A dynamic geofencing and dwell-time validation system for secure attendance tracking in higher education: methodological proposal

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ABSTRACT

Accurate attendance tracking is vital for student engagement and academic integrity, yet traditional methods are prone to error and proxy attendance. While technological solutions like biometrics and QR codes exist, they often suffer from high costs, privacy concerns, and an inability to verify continuous presence. This study proposes a dynamic geolocation-based attendance system to address these gaps. Developed with Flutter and Node.js, the system employs lecturer-defined geofences and a dwell-time validation rule, confirming attendance only if a student remains within the designated area for at least 80% of the class duration. It features cross-platform accessibility, role-based dashboards, real-time notifications, and exportable reports. The methodology followed an Agile approach, focusing on user-centered design and robust backend development. The resulting system offers a cost-effective, scalable solution that enhances accuracy, prevents proxy attendance, and supports the digital transformation of higher education administration.

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1. INTRODUCTION

Accurate attendance tracking is vital for promoting student engagement, supporting academic integrity, and informing institutional decision-making. In higher education, attendance records help enforce policies, identify at-risk students, and evaluate teaching effectiveness [1]. However, traditional methods such as roll calls and paper registers are time-consuming, error-prone, and vulnerable to proxy attendance, which can compromise up to 15–20% of records [2]. Technological alternatives, including biometric systems and QR-code verification, have been introduced to address these challenges. While improving accuracy, these solutions often involve high costs, hardware dependency, privacy concerns, and limited adaptability to mobile or dynamically scheduled classes [3]. Geolocation-based systems, which use global positioning system (GPS)-enabled devices to confirm physical presence within a defined area, have emerged as a promising option [4]. Examples include QR integration with location checks [4], proximity measurement using the Haversine formula [5], and geofencing combined with biometric verification [1]. However, many existing solutions rely on static geofences, validate attendance only at entry, lack continuous presence tracking, or offer limited reporting capabilities [6], [7]. The evolution of automated attendance management systems represents a significant technological advancement aimed at eliminating proxy attendance and streamlining administrative duties. Prior studies have primarily leveraged mobile and positioning technologies, employing a combination of geolocation, biometrics, and unique identifiers to achieve this goal [6]. The collective body of work demonstrates a dynamic field focused on enhancing accuracy, security, and adaptability. A prominent approach involves the use of geolocation and geofencing. For instance, Sandhya *et al.* [4] developed a system integrating QR codes and the Google Maps application programming interface (API), requiring students to scan a time-sensitive code from within a designated classroom. Similarly, Jeevarathinam and Janani [5] and Kundariya *et al.* [7] utilized GPS technology and the Haversine distance algorithm to automate tracking based on a student's proximity to a predefined location, with proposals for customizable geofencing radii to improve institutional adaptability.

To further enhance security, several studies integrated biometric authentication. Bailke *et al.* [1] created a system using teacher-controlled sessions, proximity detection, and biometric verification, though they later proposed a simpler Google Maps API integration to address potential hardware and privacy concerns. Kumari and Kumar [8] addressed this in their QR-based system by proposing caching and local storage mechanisms for offline functionality. Computational expense was another limitation. Babatunde *et al.* [9] combined geofencing with facial recognition to automatically record attendance upon entry or exit from a verified location. A critical challenge identified across multiple systems is the dependency on continuous internet connectivity. Pagare *et al.* [3] noted the high costs of their GPS-integrated system and advocated for designs with lower computational and data training requirements. The research also reveals significant conceptual gaps in system design. A critical review by Chauhan *et al.* [6] identified that many systems only verify initial entry into a geofence, not continuous presence. Their proposed solution involves validating attendance only if a student remains within proximity for at least 80% of the class duration. Conversely, Vimalathithan *et al.* [10] employed facial recognition but lacked full geolocation tracking, leading to a recommendation for sign-in only within an educator's immediate vicinity. Ramon *et al.* [11] establish a dual-verification system that combats proxy fraud by combining geofencing with biometrics. Despite this robust initial authentication, the system does not monitor for continuous presence after the check-in, a significant limitation for session-long attendance validation. Shifting from authentication to broad logistical tracking, Valdez *et al.* [12] employ radio frequency identification (RFID) technology to automate campus access control and monitor movement. While this offers high reliability for perimeter security, the system's focus on general access points, rather than specific rooms, renders it too coarse-grained for direct academic attendance purposes. Moving towards a more accessible and cost-conscious model, Nazara and Nasien [13] prioritize practical deployment with a smartphone-based application built using GPS and rapid development methods. This software-centric approach enhances scalability and reduces hardware dependency, but it introduces new challenges tied to the variable accuracy and security of consumer-grade location services. Finally, moving away from complex hardware, Galgale *et al.* [14] demonstrated a GPS-based system and proposed a simplified, cross-platform application requiring only smartphones to improve deplorability.

