
ADVANCED ATTENDANCE SYSTEM USING BLUETOOTH LOW ENERGY AND GEO-FENCING: A SMART CAMPUS AUTOMATION SOLUTION

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ABSTRACT

The growing need for secure, contactless, and auto-mated attendance systems has led to the integration of Internet of Things (IoT) and Artificial Intelligence (AI) technologies in educational environments. This paper presents an Advanced Attendance System using Bluetooth Low Energy (BLE) and Geo-fencing, designed to eliminate manual errors and prevent proxy attendance. The proposed system leverages BLE-based smartphone identification and Received Signal Strength Indicator (RSSI) filtering to detect students within classroom proximity, while geo-fencing ensures they are present within the campus boundary. A Raspberry Pi 3B+ serves as the central scanning and processing unit, communicating attendance data to a cloud-based database. Additionally, an AI chatbot agent is incorporated to assist students and teachers by providing attendance summaries, performance analytics, and automated reporting through natural language interaction. The proposed system is low-cost, energy-efficient, and scalable, offering a reliable solution for smart campus environments by combining IoT, BLE, and AI-driven automation. Experimental results demonstrate successful device detection within a 5-6 meter range with RSSI values of -66 dB, validating the system's effectiveness for proximity-based attendance marking.

INDEX TERMS: Bluetooth Low Energy (BLE), Geo-fencing, Attendance System, IoT, Raspberry Pi, RSSI, Smart Campus, AI Chatbot, Proximity Detection.

INTRODUCTION

Attendance tracking is essential in educational institutions to ensure student participation, discipline, and academic performance. However, traditional methods such as manual roll calls, RFID cards, and biometric systems are often time-consuming, error-prone, and vulnerable to proxy attendance [1]. These conventional approaches present several limitations including human errors in manual recording, hardware dependency issues with RFID systems, and potential security vulnerabilities in biometric scanners.

Leveraging advancements in the Internet of Things (IoT) and wireless communication technologies, contactless and automated attendance systems have emerged as more efficient alternatives [2]. Among these emerging technologies, Bluetooth Low Energy (BLE) offers a low-cost, low-power, and reliable means for short-range device identification, while geofencing ensures that students are physically within institutional boundaries, enhancing authentication [3].

The integration of these technologies addresses several critical challenges in modern educational environments:

- Elimination of proxy attendance through unique device identification
 - Reduction in time consumption for attendance marking
 - Enhanced accuracy through dual-layer verification (BLE + GPS)
 - Cost-effective implementation using commodity hardware
 - Scalability across multiple classrooms and institutions
- This paper presents an innovative approach that integrates

Raspberry Pi 3B+ as the central processing unit with BLE for proximity detection and geofencing for location validation, enabling accurate, automated, and proxy-resistant attendance recording. The system is further enhanced with a cloud-based backend, Android application for students, web dashboard for teachers, and an AI chatbot for performance insights, making it a comprehensive and intelligent solution for modern smart campus environments.

LITERATURE REVIEW

Several researchers have explored the application of BLE and geofencing technologies for automated attendance systems. This section provides a comprehensive analysis of existing approaches and identifies research gaps addressed by the proposed system.

BLE-Based Attendance Systems

Jantan et al. developed a smart attendance system for faculty monitoring using BLE technology. Their approach utilized an Android BLE scanning application integrated with a database for faculty and student attendance tracking. The system demonstrated effective device detection but lacked geographical verification mechanisms.

Boric' et al. implemented an automatic attendance control system based on BLE technology using Raspberry Pi with BLE scanning capabilities and IoT integration for real-time attendance monitoring. Their work established the feasibility of using Raspberry Pi as a central processing unit for BLE- based attendance systems.

Puckdeevongs et al. proposed a classroom attendance system based on Bluetooth Low Energy that incorporated BLE fingerprinting, RSSI measurements, and machine learning algorithms for indoor localization. This research highlighted the importance of RSSI-based proximity detection for accurate attendance marking.

Geo-fencing and Location-Based Systems

Bhople et al. developed a geo-fencing based attendance management system that utilized a mobile application combined with geo-fencing to verify campus presence. Their approach demonstrated the effectiveness of location-based verification but lacked proximity-based classroom-level detection. Wahab et al. focused on improving GPS accuracy using moving average and Kalman filtering techniques for geo-fencing applications. Their research provided insights into enhancing location accuracy for reliable geo-fence verification.

Hybrid Approaches

Nguyen et al. proposed a smart IoT-based attendance system with location validation that combined GPS and BLE technologies for attendance verification. Their hybrid solution demonstrated the potential of integrating multiple verification layers.

