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IoT-Based School Bus Transportation Safety and Tracking System

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Abstract

The safety of children during school commutes is a growing concern for both parents and school administrations. This paper presents an Internet of Things (IoT)-based school bus transportation safety system that offers real-time tracking, biometric authentication, and emergency detection to ensure the safety of school children. The system utilizes a combination of NodeMCU, Arduino Uno, GPS, fingerprint modules, and sensors to provide a secure and efficient school transportation process. Parents and administrators can access real-time data such as bus location, driver drowsiness, and alcohol detection, and can view children's boarding and departure from the bus via a web page interface. The proposed solution addresses safety challenges, providing peace of mind for all stakeholders involved. GPS satellites circle the Earth twice a day in a precise orbit. Each satellite transmits a unique signal and orbital parameters that allow GPS devices to decode and compute the precise location of the satellite. GPS receivers use this information and trilateration to calculate a user's exact location. Essentially, the GPS receiver measures the distance to each satellite by the amount of time it takes to receive a transmitted signal.

Keywords: IoT, school bus, GPS, fingerprint, safety system, tracking, transportation

INTRODUCTION

In recent years, incidents of schoolchildren being locked inside buses or getting on the wrong bus have raised significant concerns about school transportation safety. Communication gaps among school management, bus drivers, and parents further exacerbate these issues. This paper presented an Internet of Things (IoT)-based solution for monitoring and tracking school buses, aiming to prevent such incidents and ensure a safe commute. The system improves overall efficiency and security by integrating real-time tracking with fingerprint authentication.

LITERATURE REVIEW

In recent years, the safety of school bus transportation has become a focal point of research because of the increasing frequency of incidents involving lost or unmonitored children. Several studies have proposed solutions based on the IoT, emphasizing the role of real-time tracking, automated alerts, and sensor integration in improving transportation safety.

Srinivas et al. (2023) [1] developed an *IoT-based school bus monitoring system* that incorporates GPS tracking, fingerprint authentication, and emergency notifications. The system allows parents and school administrators to monitor the location of buses and track children's boarding and deboarding activities in real-time. The authors highlighted the benefits of integrating IoT devices to provide automated alerts in the case of route deviations or emergencies. However, the system's limitations include high

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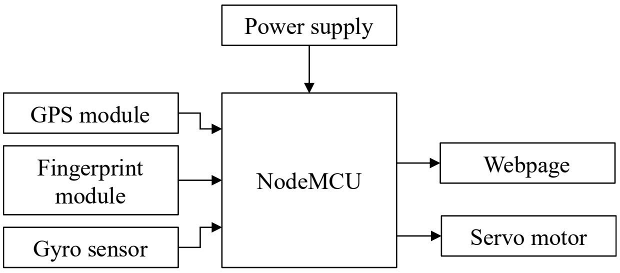

Figure 1. Block diagram of power supply—NodeMCU.

implementation costs and concerns about the privacy of children's biometric data. The block diagram of the power supply—NodeMCU is shown in Figure 1.

Similarly, Reddy et al. (2023) [2] proposed an *IoT-based school children's transportation safety system* that extends the basic tracking functionality by adding environmental sensors to monitor the conditions inside the bus, such as temperature and gas leaks. The system includes RFID-based boarding, GPS-based tracking, and sensors to detect environmental hazards such as excessive heat or harmful gas emissions. While the system effectively enhances children's safety, challenges such as network reliability and data security issues limit its practical use in remote areas.

In 2019, Rao et al. [3] introduced an *IoT-based Framework* utilizing RFID and GPS to track school buses. Their system provides real-time location updates and automates boarding processes using RFID tags. This paper also emphasizes the low-cost nature of their solution, which makes it scalable for large deployments. Despite its advantages, this study points out potential drawbacks, such as the limited range of RFID detection and the potential risks of network breaches in cloud-based data storage.

