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Design and Implementation of an IoT-Based Smart Attendance System

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Abstract
In this paper, a smart attendance system designed on IoT with Radio Frequency Identification (RFID) technology has been implemented. The system helps resolve the inefficiencies of manual attendance management methods, including roll calls and paper registers that are time-consuming, error-prone, and easy to impersonate. It combines an RFID device (RC522), a microcontroller with Wi-Fi features (ESP32), and cloud-based solutions (Google Sheets and API) to automate classroom attendance and examination hall attendance. Every student will be given an RFID card in which the Unique Identifier (UID) is captured, processed, and logged in real time to a cloud database. The system was tested to correctly record attendance and update information to the cloud within approximately 2 seconds, run continuously with no failures, and achieve 98.9 percent uptime, with a positive user rating for speed and ease of use. Although the system had some minor drawbacks, such as a limited reading range, reliance on Wi-Fi, and the possibility of card duplication, it was an effective, cost-effective, and efficient alternative to manual attendance systems. The research finds that RFID and IoT technologies can significantly enhance transparency, accountability, and administrative efficiency at academic institutions.

Keywords: *RFID, Smart Attendance System, Internet of Things (IoT), ESP32 Microcontroller, Google Sheet, Embedded Systems, Wireless Communication.*

1.0 Introduction

The increased application of digital technologies in the industries has greatly changed the administrative processes used in learning institutions. Student attendance management is, however, manual and inefficient in Nigerian universities. In some institutions, such as the Federal University of Technology, Akure (FUTA), attendance is recorded using oral roll calls or physical signature sheets, which are slow, laborious, and prone to proxy attendance, where students sign the sheets on behalf of those who are absent [1]. These weaknesses demonstrate that a more secure, reliable, and automated way is needed.

Radio Frequency Identification (RFID) has become a viable option for addressing such challenges in attendance management. RFID technology operates on the principle that tags on objects or people are identified and authenticated using an electromagnetic field, enabling real-time data capture and processing without physical contact [2]. In its implementation in learning institutions, RFID has the potential to provide a real-time tracking mechanism readily available to lecturers and administrators, enhancing monitoring and control [3]. In this regard, RFID provides an effective way to streamline attendance processes, both in the traditional classroom setting and in the examination room.

Although there is rapid adoption of digital solutions, several tertiary institutions in Nigeria have yet to fully leverage these technologies to manage attendance. This slow pace of using manual systems is especially cumbersome for lecturers in large classrooms, who must handle long registers and intentional impersonation [4]. The lack of strong authentication procedures, particularly when exams are being administered, leaves loopholes that allow people without the right to the exams to enter examination halls undetected. These inefficiencies do not just bring down academic accountability but also the credibility and integrity of the institution as a whole.

1.1 Literature Review

The Attendance Management System (AMS) is an official procedure and mechanism that is implemented to capture, track, and assess student attendance at academic events like lectures, laboratory sessions, and exams. They assist in imposing discipline in the institutions, quantifying student involvement, and offering credible statistics on reporting, planning, and decision making [5]. Attendance in the form of manual roll calls or paper registers has traditionally been used, which, though easy, is ineffective in large courses and consumes valuable time. It can easily be exploited through human error and impersonation, as well as record manipulation.

To address these difficulties, institutions have been moving towards automated attendance systems like biometrics, RFID, barcodes/QR codes, Near Field Communication (NFC), and mobile-based attendance systems. Face recognition technologies can also be used to identify individuals with a high accuracy rate of up to 95.7%, but typically demand complicated configurations, deep learning tools like Face API JS, hygiene issues, and can be somewhat costly to use and maintain [6]. Barcode and QR code solutions are cheap and simple to apply, but

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require line-of-sight scanning, are slow when dealing with large groups, and are susceptible to code-sharing cheating. NFC solutions are based on short-range wireless communication, usually through smartphones, although they usually only support one-to-one communications, which restricts their application in a very large classroom. Comparatively, RFID provides a trade-off balance between price, performance, and scalability since it allows contactless, multi-tag response even when out of view, making it a viable solution in high-throughput conditions of lecture theatres and examination halls. The use of passive RFID tags is especially popular in resource-intensive environments since it is quicker and more affordable than the iris or fingerprint scanners [7].

Radio Frequency Identification (RFID) is an automatic identification and data capture technology that makes use of electromagnetic fields in identifying and communicating with tagged items. An average RFID system is composed of tags (microchips with distinctive numbers), readers (interrogators that activate and read the tags), and antennas (that help in the wireless communication between tags and readers). The RFID tags can be passive, which means that they use the power of the reader field, or active, which means that they have an internal power source to offer a greater range and performance. Academically, student identity cards frequently include tags, and a student passing a reader will automatically have his or her presence recorded [8]. This non-contact and fast data acquisition renders RFID apt in institutions that have a high number of students and often hold functions of high attendance.