From the foregoing, existing systems are often vulnerable to proxy attendance and lack ways to confirm that a student stays for the entire class. They can also be inflexible, difficult to adapt to different locations, and limited to specific device platforms. Many models require specialized hardware, like biometric scanners, which raises cost and privacy concerns. Furthermore, most systems provide only basic data and fail to offer useful, exportable reports for analysis. The proposed system addresses these issues with dynamic geofences, a dwell-time check, cross-platform access, and exportable Excel reports. This study proposes a dynamic geolocation-based attendance management system that verifies student presence in real time and ensures they remain within the lecturer-defined radius for at least 80% of the class duration before attendance is confirmed. Developed using Flutter for cross-platform mobile access and Node.js for backend services, the system integrates adjustable geofencing, role-based dashboards, real-time notifications via Firebase, and exportable attendance reports. By enhancing accuracy, adaptability, and transparency, this system offers a cost-effective, scalable solution to improve attendance management and support the digital transformation of higher education.

This study aims to design and implement a geolocation-based student attendance management system. The specific objectives are to: design a user-friendly mobile interface using Figma and define a scalable database schema with PostgreSQL to support user management, attendance tracking, and geolocation data storage. Implement the mobile application front-end using Flutter and Dart, and develop a secure backend system using Node.js to handle user authentication, geolocation validation, attendance session control, and communication with the database. Test the system through simulations of real-world academic scenarios to evaluate geolocation accuracy, session tracking reliability, and the effectiveness of proxy attendance prevention. Evaluate the system’s usability, performance, and effectiveness through users’ feedback, functional testing, and analysis of attendance data accuracy and reporting capabilities.

2. METHOD

The software development life cycle (SDLC) model employed for this study is the Agile methodology, specifically an iterative approach. Agile was chosen due to its flexibility, responsiveness to changes, and ability to produce functional prototypes early in the development cycle. According to Sharma and Pandey [15], Agile methodology enhances customer satisfaction through continuous delivery of valuable software and encourages adaptive planning, evolutionary development, and early delivery. This was especially relevant in building a system that required ongoing user feedback from students and educators during development and testing phases.

The proposed attendance management system was conceptualized as a geolocation-based platform designed to improve attendance accuracy and reduce proxy attendance. The system architecture consists of two major components: the frontend (client-side) and the backend (server-side). It supports three user roles, namely students, lecturers, and administrators, each having different access privileges and interaction flows. Core design considerations included responsive mobile user interface (UI), secure backend processing, real-time geolocation validation, and role-based access management.

To actualize the objectives of this study, the UI was designed using Figma, incorporating wireframes, navigation flows, and interactive prototypes. The design process considered role-specific interfaces, including dashboards, attendance monitoring pages, course management modules, and geolocation permission screens. In parallel, a PostgreSQL database schema was defined to support scalable storage of user profiles, course information, attendance records, session logs, and geolocation data. Entity relationship modelling was employed to ensure data integrity and efficient retrieval of information.

