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Automated Attendance System using RFID and IoT

Dhanush C.[1], Sumit Singha Chowdhury[2], Aparna K. Shekadar[3]

[1-3]Department of Master of Computer Applications, Acharya Institute of Technology, Bangalore, India.

E-mail: [1]dhanushchandru28@gmail.com, [2]sumit2432@acharya.ac.in, [3]aparnashekadar123@gmail.com

Abstract

In educational institutions and workplaces, the manual tracking of attendance can be subject to human error, be time-consuming, and be administratively taxing. In recent years, IoT and wireless technologies have developed automated attendance tracking systems based on Radio Frequency Identification (RFID). In this document, we describe a cloud-based RFID attendance tracking system to improve accuracy, minimize manual effort, and enable real-time tracking. The hardware system uses a NodeMCU (ESP32) microcontroller, coupled with an RFID reader module, an LCD module, LED indicators, and an NTP server to maintain accurate time. The attendance information is gathered through unique RFID tags that are directly linked to user profiles in the Firebase cloud. When the RFID tag is in range and scanned, the app will verify the user, and then read, track, and log the UID, name, timestamp, and email of the user. If an unauthorized person or tag is scanned, the system will request permission to scan from an admin user, enhancing the security and reliability of the system. Admin users can view all users and their attendance, as well as view attendance in real-time, as dashboards, graphs, and analytic reports via the web-based portal of the attendance system. This system is designed to be scalable and adaptable for use in a variety of settings, including educational institutions and office spaces. Not only does it simplify the management of attendance, but it can also provide valuable data and details regarding patterns of attendance, which help verify and justify the use of resources and determine performance. The solution offers secure access, ease of use, and rapid data access and control, which improves the overall management of the institution.

Keywords: RFID attendance system, IoT attendance tracking, automated attendance, NodeMCU, ESP32, NTP Server, Firebase integration.

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1. Introduction

Keeping track of attendance is a regular, routine task in educational and workplace settings. Conventional systems, such as roll call or paper-based registers, are not only inefficient but also heavily reliant on human effort, manipulation, and accuracy, and can even lead to mismanagement, especially in circumstances where large groups of students or employees are involved. These types of systems often impact data accuracy and decisions made by an administrator, which could be time-sensitive [1]. In developed countries, as educational institutions and workplaces use more digital infrastructure, it is becoming increasingly important to implement a regular, trustworthy, safe and automated attendance system [2].

Radio Frequency Identification (RFID) has grown into a reliable and automated identification, and attendance, tracking alternative. RFID is a method of wireless communication that transfers information between a reader, and a uniquely tagged object or person. RFID allows for fast, contactless identification [3], [4]. RFID is different from a traditional barcode system because RFID technology does not require line of sight, and can scan multiple tags simultaneously. Because of these differentiating characteristics, RFID is an excellent solution to utilize in physical high-throughput settings such as classrooms and entries to chase or be chased [5]. There are several technologies that can be utilized for attendance automation, each with its own pros and cons. Biometric systems such as fingerprint and facial recognition provide some improvement in security by ensuring identity verification but are impacted by environmental sensitivity, hygiene factors, and cost [6]. Mobile-based attendance tracking using GPS, QR codes, and Bluetooth Low Energy (BLE) handsets provides a portable solution but are subject to spoofing and connectivity issues [7], [8]. Low-cost, highly reliable RFID tags provide a good mix of reliability, scalability, and cost, making them a good solution for applications wanting rapid identification and low user interaction [9].

The addition of RFID systems with the Internet of Things (IoT) improves the functionality of attendance systems through immediate data transfer, centralized cloud storage, and remote access options. IoT is a form of technology that enables devices and databases to communicate via wireless networks and allows the central authority to monitor the system via online channels. This connectivity allows data to be synchronized in real-time, and it can also provide live analytics dashboards for administrators [10], [11]. Cloud providers like Firebase, paired with real-time clock synchronization on NTP servers, help record attendance that are date-stamped correctly and accessible anywhere [12].

This research provides an RFID and IoT-based smart attendance tracking system for educational institutions and workplaces. The hardware used in the system consists of a NodeMCU (ESP32) as the control board, an RFID reader, an LCD display, two LEDs, and a valid internet connection via Wi-Fi. The proposed system assigns a unique RFID tag to each user, which is linked to the user's profile in a Firebase database. When the user scans their RFID tag, the system saves the UID, name, time, and email address. If the user does not exist in the Firebase database, they must go through an admin approval process to enhance security. The web-based dashboard enhances real-time monitoring of attendance and also provides visualizations and exportable reports for stakeholders to make data-driven decisions. While there have been leaps forward in biometric systems, such as face and fingerprint recognition, RFID has a number of advantages that sustain its relevance. RFID systems are cheaper to deploy at scale; they are non-invasive; and, unlike fingerprint scanners and the associated hygenic issues of disease transmission through touch, RFID brings no hygiene concerns. In spaces where privacy and consent are critical issues, RFID is a viable option as it does not store or process any biometric identifiers. RFID tags can quickly be scanned (and re-scanned) when throughput is high (as in a large classroom or entry gate), are not susceptible to dirt or surface wear related recognition issues, work very well outdoors or indoors, and are cost-effective for organizations with limited infrastructure funding. RFID provides a solid and scalable solution in terms of cost, speed, and acceptable security.

