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Enhanced student attendance and communication in educational management systems

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ABSTRACT

The internet of things (IoT) and radio frequency identification (RFID) technology were explored to devise a beneficial approach for managing student attendance. The research developed a system that uses RFID tags embedded in student bracelets to gather presence data via strategically placed sensors. The system leverages real-time databases and Google technologies to enhance the student experience through an online platform, while also utilizing RFID for authentication. Focusing on improving user experience (UX) through effective design, the proposed system offers a pleasurable and cost-effective solution. Developed using popular web technologies such as Firebase, React.js, and Tailwind, along with Arduino chips and sensors, the system provides a practical solution for managing student attendance, academic performance, and administrative communication. The research highlights the potential of RFID technology in improving student management and academic performance. By decreasing the effort needed by traditional systems and proving cost-effective in the long term, it could act as a potential choice for implementation in educational institutions worldwide.

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1. INTRODUCTION

As the demand for efficient and high-cost systems in educational institutions continues to grow, especially if they are running artificial intelligence (AI) model inference [1], choosing the technologies that schools need to apply, especially for maintaining student data securely and effectively, can be confusing [2], in student attendance management, the adoption of smart attendance systems has shown promise in providing numerous benefits for both teachers and students. This can help to overcome issues such as misplaced attendance sheets [3], which implies that there is a lack of reliance on long-term storage; modern storage solutions need to be more advanced, particularly with cloud-based options [4], [5], without persistence, data becomes unusable for further applications and deriving insights, the selection of database type can also influence the system's performance when handling large-scale data, particularly in university settings. Numerous studies indicate that NoSQL databases offer greater scalability than SQL databases [6]–[9], which is crucial in handling the high volume of data generated by attendance systems in educational institutions, the cost of the attendance system is also influenced by the type of sensors used, such as cameras that track student attendance using AI [10]–[12]. Identifying students using AI in a classroom can be effective, but for larger classes, the implementation of such a system may result in fewer faces detected. Additionally, high-quality cameras are necessary to ensure accurate identification, leading to increased data storage requirements and computational costs. While these technologies might be advanced, their feasibility is limited by the significant expenses and complexities involved in large-scale deployments, which may pose challenges for educational institutions with limited resources. Furthermore, utilizing code scanners or QR code-based attendance systems [13]–[18] may offer a more cost-effective solution that still provides accurate tracking of student attendance but the reading time of this technology may lead to a low level of efficiency compared to other technology such as radio frequency identification (RFID), in the other side the choice of fingerprint or biometric-based attendance systems is another option [19]–[22] but the tradeoff of this technology is linked to hygienic concerns [23]–[25], especially during the COVID-19 pandemic, which has taught us valuable lessons in practicing good hygiene and reducing physical interactions. Lastly there is RFID sensors that have been used in student attendance systems [26]–[32], previous studies have shown the effectiveness of RFID technology. However, to improve its functionality for large-scale institutions and high levels of requests from multiple RFID readers simultaneously, it is important to enhance the infrastructure of this technology. Our contribution to the field involves creating an RFID-based attendance system that utilizes cloud computing platforms and NoSQL databases for enhanced efficiency and cost-effectiveness. This system not only enables fast data retrieval, but also extends its functionality to include web authentication via an RFID bracelet on an Android device for accessing platforms with a user-friendly interface. Additionally, it goes beyond just attendance management, encompassing administration-student relationships, mark management, and other academic processes as well.

2. METHOD

The proposed methods for implementing an automated attendance system [33], and student services and facilities make use of various technologies like RFID, cloud computing, NoSQL databases, and android devices. Choosing the right hardware and software tools is important to ensure cost-effectiveness, time efficiency, availability, and reliability when combining these technologies. Figure 1 represents the proposed overall architecture and how components are interconnected within the system to achieve the solution. The process begins by presenting the student tag to readers. The mobile app retrieves user data from firebase authentication and documents from cloud firestore. It also demonstrates how we locally store students after they enter their classrooms before sending them to the cloud solution, allowing for attendance record management and other tasks to be performed simultaneously without being blocked even under high demand.