The frontend application was designed using Flutter and Dart, enabling cross-platform deployment across Android and iOS devices from a single codebase. The frontend module provides location permission requests, attendance status monitoring, course management interfaces, notification displays, downloadable reports, and map-based geofence visualization. Cross-platform development was adopted to improve accessibility and reduce maintenance costs while ensuring consistent user experience (UX) across devices [14], [16], [17].

The backend system was designed using Node.js and the Fastify framework to manage application logic and communication between system components. RESTful APIs facilitate communication between mobile clients and server resources. The backend architecture comprises several functional modules: i) user authentication: implemented using JSON Web Token (JWT) with an authorization framework, OAuth2, providing secure stateless sessions and optional integration with external identity providers; ii) role-based access control (RBAC): middleware-enforced permission rules for students, lecturers, and administrators; iii) geolocation validation: the backend compares GPS coordinates from the student and lecturer devices against a dynamic, lecturer-defined geofence radius. Dwell-time validation ensured students remained within range for at least 80% of the session. This mechanism was motivated by recommendations from Chauhan *et al*. [6], who identified continuous presence validation as a major limitation of existing attendance systems; iv) attendance management: verified attendance data was stored in PostgreSQL and made accessible for review or modification; v) notifications: implemented via Firebase Cloud Messaging (FCM) to send class reminders and attendance confirmations; and vi) API security middleware validated JWT tokens, enforced expiry checks, and restricted endpoint access.

The tools and technologies selected for the proposed system are presented in Table 1. The combination of Flutter, Node.js, PostgreSQL, Google Maps API, and Firebase was selected to ensure scalability, cross-platform compatibility, real-time communication, and efficient geolocation processing. By integrating these technologies with dynamic geofencing and dwell-time validation mechanisms, the proposed methodology addresses limitations identified in existing attendance management solutions while supporting flexible deployment within higher education institutions.

Table 1. Tools and technologies used

Technology	Purpose
Flutter and Dart	Mobile frontend development
Node.js	Backend server logic
Fastify	HTTP server framework for routing and API handling
PostgreSQL/Firebase Firestore	Database for storing attendance records, user info, and location data and real time notifications
Figma	UI/UX design and prototyping
Google Maps API	Geolocation tracking and geofence validation
Postman	API testing during backend development
Git and GitHub	Version control

3. RESULTS AND DISCUSSION

The outcome of this study is a conceptual and architectural design for a dynamic geolocation-based attendance management system intended to improve attendance verification accuracy in higher education environments. The proposed solution addresses several shortcomings identified in previous studies, including fixed geofence configurations, limited reporting functionality, and the inability to verify continuous student presence throughout a lecture session [6], [11].

Figure 1 illustrates the workflow of the existing geolocation-based attendance system adapted from Chauhan *et al.* [6]. In this model, attendance is recorded once a student enters a predefined geofence area. Although this approach automates attendance collection and reduces manual effort, it primarily verifies initial presence and does not provide mechanisms for confirming that students remain within the designated area throughout the lecture period. Similar limitations have been reported in other geolocation-based attendance solutions that rely solely on proximity verification without continuous monitoring [1], [11], [18], [19]. Consequently, students may be marked present despite leaving the lecture venue shortly after check-in.

Figure 2 presents the workflow of the proposed attendance management system. Unlike the existing model shown in Figure 1, the proposed workflow incorporates continuous location monitoring and dwell-time validation. Attendance is confirmed only when a student remains within the lecturer-defined geofence for at least 80% of the scheduled class duration. This mechanism directly addresses the continuous presence verification challenge highlighted by Chauhan *et al.* [6] and strengthens protection against proxy attendance practices [20]. The workflow begins with user registration and authentication, followed by geolocation verification, dwell-time monitoring, attendance confirmation, and report generation.