The proposed attendance system is scalable, affordable, reduces workload, minimizes manual errors, and provides safe and accessible attendance data for schools, colleges, offices, and secure areas and buildings.

2. Background Study

Student attendance is at the highest level associated with the success of the student academically and institutionally [13][14]. Having students regularly attend confirms their engagement with the course material, their engagement with their fellow students through class discussions, and the creation of academically engaging habits that are consistent in the context of the educational advancement they have undertaken [15][16]. The evidence for a positive relationship between attendance and academic performance is clear, and attendance is a vital component of educational success and retention rates. Institutions also use attendance as a compliance mechanism relating to relevant academic policies, as well as an important data point to allocate resources and understand institutional performance with respect to archived attendance.

2.1 Existing Methods

Several limitations exist with traditional paper-based approaches; namely, they are subject to errors, manipulation, and inefficiencies [1][2]. In order to overcome these issues, digital systems have introduced QR codes, as well as various biometric, GPS, and RFID systems. [3] demonstrated that it is possible to use RFID in-line with a fast, contactless method of confirming student identification in institutional settings.

Table 1. Comparison of Existing Systems

Methods	Advantages	Disadvantages
Manual (Paper-based) [1], [2]	Simple No Setup Required	Time consuming Easy to manipulate
Barcode/QR Code [3], [5]	Low Cost Easy to Use	Requires Line of Sight Susceptible to duplication
Biometrics [5], [6]	High Accuracy Unique to Individuals	Hygiene Issues Expensive
GPS/Geolocation [5], [6]	Mobile Enabled Remote Tracking	Can be spoofed Requires Internet Access

Customizations to address the prior disadvantages from Table 1 include:

1. **Manual systems:** Errors are eliminated by utilizing automatic, time-stamped digital logging
2. **Barcode/QR systems:** RFID doesn't require sight; users do not duplicate their ID through a unique hardware ID in addition to admin approval.
3. **Biometrics:** Our system solves hygiene problems because it is touchless and much cheaper. Empowering admins to control who is enrolled improves security.

4. **GPS/Geolocation:** Our system does not depend on each user having mobile phones or connections to other networks: scans happen immediately and without spoofing due to physical presence at the scan.

3. Methodology

The approach for the proposed RFID and IoT-based Automated Attendance System implementation consists of a multi-layered solution that brings together embedded systems, cloud-based applications, and real-time analytics. The whole process has been designed from conception to deployment to be as efficient, reliable, secure, and scalable as possible. Each module of the system was developed and improved so it would work well across the hardware and software layers.

3.1 System Design and Workflow

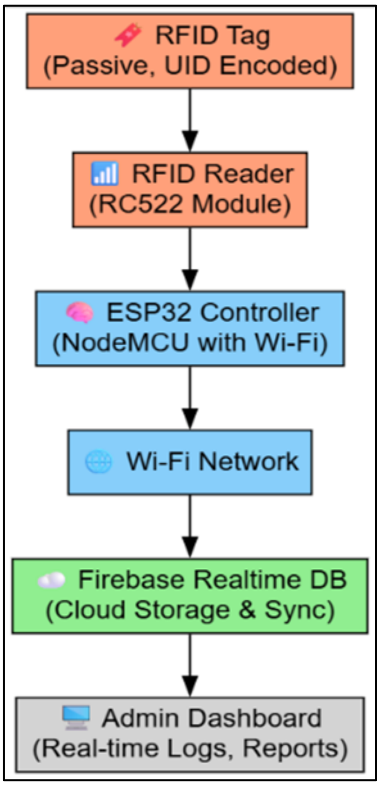

Figure 1. Workflow of the System

Figure 1 shows the workflow of the proposed work. The intended RFID-based attendance system combines wireless ID and cloud technologies to provide a contactless and seamless attendance tracking system. The procedure starts with the scanning of a user's RFID tag close to a reader, which wirelessly sends the tag's unique identifier (UID) to a NodeMCU (ESP32) controller. The controller acts as the system's brain, transmitting the UID to a Firebase cloud database through a secure Wi-Fi connection. If the UID matches one that is registered, the system marks the attendance of the user along with important information such as name, timestamp, and email, and provides visual feedback through a green LED and an LCD message. If the UID is unknown, the system stops the process and sets up a real-time admin approval process, enabling administrators to remotely authenticate and respond to the request. Lastly, all attendance information is displayed in real-time on a centralized dashboard, providing educators and administrators with metrics, visual reports, and monitoring tools.

3.1.1 Real Time Feedback Loop

The system implements instantaneous feedback using hardware and software components. Upon successful tag scans, the LCD and/or LEDs on the device notify the user. If an unauthorized or invalid tag is presented, the system displays a message and requests the user to scan the tag again; additionally, a message is sent to the administrator, which provides a method to approve or correct the status in real-time. The dashboard is also updated nearly instantaneously for all parties involved. If a wrong tag, or proxy tag, is presented, the system checks the UID against the database. If there is a mismatch, the provided scan will be recorded as unauthorized, and the scan will be flagged for later review. Administrators are responsible for providing approvals in the approval process, as mentioned earlier, which means only verified tag scans are allowed. The system also keeps records of unusual scans (scans at unusual times, people repeatedly scanning after denial), which can be appropriately audited, enabling retrospective verification investigations.

