accuracy and reduced manual intervention through RFID technology. The study demonstrates the practical applicability of combining RFID attendance management with GPS tracking in educational transportation.

Patel and Shah [11] developed a smart transportation monitoring framework using IoT and embedded systems technologies. The authors focused on real-time monitoring, data acquisition, and centralized management of transportation assets. Their work validates the deployment of embedded IoT architectures for fleet monitoring and passenger safety applications. Kumar and Bharti [12] introduced an ESP32-based IoT vehicle monitoring system integrated with GPS tracking functionality. The study highlighted the advantages of ESP32 microcontrollers in handling sensor data processing, wireless communication, and cloud connectivity. Their findings support the adoption of ESP32 as the central controller in smart school bus monitoring systems.

3. Proposed System

The proposed methodology presents an intelligent and automated student transportation monitoring framework that integrates RFID-based identification, IoT communication, GPS tracking, GSM notification services, and embedded control mechanisms to improve student safety during school bus travel. The methodology follows a structured workflow that begins with student authentication through RFID cards, followed by attendance verification, access control, location tracking, and cloud-based data transmission. By combining real-time monitoring with wireless communication technologies, the system provides accurate tracking of student boarding and deboarding activities while ensuring that transportation records are continuously updated and accessible remotely. The integration of multiple hardware and communication modules enables reliable operation, enhanced security, and improved transparency throughout the transportation process.

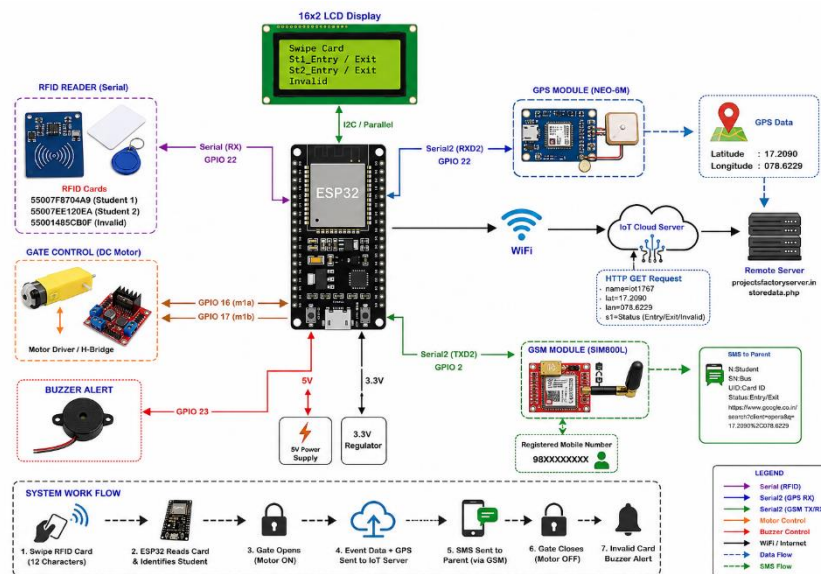


Figure 1: Proposed system architecture.

RFID Card Authentication Module

- Students are provided with unique RFID cards containing predefined identification numbers.
- When a card is swiped near the RFID reader, the reader captures the card ID and transmits it to the ESP32 controller through serial communication.
- The controller compares the received card information with the authorized records stored in the system.
- Based on the verification result, the student is identified as a valid or invalid user.
- This module serves as the primary access control mechanism for attendance monitoring.

ESP32 Control and Processing Unit

- The ESP32 acts as the central processing unit responsible for coordinating all system operations.
- It receives RFID data, validates student identities, controls peripheral devices, and manages communication with cloud and notification services.
- The controller processes entry and exit events, updates attendance status, and initiates subsequent actions such as gate control and data transmission.
- It also handles Wi-Fi connectivity and communication with external modules.

Student Entry and Exit Monitoring Module

- The system maintains separate attendance states for each registered student.
- During the first RFID scan, the student is marked as entered into the bus.
- During the next scan of the same RFID card, the student is marked as exited from the bus.
- Attendance status is updated automatically without requiring manual intervention.
- The generated attendance records are forwarded to cloud services for storage and monitoring.

