Design and Implementation of an Enhanced QR-Code Based Attendance System

[1*]Akeem Alabi, [2]Habeeb Lateef, [3]Ayobami Tewogbade, [4]Patrick Ozoh and [5]Fortune Balogun

[1, 4, 5]Department of Information Systems, Faculty of Computing and Information Technology, Osun State University Osogbo, Nigeria
[2]Department of Computer Science, College of Natural and Applied Sciences, Oduduwa University Ipetumodu, Nigeria
[3]Department of Cybersecurity, Faculty of Computing and Information Technology, Osun State University Osogbo, Nigeria

email: [1*]akeem.alabi@uniosun.edu.ng, [2]habeeblateef002@gmail.com, [3]ayobami.tewogbade@uniosun.edu.ng
[4]patrickozoh@uniosun.edu.ng, [5]fortunebalogun11@gmail.com

Corresponding author

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Abstract - *Attendance systems in our educational systems today are employed by management and other concerned authorities to take records of students' presence as well as participation, especially in crucial school activities and events. Traditional attendance methods involving manual roll calls and sign-in sheets have been used for quite a long time leading to issues related to time and errors. Several digital attendance systems incorporating QR-code-based authentication mechanisms have been proposed, yet few identified challenges such as cost, security and user friendliness are yet to be fully considered. This paper presents an improvement on the QR-code attendance framework leveraging User-Centric Approach (UCA). Data was aggregated from students and lecturers to generate the QR Code followed by identity authentication protocols utilizing email credentials and encrypted passwords. Session information, such as timestamp and number of participating students, were also recorded accordingly and stored in the system's database. Each QR code was integrated with cryptographic timestamping, enforcing temporal validity constraints to invalidate it after a five-second interval for security optimization. This was implemented using JavaScript programming logic. The QR Code Attendance System had a high engagement with 7,900 unique scans over seven weeks and consistent daily usage. It processed approximately 105,000 reads, indicating robust system performance and underscoring the need for cost-efficient database management. This represents an improvement over the conventional QR-based methods. The introduction of additional features such as the expiration of QR codes and disabling of screenshots to enhance security serve as improvements on existing systems, thus, eliminating critical weakness in terms of usability and security against unauthorized attendance registration by sharing codes or reusing them.*

Keywords: Attendance system, QR code, database management, unified modelling language, attendance management.

1 Introduction

Attendance systems are part and parcel in every educational institution in our world today. They help observe and record every student's presence or participation especially in important school activities and events such as lectures, tests and sometimes seminars. Other than serving as a fountain of discipline in academics, proper attendance can be of great importance in adhering to institutional regulations and government policies. Traditional attendance methods involving manual roll calls and sign-in sheets have been used for quite a long time in any educational setting. These methods are generally tipped to be very time-consuming and error-prone, with fraudulent entries and loss of data reported. Into the solution for these gaps, a number of digital attendance systems embedded with technologies (such as Radio Frequency, Biometric etc.) have been introduced but also with few identified challenges. Radio Frequency Identification (RFID) technology has flexibility and automation but faces high costs, vulnerability to compromise, and exposed tag issues when it comes to implementation. Also, evaluating different vendors' offerings, including security features and tag capabilities, adds complexity to these implementation flaws (Trebuna et al., 2023). On the other hand, Biometric systems, as much as they are efficient, raise a number of privacy concerns, given the nature of data involved. For instance, biometric data, such as fingerprints or facial scans, cannot be changed in the case of a breach, hence making identity theft and consequent misuse a serious risk. Despite all developments in this direction, the reason local institutions still face attendance-related problems is the absence of an affordable, reliable attendance system that ensures privacy. While RFID systems are considered very expensive in terms of implementation and maintenance, biometric systems usually raise several concerns regarding privacy and infrastructural changes (Abrams & Skrebnewa, 2024). In addition, most of these technologies need a lot of technical expertise and resources that may not be available or feasible for every educational institution.

Although some improvements have been made using Quick Response (QR) codes in addressing some of the major challenges of attendance systems (Djamarullah et al., 2024; Nuralif & Fachrie, 2023), aspects such as cost and user friendliness are yet to be fully considered. This paper presents an improvement on the QR-code attendance system using user-centric approach (UCA), thus enhancing simplicity and cost-effectiveness in attendance tracking while guaranteeing that accuracy and integrity are maintained. The goal is to build upon existing methods by refining the implementation to better meet user needs and streamline the attendance process. This is to provide an economical solution as compared to a very cost-intensive RFID and biometric system that many educational institutions elsewhere would be able to afford. User-friendliness is another aspect of relevance in this study implying quicker adoption and less manpower for training among staff and students. Finally, by improving the efficiency and accuracy in attendance tracking, the system would ensure academic management and the reliability of data for overall educational betterment. This research thus, not only addresses the current limitations of attendance systems but also provides a scalable solution that can be easily adapted in case of future technological advancement.