3.2 Research Framework and Component Selection

3.2.1 Research Methodology Approach and Requirement Analysis

This project is characterized as design and implementation-based research. As such, the emphasis will be on building a working prototype of the product to solve real-world problems of monitoring attendance. The first part of the requirements analysis was to identify the known issues with the traditional system of attendance including important issues such as proxy attendance, manual entry errors, and lack of real-time attendance monitoring, and finding IoT and automation solutions to address these issues.

The essential system requirements identified were:

i. Real-time and automatic capturing of attendance
ii. Secure and scalable cloud-based storage
iii. Web/mobile interface for administrator access
iv. Analyzing and visualizing attendance

3.2.2 Hardware Components

3.2.2.1 RFID Modules

The RC522 RFID Reader Module uses 13.56 MHz and is compliant with the ISO/IEC 14443 standard for RFID tags. The RC522 RFID Reader Module communicates using SPI/I2C, and is optimized for secure short-range scanning. Its small size, low power consumption, and compatibility with Arduino and ESP32 platforms make it a great option for classrooms or institutional use.

Figure 2. RC522 RFID Module

3.2.2.2 Microcontroller

The ESP32 NodeMCU microcontroller has a dual-core, low-power SoC that comes with integrated Wi-Fi and Bluetooth. It has enough GPIO pins and can use SPI to communicate with the RFID reader. Additionally, it can connect easily to cloud platforms like Firebase. The ESP32's built-in NTP support can ensure accurate timekeeping even without an RTC module.

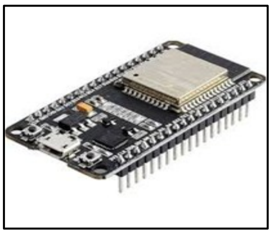

Figure 3. ESP32 Microcontroller

3.2.2.3 Display and Indicators

The 16x2 LCD display is a component that is used to provide real-time feedback, such as welcome messages, scan complete, or even error messages. It utilizes the I2C interface to connect to the ESP32, and the I2C interface maintains minimal wiring. In some instances, an OLED display is used to provide more clarity and a modern look as configured.

Figure 4. 16x2 LCD Display with I2C Interface

A buzzer and LED indicators allow a user to receive immediate audio-visual feedback. A quick beep with a green LED indicates a successful scan, while a long beep with a red LED indicates that the user either failed or tried to perform an unauthorized scan. These indicators are not intrusively distracting and enhance the user experience by improving system feedback and user responsiveness.

3.2.3 Software Platform and Programming Language Selection

The ESP32 microcontroller was programmed using the Arduino IDE and the C++ programming language to leverage well documented libraries to manipulate RFID input, manage Wi-Fi connections, and send HTTP requests to cloud services. The tools also enabled a real-time experience for working with hardware peripherals like buzzers, LEDs, and LCDs. Firebase Realtime Database was utilized as a cloud backend for attendance records. It provides structured JSON-based data storage, real time data updating capabilities, and REST API endpoints for quick integration with IoT devices. It's scalable storage while maintaining built-in authentication is advantageous to educational systems. The frontend dashboard was built in HTML, CSS, and JavaScript to enable administrators access to attendance records in a web-based user interface for viewing, filtering, and exporting attendance records. Using Firebase's JavaScript SDK meant that the dashboard could interact with the database in real time. Chart.js was also integrated for the purpose of visually formatting data with interactive bar graphs, pie charts, and timelines so administrators can view trends in attendance over time, track how many students check in each day, and provide visual representations in reports with a clean user interface.

3.3 Implementation and Integration

3.3.1 RFID Technology Specifications

The system implements the MFRC522 RFID module, which operates at 13.56 MHz according to the ISO/IEC 14443 Type A standard. This means that it will work with any MIFARE classic RFID cards and tags, all of which are passive, without an internal power source. Tags are typically read from a distance of up to 3–5 cm, allowing for close-range secure authentication that prevents accidental scans.

3.3.2 Hardware-Software Integration Protocols

The MFRC522 RFID reader communicates with the ESP32 microcontroller via the SPI (Serial Peripheral Interface) protocol, allowing for rapid and reliable data transfer. The ESP32 is programmed using the Arduino IDE, and it utilizes the MFRC522.h and WiFi.h libraries to read tags and communicate wirelessly. When an RFID tag is read, the UID from the tag is processed, a timestamp is applied using NTP, and the information is pushed onto the Firebase database via HTTP POST requests over SSL. Figure 3 shows the system implementation diagram.