Gate Control and Access Management Module

- After successful authentication, the ESP32 activates the motor control mechanism.
- The motor driver controls the gate movement by operating the DC motor connected to the bus entrance.
- The gate opens when an authorized student enters or exits.
- After the operation is completed, the gate returns to its normal position.
- This automated access control mechanism minimizes unauthorized entry and improves student safety.

LCD Display Module

- A 16×2 LCD module provides real-time visual feedback regarding system operations.
- It displays messages such as "Swipe Card", "Student Entry", "Student Exit", and "Invalid Card".
- The display helps students and operators understand the current status of the system.
- It also provides confirmation of successful attendance registration.

GPS Location Tracking Module

- The GPS module continuously acquires geographical coordinates of the school bus.
- Latitude and longitude values are extracted from GPS signals and processed by the controller.
- The location information is associated with attendance events to provide contextual tracking information.
- GPS data enables real-time monitoring of bus movement and location awareness.
- The generated coordinates are forwarded to cloud services and notification modules.

Wi-Fi Communication and IoT Cloud Module

- The ESP32 establishes a wireless connection through a Wi-Fi network.
- Attendance records and GPS coordinates are transmitted to a remote cloud server using HTTP requests.
- The server stores student status information, location details, and transportation events.
- Authorized users can access transportation records remotely through the cloud platform.
- This module enables centralized monitoring and long-term data storage.

GSM Notification Module

- The GSM module is responsible for sending SMS notifications to registered mobile numbers.
- Attendance events, student identification information, and location details are included in the transmitted messages.

- Parents or guardians receive immediate updates regarding student boarding and deboarding activities.
- The notification mechanism enhances communication and provides additional assurance regarding student safety.
- GPS coordinates may also be included in the message for location reference.

Buzzer Alert Module

- The buzzer functions as a security alert mechanism.
- When an unauthorized or invalid RFID card is detected, the controller immediately activates the buzzer.
- The audible alert notifies the driver or operator about suspicious access attempts.
- This mechanism improves security and prevents unauthorized usage of the transportation system.

Cloud Data Storage and Monitoring Module

- Attendance information, GPS coordinates, and student status records are stored on a remote server.
- The stored information can be used for monitoring, reporting, and transportation analysis.
- Cloud storage ensures that records remain available even after system restart or power interruption.
- The centralized repository supports future auditing and administrative decision-making.

Final Output and Monitoring Module

- The integrated system generates three primary outputs:
 - Student Entry Status
 - Student Exit Status
 - Real-Time Bus Location Information
- Attendance events are displayed on the LCD screen, uploaded to the cloud server, and transmitted through GSM notifications.
- Invalid access attempts trigger buzzer alerts and are also recorded for monitoring purposes.
- The complete workflow provides an intelligent and automated mechanism for student transportation safety, attendance tracking, and real-time monitoring.

4. CONCLUSION

The Smart School Bus Safety System with Real-Time Tracking developed in this research successfully demonstrates a practical and cost-effective approach to automated student safety monitoring and real-time transportation management using an ESP32-based embedded IoT platform. The system integrates RFID-based automated student identification, GPS-based continuous bus location tracking, local CD-Drive data logging, LCD and buzzer-based local feedback, and IoT-based remote monitoring to deliver a comprehensive school bus safety solution that addresses the critical limitations of conventional manual transportation management systems. The automated RFID student identification eliminates the errors and delays associated with manual attendance recording, providing instant and reliable detection of each student's boarding and alighting events. The real-time GPS tracking and IoT-based parent and school notifications ensure that all stakeholders have continuous visibility of student whereabouts and bus location throughout the journey, enabling rapid detection of and response to any safety incidents. The local CD-Drive data logging provides essential operational resilience, ensuring complete attendance and journey records are retained on-bus regardless of network connectivity conditions. The use of the ESP32 microcontroller with its integrated Wi-Fi module provides a particularly effective and cost-efficient hardware foundation for the system, eliminating the need for a separate IoT communication module while delivering the processing resources required to simultaneously manage

all system functions. The modular design of the proposed system supports straightforward future enhancements including integration of a GSM module for cellular connectivity in Wi-Fi dead zones, addition of a camera for visual monitoring, implementation of geofencing alerts for route deviation detection, and development of a dedicated parent mobile application for enhanced notification and tracking usability. In conclusion, the Smart School Bus Safety System demonstrates the effective application of embedded IoT technology in addressing a critical public safety need, contributing to safer and more accountable school transportation.

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