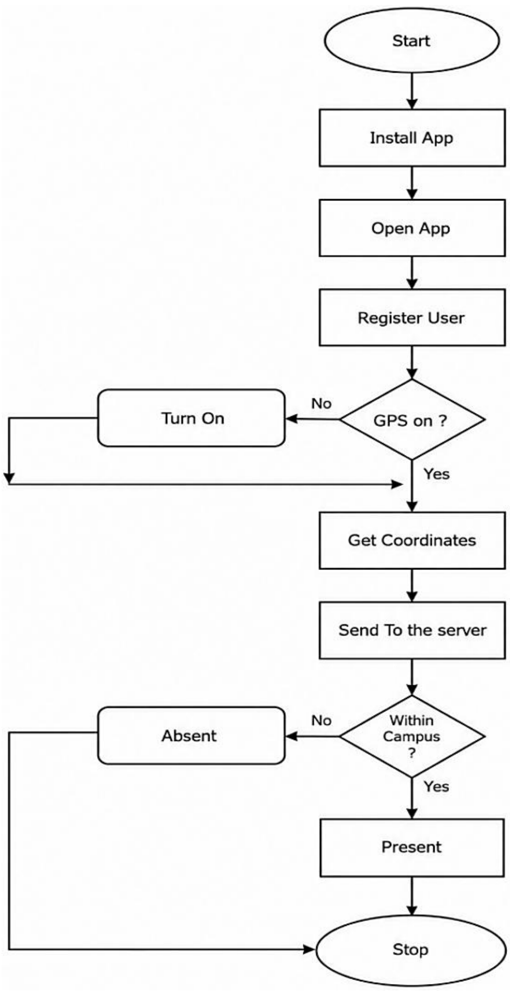

Figure 1. Workflow of the existing system (Chauhan *et al.* [6])

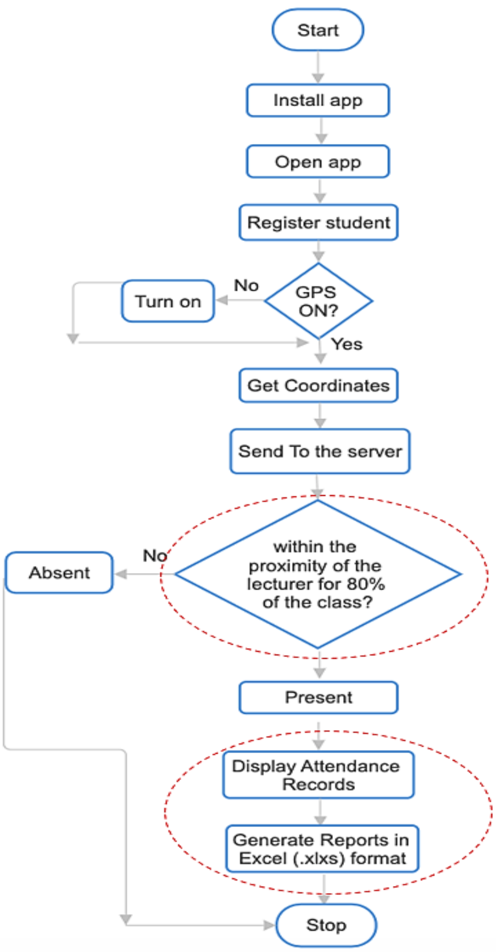

Figure 2. Workflow of the proposed system

Another significant improvement shown in Figure 2 is the implementation of dynamic geofencing. While many existing attendance systems rely on fixed geofence boundaries [5], [7], the proposed system enables lecturers to adjust the attendance radius according to classroom conditions, venue changes, and instructional requirements. This flexibility increases adaptability and improves applicability across different academic environments. The approach also aligns with recommendations from previous studies that emphasized the need for more flexible and scalable attendance management systems [13], [14].