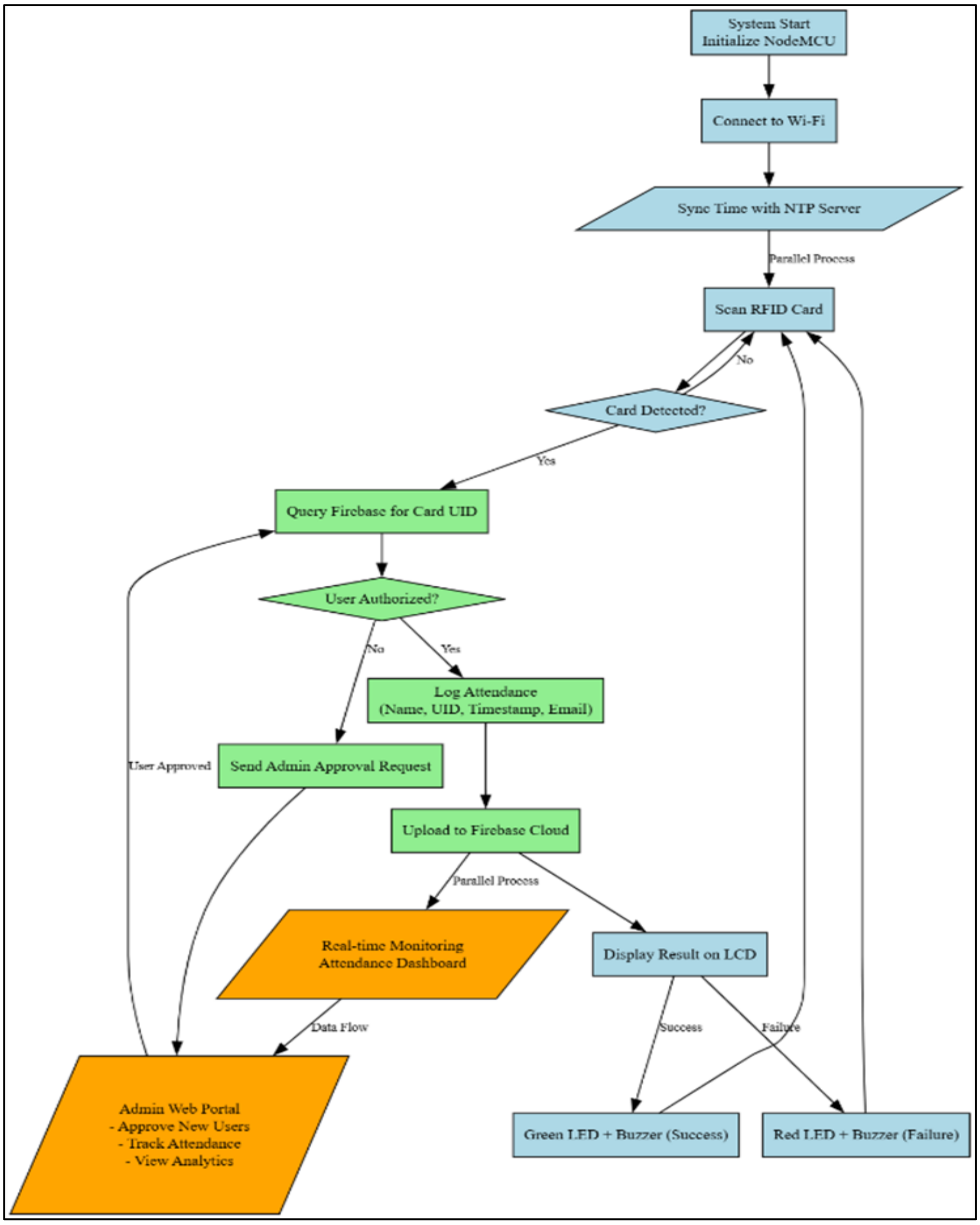

Figure 5. System Implementation Diagram

3.3.3 Anti-Collision and Read Optimization

The MFRC522 anti-collision protocol allows the reader to detect a single UID at a time, preventing inaccuracies when more than one tag enters the reader area. There are built-in anti-collision protocols, part of the ISO/IEC 14443 standard, that the MFRC522 uses to provide accurate reads without issues. The scan cycle of the reader's scanning area can be adjusted; we intentionally set a small delay in the scan cycle that will be utilized by the environmental conditions to cause a stay-in-the-read area each time the tag is presented. This ensures that each session is consistent at a range of 3–4 cm which also helps to reduce read inaccuracies by preventing false reads or tag bouncing.

3.3.4 Real Time Data Capture and Processing Mechanisms

As a user brings their RFID tag into range of the reader, the system captures its Unique Identifier (UID) and immediately sends it to the ESP32 microcontroller. The microcontroller then takes the UID, appends a timestamp using NTP (Network Time Protocol) to manage precise time, and sends it to the Firebase Realtime Database using an HTTP request. If the UID matches a registered user in the database, then attendance is taken and feedback events, like a green LED blink and a short beep, are also triggered at the same time. In other situations, when the UID is not found (not matching an existing user in Firebase), the user should be marked as unauthorized in the system, and notification should occur to the admin dashboard, flagging the entry for pending approval. This will permit only verified users to log attendance while also enabling a process for the administrator to review and register new cards as needed. Thus, the two-path logic (verified vs. unverified) provides real-time attendance validation while ensuring security and administrative oversight of database entries. Since Firebase is established as a real-time database, all successful reads and all unauthorized scans will be displayed on the dashboard virtually immediately for action, as shown in Figure 6.