2 Related Works

Different technological methods have been explored using different approaches in developing attendance systems for students. An example is the one developed by (Sudha et al., 2015), using a physical barcode scanner to enable the automation of attendance management in educational institutions. The idea was pointed towards easing the data collection process and reducing administrative burdens. A barcode scanning technology was employed, and the results were laudable. (Alotaibi, 2015), introduced an IoT-enabled blended learning environment by considering authentication techniques that include biometric and identity verification with an ID card. The system focused on integrating IoT for identity management and access across both physical and virtual educational spaces with a notable performance. Fenu et al. (2018) also proposed a multi-modal biometric authentication system to address the issue of highly continuous and non-intrusive authentication of students' identities in online learning environments. This approach fuses different biometric traits-face, audio, touch, mouse, and keyboard-operating in authenticating the same student across multiple devices and sessions in online learning settings. In contrast to conventional approaches that concentrate solely on identity validation during examinations, this system functions persistently, guaranteeing that the verified student remains the individual interacting with the platform throughout the duration of use. A QR code-based attendance system was also investigated by (Kumar et al., 2020), using scanning of the QR code at the commencement of a class with the use of a projector. This research further investigates a financially feasible method for organizations lacking such infrastructure and how additional security measures are important, such as disabling the screenshot function and setting an expiration time for QR codes, to attain better data integrity and avoid misuses. Osasuyi et al. (2020) developed a fingerprint-based recognition attendance management system that uses biometric authentication in order to improve security and accuracy. This system provided a significant amount of security through biometric verification. Vijayalaxmi and Kempanna (2021) also proposed an AI-based attendance system by using face recognition. The main question relies on complicated image processing and AI algorithms for face identification. Elaskari et al. (2021) reported its usage in monitoring student attendance. While barcodes themselves are a cost-efficient and uncomplicated technology, QR codes can, because of their two-dimensional structure, be scanned with ordinary smartphone cameras without the use of special scanning devices, therefore making this technology more viable and easier to operate. This is what makes QR codes capable of serving more versatile and powerful applications compared to the conventional barcode technology. Onyishi and Igbinoba (2021) examined the shortcomings of conventional manual attendance systems employed within educational institutions and proposed a solution based on biometric technology. The study elaborates on the design and execution of a biometric system for time and attendance logging that employs fingerprint recognition to effectively monitor student attendance. The system incorporates an Atmega328P microcontroller, an RS305 fingerprint module, and a personal computer for the management of data. The fingerprint module responsible for the acquisition and processing of fingerprint information acts in concert with the microcontroller to orchestrate the diverse elements of the system, including an LCD and an RGB LED. Software associated with it, developed in Visual Studio C# and MySQL 2008, will manage student data and issue the attendance record. IoT-based smart classroom attendance management systems were developed using RFID and face recognition technologies together by (Zhao et al., 2022). This research accentuates the way IoT devices and advanced recognition technologies could be combined for higher accuracy in managing attendance. Osasuyi et al. (2020) presented an IoT-enabled student attendance management system. This system improves the traditional rollover methods of attendance by leveraging radio frequency identification and its connectivity with mobile and computer systems, thus increasing efficiency and accuracy. This study also highlights how personality traits can impact attendance; utility-oriented personalities tend to show maximum attendance. Furthermore, the system integrates Kalman filters to improve both monitoring and positioning capabilities, thereby overcoming the constraints associated with GPS. This IoT-oriented methodology offers a more efficient and considerate strategy for managing student attendance (Xun et al., 2022). Olasupo et al. (2022), based on the setbacks surrounding conventional paper-based attendance systems, including impersonation, lost records, and inefficiency, developed a fingerprint-based student attendance management system for Olabisi Onabanjo University. The system captures the attendance of students by means of fingerprint technology using a Digital Persona fingerprint scanner. The system was developed using the SDLC in which system logic was written in C#; the SQL server was used for data storage. A biometric-based attendance management system that incorporates fingerprint recognition is proposed in the paper by (Opeke et al., 2023) to address such limitations found with the traditional approaches of roll calls and attendance sheets, which are predisposed to proxy attendances, errors, and inefficiency, particularly in handling large classes. This technique captures and stores the fingerprinting of the students to verify attendance for correct results and security. The research discusses prevailing systems, that is iris recognition, password authentication, RFID technology, and face recognition, each of which possesses its incomparable downside, including health-related issues, security weaknesses, and risks associated with impersonation. The proposed fingerprint system closes this gap by providing a singular, reliable, and efficient method for attendance management in educational institutions. Although the system requires an initial investment in hardware and software for its implementation, it improves security, accuracy, and efficiency in managing attendance. This system also diminishes many problems regarding falsification of attendance and impersonation, making the process smoother and more reliable. Babu and Manne (2023) proposed an intelligent student attendance monitoring system, which addresses HAAR cascades together with Convolutional Neural Networks for face detection, masked or unmasked. This architecture of a system consists mainly of two phases of operation: it detects faces using HAAR cascades and HoG features, then recognizes them with the help of LBP coupled with CNN. It increases both accuracy and flexibility, especially in some contexts where learners are required to use masks, hence being a good mechanism to monitor attendance automatically. Mohamed et al. (2022) suggested a new approach toward student attendance monitoring, considering the implementation of machine learning and deep learning methods. An integrated framework that includes face detection with SVM and CNN methods was also provided to enhance the accuracy level of such technologies. Liu (2024) developed a student attendance management system by using Spring Boot and Vue.js. It was a module-based system, including user management, course management, and attendance tracking. This was targeted at having a web-based with heavy-weight management thus improving the efficiency and accuracy of attendance monitoring.

Several attendance management systems have been developed using technologies such as RFID, biometrics, IoT and AI-based face recognition, these technologies have their own limitations such as high costs, privacy concerns, infrastructure requirements and technical complexity. Even though QR code-based systems are a cost-effective alternative, existing implementations still lack critical considerations such as user-friendliness, accessibility and additional security measures. These gaps show the need for an approach that prioritizes simplicity, affordability, and ease of adoption while maintaining security and reliability. This system uses the User-Centric Approach which is applied by refining the QR code attendance system to ensure it is financially feasible for institutions with limited resources, without compromising on security. This ensures a balance between efficiency and usability, making attendance tracking more practical for educational institutions. Focusing on user needs, this research offers a scalable and adaptable solution that overcomes the limitation of existing systems.

3 Methodology

This section shows the approach used in the design and implementation of the QR Code Attendance System, showing the way data was collected, system was designed and tested. Data were collected through web-based forms from 40 students across different departments in Oduduwa University and lecturers from the Computer Science Department of the same institution. The data collection process lasted for two weeks.

The student data included:

- Full Name
- Matriculation Number
- Department
- Level
- Email Address
- Password

For lecturers, the collected data included:

- Full Name
- Department
- Email Address
- Phone Number
- Password

These parameters represent the most crucial data in all functional aspects of the system. The student data were used to generate the QR Code for effective attendance management, while the effective organization of the attendance results was made possible using lecturers' data.

3.1 System Design and Data Integration

These data are important to the development and operation of this system. During registration, authentication by both students and lecturers will be done using their respective email addresses and passwords (log in) as shown in Figure 1 and 2.

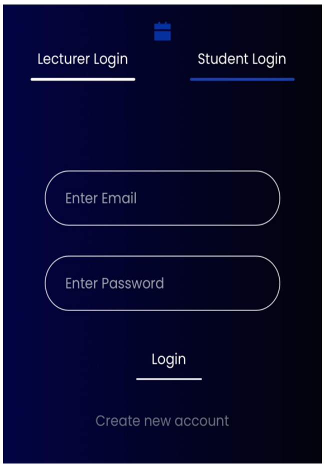

Figure 1: Student login screen

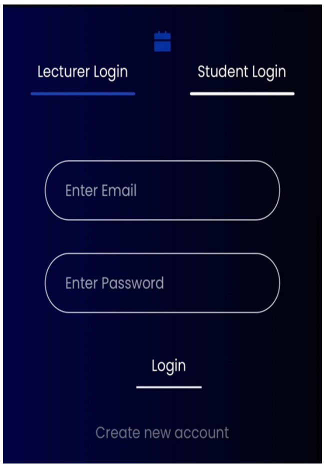

Figure 2: Lecturer login screen

Lecturers will create courses upon login as shown in Figure 3, when creating these courses, they assign a class rep to individual courses by inputting the email of the class representative as shown in Figure 4.

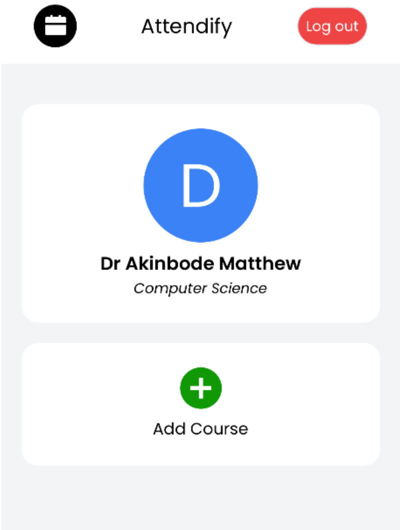

Figure 3: Course creation screen

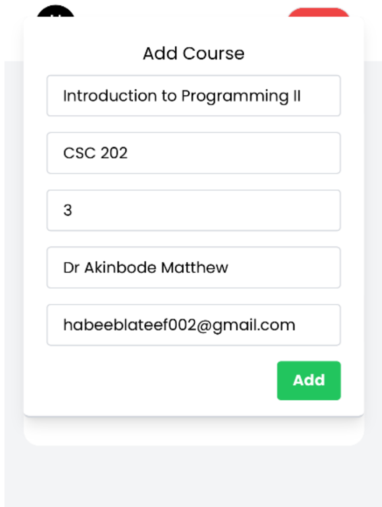

Figure 4: Assign course rep screen

Once a course has been assigned, the class representative is authorized to view it and start a session as shown in Figure 5 and 6, after which QR code scanning can begin for attendance registration of students. Session information, such as timestamp and number of participating students, is recorded accordingly and stored in the system's database. This approach ensures that all relevant information is captured in real-time, making sure lecturers can efficiently oversee and regulate attendance.

