

Design and Development of Network-based Geo-fencing Child Tracking and Safety System

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Abstract: There is growing worry for child safety as the number of missing children and unauthorized movements in public and semi-public areas increases. In this paper we describe the design and implementation of an Internet of Things (IoT) based child tracking and safety system that incorporates GPS tracking, RFID authentication, cloud monitoring and geo-fencing into a wearable platform. The suggested system integrates real time location tracking, secure authentication and automatic border monitoring to provide enhanced kid protection.

The system is designed on a microcontroller ESP32 with a GPS module, an RFID reader and a Wi-Fi communication module. Location data is periodically sent to a cloud server that allows parents and guardians to track a child's location using a web-based dashboard. The geo-fencing feature allows users to create safe zones for the child and generates alerts when the child leaves the predefined bounds. RFID authentication enhances system security and unauthorized persons are prevented from access.

The system was tested in outdoor and semi-outdoor situations with 50 GPS tracking trials and 100 RFID authentication tries. The experiments show that the GPS localization accuracy is 3-5m, RFID authentication accuracy is 98%, alert response time is 2-5s and communication efficiency is over 95%. In addition, the system consumes low power, which makes it suited for wearable applications. The comparative analysis shows improved tracking accuracy, response speed, communication reliability and security in comparison to existing child tracking systems. The suggested framework is a low-cost and effective solution for real-time kid safety monitoring.

Keywords: Child Safety, IoT, ESP32, GPS Tracking, RFID Authentication, Geo-fencing, Cloud Computing, Wearable Device, Real-Time Monitoring.

1. Introduction

The increasing frequency of missing children and unauthorized movements in public and semi-public spaces such as schools, shopping malls, parks, railway stations and bus terminals has made the protection of children a key social concern. Children are often lost or wandering away from their parents or guardians and are difficult to find quickly in an emergency. Traditional supervision methods rely more on direct observation or mobile communication, which may not always be successful in congested circumstances. This has created the need for intelligent monitoring systems that provide continuous tracking of location and prompt safety notifications.

Recent advances in Internet of Things (IoT) have led to invention of smart wearable gadgets for real time monitoring and safety applications Technologies such as Global Positioning System (GPS),

Radio Frequency Identification (RFID), Wi-Fi communication, cloud computing, and geo-fencing have significantly improved remote monitoring and location awareness. When these technologies are combined, it is possible to construct wearable devices able to monitor the movement, to issue warnings and to help in the continuous supervision through cloud platforms.

Recent works have been devoted to wearable IoT devices, cloud-assisted monitoring, geo-fencing techniques and intelligent alert generation for kid safety applications. Recently, the IoT-enabled wearable devices have been reported in literature to provide real-time location monitoring and emergency alerting services for improving parental awareness and kid protection. Monitoring techniques based on geo-fencing have showed the potential to automatically detect boundary violations and deliver timely alerts for safety-critical areas. Recent studies have also highlighted the need for secure authentication, RFID-based identification and secured communication protocols to improve security and prevent unwanted access in IoT-based monitoring systems.

Several child tracking systems have been proposed, however most of them mainly focus on location monitoring and provide minimal support for authentication, security and automated safety management. Furthermore, the issues of tracking accuracy, communication dependability, alert response time and power consumption still challenge the performance of wearable kid safety devices. In many circumstances, the absence of inherent security measures increases the vulnerability to illegal access and device misuse.

Different from traditional child tracking system that largely concentrates on location monitoring, the suggested framework combines GPS tracking, RFID-based authentication, geo-fencing and cloud-assisted alert management into one child safety ecosystem. Multiple levels of safety mean more reliable monitoring and works to increase security from illegal access. The geo-fencing technology automatically detects the boundary violations and generates notifications and RFID authentication offers the additional security layer for the device access and administration.

The key contributions of this work can be summarized as follows.

- Design and implementation of wearable IoT based child tracking and safety system using ESP32, GPS, RFID and cloud.
- Use RFID-based authentication in conjunction with real-time location tracking to enhance operational security.
- Creating a geo-fencing technology that automatically informs when a youngster goes beyond pre-set safe bounds.
- Web dashboard for cloud monitoring to continuously supervise and handle alerts.
- Experimentally evaluate the suggested system in terms of GPS tracking accuracy, RFID authentication efficiency, communication efficiency and alert response time.