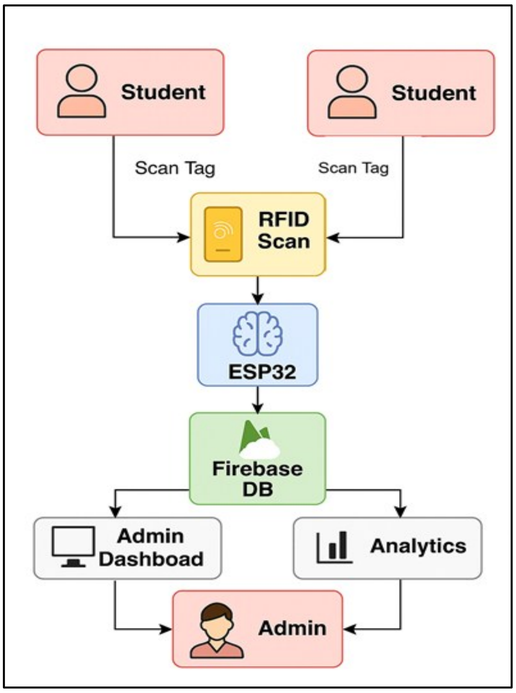

Figure 6. Conceptual Framework

3.4 Database Design and IoT Connectivity

3.4.1 Database Architecture and Schema Design for Attendance Records

The backend consists of Firebase Realtime Database, a NoSQL, cloud-hosted database that stores attendance data in a JSON tree structure. Each user has a unique node identified by their RFID UID, and within their UID node reside fields that consist of a name, email, timestamp, status, and approval_state. For instance, if we look at attendance records in the database for John Smith, the Firebase structure would resemble the tree shown in Figure 7. This structure provides relevant speed for querying and a hierarchical organization of fields for reports or a review of the log. Entries for UIDs that cannot be identified are stored in a separate pending_requests node for the administrators to approve and register at a later time.

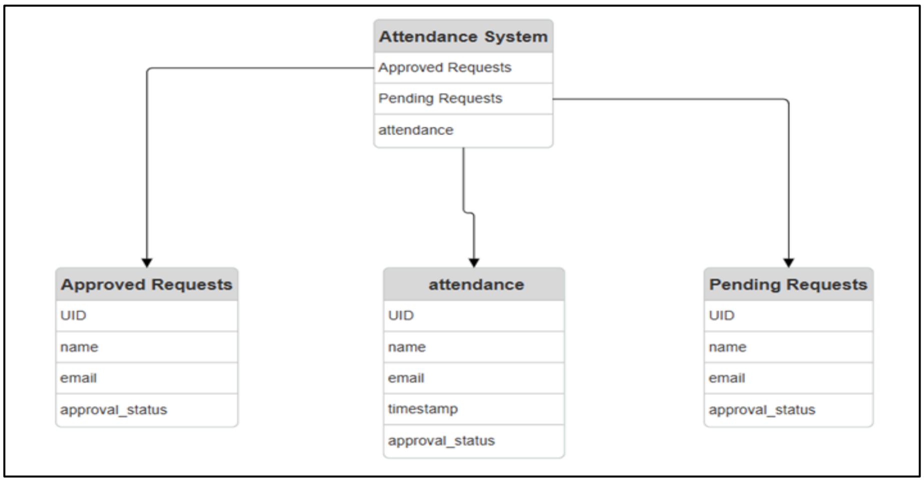

Figure 7. Schema Diagram of Attendance System

3.4.2 IoT Communication Protocols

The system employs Wi-Fi (IEEE 802.11 b/g/n) to connect the ESP32 microcontroller and the Firebase cloud. It uses HTTPS POST to transmit the data and the Firebase REST API to push attendance data directly from the ESP32, without the need for a middleware backend. When the ESP32 fails to push the data due to a temporary network failure, it is programmed to retry the transmit until it is successful.

3.4.3 Data Synchronization and Storage Methodologies

Firebase enables real-time two-way synchronization, guaranteeing that any and all data changes (new scans, updates, deletions) immediately reflect on all connected devices. With this architecture the admin dashboard can update in real time, without needing to refresh. Firebase also features offline caching, allowing the data collected by the ESP32 to be cached and loaded back into a user's screen after a connection is reestablished, maintaining data integrity.

3.4.4 Network Connectivity and Real-Time Transmission

The system functions in a real-time capacity with little latency. Upon scanning an RFID tag, the UID, timestamp, and status will be sent within milliseconds to the Firebase server. NTP synchronization was implemented to ensure all records are stored with standardized time values. Lastly, Firebase rules are implemented to enforce access control and prevent unauthorized read/write activity, which enhances data security and integrity of the transmission over the IoT network.

3.5 User Interface and Web Application Development

3.5.1 Web Dashboard Development

The system consists of a lightweight web-based admin dashboard interface built using HTML, CSS, and basic JavaScript with Firebase's JavaScript SDK. The dashboard allows administrators to view attendance, approve pending tag requests, and generate reports on a real-time basis. Instead of a native mobile application, it was developed as a web app that is minimally responsive, allowing it to work on mobile browsers, as illustrated in Figure 8.