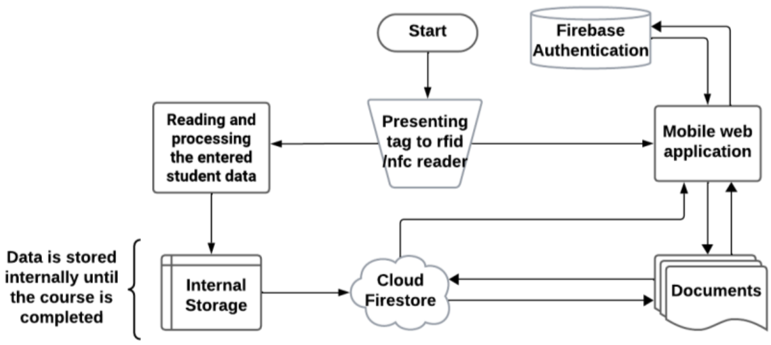


Figure 1. A graphical representation of the system's architecture

The hardware components utilized in our system include; i) RFID reader: this crucial component serves as a radio frequency transmitter and receiver, under the control of a microprocessor or digital signal processor. Its primary function is to emit signals at specific frequencies via an antenna, facilitating the detection and powering of nearby RFID tags. These tags, in response, transmit a unique identifier and potentially additional information from their embedded chips [34], [35]. For the attendance management system, the RFID reader is strategically positioned at the classroom's entrance, whereas, for the student ID system, it resides near the information display screen. Its primary responsibility lies in the accurate reading of student IDs (tags); ii) RFID tag: at the core of its functionality, the RFID tag is tasked with the identification, reading, or writing of data stored within an integrated circuit (IC). It subsequently transfers this data, representing student IDs, to the RFID reader through an integrated antenna [36]; and iii) processing unit (microcontroller and microprocessor): the processing unit plays a pivotal role in transmitting information about each student's presence in the classroom to firestore, a real-time database, using the Wi-Fi protocol. In our prototype, we employed an Arduino along with its RFID reader to capture student information. This data is then transmitted via serial communication to our laptop. The laptop further enriches this dataset by including additional details such as the date of attendance and whether the student arrived late. After processing, the data is subsequently transferred to our database. During the development phase, we utilized embedded C for programming the microcontroller and Python for data processing and management on the laptop.

The selection of these hardware components is determined by their suitability for the system's intended functionalities. It was observed that a greater investment in the software infrastructure would be beneficial [37], leading to cost reduction through the purchase of dependable and effective RFID readers and tags for students and classrooms respectively. Additionally, a sheep microcontroller can be used for serial communication with the server. The figures present a test of a student entering their classroom using an RFID tag. The tag ID is read using an Arduino RFID and the information is passed to a laptop through a serial port, as seen in Figure 2. Figure 3 shows how the user is authenticated using an RFID bracelet. This is read using web near field communication (NFC) and the gathered information is checked to validate the authentication and grant the user access to the platform navigation.

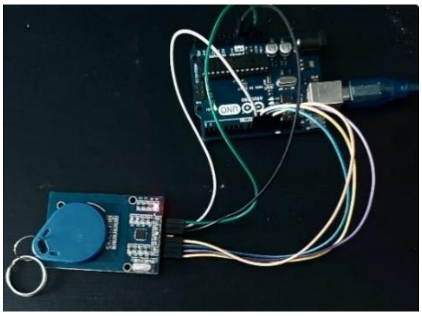


Figure 2. RFID and Arduino integration for student access control prototype

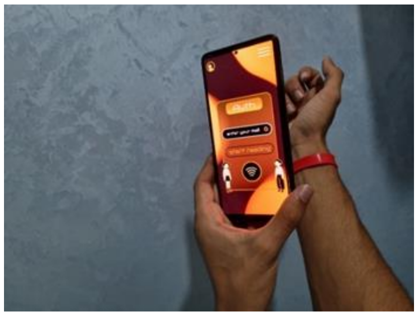


Figure 3. Authentication processes using RFID bracelets

The software used to implement this solution comprises: firebase authentication is primarily used for authentication purposes, verifying the user's identity and storing their email along with associated IDs. Subsequently, firestore is employed to manage the personal information of both students and their instructors, while also facilitating the storage and management of related documents. As a technology, it is used in several applications such as a real-time e-ticketing police system [38], data storage in service electronic applications [39], and factories that connect smart webcams (for object classification purposes) on conveyors and use Firebase to store data and gather them instantly to be displayed in web-based dashboards [40].

