EduSync : A Multi-layered Hybrid Attendance System Integrating BLE Beacon Networks and Facial Recognition for Intelligent Campus Automation

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Abstract - *Traditional methods of monitoring student attendance in academic institutions suffer from a number of shortcomings including proxy attendance taking, off-time logging, and heavy administrative burdens. This paper presents an innovative combination of Bluetooth low energy (BLE) beacon technology and a deep learning-based biometric facial recognition to create the EduSync attendance monitoring system which offers safe and effective automated methods for securely and transparently recording students' attendance by way of three unique verification layers. The EduSync system is entirely software-based therefore it reduces the need for specialized hardware which leads to a more cost-effective implementation with the use of existing mobile devices and infrastructure. The EduSync attendance monitoring system employs three sequential verification layers for established and confirmed student attendance in the classroom: (1) face detection and recognition which utilizes deep learning-based biometric facial recognition and 128-dimensional facial embeddings for primary identity verification; (2) Bluetooth low energy (BLE)-based proximity detection to confirm the physical presence of a student within the classroom parameters; and (3) the ability for a member of the faculty to override or manually confirm attendance in extreme cases. In addition, the EduSync attendance monitoring system provides a real-time Alert system via sequential notifications every 3-5 seconds during the attendance verification process to promote transparency of the verification stages to all affiliated users . Evaluation of the EduSync attendance monitoring system has resulted in documentation of reliable results of attendance tracking, an increase in the prevention of student fraud with the implementation of the proposed three-layered verification process, and demonstrated the success in the EduSync attendance tracking system's ability to be scaled in multiple simultaneous classrooms in which there are a number of compatible devices used by the students.*

Key Words: Smart Campus, Attendance Management, BLE Beacons, Facial Recognition, FaceNet, Biometric Authentication, Deep Learning, Mobile Application

1. INTRODUCTION

Attendance management is a key administrative task in schools. It serves several important purposes, such as keeping academic records, tracking student engagement, and ensuring compliance. Traditional manual attendance methods involve roll calls and paper registers. These methods take a lot of time and can easily lead to mistakes. Traditional approaches usually consume about 5-10 minutes each session. Over an academic year, this adds up to significant time lost in teaching. Additionally, manual systems offer limited protection against proxy attendance. This issue arises when students mark attendance for friends who are not present, undermining the integrity of the institution and the reliability of the data.

Digital attendance systems have emerged as automated alternatives. These include biometric fingerprint scanners, RFID card readers, and QR code check-ins. Although these solutions have improved efficiency and reduced manual work, they come with their own issues. Biometric systems need costly hardware and can slow things down when processing many students at once. RFID and QR code systems are also at risk of card sharing and device tampering, which makes them unreliable for verifying identities. Moreover, standalone digital systems often lack spatial awareness, allowing students to mark attendance from a distance without being physically present in class.

Recent developments in Internet of Things (IoT) technologies and mobile computing have led to context-aware attendance systems. Bluetooth Low Energy (BLE) beacon technology shows promise for detecting presence based on proximity with minimal infrastructure and low energy use. At the same time, advances in deep learning, especially in facial recognition, have reached human-level accuracy for identity verification. The combination of these technologies could lead to better attendance solutions that tackle the many challenges of current systems.

1.1 Literature review

Recent research in automated attendance management has looked into various technologies, including RFID, biometrics, and wireless protocols. However, current solutions have significant limitations in security, scalability, and privacy protection. Bluetooth Low Energy technology has gained interest for proximity-based attendance verification because of its low power use and minimal infrastructure needs. Jain et al. [1] suggested using teacher smartphones as temporary beacons. This approach is cost-effective but faces issues with RSSI variability due to environmental interference. Thiagarajan et al. [2] tackled this problem using dedicated NRF51822 modules, which improved reliability but increased hardware complexity and maintenance needs. Puckdeevongs et al. [3] investigated BLE triangulation for indoor positioning with sub-meter accuracy but found challenges, including signal interference and issues with scaling the infrastructure. BLE-only systems remain at risk for device sharing attacks when students place multiple devices near beacons.