A comparative study by Ubale et al. (2022) [4] explored various techniques to ensure school bus safety using GSM and RFID technologies. The proposed solution sends real-time SMS notifications to parents regarding their children's pickup and drop-off statuses. The inclusion of a mobile application to track buses in real-time adds an extra monitoring layer. However, the authors noted that GSM network dependency can lead to delays in information delivery, especially in rural or low-coverage areas.

While these studies provide important insights into enhancing the safety of school transportation, they also highlight several recurring issues such as high costs, privacy concerns, and the limitations of existing sensor technologies. The proposed system addresses these challenges by using cost-effective components like NodeMCU and Arduino Uno, improving security through fingerprint-based authentication, and ensuring real-time monitoring using GPS and cloud-based data storage [5–7]. Moreover, our system integrates additional safety features, such as drowsiness detection and harmful gas monitoring, to mitigate the risks posed by environmental hazards and unsafe driving practices.

PROPOSED SYSTEM

The proposed system consists of hardware components integrated into two primary units: the NodeMCU and the Arduino Uno. These components work together to provide real-time tracking and emergency detection capabilities. A block diagram of the power supply of Arduino Uno is shown in Figure 2. The circuit diagram of the integrated sensors with the Arduino Uno is shown in Figure 3. The circuit diagram of integrating sensors with NodeMCU is shown in Figure 4 [8]. The system architecture was designed to offer the following features:

1. *Tracking and monitoring:* The system tracks the location of the bus using GPS and updates the data to a central database in real-time.
2. *Biometric authentication:* Fingerprint sensors ensure that only authorized drivers and students board the bus.
3. *Emergency detection:* Sensors for drowsiness, alcohol detection, and collision monitoring ensure the safety of passengers by triggering automatic responses such as stopping the bus and sending alerts.

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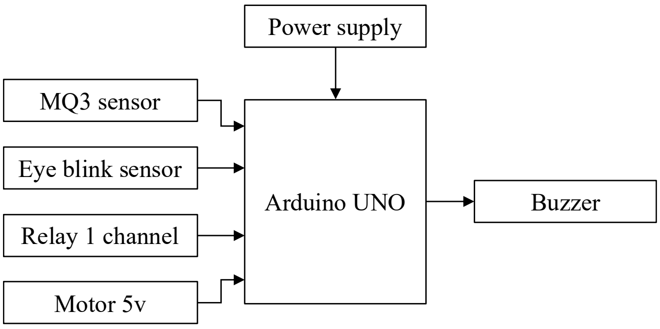

Figure 2. Block diagram of power supply Arduini Uno.

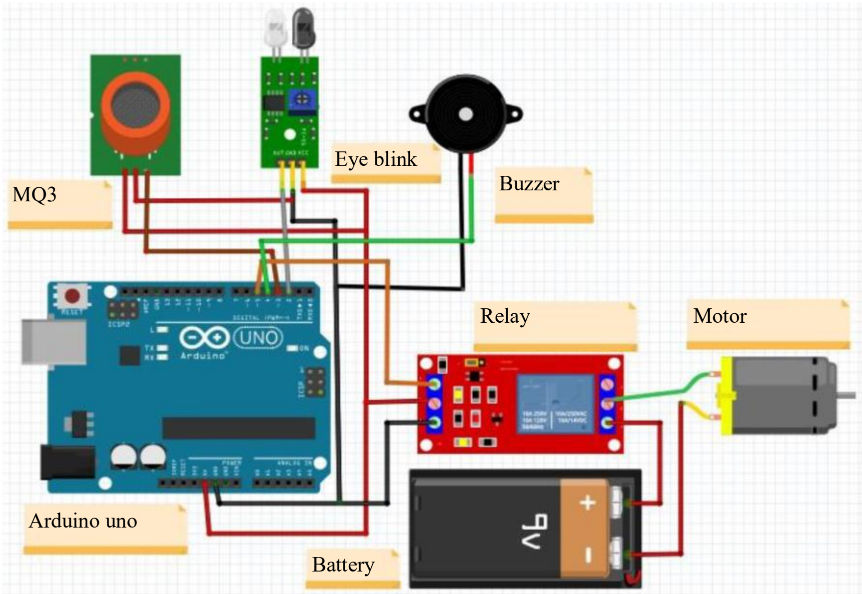

Figure 3. Circuit diagram of Integrated sensors with Arduino Uno.