We commenced the development of our application using Vite.js, a choice that significantly accelerated our front-end development process. Vite.js provides features such as hot-module replacement, enabling real-time changes seamlessly, and it leverages build-powered bundling to ensure swift and efficient builds during production. This approach enabled us to concentrate on enhancing the app's functionality and user experience (UX) while minimizing the time allocated to configuration and build optimizations.

For the user interface (UI), we developed a web application using React.js. This JavaScript library utilizes JSX syntax to create components, such as text fields and authentication layout. Naturally, hypertext markup language (HTML) serves as the foundation, defining the structure of the application with elements like text and buttons. For styling, we employed CSS, combined with Tailwind, to ensure a visually appealing and user-friendly UI. We find ourselves obligated to build a web-based solution since the technological approach makes the learning process more enjoyable for students, such as learning from web-based animations for elementary students [41] or demonstrating software security weaknesses through lightweight web applications for cyber security students [42]. The cited software tools require minimal code compared to other technologies used in previous works that utilize Android applications [43] or programming languages like VB, VC++ [44], or systems created within the visual studio. NET environment [45]. Additionally, the utilization of cloud computing and NoSQL databases ensures seamless data storage, retrieval, and management while also providing scalability, high availability, and cost savings.

Our application comprises two distinct modules, both utilizing a single student bracelet equipped with an RFID tag, focusing on tracking student attendance within classrooms. Each student is provided with an RFID bracelet wristband embedded with a distinctive identifier along with their details. Upon entering the classroom, students are recognized by the RFID reader positioned at the door. This data is instantly recorded and saved in firestore. Figure 4 depicts the flowchart detailing the attendance management procedure. The microprocessor algorithm initiates by retrieving student data and classroom schedules from firestore. This data is then transmitted to the microcontroller (in this instance, an Arduino) via a serial port. The microcontroller awaits this data before it starts the reading of RFID bracelets. This information aids the subsequent algorithm in identifying the RFID IDs of students and the course start times. We then begin to verify if the current time aligns with the course's start time. If there isn't a match, we continue to check until a match is found. Once aligned, we start the RFID bracelet reading at a high baud rate (for instance, at 115,200 bps). This ensures that we capture the maximum number of students while avoiding data collisions. When a student is detected, a confirmation beep sounds (a musical tone for validation). We then internally log the recognized student along with their timestamp of presence. Anticipating a worst-case scenario, where time is limited, we don't immediately transmit the data to the microprocessor after acquisition. Instead, a more time-efficient approach is to temporarily store this data internally. Once the student's waiting period concludes, we send the stored data to the microprocessor, erase all stored data, and then loop back to check if the current time matches the course's start time. After transmitting the data, our second algorithm is primed to identify absentees and tardy students. This stage emphasizes filtering out extraneous data to optimize our database. Subsequently, alerts are sent to the absent and late students, reminding them to explain. We then revert to awaiting data for the next courses.