Nigerian Universities like Federal University of Technology, Akure (FUTA) and University of Ilorin (UNILORIN) have explored RFID-based models to implement the 75% attendance quota in order to be eligible to attend exams [4]. Equally, the West African Examinations Council (WAEC) has implemented RFID-based identity cards to confirm the identity of the candidates in the national exams, thus enhancing the validity and openness of the assessment procedure. Although these advantages exist, the high initial cost of deployment, possible signal interference, privacy, and constant monitoring issues have limited the large-scale deployment in institutions. The challenges explain why special attention needs to be paid to system design, sound policy frameworks, and relevant data protection mechanisms when an RFID-based solution is implemented in a learning institution.

The integration of RFID with the Internet of Things (IoT) has also turned the management of attendance into a real-time and data-driven process. Attendance information can be sent through HTTP requests to cloud databases to be stored and analyzed using microcontrollers like the ESP-12E or ESP32 [9]. IoT-based smart attendance systems connect edge devices (e.g., RFID readers and microcontrollers) to cloud services, enabling automatic transmission and centralized storage of attendance records. These systems assist in real-time attendance checking and quick identification of absentees or suspicious patterns. IoT-enabled solutions enhance the accuracy and reduce human error by automating data aggregation and reducing administrative workload by reducing manual recording, and creating rich datasets to be utilized in analytics, performance monitoring, and policy enforcement. Furthermore, they are in line with the broader digital transformation agendas in the field of higher education, where cloud-based platforms are becoming more popular in institutional reporting and quality assurance. In turn, smart attendance systems based on RFID and IoT are becoming feasible and scalable options to the conventional ones in the settings that demand high-throughput, integrity, and prompt access to attendance data. Such IoT system performance assessments in Nigeria have also reported on average response times of about 1.50 seconds, which is still very low compared to the industry standard of 5-second response time [10].

Although many studies have explored this area, most focus on improving certain parts of attendance management instead of offering a complete and unified solution. For example, biometric systems are good at accurate authentication but often overlook scalability and deployment costs, which makes them less practical for settings with limited resources [6]. RFID-based systems are popular because they are efficient and affordable, but they can still be misused through card sharing and face security risks like cloning and spoofing [8].

Studies on IoT-based attendance systems show they can provide real-time monitoring and easy data integration. However, these systems depend on stable networks and can face problems with reliability and data security, especially where connectivity is weak [7]. Cloud-based systems make data more accessible and easier to manage, but they also rely heavily on internet access and raise issues about data privacy and system strength [9].

Some systems have improved by combining different technologies, like using RFID with web platforms or extra monitoring tools. These hybrid systems are easier to use and make data more accessible, but they can also become more complex, cost more to set up, and be harder to maintain. This can make them less practical for large academic settings [1].

A systematic review of IoT-based RFID attendance systems further confirms that although many solutions achieve automation and real-time tracking, limited attention has been given to addressing issues such as system reliability under poor network conditions, proxy attendance prevention, and adaptability across multiple academic scenarios [7]. Similarly, existing implementations of RFID and IoT systems have primarily focused on classroom attendance, with minimal consideration for other critical applications such as examination monitoring and institutional compliance tracking [3].

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Therefore, despite extensive research and numerous existing solutions, there remains a clear gap in developing an attendance management system that simultaneously ensures cost-effectiveness, scalability, real-time synchronization, operational reliability, and adaptability across multiple academic use cases.

This study addresses these limitations by implementing an IoT-based smart attendance system that integrates RFID technology with real-time cloud synchronization. The system prioritizes simplicity, cost-effectiveness, scalability, reliability under unstable network conditions, and supports both classroom and examination attendance within a single framework.

2.0: Methodology

The research approach adopted in this study takes a systematic and modular design approach to guarantee reliability, scalability, and portability. The general system design is divided into four key phases, namely requirement analysis, system architecture and component selection, system integration, and complete system assembly. This detailed workflow, as shown in Figure 1, gives a vivid explanation of how the RFID-based smart attendance system was designed.

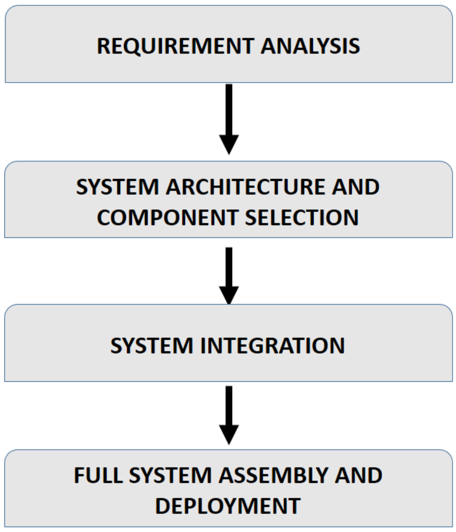

Figure 1: A clear representation of the design process of the RFID-based smart attendance system

a. Requirement Analysis and Problem Identification.