The produced prototype was tested in outside and semi-outdoor situations with several GPS tracking and RFID authentication trials. The experiments indicated that the system achieved GPS localization accuracy of 3–5 m, RFID authentication accuracy of 98%, alarm reaction time of 2–5 s, and communication efficiency of more than 95%. These results show that the suggested system can be used for reliable tracking, secure monitoring and timely notification for child protection applications.

2. Literature Survey

The fast development of Internet of Things (IoT) technology has considerably improved child safety and monitoring systems. Today's child tracking technologies use GPS, RFID, wireless communication, cloud computing, geo-fencing and wearable devices to offer real-time location monitoring and emergency notifications to parents and guardians.

Early works mainly address position monitoring and alert generating. Gupta et al. [1] proposed a child monitoring system which includes tracking and notification support. Netravati and Savita [2] created Android based child tracking application. Poonkuzhlai et al. [3] incorporated Wireless Sensor Networks (WSN) and IoT technologies for continuous monitoring. Similarly, Manjunatha et al. [4] and Nandini et al. [5] created IoT based kid safety devices with features of location monitoring and alarm. These systems proved the possibility of real-time monitoring, but provided limited support for security, authentication, and intelligent monitoring.

The cloud has helped make monitoring more accessible and scalable for child protection applications. Senthamilarasi et al. [6] suggested an IoT based child monitoring architecture which uses embedded sensors and cloud services. Dhanalakshmi et al. [7] and Ahire et al. [8] have designed GPS based tracking systems that are capable of providing emergency alerts. However, the appropriateness for wearable applications was limited by the higher latency and battery consumption associated with GSM transmission. The usefulness of geo-fencing technology in identifying safe-zone violations and generating notifications was shown by Gupta and Harit [10].

Wearable technology has been gaining more and more importance for child safety monitoring. Agarwal et al. [13], Jayanthi et al. [14] and Lavanya et al. [15] studied the wearable kid safety devices with GPS, IoT sensors and cloud connectivity. These technologies improved the portability and convenience of use, but did not handle well secure authentication and tamper-resistant protection measures. The necessity of low-power embedded system design for wearable monitoring applications was stressed by Vahid and Givargis [11].

In recent years, research have reported an increasing use of digital location tracking devices. Davis et al. [19] stated that GPS-enabled smartphones, wearable gadgets and tracking tags are being employed for monitoring children and adolescents. They also pointed to issues around privacy, data security, and ethical monitoring procedures, thereby underlining the requirement for secure child tracking structures.

Today's kid protection solutions are built with geofencing as a core feature. Naveen et al. [20] proposed a kid monitoring framework with geo-fencing enabled that can automatically identify boundary infractions and generate real-time notifications. Their findings showed that virtual safety zones substantially enhance parental awareness and responsiveness.

Much emphasis has been paid to the integration of wearable IoT devices with intelligent monitoring approaches. Daood et al. [21] proposed an embedded wearable IoT system that incorporates GPS tracking, health monitoring sensors and a hybrid CNN-LSTM model for anomaly detection. The system achieved high classification performance and revealed the potential of intelligent monitoring for real-time safety applications. These technologies also reflect the increasing tendency for edge-based processing, where sensor data are assessed locally before being transmitted to the cloud servers.

Recently, RFID-based kid tracking systems have become a potential tool for monitoring children in crowded places. The work of Mallick et al. [22] examined reconfigurable RFID wearable devices with cloud-based monitoring and geo-fencing features. Similarly, Jachak et al. [23] developed an RFID based child tracking system for public settings, including RFID tags and readers to monitor continuously. The research showed the usefulness of RFID technology in enhancing security, authentication and monitoring reliability.

Related applications have also investigated machine learning and intelligent safety systems. Sharma et al. [16] designed a wearable safety device, and Kumar and Aggarwal [17] employed machine learning approaches for safety related data processing. Mangnale and Deshmukh [18] suggested a

real-time threat detection and warning generation architecture based on IoT and AI. These trends reflect a transition from conventional tracking systems to intelligent safety platforms capable of autonomous decision-making.

From the literature survey, it is found that the existing kid safety systems are successful in location monitoring and alarm generating however there are various problems. Most of the solutions are largely focused on tracking capabilities and have limited support for secure authentication, encrypted connection, edge-assisted processing and integrated monitoring. The importance of geo-fencing, wearable devices, RFID-based identification, cloud-assisted monitoring and intelligent analytics has been revealed in recent studies [19–23]. The discoveries above lead to the proposed work that merges GPS tracking, RFID-based authentication, cloud communication, geo-fencing and wearable IoT technologies into a unified framework for secure and reliable real-time kid safety monitoring.