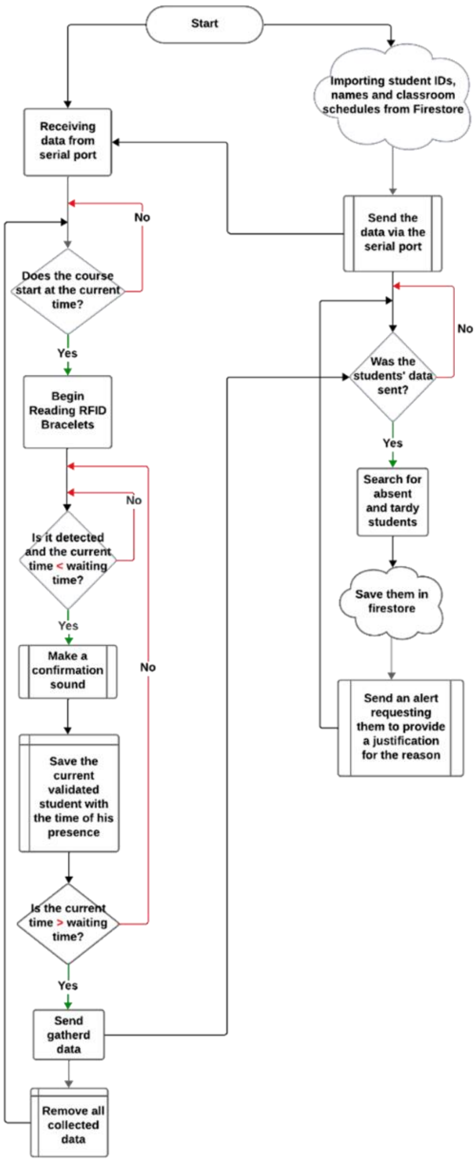


Figure 4. Flowchart of the attendance management system

Using internet of things (IoT) and cloud technologies to facilitate student-mentor interaction, the entire process begins when a user accesses the web application as illustrated in Figure 5. The first interface encountered is an authentication page that operates via email and an RFID ID, which is obtained by swiping a bracelet over the phone's NFC reader to ensure the RFID tag is read. This step employs IoT technology to facilitate data transfer from hardware to software. After this, a request is sent to Firebase authentication to validate if the entered criteria match any existing records. Once authenticated, the system checks if the user is a student, or a mentor based on the tag ID.

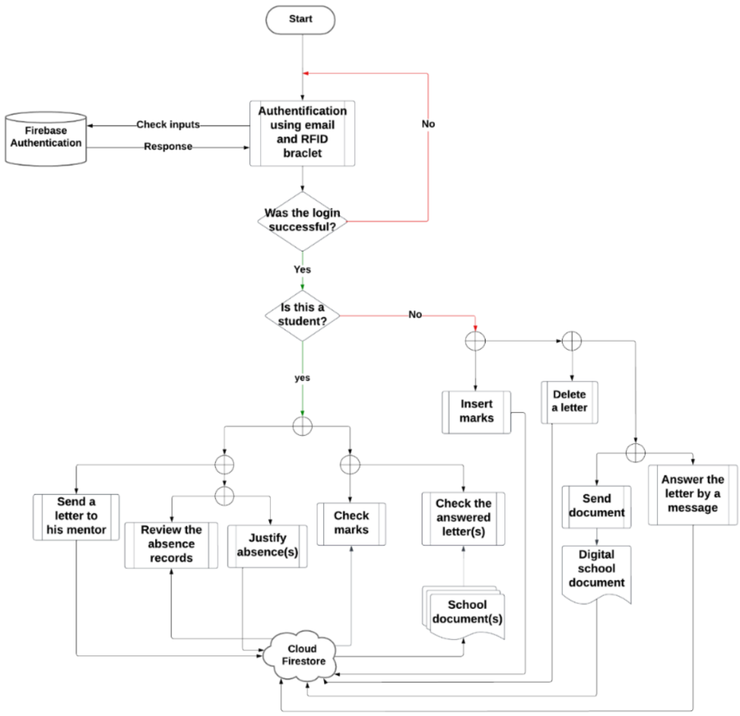


Figure 5. Flowchart deployed on RFID reader and server of the student ID system

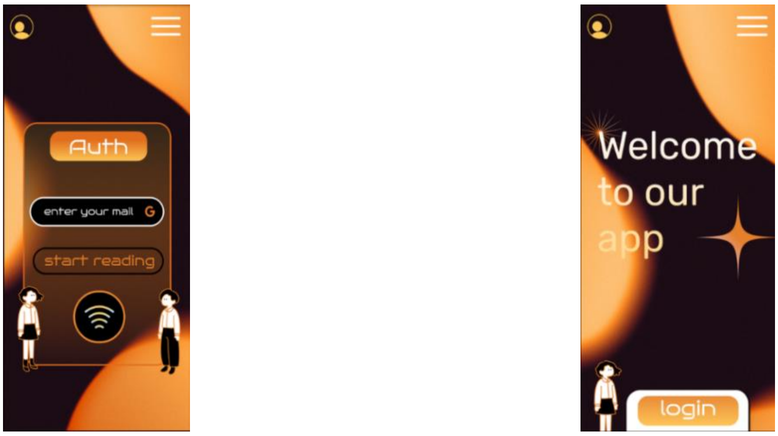
If the user is a student, they are granted permission to send letters to their mentor, view their attendance record, justify absences directly via the platform, check their grades, and review previously answered data. All this information is retrieved from cloud firestore; for the last student option, the data is stored in document format. On the other hand, if the user is a mentor, they are authorized to enter student grades and respond to student letters with either messages, digital school documents, or both. Additionally, they are authorized to delete a letter if it corresponds to a justified reason (e.g., an out-of-service message). All these actions are processed and stored in cloud firestore for subsequent use by students.