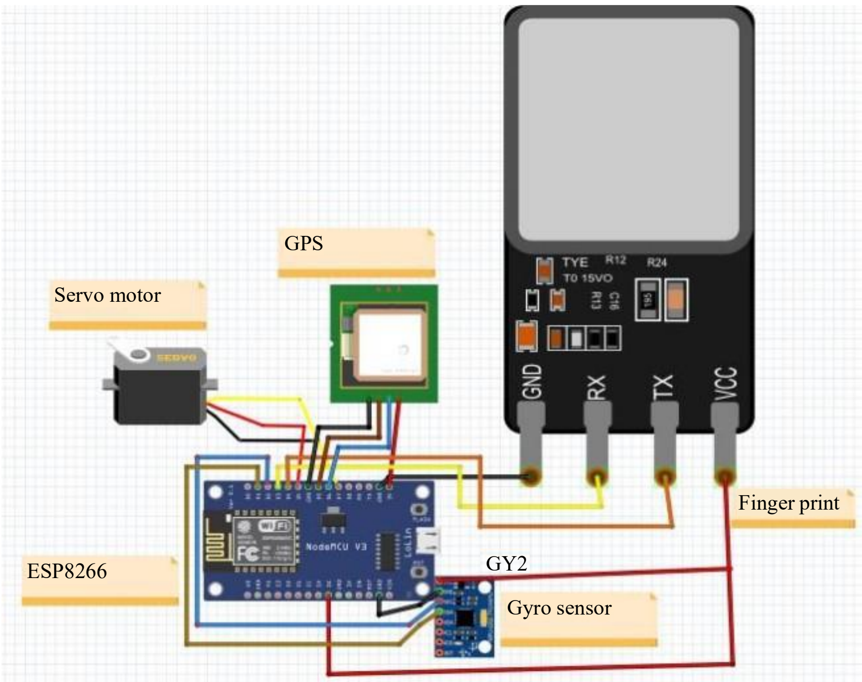

Figure 4. Circuit diagram of integrating sensors with NodeMCU.

SYSTEM IMPLEMENTATION

Hardware Architecture

The proposed system is built around the following key hardware components.

NodeMCU

NodeMCU serves as the central processing unit for communication between hardware components and the cloud server (Firebase) [9, 10]. This microcontroller is responsible for managing GPS tracking, fingerprint authentication, and collision detection.

- *GPS module (NEO6M):* The NEO6M GPS module continuously fetches the bus's geographic coordinates and updates this information in the Firebase Realtime Database. The system ensures that these data are refreshed every few seconds, thereby providing real-time location updates to parents and school administrators.
- *Fingerprint module:* A fingerprint scanner attached to the NodeMCU was used to authenticate the driver and students. Only those registered in the system are allowed to board the bus. For example, at the start of the journey, the driver must authenticate their fingerprints to start the bus. Similarly, each child's fingerprint is scanned and recorded as they board or deboard the bus, which is relayed to the system in real-time.
- *Gyro sensor:* The gyro sensor detects irregularities in the bus motion, such as sharp turns or sudden braking. If the sensor detects an unusual angular velocity, which could indicate an accident or unsafe driving conditions, it immediately sends an alert to the database. This data is also updated on the web interface for review by parents and administrators.
- *Servo motor:* A servo motor is used to control the bus doors. The motor is connected to the fingerprint module and is triggered to open doors only when an authorized driver or student scans their fingerprints. This feature ensures that unauthorized individuals cannot access the bus, thus enhancing the security of the system.