A comparative analysis between Figures 1 and 2 highlights the major contributions of the proposed system. First, the proposed model introduces dwell-time validation rather than relying solely on entry-based attendance confirmation. Second, it replaces static geofences with lecturer-configurable geofence boundaries. Third, it provides attendance reporting and monitoring capabilities that extend beyond simple attendance recording. These enhancements collectively improve attendance reliability, accountability, and administrative efficiency. Compared with existing approaches that focus primarily on location verification [4], [5], the proposed model integrates both spatial and temporal validation to provide a more robust attendance management mechanism.

The proposed system also introduces enhanced attendance reporting capabilities. Unlike several existing solutions that provide only attendance records [3], [4], the proposed design generates exportable attendance reports and attendance summaries that can assist lecturers in monitoring participation trends and identifying students with low attendance rates. These reporting functions support evidence-based academic decision-making and improve administrative efficiency. Furthermore, students can monitor their own attendance percentages through the dashboard, thereby encouraging accountability and engagement.

Figure 3 presents the developed UI/UX prototype for the application's introductory screens. The interface was designed to provide users with a clear understanding of the application's purpose and functionality upon first use. The design emphasizes simplicity, accessibility, and intuitive navigation. By incorporating modern mobile design principles through the Figma platform, the interface seeks to enhance user engagement and facilitate adoption among both students and lecturers.

Figure 4 illustrates the authentication and dashboard interfaces developed for the proposed system. The role-based dashboard architecture provides customized functionalities according to user responsibilities. Students are provided with attendance monitoring, course information, and notification features, while lecturers are granted additional privileges for attendance session creation, course management, and report generation. This role-specific interface design improves usability by minimizing unnecessary functions and streamlining user interactions.

From a technological perspective, the integration of Flutter and Dart enables deployment on both Android and iOS devices through a unified codebase. This approach is consistent with recommendations advocating smartphone-based attendance solutions to improve accessibility and scalability while minimizing hardware dependencies [13], [14]. Similarly, the use of Node.js, PostgreSQL, JWT authentication, FCM, and Google Maps API provides a secure and scalable backend infrastructure capable of supporting real-time attendance monitoring, geolocation validation, and communication services.

Overall, the proposed system demonstrates how dynamic geofencing and dwell-time validation can be integrated within a mobile attendance management platform to enhance attendance accuracy, reduce opportunities for proxy attendance, and improve administrative oversight. The combination of continuous presence verification, flexible geofence management, role-based access control, and reporting functionality represents a substantial improvement over many existing geolocation-based attendance systems reported in the literature [1], [6], [11]. The design establishes a strong foundation for future implementation and real-world evaluation in higher education institutions, where performance metrics such as geolocation accuracy, usability, reliability, and user satisfaction can be empirically assessed.

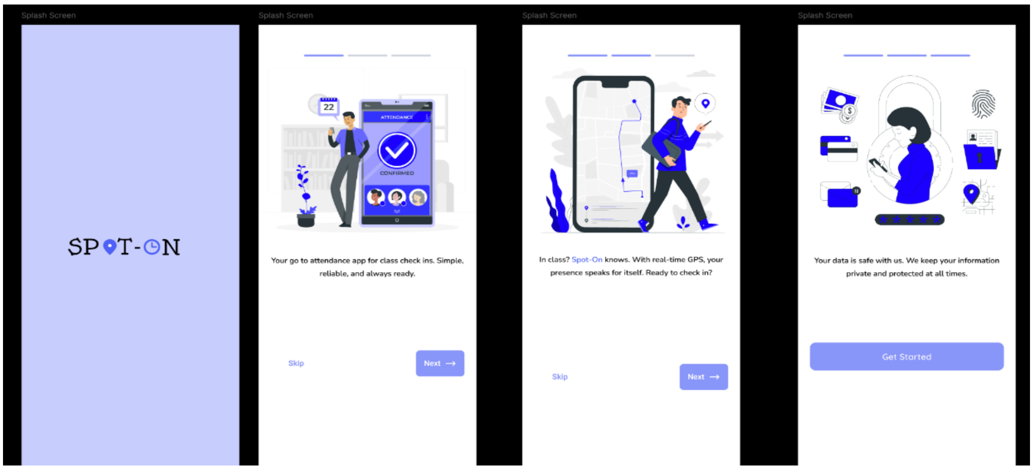

Figure 3. UI/UX design of first interface of the proposed geolocation-based attendance system