The table presents various methods for improving student attendance tracking using different technologies. However, the research focused on AI may produce accurate [46]–[50] results but lacks a study on cost efficiency and computing resources required in small and large institutions. On the other hand, biometric fingerprint systems [51] aim to secure the system against fraud but have hygienic consequences and may cause discomfort to users [23]–[25]. QR code-based systems [13]–[18], [52] are time-consuming despite their effectiveness in small-scale environments, while RFID technology [34], [49] offers a cost-effective and practical solution for student attendance tracking but needs further advancement for maximum efficiency. Based on the identified issues and proposed solutions, our goal was to push the RFID-based system to its limits by offering a wide range of features from an applicability standpoint. To achieve this, we sought to incorporate cutting-edge technologies like IoT and cloud into the proposed solutions to improve functionality and create a UI that enhances student and administrative services as well as their interaction.

3. RESULTS AND DISCUSSION

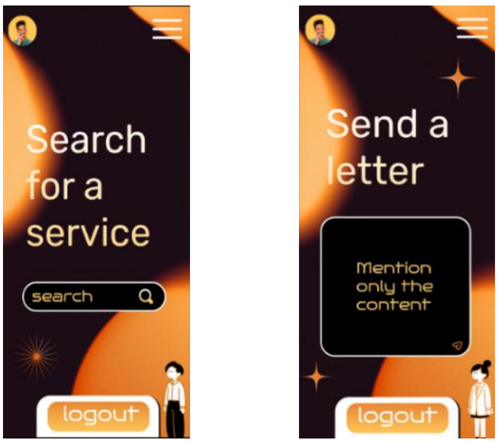
In the context of ISO 9241-210 [53], a UI [54] is understood as how a user interacts with a software application, system, or device. The standard emphasizes the importance of designing UI that are user-friendly, intuitive, and provide a positive UX. Our application has a UI composed of several components, designed to make it easy for students and managers to use and have a good experience. The UI includes an authentication screen can be seen in Figure 6, where users can enter their email to log in, and a 'Start Reading' button for the RFID tag reading process in Figure 6(a). There is also a welcome screen that introduces users to the app in Figure 6(b). Users can search for a specific service can be seen in Figure 7.

Figure 7(a) using the search bar and send letters and Figure 7(b) by mentioning the content they want to share. The UI also displays justified and unjustified absences can be seen in Figure 8. Figure 8(a) of a student, as well as an overview of academic marks and Figure 8(b) in various subjects like Mathematics, computer science, and physics. Letters that have been answered can be seen in Figure 9, Figure 9(a) are also shown, and administrators can input academic marks and Figure 9(b), select an unread letter can be seen in Figure 10, respond to it Figure 10(a), and delete a letter Figure 10(b) with a field to select the reason for deletion. The bottom of the UI has a 'Logout' button for users to exit their session, and the user's picture is gathered from their Google account, displaying an empty avatar before logging in. Table 1 presents a comparative analysis of our solution against other existing approaches, with a focus on the addressed problems and the proposed solutions. On the other hand, Table 2 outlines the technologies and tools utilized in our study, in comparison to the existing solutions presented in Table 1.