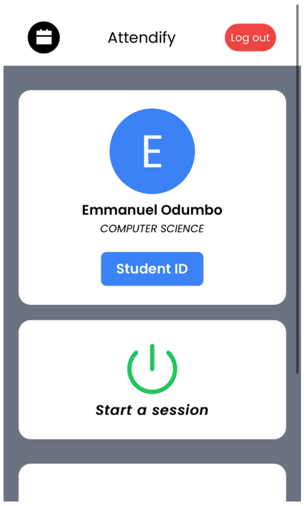

Figure 5: Course rep screen

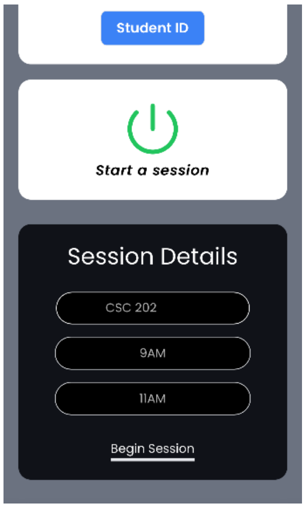

Figure 6: Begin session screen

A student will be able to log into the system, which allows the generation of a QR code containing his personal information: matriculation number and full name as shown in Figure 7. This QR code is then created as shown in Figure 8, by associating a timestamp, making sure it becomes invalid after a duration of two to five seconds. This measure is implemented for security purposes, preventing its utilization or dissemination by unauthorized entities. The system also prevents replicating the QR Code, and further uses the timestamp feature to improve security by making sure the QR Code is immediately scanned after generation.

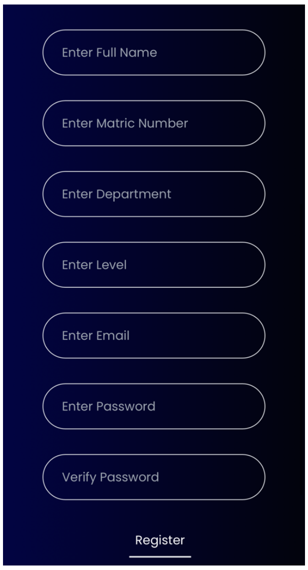

Figure 7: Student register screen

Figure 8: QR code generation

3.2 Database Design

The architecture of the QR code attendance system follows a structured approach to ensure usability, security, efficiency and accessibility.

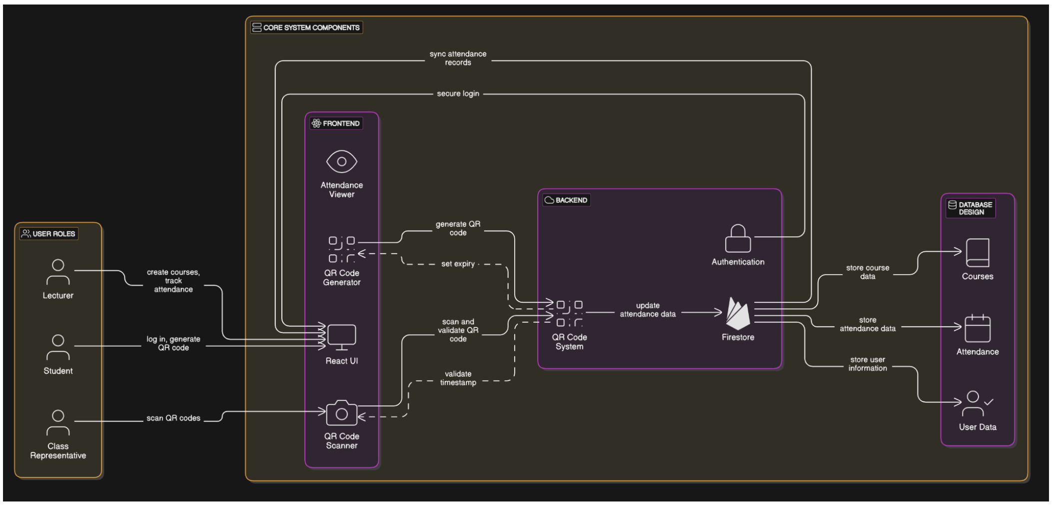

Figure 9: System architecture

The system is developed using a three-tier architecture as shown in Figure 9. The system is broken down to the following categories:

1. The Frontend: This was developed using React.js Javascript library for an interactive user interface, the system was designed to ensure responsiveness across various devices, enhancing user experience. The system also provides forms for user authentication, attendance-scanning and real-time feedback.
2. The Backend: The backend was implemented with Javascript, the backend handles API requests, it manages authentication, QR code generation, validation and database interactions.
3. The Database: The database was implemented using Firestore for efficient storage of users, attendance records, and QR code metadata. The database ensures fast query execution for verification of attendance.

The QR Code Attendance System is designed to automate and streamline the attendance process within educational institutions. It integrated various roles, including Lecturers, Students, and Class Representatives, to ensure a smooth flow of operations and communication. The architecture of the system was represented using a

UML (Unified Modeling Language) diagram, which outlines the relationships between different components, including database connections, user interfaces, and the flow of operations across different user roles.

1. Lecturer role:
   i. Create courses: Lecturers can create courses and assign class representatives to manage attendance.
   ii. Track attendance: Lecturers can view and track attendance records for their courses in real time.
   iii. Generate reports: Lecturers can generate attendance reports for specific periods, enabling them to monitor student attendance trends.
2. Student role:
   i. Generate QR code: Students generate a personal QR code containing their student details. This QR code is unique to each student and is used to mark their attendance.
   ii. View attendance records: Students can view their attendance history for each course they are enrolled in.
3. Class representative role:
   i. Scan QR codes: Class representatives use a smartphone application to scan student QR codes during class sessions. The scanned data is instantly updated in the database.
   ii. Monitor attendance: Class representatives can monitor attendance in real time and ensure that all students have marked their presence.

3.3 Database Design

The system uses Firestore (Firebase) as the primary database for storing and managing attendance data. Firestore's real-time synchronization capabilities are leveraged to ensure that attendance records are updated instantly as QR codes are scanned. The database is structured to store information about students, courses, lecturers, and attendance records as shown in Figure 10. Each student's QR code is linked to their unique student ID, and attendance records are associated with specific courses and dates.