Table 1. Comparative Analysis of Existing Child Tracking Systems and Proposed System

Reference	GPS	Geo-Fencing	RFID	Cloud	Intelligent Monitoring	Limitation
Davis et al. [19]	√	X	X	X	X	Privacy concerns
Naveen et al. [20]	√	√	X	√	X	No authentication
Daood et al. [21]	√	√	X	√	√	High system complexity
Mallick et al. [22]	√	√	√	√	X	Infrastructure dependency
Jachak et al. [23]	X	√	√	√	X	Limited outdoor coverage
Proposed System	√	√	√	√	X	Low-cost wearable design

The comparison of existing child tracking systems and the proposed approach is shown in Table 1. Existing approaches are mostly focused on basic GPS tracking and monitoring, but have shortcomings in terms of weak security, high power consumption and no wearable support. The proposed solution, by comparison, uses modern technologies to address these problems.

3. System architecture and Methodology

The proposed system is a child tracking and safety device developed using ESP32, GPS, RFID, Wi-Fi, and cloud technology. The system is mainly designed to help parents know the current location of their children and improve safety monitoring in daily life. The device is designed in wearable form so that children can use it comfortably.

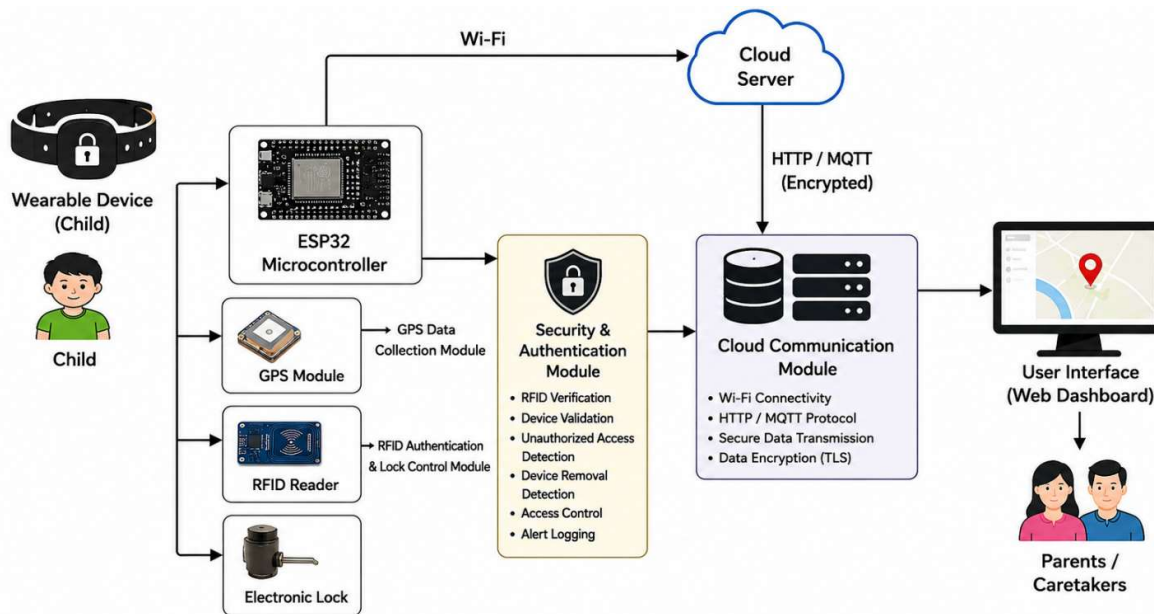


Fig. 1. System Architecture of the Proposed IoT- Based Child Tracking and Safety System

Fig. 1 illustrates the proposed system architecture. ESP32 is used as the main controller because it supports Wi-Fi communication and consumes less power. The GPS module connected to ESP32 collects the child's live location continuously in the form of latitude and longitude values. RFID is used for security purposes to avoid unauthorized access and to protect the wearable device from removal by unknown persons.

To strengthen system security, a special authentication method is added employing RFID tag verification. Only approved RFID tags are permitted to access the device. Invalid access attempts are automatically detected and reported. It also monitors unapproved devices and sends security notifications to the cloud server. These security methods contribute to better access management and also enable more effective monitoring of child safety.

After collecting the GPS and RFID information, ESP32 processes the data and sends it to the cloud server through Wi-Fi communication. HTTP or MQTT protocols are used for transferring information between the wearable device and cloud server.