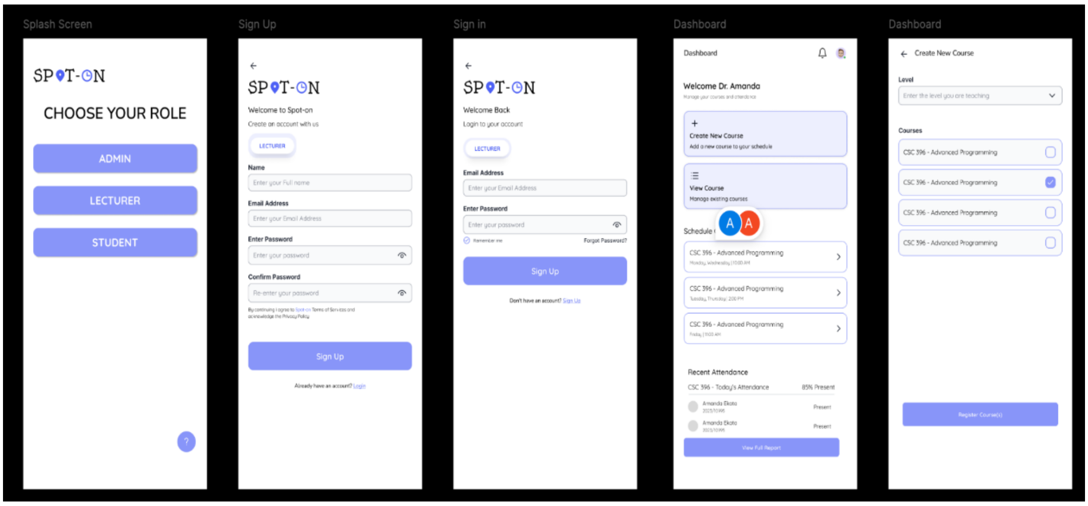

Figure 4. UI/UX designs for the login interface of the proposed geolocation-based attendance system

4. CONCLUSION

This study successfully designed, developed, and proposed a dynamic geolocation-based attendance system to address the significant limitations inherent in traditional and existing technological methods. By integrating lecturer-defined dynamic geofences with a robust dwell-time validation rule—requiring students to remain within the designated area for at least 80% of the class duration—the system effectively mitigates the risks of proxy attendance and ensures verification of continuous presence, not merely initial entry. Developed using an Agile methodology with a Flutter frontend and a Node.js backend, the solution offers a cost-effective, scalable, and privacy-conscious alternative to hardware-dependent systems like biometrics. Its cross-platform accessibility, role-based dashboards, real-time Firebase notifications, and exportable reporting capabilities provide a comprehensive tool that enhances administrative efficiency, supports academic integrity, and promotes student engagement.

The proposed system represents a meaningful contribution to the digital transformation of higher education administration. It not only improves the accuracy and reliability of attendance tracking but also offers a flexible framework adaptable to diverse institutional needs. Future work will involve rigorous real-world testing in multiple classrooms to further validate its performance, usability, and effectiveness in live academic environments.

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AUTHOR CONTRIBUTIONS STATEMENT

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C : **C**onceptualization	I : **I**nvestigation	Vi : **Vi**sualization
M : **M**ethodology	R : **R**esources	Su : **Su**pervision
So : **So**ftware	D : **D**ata Curation	P : **P**roject administration
Va : **Va**lidation	O : Writing - **O**riginal Draft	Fu : **Fu**nding acquisition
Fo : **Fo**rmal analysis	E : Writing - Review & **E**diting	

CONFLICT OF INTEREST STATEMENT

The authors state no conflict of interest.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

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