The first phase was a thorough requirements analysis to identify flaws in the traditional manual attendance systems that most tertiary institutions use. Such systems are usually described as inefficient, prone to impersonation, inaccurate in recordkeeping, and slow to process data. To overcome these hurdles, both functional and non-functional requirements were established, including automated attendance capture, real-time data synchronization, system reliability, cost-effectiveness, and ease of use. These were the requirements that gave the basis to the system architecture on which all design and implementation choices were made.

b. System Structure and Choice of Components.

In accordance with the established requirements, an appropriate system architecture was created to facilitate efficient data acquisition, processing, and cloud-based storage. The ESP32 microcontroller was chosen as the central processing unit because it has built-in Wi-Fi, low power consumption, and adequate computational power. Contactless user identification using RFID cards was performed with an RC522 RFID reader. Components such as an LCD and an LM2596 DC-DC buck converter were added to support user feedback and stabilize power flow, respectively. Software development was done in the Arduino Integrated Development Environment (IDE). On the software side, the cloud storage was done on Google Sheets, which also facilitated real-time transfer of attendance data and storage.

c. System Integration and Interaction Hardware-Software.

System integration concerns the creation of smooth communication among software and hardware modules. During operation, the RFID reader reads the unique identification number stored on each RFID card and sends it to the ESP32 microcontroller via SPI. The microcontroller interprets the data sent and provides visual feedback on the LCD. After that, the processed attendance data is sent wirelessly to a remote database (Google Sheet) using an application programming interface (REST API). This integration enables real-time attendance recording and

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remote access to records, making the systems efficient and reliable. Figure 2 represents a block diagram of the system workflow of the RFID-based smart attendance system.

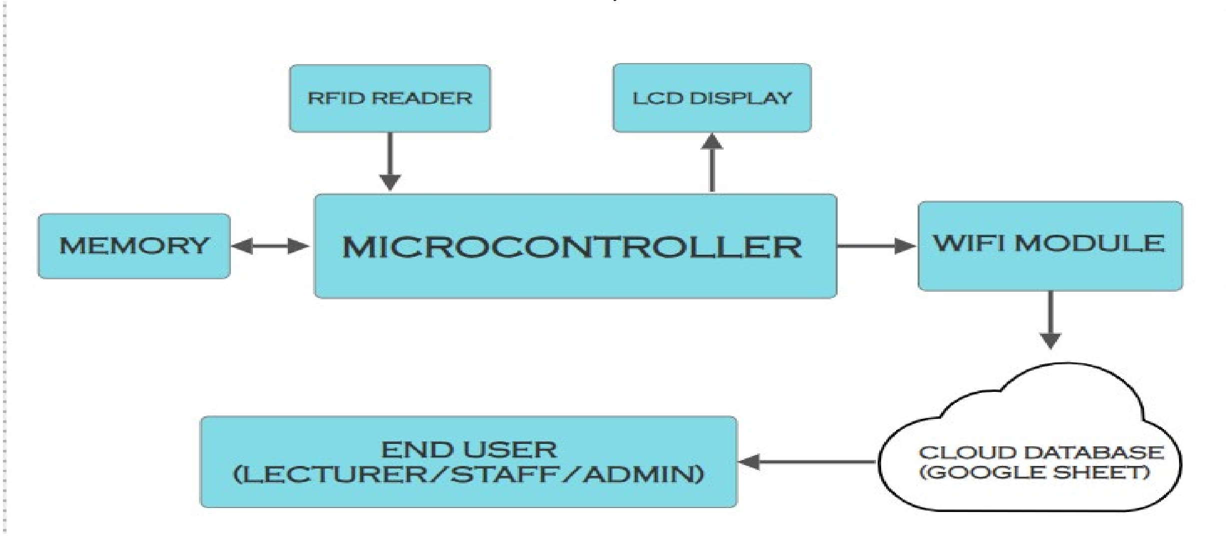

Figure 2: Block diagram of the RFID-based smart attendance system workflow.

d. **Full System Assembly and Deployment**

The developed system provides a viable, scalable, automated approach to attendance management in institutions of learning. The Fritzing circuit diagram of the system is presented in Figure 3. The completed system was then subjected to functional testing to verify data accuracy, communication reliability, and power stability. Upon successful testing, the system was implemented as an independent attendance unit that could be used in classroom and examination settings. Overall, in the last phase, all hardware components were permanently integrated into a small casing, as shown in Figures 4 and 5.