The cloud server stores the received data and checks the child's position using geo-fencing. Parents can create a safe area through the monitoring dashboard. If the child moves outside the selected area, the system automatically sends alert messages to parents and caretakers.

Monitoring is given via a web-based dashboard. The parents can login and trace the child's live position on the map. The dashboard also shows warning alerts, safe-zone information, RFID status and device specifications. The proposed system can be used for real time tracking, encrypted communication and low power operation for child protection applications.

Table 2. Hardware Specifications

Component	Model	Purpose
ESP32	ESP32-WROOM-32	Main Controller
GPS Module	NEO-6M	Location Tracking
RFID Reader	RC522	Authentication
Electronic Lock	Solenoid Lock	Unauthorized Removal Detection
Security Module	Software-Based	RFID Verification and Alert Generation
Wi-Fi Module	Inbuilt ESP32	Secure Cloud Communication
Battery	3.7V Li-ion	Power Supply

Table 2 shows the hardware specification and the ESP32 microcontroller acts as the central processing unit, while GPS, RFID, and Wi-Fi modules provide location tracking, authentication, and cloud communication functionalities, respectively. The system incorporates RFID-based authentication, secure communication, and tamper detection mechanisms to reduce the risk of unauthorized access and device misuse.

3.1 Modules of Proposed System

- **Device Initialization Module:** This module starts all hardware components when the system is powered on. Before regular functioning begins, ESP32 verifies the GPS module, RFID reader, Wi-Fi connectivity and electronic lock.
- **GPS Data Collection Module:** The GPS module continuously gathers the child’s current position coordinates. The ESP32 periodically scans the latitude and longitude values and prepares the information for transmission.

Here’s the formula written clearly:

$$D = 2r \arcsin \left(\sqrt{\sin^2 \left(\frac{\phi_t - \phi_c}{2} \right) + \cos(\phi_c) \cos(\phi_t) \sin^2 \left(\frac{\lambda_t - \lambda_c}{2} \right)} \right) \dots\dots\dots(1)$$

D=Distance between child location and safe-zone center (in meters or kilometers)

- r = Radius of Earth ≈ meters / km
- φ_c = Latitude of safe-zone center
- φ_t = Latitude of child position
- λ_c = Longitude of safe-zone center
- λ_t = Longitude of child position

- **Security and RFID Authentication Module:** RFID authentication is used to verify authorized users and prevent unauthorized access. The system generates security alerts whenever invalid RFID access or device tampering is detected.
 - **Local Data Processing Module:** The ESP32 processes the GPS coordinates, RFID information, timestamps and alert circumstances prior to transmitting the data to the cloud server.
 - **Cloud Communication Module:** This module transmits GPS location, RFID status and alarm information from ESP32 to cloud server over Wi-Fi connectivity and HTTP/MQTT protocols.
- Cloud Processing and Geo-Fencing Module:** The received information is stored in the cloud server checking constantly if the youngster is in or out of the set safe area.

Fig. 2. illustrates the working flow of the proposed IoT-based child tracking and safety system. The procedure starts with device initialization where ESP32 microcontroller initializes the GPS module,

RFID reader, Wi-Fi connectivity and electronic lock system. After successful activation, the GPS module keeps collecting the current location of the kid in terms of latitude and longitude information.

RFID authentication module authenticates approved RFID tags for secure access. In case of any illegal access or forceful pull-out of the device, the system instantly sends warning alarms. The gathered GPS coordinates, RFID status, timestamps and alarm conditions are locally processed by ESP32, before transmitting.