(a) (b)

Figure 6. Screens illustrating the user interaction with the authentication system; (a) the authentication screen where the user can enter their credentials and (b) depicts the welcome interface that greets the user after successful authentication



(a) (b)

Figure 7. Screens illustrating the user interaction with the app's service and letter-sending functionalities; (a) the interface where users can search for a service and (b) depicts the interface for sending a letter with the option to mention specific content

(a) (b)

Figure 8. Screens illustrating the user interaction with absence and marks records; (a) the absence records interface, allowing users to track and manage attendance and (b) displays the marks records interface for viewing academic performance data

(a) (b)

Figure 9. Screens illustrating the user interaction with answered letters and the marks input system; (a) the answered letter interface, where users can respond to unread letters and (b) depicts the insert marks interface for inputting academic marks

(a) (b)

Figure 10. Screens illustrating the user interaction with letter management; (a) the interface for answering letters, allowing users to select and respond to messages and (b) depicts the interface for deleting a letter, where users can choose a letter and provide a reason for deletion

Table 1. Comparison of various proposed solutions for tracking attendance

Solutions	Problems addressed	Solutions proposed
[46]	Inaccurate face recognition due to lighting and pose variations.	Improved face recognition algorithm for enhanced accuracy.
[47]	Manual attendance inefficiencies and inaccuracies in automated systems.	Eigenface, PCA and CNN algorithms to improve face recognition for attendance.
[48]	Inefficiencies in manual attendance recording and data management.	RFID-based system for automatic attendance recording and data management.
[33]	Security risks and inefficiencies in manual attendance systems.	RFID solution for secure and efficient attendance tracking and data centralization.
[49]	Children's academic performance declines due to lack of respect for phone usage.	Integration of mobile phone detection solution with attendance system for improved authentication.
[50]	Challenges in face recognition for attendance due to computational limitations.	Deep learning models for accurate and efficient face recognition in attendance systems based on DCNN and trained using KNN.
[55]	Manual attendance taking, security concerns, and data manipulation.	Biometric fingerprint authentication system for secure and automated attendance recording.
[52]	Problems with traditional attendance methods, including inefficiency and inaccuracy.	A QR code-based system for quick, efficient, and accurate attendance tracking is used by scanning the classroom's QR code with a mobile phone.
[51]	Security issues, access control, and the risk of attendance fraud.	Fingerprint-based biometric system to address security and fraud in attendance management.
Proposed system	Challenges faced with limited RFID system scalability, persistent storage risk, traditional authentication process, and poor UI.	An RFID-based system utilizes cloud computing platforms and NoSQL databases to enhance efficiency, reduce costs, enable login using tags, and improve UX.

Table 2. Primary findings of the proposed management system

Features	AI-based	Cloud-based	Friendly UI	Platform+authentication using RFID tag	Scalability	Cost-effective
Proposed system	✗	☑	☑	☑	☑	☑

Our findings indicate that we should know how far RFID technology could take us to invest more research to perform fields like student management. Our study focused on completing other proposed research which integrates RFID technology by developing a new architecture based on cloud computing for data storage and providing real-time access for all (students, teachers, and administration) as well as persistent storage to build a strong foundation for further research in fields like AI. We developed a user-friendly UI to facilitate navigation through our platform and managed to keep the platform lightweight. The authentication process is done only using the personal student tag, the solution is scalable and can be easily implemented in different educational institutions (large, medium, and small ones). The cost compared to other solutions is much lower and more affordable. However, additional research is needed to fully explore the potential of RFID technology in improving student management and academic performance particularly in cases of fraud when students may share their bracelets with others or confirm attendance falsely. We propose that this is feasible through AI, further work should be invested into counting the number of present students through methods such as LiDAR scanning or computer vision [56] while also considering cost efficiency measures, scalability, and safety.

4. CONCLUSION

Recent observations indicate that school management is dealing with several problems, such as attendance tracking mistakes, inefficient data manipulation, gaps in the relationship between administration and students, and the high cost of smart solutions. Our findings offer an intelligent solution based on IoT and RFID systems, along with web technologies for identifying and managing student attendance within universities. This multifunctional automated system offers numerous advantages including reliability, flexibility, user-friendliness, traceability of statistical data, and the elimination of deficiencies related to manual attendance systems. It also provides robust secure automatic management of student attendance along with other features. Moreover, the system can be applied in any educational institution. Its added value lies in digitalizing the scholarly framework, making it easier for all participants to interact with technologies and replacing the traditional system to establish a strong foundation for research in areas such as smart AI agents, real-time monitoring, and alert administration systems in case of any regression in student's performance, future work may focus on enhancing our system by implementing a logging mechanism to track any potential manipulations, as well as developing an AI-powered system to detect and prevent fraud, while also ensuring the security of student data.

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