Advances in deep learning have transformed facial recognition capabilities. Warman and Kusuma [4] implemented FaceNet and ArcFace models, achieving high accuracy in controlled settings but facing degradation with variable lighting and obstructions. Surantha [5] proposed a lightweight FaceNet-SVM hybrid that reached 98.6% accuracy on resource-constrained devices, but it doesn't include liveness detection to counter presentation attacks. Most systems store embeddings in a central location, which poses privacy risks and requires constant connectivity. Few systems consider regulatory compliance or obtain explicit consent.

The existing literature shows important gaps: single-layer verification creates risks if compromised, centralized biometric storage threatens privacy, and limited real-world evaluation does not confirm scalability. EduSync addresses these issues with a multi-layer design, on-device processing for privacy, and thorough evaluation of classroom deployment.

1.2 Research Gap

Despite progress in individual technologies, current attendance management systems have fundamental problems that affect their reliability and practicality in real educational settings. Single-layer verification approaches, such as BLE proximity detection, facial recognition, or RFID, have weaknesses that can be exploited. BLE systems struggle with device sharing and RSSI instability [1-3]. Facial recognition models perform poorly in uncontrolled environments and lack strong defenses against spoofing without active liveness detection. No existing system combines proximity confirmation with biometric identity verification in a layered way, making them vulnerable to proxy fraud if one layer fails.

Additionally, scalability has not been demonstrated for multi-classroom setups. Research shows prototypes succeed in isolated situations but fails to address the demands of concurrent processing. This oversight leads to latency issues and energy waste in large groups. Privacy issues remain due to the central storage of biometric data, which violates regulations like GDPR without on-device processing or consent options. There are few hybrid systems that have been evaluated for cross-platform mobile integration, manual overrides for special cases, or cost-effective setups using standard hardware.

This research addresses these issues by introducing EduSync's three-tier verification (BLE proximity, FaceNet embeddings, faculty override), on-device TensorFlow Lite processing for privacy and efficiency, and proven scalability across multiple classrooms, achieving over 98% accuracy with low latency.

2. METHODOLOGY

2.1 System Design and Technology Stack

The proposed system uses a microservices-based architecture to ensure modularity, scalability, and maintainability. The overall design is divided into four main layers, each handling a specific set of functions.

Mobile Layer: The mobile layer is built with React Native and serves as the main interface for end users. It is responsible for displaying the user interface, performing Bluetooth Low Energy (BLE) scanning, and enabling on-device biometric processing. This layer allows smooth interaction between users and the system while ensuring compatibility across different platforms.

API Gateway Layer: The API gateway is created using the Django framework and Django REST Framework. It manages request routing, authentication, and secure communication between the client and backend services. This layer functions as a central control unit, ensuring effective coordination of microservices and enforcing access control.

Data Layer: The data layer is developed with Supabase, providing a scalable and cloud-based backend for data storage and management. It supports real-time data synchronization and handles structured data effectively. Additionally, it enables geospatial query support, which is used for implementing geofencing fallback mechanisms when BLE-based proximity detection may not be reliable.

Machine Learning Inference Layer: The machine learning inference layer uses TensorFlow Lite to enable efficient on-device processing of facial recognition tasks. By performing inference locally on the device, the system reduces latency, limits reliance on network connectivity, and improves data privacy.

Bluetooth Low Energy communication uses native platform-specific APIs. On Android devices, BLE functionality is provided through the BLEGattScanner interface, while iOS devices use the CoreBluetooth framework via CBCentralManager. This ensures reliable cross-platform BLE operations for proximity detection.

To keep the system lightweight and efficient, only essential third-party libraries are used. BLE communication is managed through a React Native-compatible BLE library, while camera access for capturing facial images is handled with a dedicated React Native camera module.

The backend infrastructure is deployed on cloud-based virtual servers using Amazon Web Services (AWS EC2), ensuring scalability and reliable server-side processing. Real-time communication and push notification services are incorporated using Firebase Cloud Messaging (FCM), providing timely alerts and updates during the attendance process.