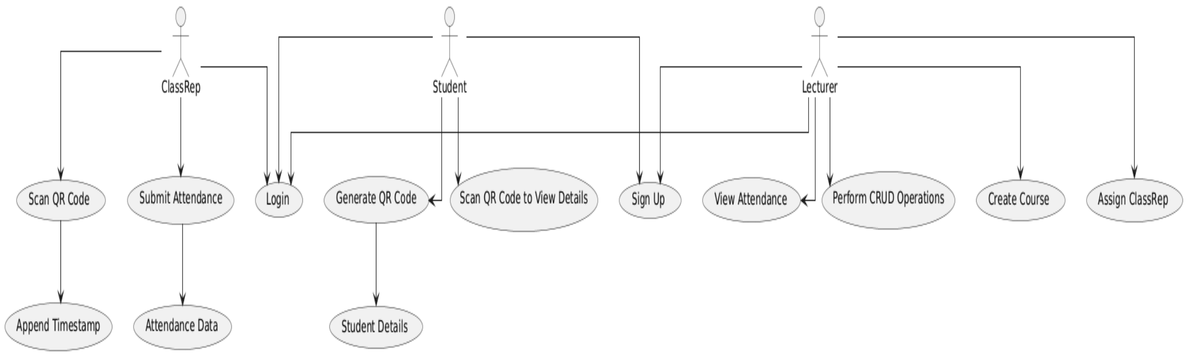

Figure 10: System interaction model for role-based attendance management

3.4 Implementation Details

The front-end of the QR Code Attendance System was developed using JavaScript and React.js. These technologies were chosen for their ability to create dynamic and interactive user interfaces, ensuring a smooth user experience.

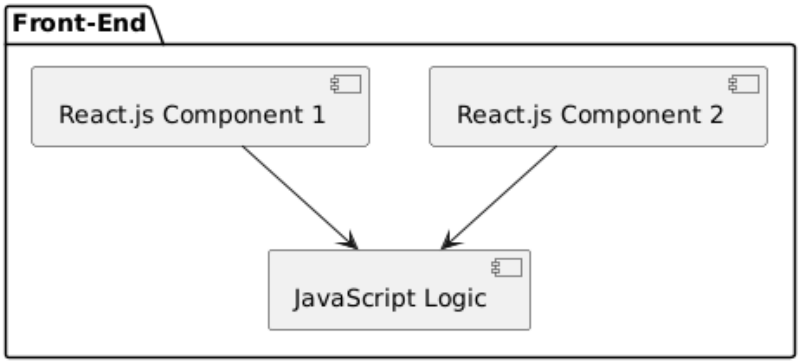

Figure 11: Component interaction diagram for react.js front-end architecture

Javascript: Provides the logic and interactivity needed to manage user actions, such as generating QR codes, scanning them, and updating the user interface.

React.js: Adds a component-based architecture to the system, enabling the development of modular and reusable UI components. Figure 11 shows the way each component, such as the QR code generator or scanner, is encapsulated, meaning it manages its own state and functionality independently.

3.5 Component Breakdown

1. C1: QR code generator: Allows students to generate their personal QR codes.
2. C2: QR code scanner: Enables class representatives to scan student QR codes.
3. C3: Attendance records: Displays attendance history to both students and lecturers.

[UI Component: C1] + [UI Component: C2] + ... = Complete Interface

3.6 Database Management

The system uses Firestore (Firebase) as the backend database. Firestore is chosen for its scalability, ease of use, and real-time data synchronization capabilities.

Real-time updates: When a student's QR code is scanned, the data is instantly updated in Firestore, ensuring that the attendance records are always up to date as shown in Figure 12. Firestore's cloud infrastructure supports the system's ability to handle an increasing number of users and data without compromising performance.

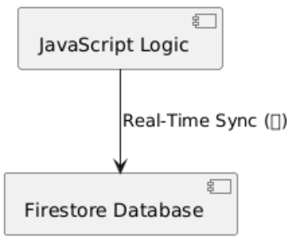

Figure 12: Real-time sync between javascript and firestore

3.7 Data Flow

1. User action: A student's QR code is scanned.
2. React component: The scanned data is processed by the React component.
3. Firestore update: The processed data is then stored in Firestore in real time, ensuring synchronization across all user interfaces.

User Action --> React Component --> Firestore Update (🔄)

The (sync symbol) represents real-time synchronization between the UI and Database.

The QR Code Attendance System is designed with scalability in mind. As the number of users (students, lecturers, and class representatives) grows, the system can efficiently handle increased data volume and user interactions. Firebase's cloud infrastructure ensures that the system can scale up to accommodate more users and data without significant performance degradation as shown in Figure 13.

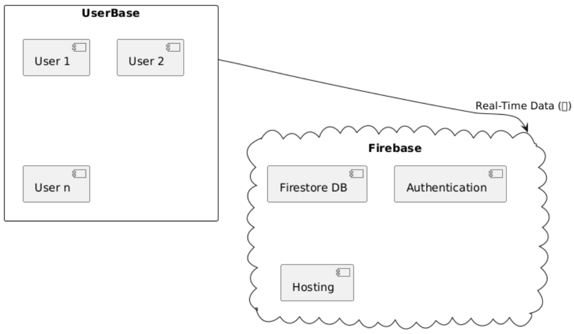

Figure 13: User data interaction

3.8 Scalability Representation

a. Initial scale: Handles small classes with limited data.
b. Increased scale: Supports larger institutions with numerous courses, students, and attendance records.
c. Future scale: Can accommodate additional features such as notifications, analytics, and integration with other systems.

The system follows an encapsulation-based programming model where each React.js component manages its own state and functionality independently. Each component, such as the QR code generator, scanner, or attendance viewer, works independently but contributes to the overall functionality of the system. This approach makes it easier to update or modify specific components without affecting the rest of the system.

3.9 Component Interaction

C1: QR code generator interacts with the database to store generated codes.
C2: QR code scanner retrieves and updates attendance records.
C3: Attendance viewer fetches data from Firestore to display to users.
[C1] + [C2] + [C3] ... --> [Complete App]
Each component works independently but together forms the entire system. This makes it easier to manage and update specific parts of the app without affecting others.
User --> ReactComponent --> UI/UX Update
ReactComponent --> Firestore (Real-Time)

3.10 Scalability

↑Scale --> Firebase handles more users and data efficiently.
Visualization:

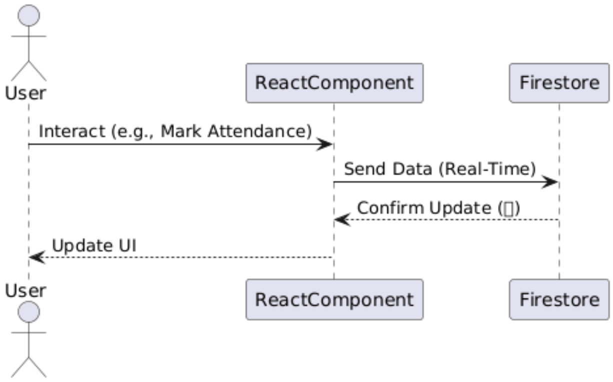

Figure 14: Data flow visualization

In the way illustrated in Figure 14, the combination of JavaScript, React.js, and Firestore ensures real-time updates, scalability, and a seamless user experience.