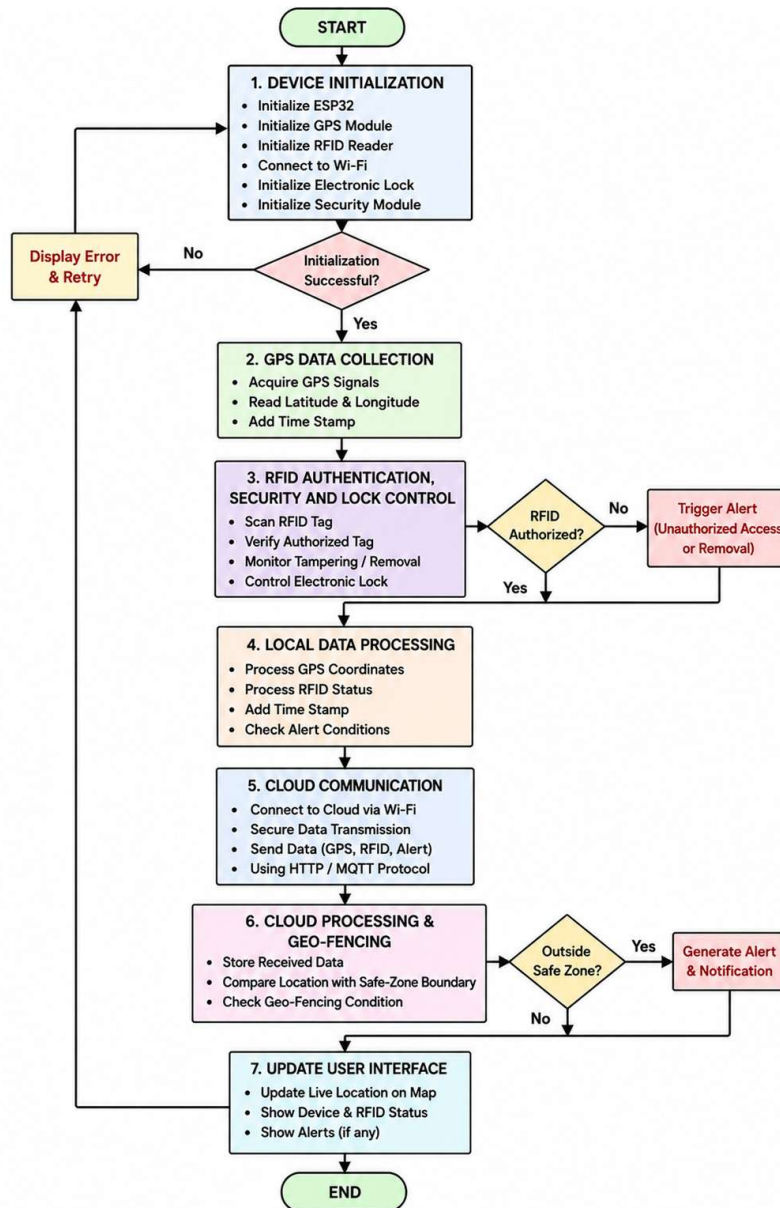


Fig 2. Flowchart

The processed information is sent to the cloud server utilizing Wi-Fi communication with HTTP/MQTT protocols. In the cloud processing stage, the incoming data is recorded and geo-fencing analysis is done by comparing child’s present location with the defined safe-zone border.

If the youngster walks outside of the safe area, the system creates alerts and transmits them to parents or guardians. Finally, the web-based user interface presents the child live position, alarm notification, RFID status and device information for ongoing monitoring and child safety management.

3.2 Methodology

The methodology describes the implementation process and performance evaluation of the proposed system without repeating architectural details.

1. **System Development:** All hardware components are integrated with ESP32 and tested individually. Firmware is developed to enable GPS tracking, RFID authentication, security monitoring, and Wi-Fi communication.
2. **Data Collection and Processing:** The GPS module collects real-time location data, and the ESP32 processes it along with RFID status, security events, and timestamps before transmission.
3. **Data Transmission:** Processed data is transmitted to the cloud server using HTTP or MQTT protocols, ensuring efficient and reliable communication.
4. **Geo-Fencing Evaluation:** The cloud server applies geo-fencing logic by comparing calculated distance with the safe-zone radius:

$$D > R$$

Algorithm

Start

1. Initialize the system and connect ESP32 to GPS, RFID, and Wi-Fi modules.
2. Continuously read the current GPS coordinates of the child:
 - Latitude $\rightarrow \phi_t$
 - Longitude $\rightarrow \lambda_t$
3. Retrieve predefined safe-zone center coordinates:
 - ϕ_c, λ_c
4. Calculate the distance D between child location and safe-zone center using:

$$D = 2r \arcsin \left(\sqrt{\sin^2 \left(\frac{\phi_t - \phi_c}{2} \right) + \cos(\phi_c) \cos(\phi_t) \sin^2 \left(\frac{\lambda_t - \lambda_c}{2} \right)} \right)$$

6. Compare the calculated distance with safe-zone radius R :
 - If $D \leq R$:
 - \rightarrow Set status = **Safe Zone**
 - \rightarrow No alert generated
 - If $D > R$:
 - \rightarrow Set status = **Alert Zone**
 - \rightarrow Trigger alert notification
7. Send alert message to parent via cloud server.
8. Update monitoring dashboard with current location and status.
9. Repeat steps 3–8 continuously for real-time tracking.