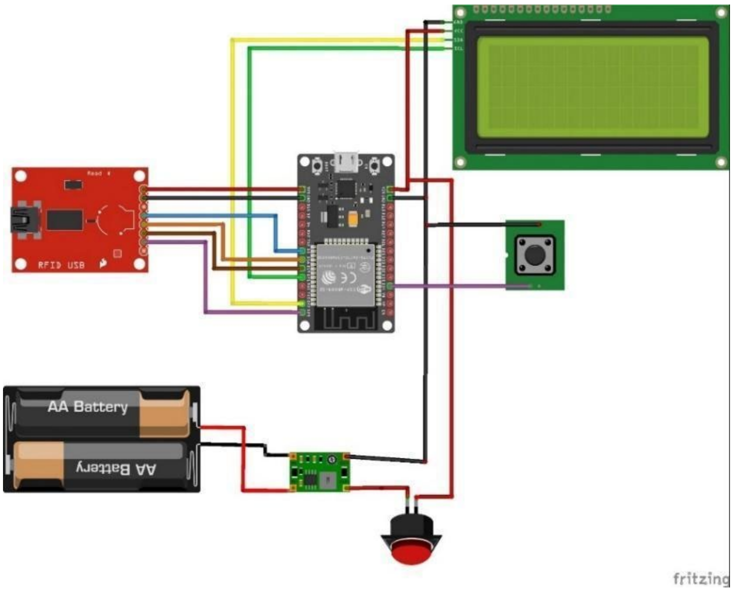

Figure 3. Fritzing diagram of the RFID-based smart attendance system circuit

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Figure 4: The RFID-based Smart Attendance System Display Showing 'Scan Your Card' Prompt

Figure 5: The RFID-based Smart Attendance System Display Showing 'Attendance Taken' and the matric number recorded

Backend Data Transmission to Google Sheets

Once the ESP32-based attendance device boots, it will connect to the configured Wi-Fi network and initiate communication with a FastAPI-based Python backend web service. Simultaneously, every RFID tag contains a unique identifier based on the student's matriculation number, which the ESP32 reads when a card is scanned by the RFID reader. The ESP32 then transmits this identifier to the backend via an HTTP POST request, along with other metadata (e.g., timestamp and date).

The back-end service provides specialized API endpoints for management. It carries out two main functions:
(i) the automatic creation of a new Google sheet when the device is powered on, and
(ii) manipulation of an existing Google sheet through the addition or updating of attendance records.

In order to enable secure programmatic access to Google Sheets, the system is registered in the Google Cloud Console, and the Google Sheets API is activated for the project. During this process, Google provides a JSON credentials file containing the service account details and authorization scopes needed for the application to interact with Google Sheets without manual user intervention.

Within the FastAPI application, the gspread library is used as an interface to the Google Sheets API. The credentials JSON file is loaded by gspread to authenticate the service account and authorize operations such as creating spreadsheets, opening existing ones, and modifying their contents. When the ESP32 first powers on and initiates an attendance session, it sends a POST request to the "create sheet" endpoint. The backend then uses gspread to programmatically create a new Google Sheet for that session and returns any necessary identifiers (such as the sheet URL or ID) for internal tracking. For each subsequent RFID card scan, the device sends another POST request to the "update sheet" endpoint, carrying the matric number and any additional data (e.g., date and time). The backend receives this payload and, via gspread, appends a new row to the corresponding Google Sheet or updates an existing row, thereby ensuring that each attendance event is recorded in real time in the cloud. The overall data flow of the IoT-based smart attendance system is illustrated in Figure 6, and the Google Sheet interface showing the recorded data is shown in Figure 7.

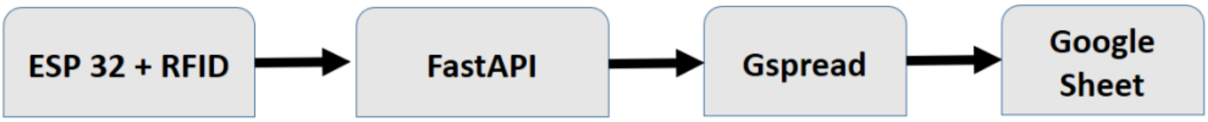

Figure 6: Data flow of the IoT-based smart attendance system from the ESP32 and RFID module to the Google Sheets cloud storage.