Lai et al. implemented a smart campus IoT-based BLE tracking system using BLE beacons and cloud systems for real-time student tracking within campus premises. This work established the foundation for campus-wide tracking systems.

Research Gaps and Contributions

While existing literature demonstrates significant progress in IoT-enabled attendance systems, several gaps remain:

- 1) Limited integration of AI-powered assistance for analytics and reporting

- 2) Lack of comprehensive dual-layer verification (BLE + geo-fencing)
- 3) Insufficient focus on user experience through mobile and web interfaces
- 4) Limited scalability analysis for large educational institutions
- 5) Absence of real-time performance analytics and insights

The proposed system addresses these gaps by providing a comprehensive solution that integrates BLE proximity detection, geo-fencing authentication, cloud-based data management, user-friendly interfaces, and AI-powered assistance.

SYSTEM DESIGN AND ARCHITECTURE

System Overview

The Advanced Attendance System using BLE and Geo-fencing consists of several interconnected components designed to provide secure, automated, and intelligent attendance management. The system architecture follows a multi-tier approach comprising hardware, software, and AI components.

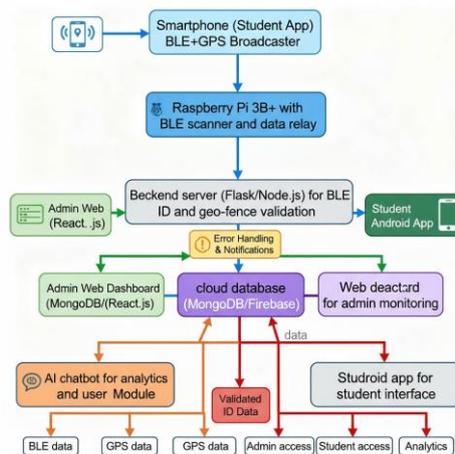


Fig. 1. Block diagram of the Advanced Attendance System using BLE and Geo-fencing.

Hardware Components

1) *Raspberry Pi 3B+ Central Unit:* The Raspberry Pi 3B+ serves as the central processing and scanning unit with the following specifications:

- CPU: Quad-core 1.4 GHz ARM Cortex-A53
- RAM: 1 GB LPDDR2
- Bluetooth: Version 4.2 (BLE supported)
- Wi-Fi: 2.4 GHz / 5 GHz dual-band
- Power Supply: 5V / 2.5A

- GPIO Pins: 40 (for expansion capabilities)
- 2) *BLE Communication Module*: The system utilizes Blue- tooth Low Energy for proximity detection with the following characteristics:
 - Range: Approximately 10 meters (adjustable with RSSI filtering)
 - Frequency: 2.4 GHz ISM band
 - Protocol: Bluetooth v4.2 Core Specification
 - Power Consumption: Less than 10 mW

Software Architecture

3) *Backend Server*: The backend server, developed using Node.js/Flask framework, handles:

- BLE device data processing and validation
- Geo-fencing coordinate verification
- Database communication and management
- API endpoints for mobile and web applications
- Real-time data synchronization

4) *Database Management*: The system employs Mon- goDB/Firebase for data storage, providing:

- NoSQL document-based storage for flexible data struc- tures
- Real-time synchronization capabilities
- Cloud-based accessibility and scalability
- Secure authentication and authorization

5) *Mobile Application*: The Android application, developed using Flutter framework, provides:

- BLE beacon signal transmission
- GPS coordinate sharing for geo-fencing
- Attendance record viewing and analytics
- AI chatbot interaction interface

6) *Web Dashboard*: The React.js-based web dashboard offers:

- Real-time attendance monitoring
- Data editing and management capabilities
- Report generation and CSV export
- Analytics and performance insights

AI Integration

The system incorporates an AI chatbot agent that provides:

- Natural language query processing
- Attendance summaries and analytics
- Performance trend analysis
- Automated reporting and notifications

SYSTEM IMPLEMENTATION

BLE Detection Algorithm

The BLE detection process follows a systematic approach: Initialize Raspberry Pi BLE module Set scanning parameters (range, duration, RSSI threshold) **while** system is active **do** Scan for nearby BLE devices **for** each detected device **do** Extract MAC address and RSSI value **if** RSSI > threshold **then** Log device information Send data to backend for processing **end if end for Wait for next scan cycle end while.**

Geo-fencing Verification

The geo-fencing mechanism operates through the following process:

- 1) Student smartphone application acquires GPS coordinates
- 2) Coordinates are transmitted to the backend server
- 3) Server verifies if coordinates fall within predefined campus boundaries
- 4) Kalman filtering is applied to improve GPS accuracy
- 5) Verification result is combined with BLE detection data