End

5. **Alert Mechanism:** Alerts are generated for boundary violations, unauthorized RFID access, and device tampering events, and are sent to parents through the monitoring dashboard.
6. **Performance Evaluation:** The system is tested under outdoor and semi-outdoor environments to evaluate GPS tracking accuracy, RFID authentication performance, alert response time, and communication reliability.

$$\text{Communication Efficiency} = \left(\frac{\text{Received Data Packets}}{\text{Sent Data Packets}} \right) \times 100 \text{-----(2)}$$

The system achieves over 95% communication efficiency.

Communication efficiency is calculated as the ratio of successfully received packets to the total number of transmitted packets.

Table 3. Experimental Setup Parameters

Parameter	Value
GPS Tracking Trials	50
RFID Authentication Attempts	100
Test Environments	Outdoor and Semi-Outdoor
Safe-Zone Radius	50 m
Communication Protocol	HTTP / MQTT
GPS Module	NEO-6M
RFID Reader	RC522
Controller	ESP32-WROOM-32
Test Duration	5 Days
Alert Type	Geo-Fencing and Unauthorized Access Alerts

Table 3 presents the experimental setup used for evaluating the proposed child tracking and safety system. The system was tested using 50 GPS tracking trials and 100 RFID authentication attempts in outdoor and semi-outdoor environments. The experiments were conducted over a period of five days using an ESP32-WROOM-32 controller, NEO-6M GPS module, and RC522 RFID reader. A safe-zone radius of 50 m was configured for geo-fencing evaluation. The collected data were used to assess GPS tracking accuracy, RFID authentication performance, alert response time, and communication reliability.

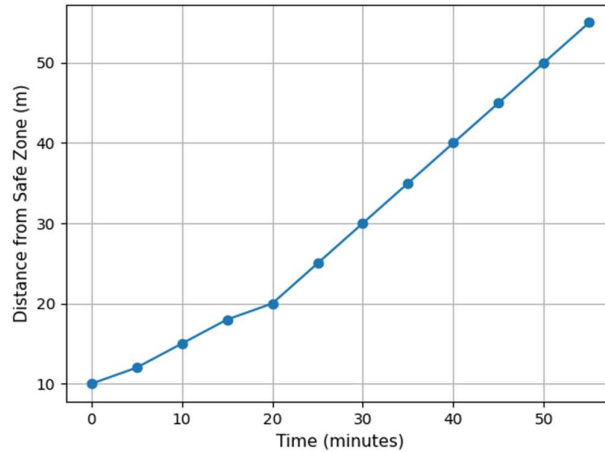
4. Results and Discussion

The proposed IoT-based child tracking and safety system was evaluated in outdoor and semi-outdoor environments to assess GPS tracking accuracy, RFID authentication performance, geo-fencing effectiveness, communication efficiency, and alert response time. The experiments were conducted over five days using 50 GPS tracking trials and 100 RFID authentication attempts.

A. Child Movement Analysis

Fig. 3 shows the movement of the child with respect to time during experimental testing. The measured distance gradually increased from 10 m to 55 m, indicating continuous movement away from the safe-zone center. The GPS module successfully tracked the child's location and updated the position in real time. The results confirm the capability of the proposed system to provide reliable location monitoring under outdoor conditions.

Fig 3. Child Movement vs Time

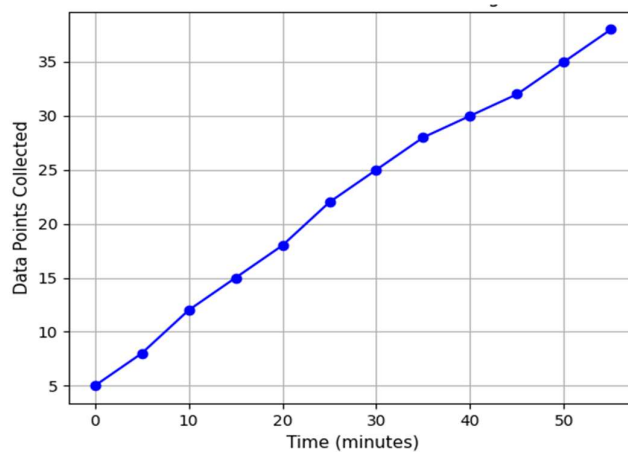


The values were collected during a GPS tracking experiment conducted on a school campus over a period of 55 minutes. The child's position was recorded at 5-minute intervals using the NEO-6M GPS module.