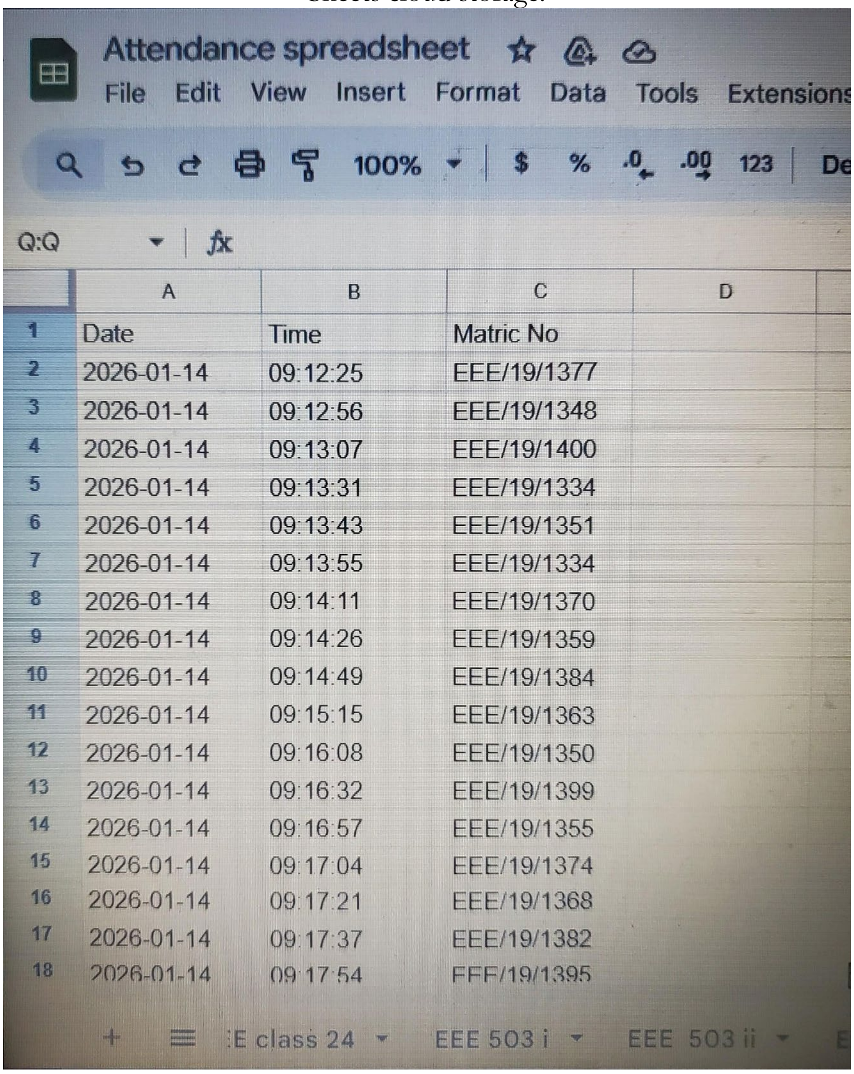

Figure 7: Google Sheets Interface Displaying Recorded Attendance Data from the RFID-based Smart Attendance System

In order to improve clarity and reproducibility, the operational workflow and backend processing logic are detailed in pseudocode showing Algorithms 1 and 2,

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```
Algorithm 1: RFID-Based Attendance Capture and Cloud Logging

Input: RFID card data
Output: Attendance record stored in cloud database

1: Initialize LCD, RFID reader, Wi-Fi module, and buzzer
2: Connect to Wi-Fi network
3: while Wi-Fi not connected do
4:     Attempt reconnection
5: end while

6: Send HTTP POST request to create new attendance sheet

7: Display "Scan your card" on LCD

8: while system is running do
9:     if new RFID card is detected then
10:        Read card UID
11:        Authenticate RFID block

12:        if authentication fails then
13:            Display "Authentication Failed"
14:            Trigger error buzzer
15:        else
16:            Read data from RFID block

17:            if read fails then
18:                Display "Read Failed"
19:                Trigger error buzzer
20:            else
21:                Extract student matric number
22:                Format registration number

23:                Send HTTP POST request to backend:
               {reg_no, attendance = true}

24:                Display "Attendance Taken"
25:                Display matric number
26:                Trigger success buzzer
27:            end if
28:        end if
29:    end if
30: end while
```

Algorithm 1: Operational workflow of the RFID-based smart attendance system.

```
Algorithm 2: Backend Attendance Processing Using Google Sheets API

Input: HTTP POST request (reg_no, attendance, timestamp)
Output: Updated attendance record in Google Sheet

1: On system initialization:
2:     Receive request from ESP32 (create sheet endpoint)
3:     Authenticate using Google Sheets API credentials
4:     Create a new Google Sheet
```

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```
      Store sheet ID

On receiving attendance data:
      Receive POST request with matric_no and attendance

      if sheet exists then
          Append new row to Google Sheet:
          [matric_no, attendance, timestamp]
      else
          Return error response
      end if

Return success response to ESP32
```

Algorithm 2: Backend processing and real-time attendance logging using Google Sheets API.

Test Environment and Conditions

The prototype was tested under controlled conditions simulating a classroom environment. RFID cards were given out as student identification cards, and the RFID reader was placed at an entry point to simulate real attendance capture.

The test environment was also configured with a stable Wi-Fi connection to facilitate real-time transmission of attendance information to a cloud-based database. The database interface was connected to a monitoring laptop so as to view live attendance updates. To assess the system's resilience, artificial disturbances, including intentional power disruptions and a temporary network outage, were introduced to evaluate recovery behavior and data integrity. Moreover, stress testing was performed by conducting frequent, continuous RFID scans to replicate the situation when large numbers of students are considered.