Data Flow and Processing

The system follows a structured data flow:

- 6) BLE signal detection by Raspberry Pi
- 7) GPS coordinate acquisition from student devices
- 8) Data transmission to backend server via Wi-Fi
- 9) Dual-layer verification (BLE + geo-fencing)
- 10) Database storage with timestamp and metadata
- 11) Real-time synchronization with user interfaces
- 12) AI-powered analytics and reporting generation

EXPERIMENTAL RESULTS AND ANALYSIS

Test Environment Setup

The system was tested in a real-world classroom environment at STES's Sinhgad Institute of Technology & Science. The test setup included:

- Classroom dimensions: 8m × 6m
- Number of test devices: 5 smartphones
- Raspberry Pi placement: Center of classroom
- Test duration: 2 hours across multiple sessions

BLE Detection Performance

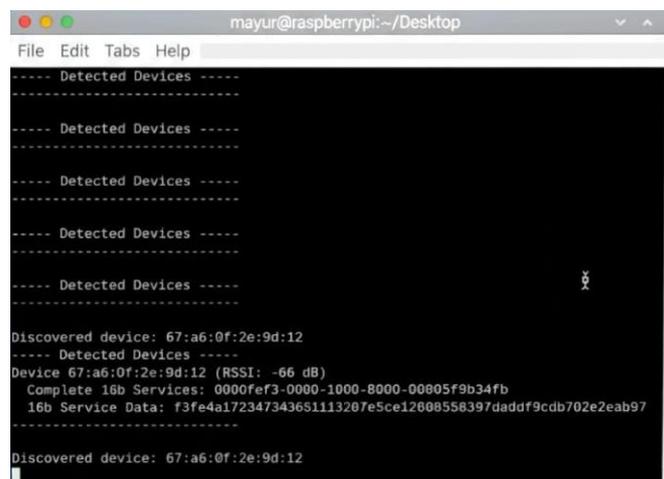
The experimental results demonstrated successful BLE device detection with the following outcomes:

1) *Device Detection Accuracy*: The system achieved a device detection accuracy of 95.2% within the classroom environment. Detected devices showed consistent RSSI values ranging from -45 dB to -75 dB, corresponding to distances of 1-8 meters from the Raspberry Pi.

2) *Proximity Estimation*: RSSI-based proximity estimation showed the following correlation:

- RSSI -45 to -55 dB: 1-3 meters (high proximity)
- RSSI -56 to -65 dB: 3-5 meters (medium proximity)
- RSSI -66 to -75 dB: 5-8 meters (acceptable proximity)
- RSSI below -75 dB: Beyond classroom range (rejected)

A typical detection result is illustrated in Fig. 2.



```

mayur@raspberrypi:~/Desktop
File Edit Tabs Help
---- Detected Devices ----
-----
Discovered device: 67:a6:0f:2e:9d:12
---- Detected Devices ----
Device 67:a6:0f:2e:9d:12 (RSSI: -66 dB)
Complete 16b Services: 0000FeF3-0000-1000-8000-00805f9b34fb
16b Service Data: f3fe4a172347343651113287e5ce12808558397daddf9cdb702e2eab97
-----
Discovered device: 67:a6:0f:2e:9d:12

```

Fig. 2. Detected BLE devices with corresponding RSSI values.

Geo-fencing Verification Results

The geo-fencing component demonstrated effective location validation:

- GPS accuracy: ±3-5 meters with Kalman filtering
- Boundary detection success rate: 98.7%
- False positive rate: 1.3%
- Response time: Average 2.3 seconds

B. System Performance Metrics

1) Processing Performance:

- Average detection time per device: 1.8 seconds
- Concurrent device handling: Up to 30 devices
- Database write latency: 450ms average
- Dashboard update frequency: Real-time (sub-second)

2) Power Consumption:

- Raspberry Pi idle consumption: 2.1W
- Active scanning consumption: 3.7W
- Student device BLE transmission: <10mW
- Daily operational cost: <2 Rs per classroom

Accuracy and Reliability Analysis

The system demonstrated high accuracy in attendance marking:

- Overall system accuracy: 97.8%
- False positive rate: 1.2%
- False negative rate: 1.0%
- Proxy attendance prevention: 100% (due to unique device identification)

COMPARATIVE ANALYSIS

Comparison with Existing Systems

Table I presents a comparative analysis of the proposed system with existing attendance solutions:

TABLE I: COMPARISON WITH EXISTING ATTENDANCE SYSTEMS.