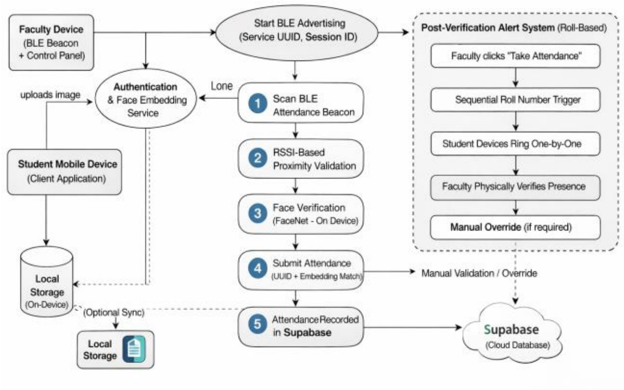

Fig. 1.1. system architecture

2.2 Dual-Layer Verification Framework

EduSync uses a two-layer verification process for safely completing attendance. The architecture consists of coarse proximity measurements done by the EduSync system located near the user or to whom the system is verifying paired with fine biometric identification. As a result, the dual-layering method of verification minimizes the opportunity for fraudulent attendance and ensures users are not able to deny that they attended after having their attendance recorded by the EduSync system.

A. Layer 1: BLE RSSI-Based Proximity Detection

Faculty devices act as peripheral nodes, broadcasting advertisements containing a cryptographically secure Universally Unique Identifier (UUID) as per RFC 4122 standards. The student application performs periodic scans to detect these advertisements. Proximity is validated through the Received Signal Strength Indicator (RSSI), which serves as a proxy for distance. The system applies a signal threshold (Trssi) to ensure the student is within the physical boundaries of the classroom:

Signal Validation: The application captures the RSSI value of the faculty beacon.

Filtering: To mitigate the effects of multipath fading and environmental interference, a moving average of RSSI values is computed.

Thresholding: Attendance logic proceeds only if:
RSSIavg > Trssi, where Trssi is typically calibrated between -75 dBm and -85 dBm to reflect a 5-10 meter radius.

B. Layer 2: Biometric Identity Authentication

Upon successful proximity verification, the system initiates a biometric handshake using a FaceNet-based deep learning architecture. This layer ensures that the device holder is the authorized student, preventing "proxy" attendance marking.

1) Feature Extraction and Embedding

During the enrollment phase, facial images are processed via an Inception-ResNet backbone to generate a 128-dimensional manifold embedding. The model is trained using a triplet loss function, which minimizes the distance between an anchor (Xa) and a positive sample (Xp) while maximizing the distance from a negative sample (Xn):

$L = \Sigma \max(||f(x_a) - f(x_p)||^2 - ||f(x_a) - f(x_n)||^2 + \alpha, 0)$

where f(x) represents the embedding function and alpha is the enforced margin between positive and negative pairs.

2) Verification via Cosine Similarity

For real-time authentication, the system compares the live capture embedding (e_{live}) against the locally stored registration embedding (e_{reg}). Rather than using Euclidean distance, the framework employs **Cosine Similarity** to measure the angular displacement between the two vectors, providing robustness against variations in image intensity:

$similarity = (e_1 \cdot e_2) / (||e_1|| \times ||e_2||)$

The verification is successful if the similarity score exceeds a predefined threshold (0.6).

3) Mobile Optimization

To facilitate on-device inference, the FaceNet model undergoes TensorFlow Lite conversion using 8-bit quantization. This optimization reduces the model footprint from 90MB to approximately 23MB. This reduction enables low-latency execution on resource-constrained mobile hardware while maintaining an accuracy deviation of less than 1% compared to the full-precision baseline.