B. Data Collection and Processing

Fig.4. the collected data points increase steadily from 5 to 38. This indicates efficient and uninterrupted data acquisition by the ESP32 system.

Fig. 4. Data Collection and Processing



Each data point represents successfully processed GPS records transmitted from the ESP32 device to the cloud server. Data collection was performed continuously during the monitoring period.

C. Geo-Fencing and Alert Mechanism

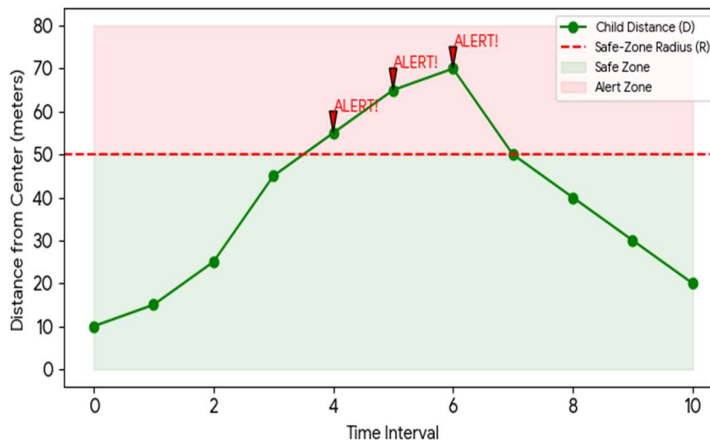
Fig. 5 presents the geo-fencing performance of the proposed system. The safe-zone radius was configured as 50 m. When the child remained within the predefined boundary ($D \leq 50$ m), the system maintained normal monitoring status. When the distance exceeded the safe-zone radius ($D > 50$ m), alert notifications were automatically generated and transmitted to parents through the monitoring dashboard. During testing, 48 out of 50 boundary events were correctly detected, resulting in a geo-fencing detection accuracy of 96%. The results demonstrate effective boundary monitoring and timely alert generation.

Table 4 child tracking log

Time Interval	Distance (m)	Status
0	10	Safe
1	15	Safe
2	25	Safe
3	45	Safe
4	55	Alert
5	65	Alert
6	70	Alert
7	50	Safe
8	40	Safe
9	30	Safe
10	20	Safe

The table 4, shows the distance of the child from the predetermined safe zone at different time periods. The technology constantly monitors the child's mobility and defines the status as either Safe or Alert based on the geo-fencing threshold. When the measured distance crosses the permissible limit an alarm condition is activated to inform parents or guardians. The dataset is utilized for evaluating the performance of the proposed real time child safety monitoring and alarm generation system.

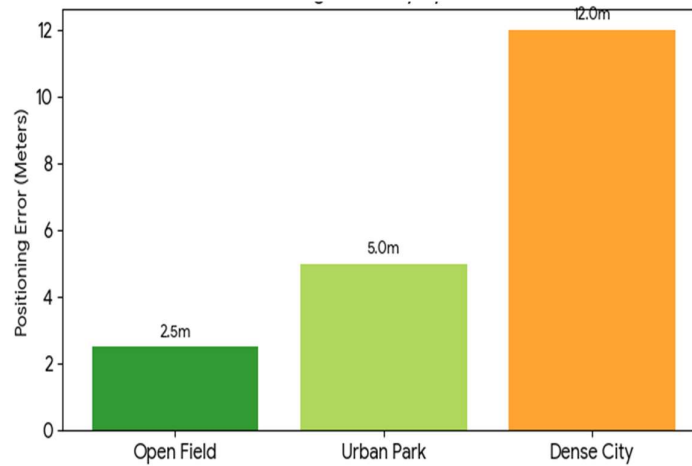
Fig. 5. Geo-Fencing and Alert Mechanism



D. GPS Tracking Accuracy by Environment

Fig. 6 shows the GPS localization accuracy measured in different environments. The average positioning error was approximately 2.5 m in open-field conditions, 5 m in urban park environments, and 12 m in dense city areas. The increase in positioning error in dense urban environments is mainly due to signal obstruction and multipath effects. However, the system maintained an average tracking accuracy of 3–5 m under normal outdoor operating conditions, which is suitable for child safety applications.

Fig. 6. Tracking Accuracy by Environment



E. Comparative Analysis

The proposed system was compared with recent child safety monitoring systems reported in the literature. The comparison considered tracking capability, security support, geo-fencing functionality, communication reliability, and monitoring features.