Performance Analysis of the Designed System

As to ensure that the RFID-based smart attendance system addresses the operational needs of academic institutions, the performance analysis was conducted comprehensively. The assessment could be divided into four key areas, namely, functional testing, reliability testing, usability testing, and performance metrics assessment.

Functional Testing

This test was conducted to confirm that the system could perform the main operations consistently. The following tests were performed:

i. **UID Capture Validity**: RFID tags were read to ensure that they were properly detected and their unique identifiers interpreted by the RC522 reader.

ii. **Accuracy of Data Logging**: The system was tested to verify proper recording of RFID UID, timestamps, and other related student information in the cloud database.

iii. **LCD Feedback Confirmation**: It was confirmed that the display unit displayed the right feedback messages. After each scan, the display indicated whether *the card was marked as* attended, *card not recognized*, or *already scanned,* depending on the situation.

These tests were conducted in both a simulated classroom and an examination hall to ensure consistency across the various use cases.

Reliability Testing

Reliability tests were conducted to evaluate the system's stability under real-world disturbances. Scenarios that were assessed were as follows:

i. **Simulation of Power Disruption**: The power supply was deliberately cut off to observe the recovery of the system and to ascertain that there was no loss of the already recorded data. When turned on, the system correctly created a new sheet with the recorded data, which was then stored safely in the Google sheet.

ii. **Network Connectivity Loss**: Wi-Fi connectivity was disabled to verify the ESP32's ability to temporarily buffer attendance records and synchronize them once connectivity was restored.

iii. **Extended Use Scenario**: Frequent scanning of more than 100 RFID cards was done to determine system stability, responsiveness, as well as resistance to crashes or sluggish performance.

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Usability Testing

The usability testing aimed to assess the system's usability and ease of use for both students and administrators.

i. **Interaction with the Student**: The ease and speed at which the card is scanned, and LCD clarity were noted.

ii. **Administrator Feedback:** Instructors assessed the accessibility and clarity of attendance records stored in the cloud database.

iii. **Interface Simplicity**: The degree of training to work with the system was considered.

Performance Metrics

To guide system evaluation, the following performance targets were defined:

i. Scan response time below one second
ii. Attendance logging accuracy of at least 95%
iii. System uptime exceeding 95% during operation
Iv. Error rate below 5%
V. Minimal data synchronization delay between scan and cloud update
Vi. Positive overall user experience

3.0 Results and Discussion

This section presents the results obtained from the design, implementation, and testing of the RFID-based smart attendance system. The outcomes of functional, reliability, usability, and performance evaluations are discussed and compared with the project objectives. In addition, the Bill of Engineering Measurement and Evaluation (BEME) is presented to highlight the cost implications of the developed prototype.

Functional Testing Results

The results of functional testing are presented in Table 1. The findings indicate that the system successfully captured RFID tag data, accurately logged attendance records, and provided appropriate LCD feedback for each scan.

Table 1: Functional Testing Result

Test Parameter	Expected Outcome	Actual Outcome	**Status**
UID Capture Validity	All RFID tags should be detected	10/10 tags correctly detected	Successful
Accuracy of Data Logging	Accurate UID, name & timestamp	100% accuracy in logging	Successful
LCD Feedback Confirmation	Correct message after each scan	All messages displayed	Successful

The results confirm that the system correctly performed its fundamental operations, validating the effectiveness of the attendance capture and feedback mechanisms.

Reliability Testing Results

Table 2 summarizes the outcomes of reliability testing, demonstrating system behavior under power interruptions, network failures, and prolonged operation.

Table 2: Reliability Testing Result

Test Scenario	Expected Behavior	Observed Behavior	Status
Power Disruption Simulation	The system should resume without data loss.	System resumed, no data lost.	Successful
Network Connectivity Loss	The system should store data temporarily.	ESP 32 buffered scans, uploaded after recovery.	Successful
Extended Use (100+ scans)	No system crash or slowdown.	The system is stable throughout.	Successful

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The results show that the system maintained stability and data integrity under all tested conditions.

Performance Metrics Evaluation

Scan Response Time

The scan response time of the system was evaluated using ten RFID cards under normal conditions. The response time for each card was recorded to assess real-time performance and consistency.

As shown in figure. 8, the scan times across all ten cards remain consistently low with minimal variation. The average response time was about 1.50 seconds, well below the 2-second target. This shows the system captures attendance in real time without noticeable delay.