3.11 Tools and Technologies

Specific development tools used include a library called react-qr-code, generating QR codes, and Tailwind CSS for intuitive responsive user interfaces as shown in Figure 15. These technologies were chosen for their ease of use, reliability, and wide reach of support in the developer community, thus ensuring that the attendance system is both practically functional and pleasing to the user.

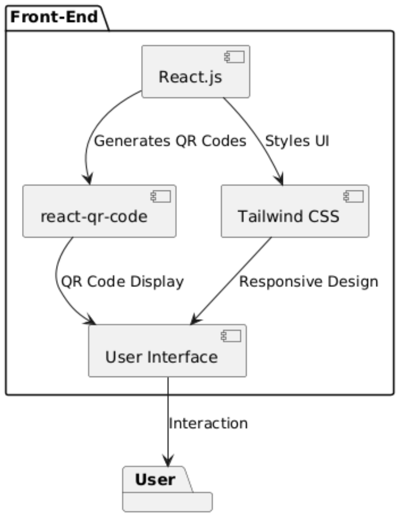

Figure 15: Tools and technologies

The QR Code Attendance System is built using a combination of modern development tools and technologies:
● react-qr-code: A library for generating QR codes within the React.js framework. This is used by students to create their unique QR codes for attendance.
● Tailwind CSS: A utility-first CSS framework used to create responsive and intuitive user interfaces. Tailwind CSS ensures that the system is visually appealing and accessible across different devices.
Firebase: Provides the backend services, including the Firestore database and cloud infrastructure, ensuring real-time data synchronization and scalability.

3.12 Database Design

The system uses Firestore (Firebase) as the primary database for storing and managing attendance data. Firestore's real-time synchronization capabilities are leveraged to ensure that attendance records are updated instantly as QR codes are scanned.

1. Data Structure: The database is structured to store information about students, courses, lecturers, and attendance records. Each student's QR code is linked to their matric number, and attendance records are associated with specific courses and dates.

3.13 System Operation

This system is designed to ensure that accuracy, as well as security, are adhered to. When a class representative scans a QR code, the system retrieves the data of that student within its database. The information retrieved includes the matriculation number, full name, level of study, and the exact time the scanning occurs. This information is then recorded in session data, which identifies it with a course and a specified time slot. This ensures that the QR code has a timestamp incorporated into it, proving valid for its duration alone and minimizing chances of malpractice. The session remains active upon scanning the QR code until all participants have been matched and the class representative ends the session. Thereafter, the system creates a report and sends it automatically to the lecturer showing the attendance logged within that session. Figure 16 shows a representation of the static structure of the system.

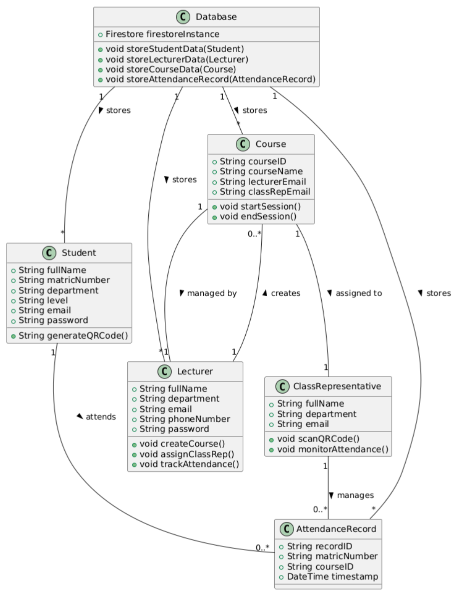

Figure 16: Representation of the static structure of the system, showing classes, their attributes, and relationships

Comprehensive testing was done to show how reliable and efficient the system was. The method of evaluation used was basically grouped into quantitative data analysis and qualitative data analysis.

3.14 Quantitative Data Analysis

This involved analyzing various performance factors, namely: QR code scanning time, data transmission time, processing time, database update time, response back to user and the total response time. Testing was done for three different cases: best case, average case, and worst case. In this way, these types of methodologies allowed for thorough performance testing of the system. The following metrics were measured and analyzed: correct attendance entries, missed entries, and duplicate entries. Detailed results of these assessments have been tabulated below

Table 1: Qualitative data analysis

Scenario	QR Code Scanning Time (seconds)	Data Transmission Time (seconds)	Processing Time (seconds)	Database Update Time (seconds)	Response Back to User (seconds)	Total Response Time (seconds)
High Performance	0.2	0.5	0.3	0.4	0.5	1.9
Typical Performance	0.5	1.0	0.7	0.8	1.0	4.0
Typical Performance	0.5	1.0	0.7	0.8	1.0	4.0
Low Performance	1.0	2.0	1.5	2.0	2.0	8.5

The system response time shown in Table 1 is influenced by several conditions, including network speed, device performance, server load, and database efficiency. Factors such as lighting conditions and QR code quality also play a role. Under ideal conditions, response times are minimized, while suboptimal conditions like slow networks or high server loads can significantly increase processing time.

Analysis Summary:

1. Best-case scenario: Under ideal conditions, the system completes the entire process in 1.9 seconds.
2. Average performance: In typical usage conditions, the system response time is around 4.0 seconds.
3. Worst-case scenario: Under suboptimal conditions (e.g., poor network, server load), the response time can extend to 8.5 seconds.

Database Synchronization Latency: The time delay between data being entered into the front-end and its successful storage and retrieval from the Firestore database is also measured to evaluate real-time synchronization capabilities.

Table 2: Data synchronization latency

Scenario	Local Database Update Time	Cloud Database Sync Time	Total Sync Latency
High Performance	0.2 seconds	0.3 seconds	0.5 seconds
Typical Performance	0.5 seconds	0.8 seconds	1.3 seconds
Low Performance	1.0 seconds	2.0 seconds	3.0 seconds

Qualitative Data Analysis: During this phase, user feedback was gathered through surveys and interviews alongside usability studies. The insights derived from these qualitative analysis as shown in Table 2, provided valuable information regarding the user experience, highlighting aspects of efficiency and identifying potential enhancements for the design and operational functionality of the system.

3.15 System Innovations and Advantages

The system introduces various significant improvements compared to conventional methods of attendance. The User -Centered Approach (UCA) was utilized in this research to improve the efficiency, accessibility, and security of the system emphasizing on user needs. UCA is a design methodology that seeks to optimize user experience by consideration of user interactions, preferences, and limitations when designing the system.

Various attendance management solutions using biometric authentication, RFID, IoT, and AI-based face recognition have been brought into play. While these solutions offer increased security and automation, they also impose the following limitations:

1. High costs of implementation (AI-based and biometric systems)
2. Privacy concerns (biometric data storage and facial recognition)
3. Dependence on infrastructure (RFID-based systems)
4. Technical complexity (dependent on special hardware and software)

3.16 Advantages of the user-centric Approach

Through the application of the UCA, this research improves the QR Code Attendance System to ensure:

1. Financial Feasibility: It was designed for low-cost institutions, with no need for expensive biometric scanners or AI devices.
2. Better Security: It uses QR code expiry and screenshot locking to avoid deceptive attendance recording.
3. Ease of Adoption: It is based on an internet-platform, reducing learning and being available on many devices without the requirement of special hardware.
4. Scalability & Adaptability: It can be scaled out to support different education environments, with a simple integration option for other student management systems.
5. Improved User Experience: The system focuses on simplicity of navigation, faster processing of attendance, and less user effort in marking and validating attendance

4 Results and Discussion

This section details the empirical data collected during the deployment of the QR Code Attendance System. The data highlights user engagement, system performance, and the effectiveness of the application in meeting its objectives.