Arduino Uno

While the NodeMCU manages the primary operations, *Arduino Uno* is used for emergency detection through the following sensors:

- *MQ3 sensor:* The MQ3 sensor is employed to detect the presence of alcohol or harmful gases inside the bus. If alcohol is detected in the driver's breath or if any dangerous gases such as carbon monoxide or methane are present, the system will sound an audible alarm and stop the bus. This feature is essential in ensuring that the driver is sober and that the environment inside the bus is safe for children.
- *Eye blink sensor:* This sensor was designed to detect drowsiness in a bus driver. It monitors the blinking patterns of the driver's eyes. If abnormal blinking patterns indicative of drowsiness are detected, the system sounds like an alarm and halts the bus. Drowsy driving is a leading cause of accidents, and this feature significantly reduces the likelihood of such incidents.
- *Buzzer and DC motor:* The buzzer serves as an auditory alert in case of any detected emergency, such as alcohol detection or drowsiness. The DC motor controls the bus's movement and will be stopped in case of emergencies, triggered by either the MQ3 sensor or the eye blink sensor, ensuring that the bus stops to prevent any accidents.

Power Supply

The hardware components were powered by a combination of 5V and 9V power supplies. The *NodeMCU* and *Arduino Uno* received power through external adapters, ensuring a stable power supply for continuous operation. The servo motor, which controls the bus door, is powered by a 9V battery to allow precise door movements.

Software Architecture

The system software was designed to integrate the hardware components with a cloud database (Firebase) and a web-based interface. The main components of the software architecture are as follows.

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Arduino IDE

The *Arduino IDE* (Integrated Development Environment; IDE) was used to program the *NodeMCU* and *Arduino Uno* boards. The IDE allows the creation of custom scripts that govern the behavior of sensors and actuators. Key libraries such as

- *Adafruit_MPU6050.h* for the gyro sensor,
- *Tiny GPS++.h* for GPS data parsing, and
- *Adafruit_ Fingerprint. H* for fingerprint recognition was used to handle communication between the sensors and boards.

Firebase Realtime Database

The *Firebase Realtime Database* is the backbone of a cloud-based data management system. It is used to store and retrieve real-time data such as the bus's location, fingerprint authentication status, and emergency alerts. Firebase ensures that the data are synchronized in real-time across all connected clients, including parents, school administrators, and bus drivers.

- *GPS data:* The coordinates collected by the GPS module were uploaded to Firebase, where they were updated continuously. The location data are then displayed on a web map that is accessible via a secure login.
- *Fingerprint data:* Every time a child or driver scans their fingerprint, the system logs this data to Firebase, marking whether the individual has boarded or deboarded the bus or not. Parents receive notifications of their children's attendance in real-time.
- *Emergency alerts:* Alerts triggered by the sensors (drowsiness, alcohol detection, and accidents) are immediately stored in Firebase. The system ensures that these alerts are pushed to the web interface, allowing administrators to respond swiftly in case of an emergency.

Web Interface

The user interface of the system is web-based and is built using *Python* with the *Flask* framework. The interface allows parents and administrators to access the bus location, boarding information, and emergency alerts. The login page is shown in Figure 5.

- *Login page:* The web interface is secured, and only authorized users can log in to view the bus status. Upon login, the users are presented with a dashboard.
- *Real-time map:* A real-time map displays the current location of a bus. The map was built using *Folium* in Python, and location data were retrieved from Firebase. The webpage is shown in Figure 6.
- *Emergency status:* A separate section of the interface displays alerts generated by the sensors (e.g., "accident detected", "driver drowsiness"). These data are updated in real-time and are accompanied by details such as the timestamp and the sensor that triggered the alert.

After entering the login details, the page below opens, and the parent or administration can click on any option they want to view.