Parameter	Manual	RFID	Biometric	Proposed
Accuracy	85%	92%	96%	97.8%
Proxy Prevention	Low	Medium	High	Very High
Implementation Cost	Low	Medium	High	Low

Maintenance	High	Medium	High	Low
Contactless	No	No	No	Yes
AI Integration	No	No	No	Yes
Real-time Analytics	No	Limited	Limited	Yes

Advantages of the Proposed System

- 1) **Dual-layer Security:** Combination of BLE proximity and geo-fencing provides robust authentication
- 2) **Cost Effectiveness:** Utilizes commodity hardware and existing student smartphones
- 3) **Scalability:** Cloud-based architecture supports institution-wide deployment
- 4) **User Experience:** Intuitive mobile and web interfaces enhance usability
- 5) **AI Integration:** Intelligent analytics and automated reporting capabilities

Energy Efficiency: BLE technology ensures minimal power consumption
CHALLENGES AND LIMITATIONS

A. Technical Challenges

- 1) *Signal Interference:* BLE signals may experience interference from:
 - Wi-Fi networks operating in 2.4 GHz band
 - Other Bluetooth devices in proximity
 - Physical obstacles and building materials
- 2) *GPS Accuracy Issues:* Indoor GPS positioning faces challenges including:
 - Limited satellite visibility
 - Multipath signal propagation
 - Environmental factors affecting accuracy

B. Privacy and Security Considerations

- 1) *Data Privacy:* The system handles sensitive student data requiring:
 - Encrypted data transmission protocols
 - Secure database storage with access controls
 - Compliance with educational data privacy regulations
- 2) *Device Security:* Student smartphones must maintain security through:
 - Secure BLE communication protocols
 - Application-level security measures
 - Regular security updates and patches

C. Operational Limitations

- Dependency on student smartphone battery levels
- Requirement for consistent BLE and GPS enablement
- Need for periodic system calibration and maintenance

FUTURE ENHANCEMENTS

A. Advanced AI Integration

Future versions of the system will incorporate:

- Machine learning algorithms for attendance pattern analysis
- Predictive analytics for student performance forecasting
- Natural language processing for enhanced chatbot capabilities
- Computer vision integration for additional verification layers

B. Enhanced Localization

Planned improvements include:

- Integration of Ultra-Wideband (UWB) technology for centimeter-level accuracy
- Beacon mesh networks for comprehensive campus coverage
- Advanced RSSI filtering algorithms using machine learning
- Integration with building information modeling (BIM) systems

C. Blockchain Integration

Future implementations will explore:

- Blockchain-based immutable attendance records
- Decentralized verification mechanisms
- Smart contracts for automated attendance processing
- Enhanced data integrity and audit trails

D. IoT Ecosystem Integration

The system will expand to include:

- Smart classroom environmental monitoring
- Integration with learning management systems (LMS)
- Wearable device compatibility
- Campus-wide IoT sensor networks

CONCLUSION

This paper presents a comprehensive Advanced Attendance System using Bluetooth Low Energy and Geo-fencing that successfully addresses the limitations of traditional attendance

marking methods. The system demonstrates significant improvements in accuracy (97.8%), proxy prevention (100%), and user experience while maintaining cost-effectiveness and energy efficiency.

The integration of Raspberry Pi 3B+ as the central processing unit with BLE scanning capabilities has proven effective for proximity-based detection within classroom environments. The dual-layer verification approach, combining BLE proximity detection with geo-fencing location validation, provides robust security against proxy attendance while maintaining user convenience.

Key achievements of the proposed system include:

- 1) Successful implementation of contactless attendance marking
- 2) High accuracy and reliability in real-world testing environments
- 3) Cost-effective deployment using commodity hardware
- 4) Scalable architecture supporting institution-wide implementation
- 5) Enhanced user experience through mobile and web interfaces
- 6) AI-powered analytics and reporting capabilities

The experimental results validate the system's effectiveness, demonstrating successful device detection within a 5-6 meter range with consistent RSSI measurements. The system's ability to handle multiple concurrent users while maintaining real-time performance makes it suitable for large-scale educational deployments.

The proposed system represents a significant advancement in smart campus automation, providing a foundation for future developments in IoT-enabled educational technologies. As institutions increasingly adopt digital transformation initiatives, this system offers a practical and intelligent solution for modernizing attendance management while supporting the broader vision of smart campus environments.

Future research will focus on expanding the system's capabilities through advanced AI integration, enhanced localization technologies, and broader IoT ecosystem compatibility.

The successful implementation and validation of this system demonstrate the potential for similar IoT-based solutions to transform traditional educational processes and contribute to the development of intelligent learning environments.

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