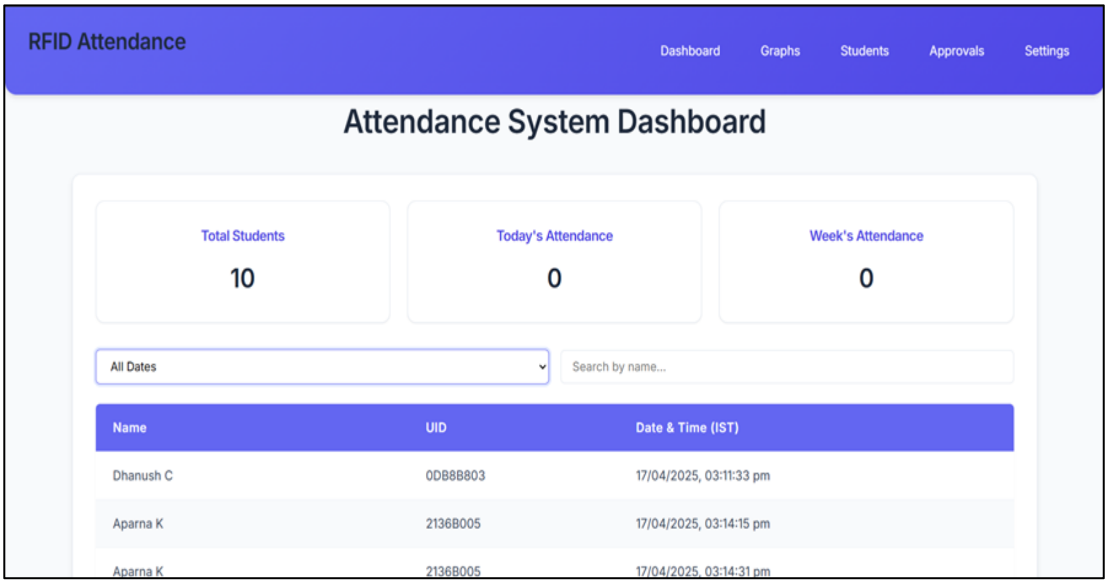

Figure 8. Attendance System Homepage

3.5.2 Real Time Notification and Reporting System Implementation

The real-time event listeners of Firebase are used to detect and push updates immediately to the dashboard, so refreshes are not needed. Whenever a scan is done or a new tag is detected, the update in the database will automatically reflect on the admin interface. Notifications intended for unregistered tags and low attendance notifications are recommended only visually as UI indicators and in real-time as an EmailJS alert to the administrators or other emails, as shown in Figure 9.

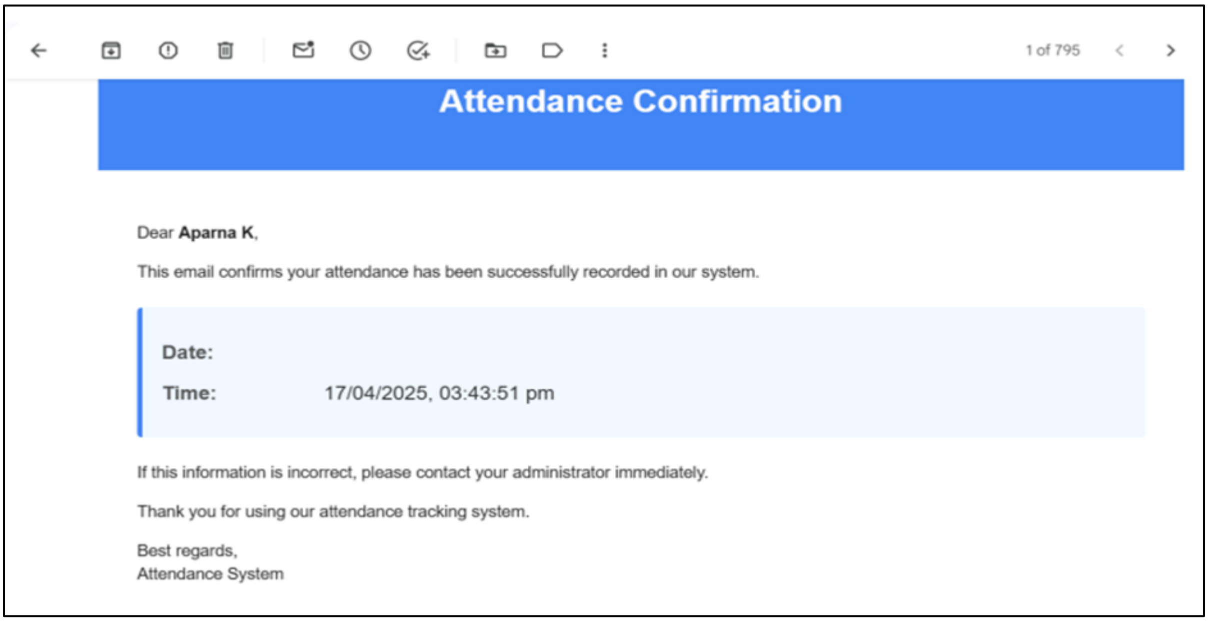

Figure 9. Attendance Confirmation through Email

3.5.3 User Experience Design and Accessibility

The UI features a clean design, high contrast color scheme, and semantic HTML structure with accessibility in mind. Buttons, charts, and tables are designed to be easily understood and usable across devices with various screen sizes. Icons and indicators, such as color-coded statuses, enhance user engagement. ARIA labels and tab navigation make the system usable and compatible with screen readers so that administrators with disabilities can access the site.

3.5.4 Analytics and Data Visualization

The dashboard showcases actionable knowledge using graphs to illustrate user attendance data in bar graphs, pie charts, and time-series graphs using Chart.js. By filtering by date, user, or any categorical status, users can notice worthwhile relationships based on the prior filters. This allows for the export of reports in PDF or CSV format, which can be utilized for monthly summaries, with individual or collective preferences on user attendance, providing actionable knowledge and useful decision-making for an educational institution. Figure 10 illustrates the attendance analytics and visualization.