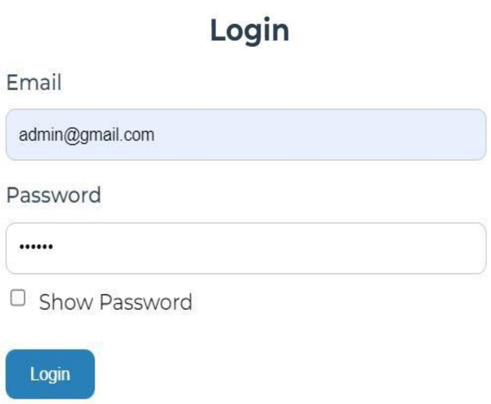

Figure 5. Login page.

Figure 6. Webpage.

IMPLEMENTATION METHODOLOGY FLOW CHART

The proposed system follows the workflow outlined below:

1. *Driver authentication:* The driver is required to authenticate their identity using a fingerprint scanner before they can access the bus. If authenticated, the door controlled by the servomotor opens, allowing the driver to start the bus.
2. *Children authentication:* At every stop, children authenticate their identities using a fingerprint scanner before boarding. This information is logged into the Firebase database and is accessible via the web interface.
3. *Real-time tracking:* The GPS coordinates are continuously sent to Firebase as the bus moves along its route. Parents and administrators can view the bus's location through the web interface.
4. *Emergency handling:* The MQ3 sensor and eyeblink sensor continuously monitor the driver's condition. If any abnormalities are detected, such as drowsiness or alcohol, the system triggers an alarm and stops the bus, ensuring the safety of passengers. Alerts are immediately reflected in the web interface so that school authorities can take action.

RESULTS

The proposed IoT-based school bus transportation system was tested under various conditions to validate its effectiveness for real-time tracking, fingerprint authentication, and emergency detection.

GPS Tracking and Location Accuracy

The *GPS NEO6M module* was tested for location accuracy and the speed of data transmission. The system was able to provide real-time tracking with an average location error of less than 5 m. The GPS NEO6M module is shown in Figure 7, and the GPS is connected to the NodeMCU, as shown in Figure 8. The real-time data were displayed on a web interface accessible to parents and school administrators. During testing, the system consistently updated the bus location every 2 s, ensuring a smooth and accurate tracking experience. The mapped live locations are shown in Figure 9.

Fingerprint Authentication

The fingerprint module effectively authenticates the driver and children. Fingerprint Authentication is shown in Figure 10, and the login/logout status on the webpage is shown in Figure 11. During testing, the system successfully verified the identities of the registered users with an accurate rate of 98%. The servo motor reliably opens the bus door for authorized individuals while preventing unauthorized access. Furthermore, the system logged attendance data in real-time, sending notifications to parents when the children boarded or deboarded the bus.

Emergency Detection

MQ3 sensor and *eye blink sensor* were tested for emergency detection scenarios. *Testing the MQ3 sensor* is shown in Figure 12, and the eye blink sensor is shown in Figure 13. The system accurately detected alcohol presence when tested with simulated scenarios of driver alcohol consumption, triggering an alarm, and stopping the bus. The eyeblink sensor effectively monitored the drowsiness of the driver, alerted the driver with a buzzer sound, and automatically stopped the bus in critical situations. The detected alcohol is shown in Figure 14, and the eye blink is shown in Figure 15.