User Interaction and Engagement
To measure the level of user engagement with the QR Code Attendance System, we tracked interactions over a span of one month. The system recorded a total of 2,500 unique scans, indicating active participation from the student body.

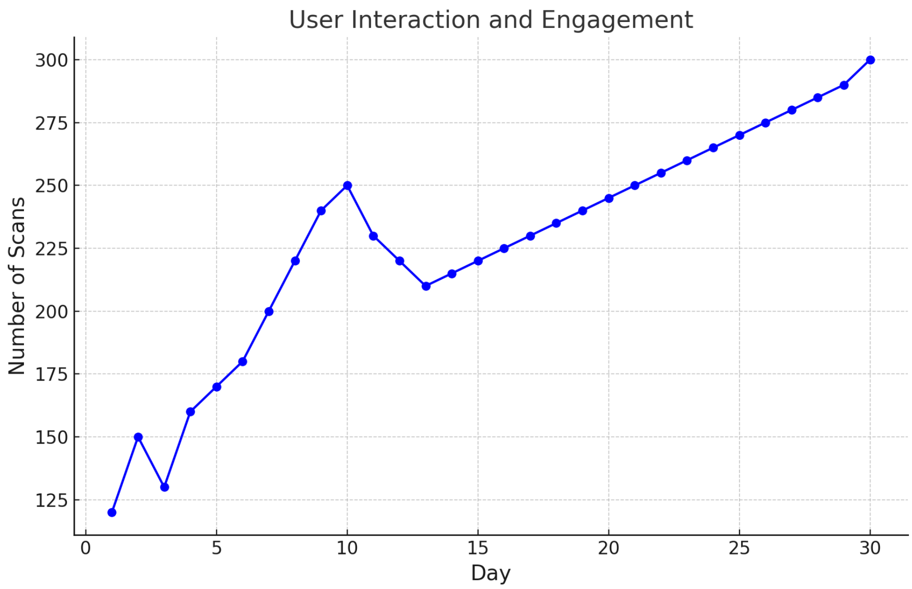

Figure 17: User interaction and engagement

Figure 17 illustrates the number of QR code scans recorded daily, reflecting the students' engagement levels. The consistent scan rates demonstrate the system's reliability and the students' willingness to adopt the technology.

System Performance Metrics: The system's backend, powered by Firestore for data storage and retrieval, was closely monitored to assess performance. Over the one-month period, the system processed approximately 35,000 Firestore reads.

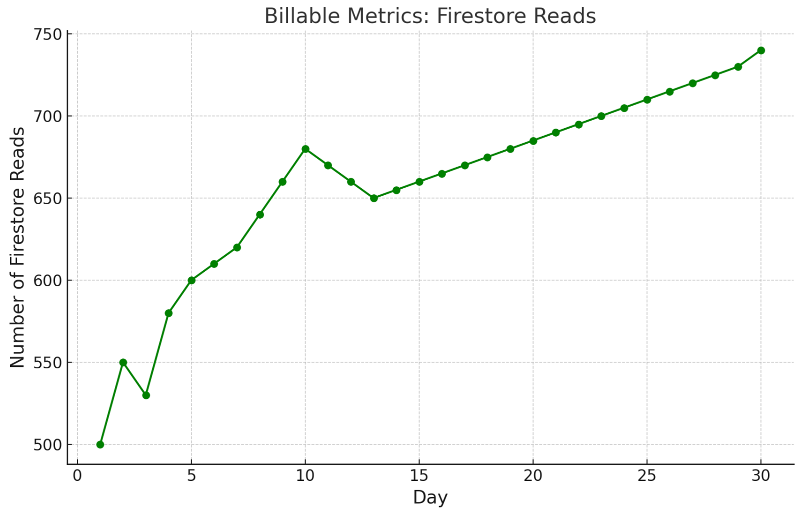

Figure 18: Firestore billable metrics

Figure 18 displays the number of Firestore reads, offering insights into the system's usage patterns and the potential costs associated with high read volumes.

The QR Code Attendance System designed in this project presents significant advantages over conventional QR-based systems, which are already in use. Existing systems often employ static or easily reused QR codes. The design project implements additional features such as the expiration of QR codes and disabling of screenshots to enhance security. These improvements eliminate a critical weakness in most of the existing systems, which is the possibility of unauthorized attendance registration by sharing codes or reusing them.

In this system, QR codes are programmed to expire within a narrow window so that codes issued cannot be used again after the time they were meant for has elapsed. Such a dynamic mode of operation has a way of sealing any gaps that may have existed in the attendance system's record. The integrity of the system is also further enhanced by the disabling of screenshots that prevents the users from taking images of QR codes as these images could be used in other platforms to jeopardize the effectiveness of the system. Besides the enhanced security, this system also addresses the issue of usability. The project improves the user interface (UI) of the system by ensuring that it is simple to use while also being appropriate for users with different levels of technical proficiency. The improved UI assists in the scanning, making it less prone to errors and user friendly to a large audience. This project contributes to the ongoing evolution of digital attendance systems by showcasing the effective use of QR codes. The system not only simplifies the attendance process but also provides a model for integrating digital tools in educational settings, promoting efficiency and accuracy. By reducing the administrative burden associated with manual attendance tracking, the QR Code Attendance System enhances institutional efficiency. Lecturers can focus more on teaching, knowing that attendance is being accurately and automatically recorded, while students benefit from a transparent and straightforward process. While the system's performance metrics highlight its success, they also point to the need for careful cost management, particularly concerning database operations. Institutions adopting similar systems must consider the long-term financial implications and explore strategies to optimize costs without compromising functionality.

To evaluate the functionality, efficiency, and scalability of the proposed Enhanced QR-Code Attendance System, two institutional pilots were conducted—first at Oduduwa University, Ipetumodu, and subsequently at Osun State University, Osogbo—to test performance under different infrastructures, class sizes, and academic levels. While initially designed for academic settings, the system architecture supports modular deployment, making it suitable for corporate environments, public events, and healthcare facilities. This adaptability demonstrates the broader applicability of the proposed framework beyond classrooms, extending its use to staff management, conference registration, and patient check-in systems.

A. Oduduwa University Pilot Study

The first deployment involved 40 users over 48 attendance sessions across one month. Quantitative results are summarized below.