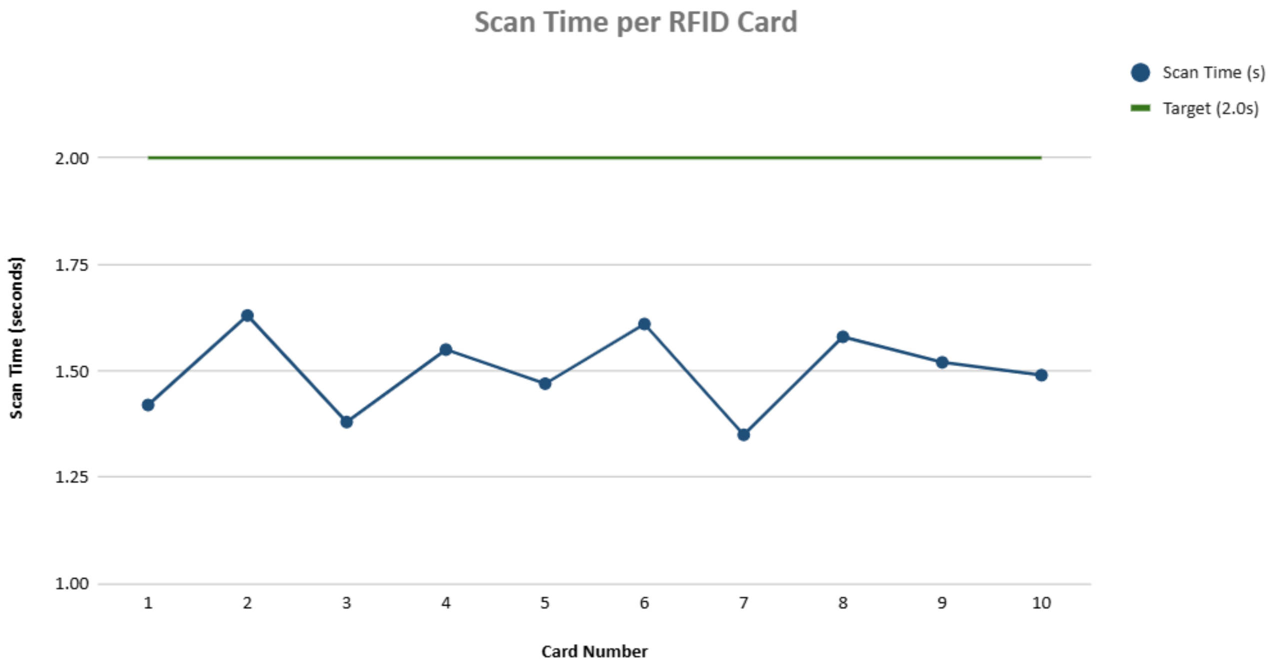

Figure 8: Line chart illustrating the scan time recorded for each of the 10 RFID cards during functional testing of the smart attendance system.

Other Performance Metrics

Figure 9 shows a comparative bar chart of the target and observed performance metrics of the RFID-based smart attendance system.

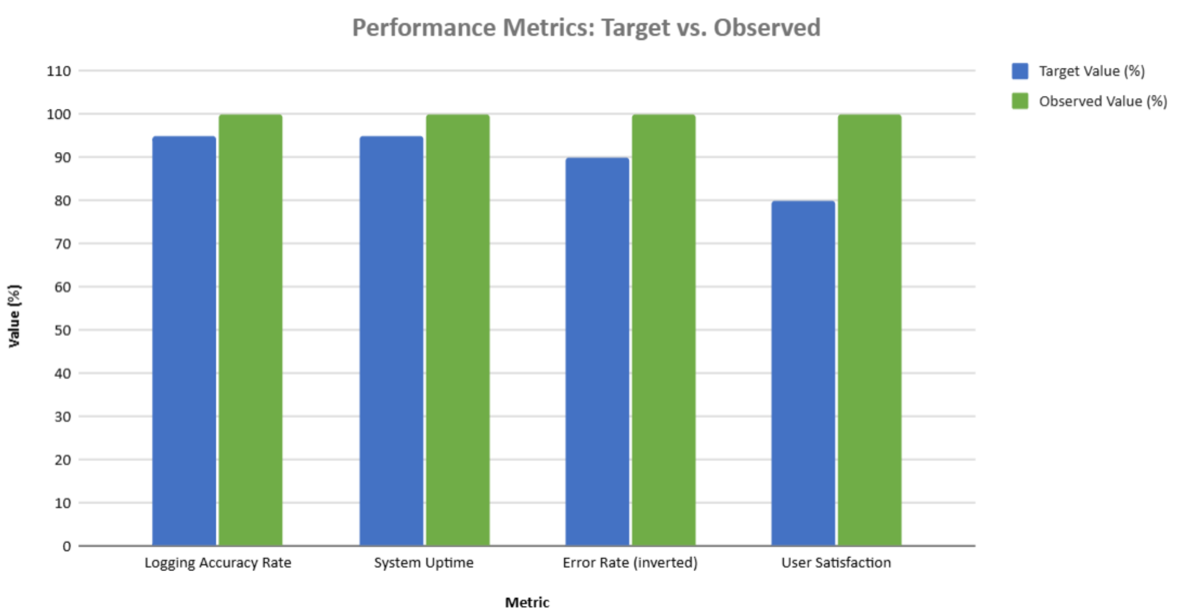

Figure 9: Clustered bar chart illustrating a comparison between target and observed performance metrics for the RFID-based smart attendance system