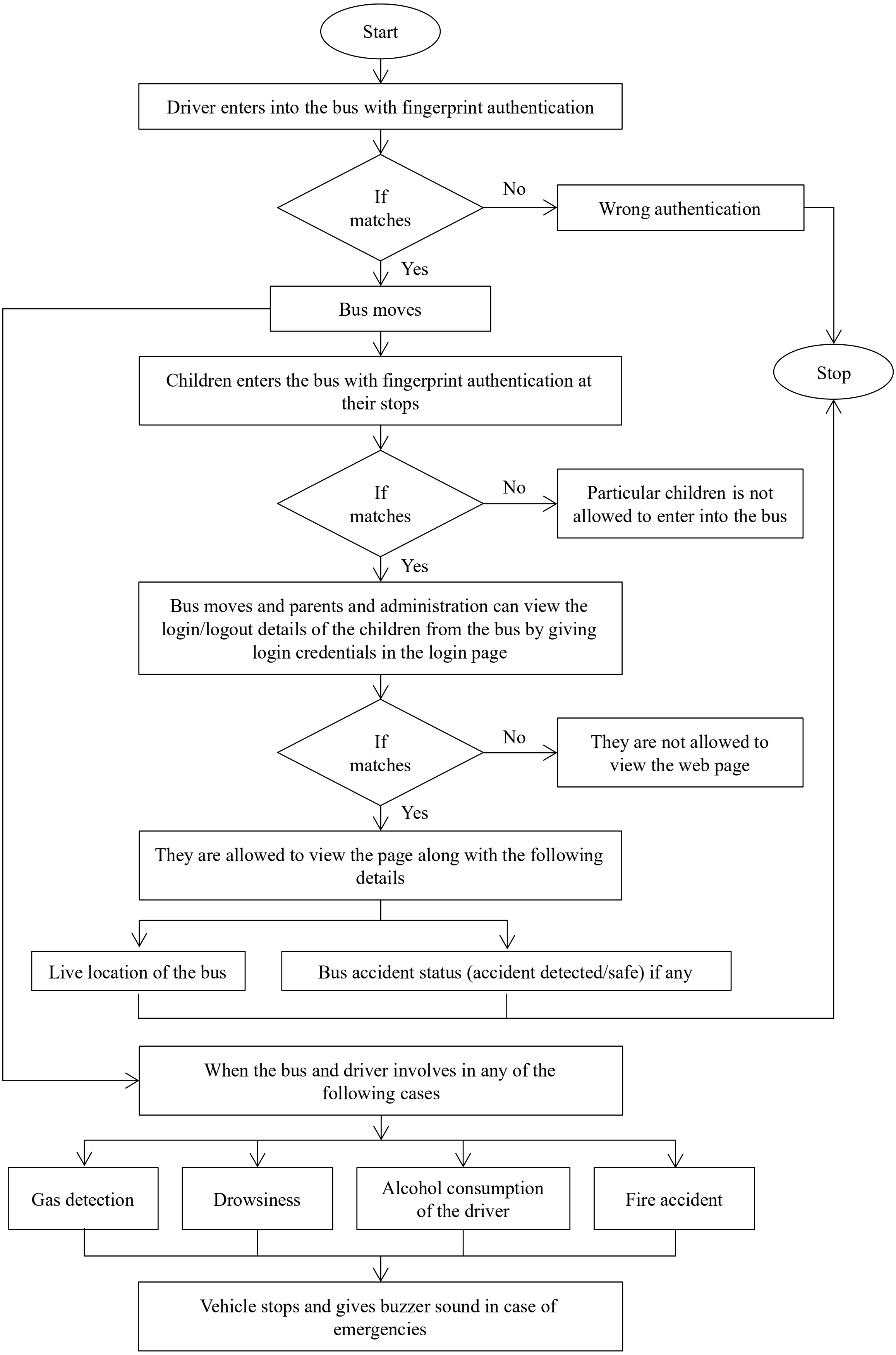

Figure 7. GPS NEO6M module.

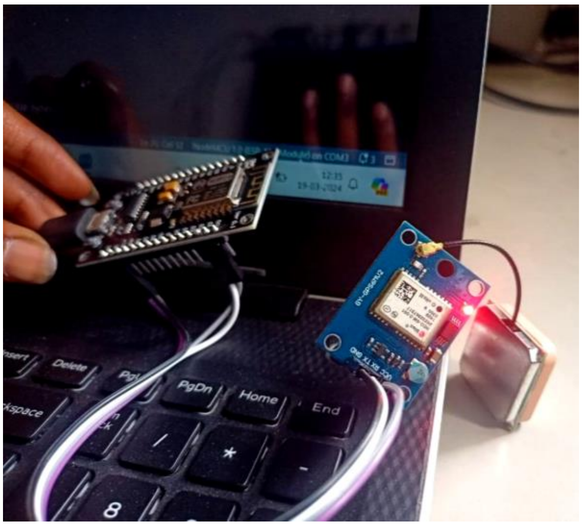

Figure 8. GPS connected with NodeMCU.