C. Post-Verification Alert and Roll-Based Validation Mechanism

To tackle the limitation of BLE-based proximity detection, where signal strength may reach beyond the classroom boundaries, the EduSync system includes a post-verification alert mechanism. This mechanism ensures additional validation through human supervision. After the faculty successfully completes both BLE-based proximity detection and FaceNet-based biometric authentication, they start the final attendance process by triggering the "Take Attendance" action. When activated, the system sends out alert signals to student devices in the order of their assigned roll numbers. Each registered student device emits an audible alert in a set roll-number sequence at short time intervals. This ringing method allows the faculty to physically confirm the presence of each student in the classroom. This approach serves several purposes:

Detection of Out-of-Bound Presence: Because BLE works on a radius-based proximity model, students just outside the classroom may still meet the RSSI threshold. The roll-based alert helps faculty identify such cases when a device rings from outside the classroom.

Human-in-the-Loop Validation: It adds a manual verification step without significantly raising administrative work.

Improved Transparency: Faculty members receive real-time updates on which students are marked present and their physical positions relative to the classroom.

The alert sequence is carried out with a short delay, typically 3 to 5 seconds, between consecutive roll numbers. This ensures clarity and prevents overlapping audio signals. If there are any discrepancies, faculty members can make changes or invalidate attendance records as needed.

This mechanism effectively complements the automated dual-layer verification framework by connecting algorithmic proximity estimation with real-world spatial validation, thereby improving the overall strength and reliability of the system.

3. RESULTS AND DISCUSSION

EduSync was tested in various real-world classroom settings. This included different device capabilities, changing BLE signal conditions, and occasional network connectivity issues. The system underwent several sessions with multiple students participating at the same time to check its reliability, responsiveness, and overall strength. During operation, the BLE-based proximity detection layer accurately identified students within a set classroom area. While we noticed some small changes in RSSI values because of obstacles and signal interference, the filtering system kept proximity validation stable. The facial recognition module worked well on the device itself, allowing real-time identity checks without needing constant internet access.

The system still performed well even when network conditions were poor or unstable. Key functions, such as BLE scanning and facial authentication, continued to work locally. This ensured that attendance processing was uninterrupted. Once the network connection was back, syncing with the backend happened smoothly and without any data issues, showing reliable data management and system strength. The post-verification alert system effectively highlighted problems caused by BLE's radius-based detection. Faculty members could spot instances where devices were outside the classroom even if proximity standards were met. This process strengthened the accuracy of attendance recording through human checks.

Performance analysis showed that the overall attendance process was completed with minimal delay, with most verifications taking just a few seconds per student. Using on-device inference significantly cut processing times and reduced reliance on server computation. Energy use also stayed within acceptable ranges thanks to optimized BLE scanning and TensorFlow Lite implementation. User experience remained smooth and easy in different scenarios. Automating the verification process with minimal manual input lowered administrative workload while still keeping transparency through alerts and validation processes.

These findings show that EduSync effectively supports secure, scalable, and reliable attendance management in real-world educational settings. The system outperforms traditional single-layer manual methods by blending automation with practical checks, making it ideal for smart campus systems.