Table 5. Comparative Analysis

Parameter	Existing GPS-Based System	Recent IoT Child Safety Systems [19–23]	Proposed System
Tracking Accuracy	Moderate (5–10 m)	Moderate to High (4–8 m)	High (3–5 m)
Alert Response Time	5–10 s	3–6 s	2–5 s
Communication Efficiency	85–90%	90–95%	95.60%
RFID Authentication	Not Available	Limited	98% Accuracy
Security Features	Basic	Moderate	RFID + Tamper Detection
Geo-Fencing	Basic	Available	Advanced
Cloud Monitoring	Limited	Available	Continuous
Intelligent Monitoring	Not Available	Available in Selected Systems	Future Scope
Wearable Support	Limited	Available	Available
Real-Time Monitoring	Limited	Moderate	Continuous

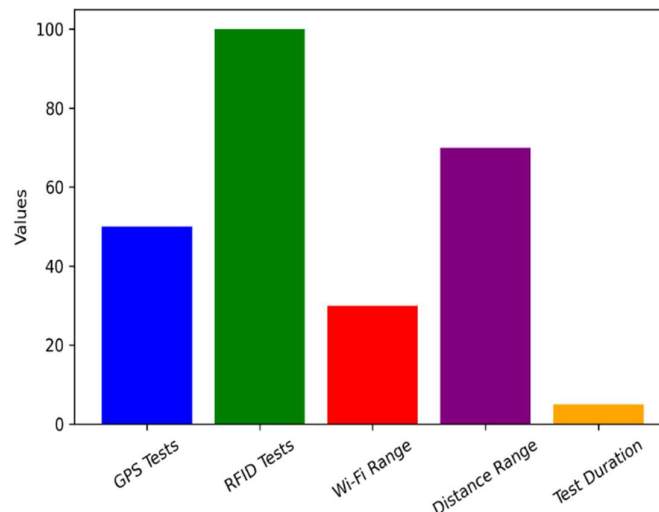
Higher Accuracy: Reduced GPS error (3–5 m) improves location precision. **Faster Alerts:** Response time reduced to 2–5 seconds. **Improved Communication:** Efficiency above 95% ensures reliable data transfer. **Enhanced Security:** RFID integration adds strong protection. **Advanced Geo-Fencing:** Accurate boundary detection with instant alerts **Low Power Consumption:** Suitable for wearable applications

F. Experimental Setup

The system was evaluated in a school campus and public park environment using 50 GPS tracking trials and 100 RFID authentication attempts. A safe-zone radius of 50 m was configured for geo-fencing evaluation, while Wi-Fi communication was tested within a range of 30 m. The experiments

were conducted over five days under outdoor and semi-outdoor conditions. The collected data were used to evaluate tracking accuracy, geo-fencing performance, communication efficiency, and security functionality. as illustrated in Fig. 7.

Fig. 7. Experimental Parameters



5. Conclusion and future work

This study described the design and implementation of an IoT based Child Tracking and Safety System using ESP32, GPS, RFID, Wi-Fi and Cloud Technologies. The suggested framework combines real-time location tracking, RFID based authentication, geo-fencing and cloud assisted monitoring in a wearable platform to enhance kid safety. The experiments were conducted in outside and semi-outdoor settings with 50 trials of GPS tracking and 100 trials of RFID authentication.

The results showed that the system achieved GPS tracking accuracy of 3-5 m under normal outdoor settings, RFID authentication accuracy of 98%, geo-fencing detection accuracy of 96% and communication efficiency of 95.6%. The alert reaction time was between 2 and 5 seconds, providing prompt notification if a safe-zone violation occurred. Moreover, the RFID authentication method and tamper detection features improved the security of the system by prohibiting illegal access and misuse of the devices. We deliver a reliable and cost-effective solution to real-time kid safety applications by integrating GPS tracking, geo-fencing, secure communication and cloud monitoring.

The suggested framework has better tracking accuracy, better security and dependable communication performance compared to existing kid monitoring system. At the same time, the proposed framework has low power consumption to be used in a wearable device. The experimental findings confirm the practicality of the suggested system for practical kid safety monitoring in schools, parks, shopping centers and other public places.

Future efforts will be directed towards refining the positioning accuracy with hybrid indoor-outdoor localization techniques, improving the communication reliability in difficult conditions, and incorporating AI-based predictive analytics for intelligent safety monitoring. The development of a specific mobile app and sophisticated edge-based processing techniques can improve further the system responsiveness, user interaction and overall monitoring performance.

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