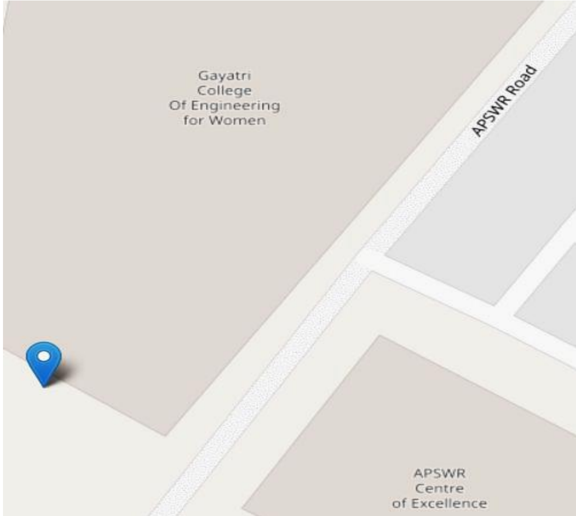

Figure 9. Live location mapped.

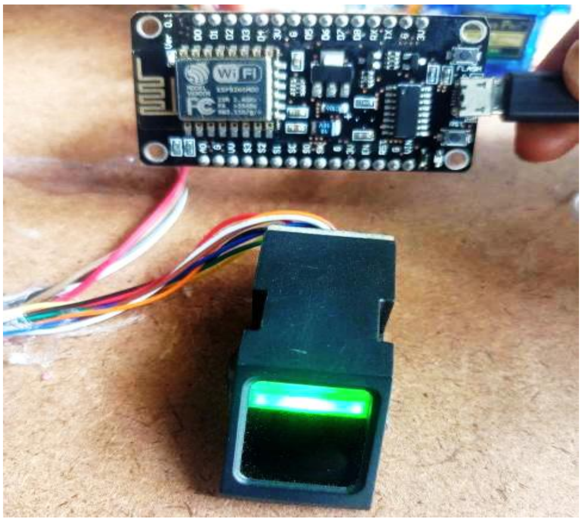

Figure 10. Fingerprint authentication.

Figure 11. Login/logout status on a webpage.

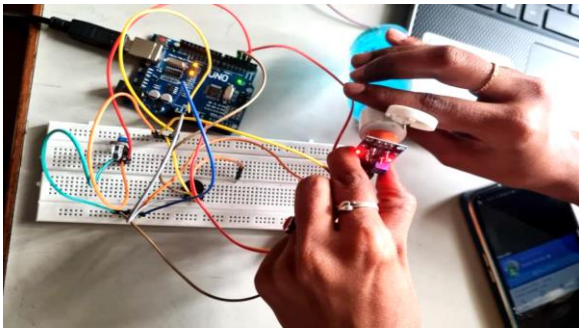

Figure 12. Testing MQ3 sensor.

Figure 13. Eye blink sensor.

Figure 14. Alcohol detected.

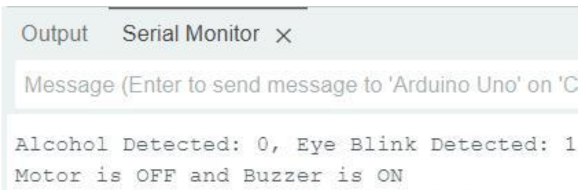

Figure 15. Eye blink detected.