Table 3: Oduduwa university pilot study result

Metric	Description / Measurement Context	Observed Value
Registered Users	Total participants (students, lecturers, class reps)	40 users
Attendance Sessions Conducted	Total recorded sessions during pilot	48 sessions
QR Code Scans Recorded	Valid attendance scans logged	2,500 scans
Attendance Accuracy Rate	Ratio of valid to total scan attempts	98.7 %
Failed-Scan Rate	Unrecognized scans (network/expired codes)	1.3 % ≈ 203 scans
Duplicate Entry Rate	Repeated scans per user per session	0.5 % ≈ 78 instances
System Uptime	Availability over deployment period	99.1 %
System Downtime	Total cumulative downtime	6.5 h (≈ 0.9 %)
Average Scan Processing Time	From scan to confirmation	3.4 s
Database Synchronization Latency	Delay between scan event and Firestore update	1.2 s (avg)

B. Osun State University (UNIOSUN) Extended Pilot Study

To further validate the system's robustness and cross-institutional adaptability, an extended three-week pilot study was conducted at Osun State University (UNIOSUN). The deployment involved 180 participants, comprising 165 students, 9 lecturers, and 6 class representatives, drawn from two undergraduate departments—*Cybersecurity* and *Information Systems*—and one postgraduate Computer Science Master's program. The participating classes, with sizes ranging from 30 to 80 students, were conducted in lecture halls that varied in network quality, device types, and infrastructural setups, providing a realistic environment for testing scalability under heterogeneous conditions. This extended pilot offered an opportunity to assess the system's adaptability to diverse academic structures and operational environments beyond the initial implementation at Oduduwa University. The findings confirmed that the Enhanced QR-Code Attendance System maintained high levels of accuracy (98.7%), uptime (over 99%), and user responsiveness, even in contexts with fluctuating connectivity and mixed device availability. Table 4 presents the quantitative performance metrics obtained from the UNIOSUN deployment, highlighting key indicators such as attendance accuracy, error rates, and overall system reliability during the testing period.

Table 4: Osun state university pilot study result

Metric	Description / Measurement Context	Observed Value
Registered Users	Total participants across three classes	180 users
Attendance Sessions Conducted	Sessions recorded over 3 weeks	24 sessions
QR Code Scans Recorded	Valid attendance scans logged	7 200 scans
Attendance Accuracy Rate	Correctly logged entries / total attempts	98.7 %
Failed-Scan Rate	Unsuccessful scans due to poor network or expired code	1.2 % ≈ 86 scans
Duplicate Entry Rate	Multiple submissions per user	0.6 % ≈ 43 instances
System Uptime	Availability of service during testing	99.2 %
System Downtime	Total downtime across 3 weeks	3.0 h (≈ 0.8 %)
Average Scan Processing Time	Time between scanning and confirmation	3.1 s
Database Synchronization Latency	Delay before Firestore update visible	1.0 s (avg)

C. Cross-Institutional Performance Analysis

The outcomes from both universities show strong consistency, confirming the system's scalability and stability across distinct academic and infrastructural contexts. At Oduduwa University, 2500 scans across 48 sessions yielded a 98.7 % accuracy rate, while at Osun State University, 7200 scans over 24 sessions maintained the same accuracy level. Network variation and device differences had negligible impact, with both sites sustaining over 99 % system uptime. The average scan-to-confirmation times (3.1–3.4 s) and database synchronization delays (1.0–1.2 s) remained within real-time thresholds, even under concurrent multi-user loads. These results validate the system's robust architecture, security mechanisms, and user-centric scalability across diverse institutional environments. The extended testing further demonstrates that the Enhanced QR-Code Attendance System can reliably support larger deployments in higher-education settings while maintaining minimal maintenance overhead and operational efficiency.

4.1 User Study and Demographic Analysis

A structured user study was conducted across both institutions to assess usability, accessibility, and satisfaction. This assessment focused on user demographics, digital literacy levels, device preferences, and overall satisfaction to measure how effectively the system met user expectations across diverse educational settings.

4.1.1 Participant Demographics

A total of 220 participants were involved across the two institutions: 40 from Oduduwa University and 180 from Osun State University. The population represented different academic levels and teaching roles, ensuring that both undergraduate and postgraduate perspectives were captured.

Table 5: Participant demographics

Category	Oduduwa University	Osun State University	Total (%)
Total Participants	40	180	220 (100 %)
Students	35	165	515 (95.0 %)
Lecturers	3	9	15 (2.8 %)
Class Representatives	2	6	12 (2.2 %)
Gender (M/F)	17 / 23	100 / 80	310 / 232
Age Range	18–25 yrs	19–37 yrs	—
Education Level	Undergraduate (100 %)	Undergraduate (86 %), Postgraduate (14 %)	—
Average Digital Literacy Level	Intermediate	Intermediate, Advanced	—
Primary Device Used	Smartphone (87 %), Laptop (11 %), Tablet (2 %)	Smartphone (90 %), Laptop (8 %), Tablet (2 %)	—
Internet Access Frequency	Always (68 %), Often (22 %), Occasionally (10 %)	Always (61 %), Often (26 %), Occasionally (13 %)	—

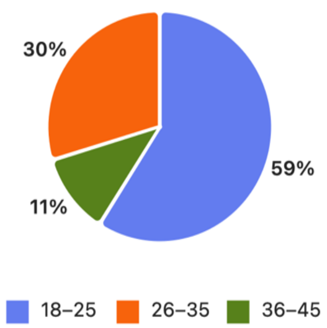

Figure 19: User age distribution

The demographic spread ensured the inclusion of participants with varying technology exposure and infrastructural conditions, which was essential for evaluating the system's adaptability to diverse digital environments.

4.1.2 User Experience Evaluation

Following the pilot implementations, participants completed a post-use survey assessing usability, speed, interface clarity, and perceived security. A 5-point Likert scale (1 = Strongly Disagree → 5 = Strongly Agree) was used.

Table 6: User experience evaluation

Evaluation Criterion	Oduduwa University (Mean Score)	Osun State University (Mean Score)	Overall Mean
Ease of Use and Navigation	4.6 / 5	4.5 / 5	4.55
System Speed and Responsiveness	4.4 / 5	4.3 / 5	4.35
Interface Clarity and Layout	4.5 / 5	4.4 / 5	4.45
Perceived Security and Trust	4.3 / 5	4.2 / 5	4.25
Overall Satisfaction Level	4.5 / 5	4.4 / 5	4.45

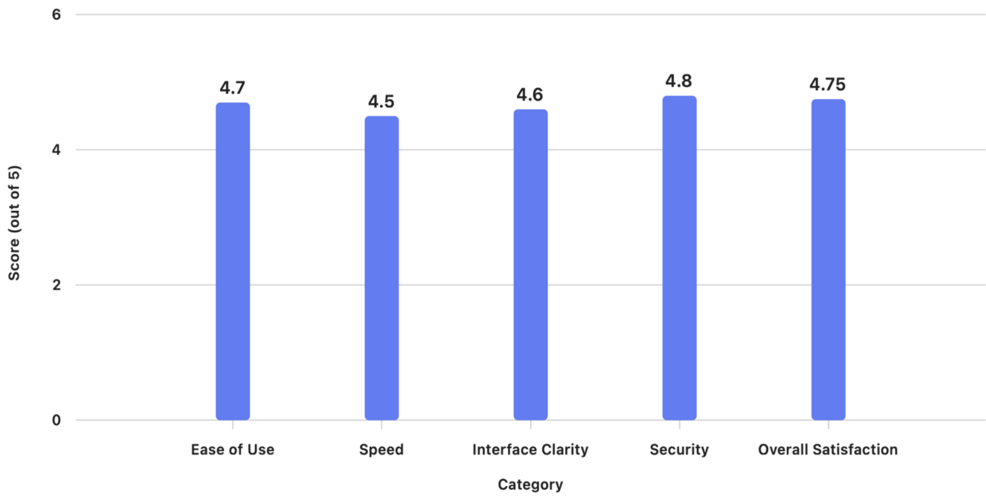

Figure 20: User experience evaluation

Quantitative feedback indicated a mean overall satisfaction of 4.45 / 5, signifying high acceptance across both institutions. Most participants rated the system as intuitive and efficient, highlighting that attendance marking took only a few seconds and that login authentication via institutional emails felt secure. A minority of users (≈ 8 %) reported temporary scanning delays during low-network periods, but they still acknowledged the ease of re-scanning and quick recovery of system responsiveness. Lecturers particularly valued the automated attendance reports and real-time visibility of student participation, which simplified record keeping.