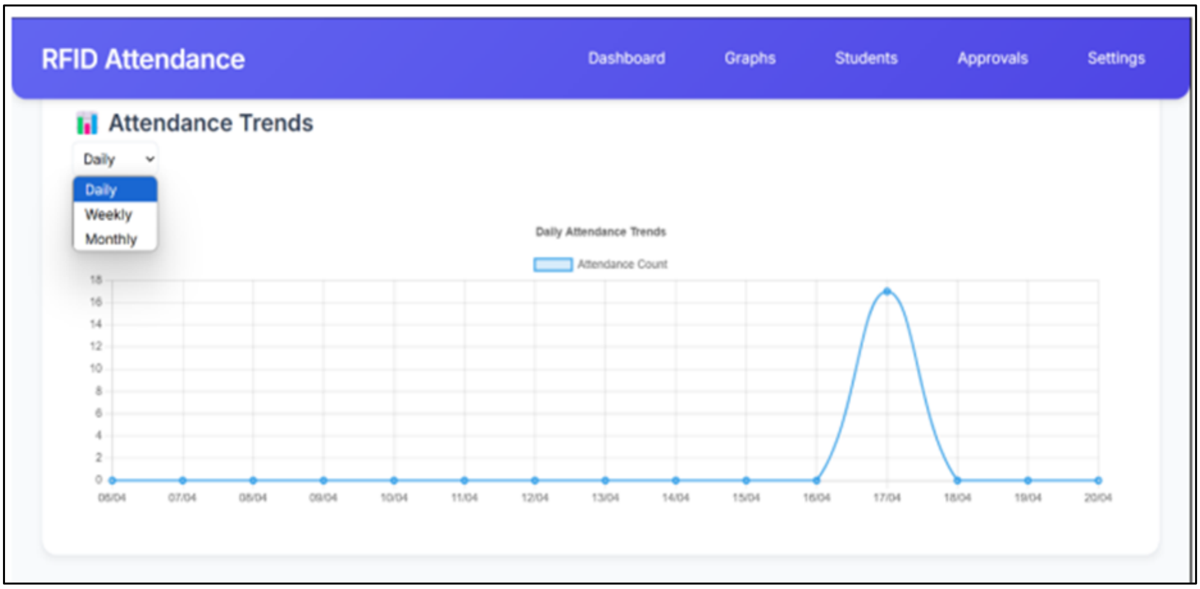

Figure 10. Attendance Analytics and Visualization

3.6 Testing Security and Deployment

3.6.1 Comprehensive Testing Framework

The system went through multiple stages of testing that included unit testing, integration testing, and performance testing. Unit testing involved testing each of the individual modules (e.g., RFID scanning, UID parsing, and Firebase communication) to validate expected consistent behavior. Integration testing was conducted to validate that the individual hardware and software layers could all work seamlessly together. Last but not least, performance testing involved assessing the system's responsiveness, data synchronization to the cloud, and load-handling potential when scans were coming in at high frequency. Testing scenarios included:

i. Successful and failed tag scans
ii. Real-time updates on the dashboard
iii. Behavior during loss of Wi-Fi service and network jitter
iv. Simultaneous tag reads (i.e., anti-collision behavior)\

3.6.2 Security Implementation

Security was considered at both hardware and software levels. RFID tags use short-range communication (3 to 5 cm), making it more difficult to have an unauthorized scan. On the software side, we installed Firebase Authentication Rules to limit database access to authorized admins. When data is pushed from the ESP32 to Firebase, it is done via. HTTPS. In addition, timestamps will be synchronized via NTP to prevent any manipulation of these timestamps. Furthermore, any unknown UID entries are not automatically registered but instead are routed to the admin for manual approval, which controls access.

3.6.3 Validation and Accuracy Measurement Protocols

The system's accuracy was measured against the traditional manual approach and demonstrated a detection rate of 100% under ideal conditions. Latency from scan to visualization on the dashboard averaged less than 300ms. Each scan was cross-checked against the backend logs for a matched UID, correct scan time (via NTP), and successful writes to the database. Cases of failed scans, misreads, and instances of admin rejection were tested, to evaluate the error handling functionality of the system.

3.6.4 Deployment and Maintenance

RFID readers and ESP32 units were deployed in a simple installation at various entry points, such as classroom or lab entryways, and powered with a stable USB power source. The microcontrollers were programmed to auto connect to the institution's Wi-Fi for live updates with Firebase. The admin dashboard was created as a web application and can be hosted on Vercel, which provides a globally distributed, scalable cloud-based serverless deployment option with continuous deployment from a Git repository. The website is designed to respond on both desktop and mobile browsers.

Regular firmware updates of the ESP32 can be made through a USB cable or Over-the-Air (OTA) updates to ensure the system's longevity and security. Firebase database logs are routinely backed up, and older records are archived or deleted based on retention policies to promote the best possible performance. The system is fully scalable additional RFID readers and users can be added without changes to the spatial architecture, other than updating the database and the interface of the dashboard.