Accident Detection

If the bus experiences a sharp turn, sudden braking, or an unexpected tilt, the gyro sensor registers these anomalies by detecting changes in the angular velocity beyond a pre-configured threshold. Such movement may indicate potential accidents. The gyro sensor is connected to NodeMCU and the Gyro sensor outputs on the web page shown in Figure 16.

In all emergency scenarios triggered by the gyro sensor, the web interface accurately reflected the detected anomalies in real-time. Detected accidents are shown in Figure 17. Parents and administrators were immediately notified of the event through the system, which provided details about the time, type of anomaly detected, and the bus's current location. The safety of the system is shown in Figure 18. This mechanism ensures contact with the driver or dispatching emergency services in the event of an emergency.

Web Interface

The *web interface* provides a user-friendly platform for parents and administrators to monitor the bus's live location, check the boarding status of children, and view emergency alerts. The hardware setup of the project is shown in Figure 19, and the live location of the GPS is shown in Figure 20. Real-time synchronization with Firebase ensured that any changes in the bus status, such as location or accident detection, were immediately reflected on the webpage.

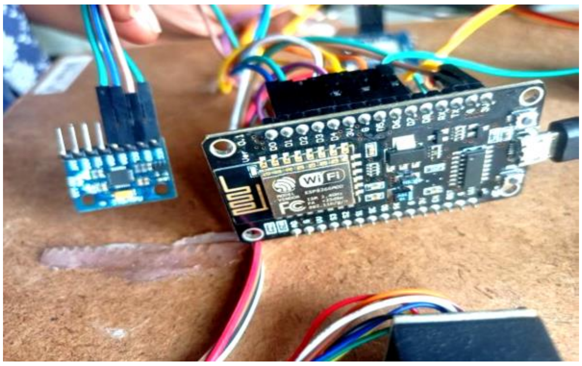

Figure 16. Gyro sensor connected with NodeMCU and Gyro sensors outputs in the Web page.

Figure 17. Accident detected.

Figure 18. Safe.

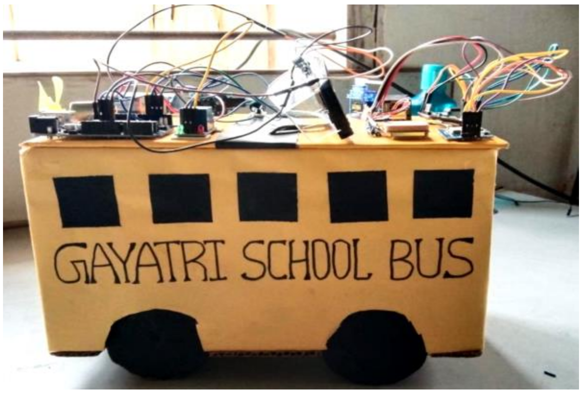

Figure 19. Hardware setup of the project.

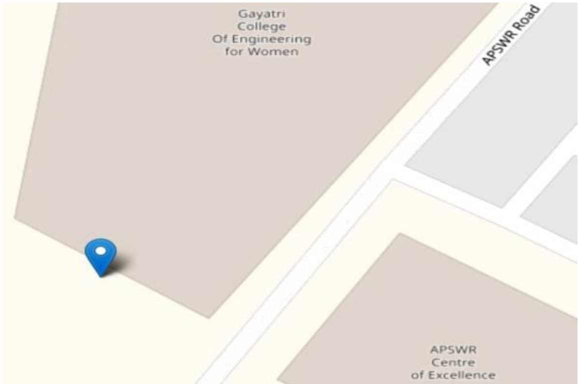

Figure 20. Live location of the GPS.

CONCLUSION

The IoT-based school bus transportation safety system effectively enhanced the security and efficiency of school transportation. The system addresses major concerns regarding schoolchildren's safety during their commute by combining real-time GPS tracking, fingerprint authentication, and emergency detection. Future work will focus on integrating mobile applications and face recognition to enhance the functionality of the system further.

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