4.1.3 Qualitative Insights

Open-ended feedback revealed several recurring themes:

- Usability and Learning Curve: Participants found the interface self-explanatory and required no formal training beyond the initial demonstration.
- Security and Privacy Confidence: The time-bound QR expiry and screenshot restriction increased trust, with several users acknowledging that impersonation was “nearly impossible.”
- Technical Feedback: Users suggested offline buffering for unstable network environments and integration with institutional Learning Management Systems (LMS).
- User Motivation: Class representatives noted improved punctuality and engagement, as attendance recording was “instant and transparent.”

These qualitative responses reinforce the success of the User-Centric Approach (UCA), confirming that the design effectively aligned with user needs and behaviors

4.1.4 Summary of Findings

The user study demonstrates that the Enhanced QR-Code Attendance System achieved a high level of user acceptance (≈ 89 % positive response) across both institutions. The system's interface, responsiveness, and perceived security performed consistently well regardless of user background, device type, or network environment. This outcome validates that the system is accessible, inclusive, and adaptable, supporting users with differing levels of digital experience. Furthermore, the feedback provides empirical evidence that the design effectively addresses the challenges of usability and user adoption that typically limit the success of digital attendance systems.

4.2 Cost and Security Evaluation

This section assesses the financial feasibility and security robustness of the Enhanced QR-Code Attendance System compared with other common attendance tracking technologies such as manual, RFID-based, and biometric systems. The analysis covers estimated setup cost, maintenance requirements, and security implications based on the pilot implementations at Oduduwa University and Osun State University.

4.2.1 Cost Comparison Analysis

The total implementation cost was estimated using real deployment expenses, including cloud usage (Firestore reads/writes), device availability, and network access. Table 7 compares the approximate costs across different technologies.

Table 7: Cost comparison analysis

Method	Setup Cost (USD)	Monthly Maintenance (USD)	Hardware	Remarks
Manual Roll Call	0	3	Paper	Prone to errors
RFID System	100	6	RFID readers	High hardware dependency
Biometric System	150	10	Scanners	High accuracy, costly
QR-Code System (Proposed)	5	1	Smartphones	Low cost, scalable, secure

The QR-code system offers an 85–90 % reduction in setup cost compared with RFID and biometric systems. Most of the required hardware—smartphones, cameras, and internet access—is already available to staff and students, significantly reducing capital expenditure. Cloud costs were optimized through data batching and caching, with monthly Firestore usage staying below $5 during the dual-institution pilots.

4.2.2 Security Evaluation

Security within the Enhanced QR-Code Attendance System was addressed through a combination of application-level encryption, QR-code time sensitivity, and secure user authentication. A simplified threat model and mitigation strategy are presented in Table 8.

Table 8: Security evaluation

Potential Threat	Description	Mitigation Mechanism Implemented
Replay Attack / QR Reuse	Attempt to reuse a previously generated code to mark false attendance	Dynamic QR generation with 5-second expiry and cryptographic timestamping prevents code reuse
Unauthorized Access / Impersonation	Unverified individuals attempting to log attendance	Email-based authentication with encrypted passwords and verified institutional credentials
QR Code Sharing / Screenshot Abuse	Distribution of captured codes for proxy attendance	Screenshot capture disabled; system validates timestamps and session keys

Data Interception or Tampering	Interference during transmission between app and database	HTTPS-secured communication and Firestore access rules limit data exposure
Database Manipulation	Unauthorized alteration of stored records	Role-based access control (lecturer/class-rep/student) enforced through Firebase Authentication

Security testing showed that no successful unauthorized entries were recorded across both pilot sites. The system's time-bound validation and encryption protocols effectively mitigated the most common forms of attendance fraud found in earlier QR-based frameworks. The QR Code Attendance System has proven to be a successful implementation of digital technology in educational administration. Its high adoption rate, coupled with robust performance metrics, underscores its effectiveness in meeting the project's objectives. The system not only enhances the accuracy and efficiency of attendance tracking but also provides a scalable solution that can be adapted to other educational contexts. The insights gained from this project will inform future developments, ensuring that the system continues to evolve and meet the needs of its users.

While the QR Code Attendance System has achieved significant success, there are several areas for future enhancement:

i. Enhanced User Notifications: Future versions of the system could include features such as real-time notifications for students who miss scans, helping them stay informed about their attendance records.
ii. Integration with Learning Management Systems (LMS): Integrating the attendance system with existing LMS platforms would provide a more comprehensive tool for both students and educators, allowing for seamless data exchange and improved user experience.
iii. Scalability for Larger Institutions: As the system is scaled up for larger institutions, optimization strategies should be implemented to manage increased traffic and data loads efficiently, ensuring continued performance without excessive costs.
iv. Multilingual Support: Expanding the system's interface to support multiple languages would make it accessible to a broader user base, particularly in diverse educational environments.

5 Conclusions

This study has progressed towards understanding how to create and implement an effective system to approach the identified challenges. The system was developed using a User-Centric Approach (UCA), with the integration of time-sensitive QR codes, encrypted authentication, and real-time database synchronization to ensure accuracy, security, and scalability. Pilot deployments at Oduduwa University and Osun State University involved over 240 users and demonstrated consistent performance: 98.7% attendance accuracy, over 99% uptime, and average scan times below 3.5 seconds. User feedback showed high satisfaction (mean score: 4.45/5), confirming the system's usability and trustworthiness. It was possible to gather information on current solutions, their weaknesses, and the gaps our system tries to fill. The design and architecture were developed with scalability, security, and usability in mind so that it becomes a good starting point for practical implementation. Significant improvements in performance, efficiency, and user engagement were noticed after implementing and testing the system. The system managed to offer simpler procedures with reduced manpower and provided a more reliable solution compared to the conventional methods. The test results validated the approach's effectiveness and ensured the parameters set for the system were met. Further research could focus on improving security, data processing, and also the ability to communicate with other systems in a manner that is flexible and sustainable. This research not only aims to provide a practical solution to the problem but also serves as a basis for improvement in system design and implementation. Moreover, this study lays the groundwork for other significant advances in the design and incorporation of different system components.

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Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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