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The system achieved a 100% logging accuracy, surpassing the 95% target. System uptime also reached 100%, exceeding the 95% threshold. The error-free rate was 100%, against a 90% target, indicating zero operational errors during testing. User satisfaction returned 100%, above the 80% baseline. Across all four metrics, observed values exceeded the defined benchmarks, confirming the system performs reliably and efficiently under tested conditions.

Bill of Engineering and Measurement Evaluation

The Bill of Engineering and Measurement Evaluation is presented in Table 3.

Table 3: Table showing the Bill of Engineering Measurement and Evaluation

S/N	Component	Unit cost (₦)	Quantity	Total Cost (Naira) (₦)
1.	ESP 32 Development Board	12,000	1	12,000
2.	RC522 RFID Reader module	5,500	1	5,500
3.	RFID Card	500	10	5,000
4.	16 × 2 OLED display	9,900	1	9,900
5.	LCD I2C Adapter	2500	1	2500
6.	Wires	500	2 set	1000
7.	Switch	400	1	400
8.	Plastic Enclosure box	4000	1	4000
9.	Buzzer	500	1	500
10	5V battery Module and Battery	3000	1	3000
11	LM2596 DC-DC Buck Converter	3000	1	3000
12	Breadboard	3000	1	3000
	Total Cost			**49,800**

4.0 Discussion of Results

The experimental results demonstrate that the developed RFID-based smart attendance system operates effectively under realistic academic conditions. Functional testing confirmed reliable RFID detection, accurate data transmission, and immediate feedback through the display unit. Capturing all RFID tags with 100% logging accuracy shows the system eliminates common errors in manual attendance methods, such as missed entries and impersonation.

The scan response time results highlight the system's efficiency. As shown in Fig. 8, the system achieved an average response time of about 1.50 seconds, well below the 2-second threshold. This shows the system can capture attendance in real time without noticeable delays. Compared to conventional systems that often require manual verification or multiple authentication steps, the proposed system operates faster and more seamlessly. This is especially important in high-density environments like lecture halls and exams, where rapid processing of many students is needed.

The comparative performance analysis in Figure 9 shows the system exceeded all predefined benchmarks. Logging accuracy and system uptime both reached 100%, surpassing the 95% minimum. This demonstrates the system's robustness and reliability in maintaining continuous operation and accurate data recording. Additionally, the system recorded a 0% error rate, well below the acceptable threshold, indicating high precision and stability.

Reliability testing showed the system is resilient to real-world challenges like power interruptions and network instability. The ESP32 microcontroller buffers attendance data during outages and synchronizes it upon reconnection, ensuring data integrity. This feature is critical in environments with unstable internet connectivity, common in many developing regions.

Usability evaluation showed the system is intuitive and easy for both students and administrators. The simple "scan-and-record" process minimizes user interaction, and using Google Sheets as a backend provides a familiar, accessible platform for data management. This reduces training needs and increases user acceptance.

Cost analysis supports the system's practicality. With a total implementation cost of ₦49,800, it offers a cost-effective alternative to more expensive biometric attendance systems. This makes it suitable for resource-constrained institutions, especially in developing countries where budget limits often hinder the adoption of advanced technologies.

Overall, the results demonstrate that the proposed system successfully achieves its design objectives in terms of accuracy, reliability, efficiency, and cost-effectiveness. The integration of RFID and IoT technologies provides

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a scalable and practical solution for modern attendance management, supporting both classroom and examination scenarios.

4.0 Conclusion

This study presented the design and implementation of an IoT-based smart attendance system using RFID technology for efficient and automated attendance management in academic environments. The developed system successfully addressed the limitations of traditional manual attendance methods by providing a fast, reliable, and contactless solution.

Experimental evaluation showed the system achieved a 100% logging accuracy rate, capturing all attendance records correctly. It also maintained 100% uptime, indicating high reliability and stability during continuous use. The average scan response time was about 1.50 seconds, well below the acceptable threshold for real-time systems, confirming its efficiency in high-throughput environments. The system showed an error rate of 0%, demonstrating robustness in handling attendance data without failure. User feedback also indicated a positive experience regarding ease of use and responsiveness.

Overall, the results validate that the system is a cost-effective, scalable, and reliable solution for modern attendance management. The integration of RFID and IoT technologies provides improved transparency, reduces administrative workload, and enhances the integrity of attendance records. Future work may focus on improving system security against RFID card duplication and extending the system for broader institutional applications.

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