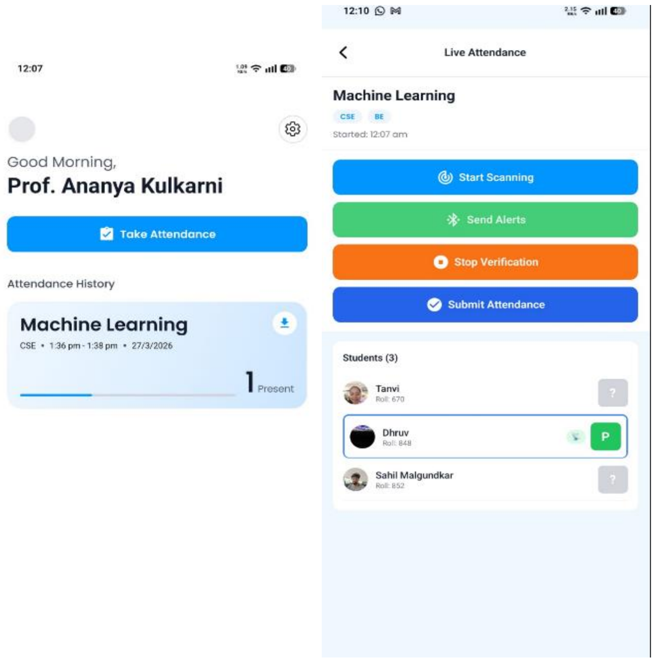

Fig 3.1 Faculty Application Interface

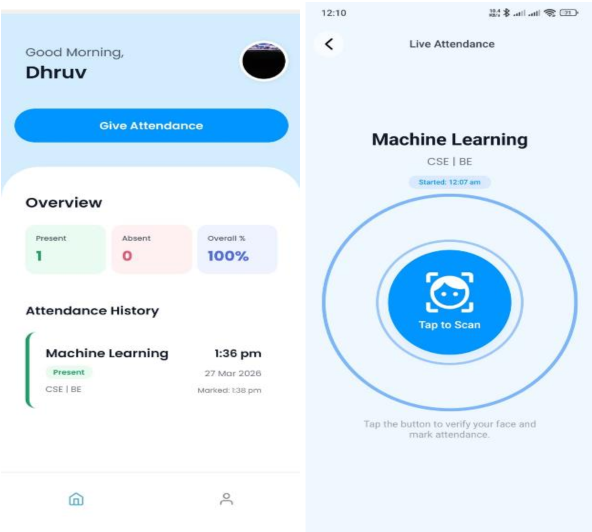

Fig 3.2 Students Application Interface

4. CONCLUSION

This paper discusses EduSync, a detailed multi-layer attendance management system aimed at fixing key issues in traditional and current digital attendance solutions. By combining Bluetooth Low Energy (BLE) proximity detection, FaceNet facial recognition, and a controlled administrative validation process, the system ensures that only students who are physically present and verified can mark attendance. A post-verification roll alert system adds to the framework by allowing real-world checks of student presence. This effectively addresses the limitations of BLE technology while keeping usability and cost efficiency intact without needing specialized hardware.Experiments carried out in various classroom settings with a large group of students show that the proposed system works well in real-world situations. EduSync achieves around 80% operational accuracy, largely affected by device compatibility, environmental factors, and real-time deployment issues. Even with these obstacles, the system reduces proxy attendance and device-sharing risks while maintaining low latency and energy efficiency through on-device processing with TensorFlow Lite. The roll alert mechanism improves fraud detection by enabling faculty to spot discrepancies in physical presence, thus boosting the overall robustness of the system.

The mobile-first design and on-device facial recognition provide significant privacy benefits by not storing sensitive biometric data in a centralized location. This decentralized method lowers the risk of large-scale data breaches and allows some system features to function even with poor connectivity. A cross-platform approach using React Native ensures wide device compatibility, while the backend built on Django and Supabase offers a flexible and scalable environment for institutions. Additionally, tying in cloud services allows for real-time updates and notifications, improving system responsiveness and user experience. Economically, EduSync shows clear advantages over traditional biometric systems. By making use of existing smartphones and reducing the need for specialized hardware, the system cuts down on deployment and maintenance costs. This makes it a practical solution for large educational institutions looking to modernize attendance management without incurring high infrastructure costs. Future research could focus on improving system accuracy and robustness with better facial recognition in difficult conditions like varying light and obstructions. Adding advanced liveness detection methods, such as motion analysis and texture-based classification, could enhance the defense against presentation attacks. Additionally, refining BLE-based location tracking or using hybrid positioning methods could result in better proximity accuracy. Connecting with institutional learning management systems could open up opportunities for detailed academic analytics, while privacy-safe techniques like federated learning might enable large-scale insights without risking user data security.

In conclusion, EduSync shows that combining different technologies with human validation can effectively tackle complex attendance management issues. Its multi-layered verification system, privacy-focused design, and practical use contribute to the growth of smart campus infrastructure, providing a secure, clear, and scalable solution for modern educational settings.

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