4. Results and Discussion

The developed RFID and IoT-based automated attendance system was successfully implemented and evaluated in a real-world situation. The system showed a high level of reliability, fast response, and smooth communication between the hardware and cloud-based components. All tags scanned by the RFID reader were registered at an average response time of 250–300 milliseconds from tag scan time to database update time. Under the best conditions, we achieved a 100% detection rate and stable performance throughout the test. The admin dashboard updated automatically in real-time through Firebase listeners, eliminating the need for a refresh. Figure 11 shows the initial scan prompt.

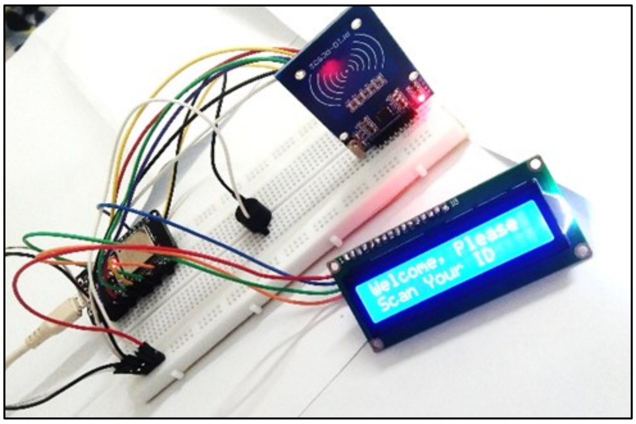

Figure 11. Initial Scan Prompt

Table 2. Response Time of the System

Metrics	Observed Value
Average Scan-to-log time	275ms
Successful Scan Rate	100%
Unauthorized Tag Detection Time	< 300ms
Dashboard Update Delay	< 1s

The system was tested on multiple hardware platforms, including the NodeMCU ESP32 and an Arduino Uno. Performance metrics (scan time, database update, dashboard delay) were assessed for comparison, and while the ESP32 offered the best combination of processing speed and built-in Wi-Fi, the detailed benchmarking results showed similar reliability and consistency. The ESP32 did have a lower dashboard update delay of less than 1 second and the potential to scan more devices concurrently, making it ideal for real-time needs. During testing, when scans of unregistered RFID, tags occurred, the system moved those scans to the

Firebase node for "pending approvals." Admins are notified on the dashboard interface, so no unsolicited entries could occur, as all unrecognized entries had to be verified. This added protection service makes it hard to manipulate attendance if the UID is not registered.

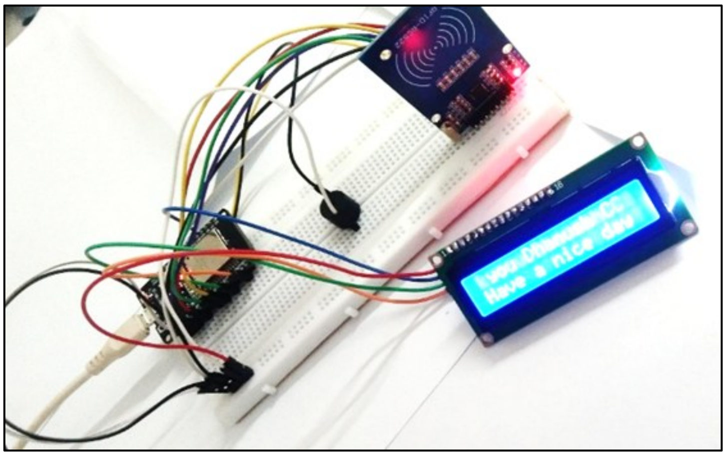

Figure 12. Successful Reading of the RFID Tag

The admin dashboard visualized daily and monthly attendance data through the Chart.js library, which provided values and breakdowns of attendance by a) time and frequency and b) student ID. From the analytics, trends emerged as clear patterns of attendance, peak scan times, and patterns of absence. These visualizations were useful in making decisions about the institution, as well as in monitoring performance. The supervising administrators and educators were surveyed about their experience using the real-time dashboard and monitoring functionalities during pilot deployments. Most reports rated the interface as simple to use and effective, with the ability to instantly check attendance and quickly identify anomalies perceived positively. Continuous feedback was solicited while in pilot, including follow-ups through interviews and logs of their usage of the system.

5. Conclusion

The use of an RFID and IoT attendance monitoring solution is a very appealing and scalable approach to the unavoidable issues of taking attendance manually. The software and hardware components used in this system follow some of the most modern techniques for attendance automation by logging attendance in real-time with the use of the RC522 RFID reader, an ESP32 microcontroller, data and metadata storage with Firebase, and a web-hosted dashboard with Vercel based on cloud technology. The system has demonstrated that it is capable of addressing significant issues, such as unwanted proxy attendance, the lagging ability to report attendance in a timely manner, and administrative concerns by being fast, reliable, and simple to use. Further expansions of the system architecture are possible, such as adding a biometric solution or SMS alerts, although the focus of this system was on modularity of design. The system's use of web technologies enhances accessibility globally from any internet-connected device for use in academic institutions, corporate environments, or secured facilities. The key component of this approach to an attendance monitoring solution highlights the importance of designing user-centered interfaces with effective and timely analytics to support administrators with digestible information that enables informed decision-making. Ultimately, the system not only demonstrates technical viability and real-world implementation of IoT and cloud computing in the context of education and workforce management but also shows minimal infrastructure requirements and a high level of efficiency. This could serve as the foundation for a future smart model and fully automated personnel management systems.

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