Arduino-Based Fingerprint Attendance System: Enhancing Security and Record Integrity in Educational Institutions Through Biometric Technology

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ABSTRACT

This paper introduces the design and implementation of a fingerprint-based attendance system built on Arduino technology, developed to overcome the shortcomings of conventional attendance-taking approaches in academic institutions. The research's aim is to provide an affordable, automated solution that records student presence through fingerprint recognition, thereby improving security and minimizing cases of proxy attendance. The framework integrates both hardware and software elements, including an ESP32-WROOM-32 microcontroller, an AS608 Fingerprint Sensor, Node-RED for flow-based programming, and a MySQL database for record storage. The system acquires fingerprint inputs, compares them with saved templates, and updates attendance logs instantly, with feedback shown on an LCD display. Multiple testing phases were conducted to validate both hardware and software reliability. Results indicate that the system can accurately enroll and verify fingerprints, maintain real-time records, and synchronize data with the database. Performance comparison shows a significant improvement in lecturer and student perceptions post-implementation: ease of use increased by approximately 60%, accuracy confidence rose by nearly 65%, and perceived time efficiency improved by over 70%. Consequently, this fingerprint-based system provides an automated, secure, and dependable alternative for attendance tracking, significantly enhancing record integrity and administrative efficiency.

Keywords- Fingerprint recognition, biometric authentication, attendance system, IoT, RFID, security, real-time monitoring.

INTRODUCTION

Monitoring student attendance plays a vital role in academic administration systems. In many institutions, attendance is still recorded through conventional means such as manual registers, paper-based sheets, or QR code scanning.

Historically, attendance tracking has relied on physical registers or logbooks, where teachers manually documented student presence. In large classrooms, attendance taking and sign-in sheets often caused delays and errors, with additional administrative work. As education systems evolved, these drawbacks encouraged the transition towards technology-based solutions [17].

Although advancements have been made, traditional and semi-digital methods still suffer from inefficiency and misuse. For instance, proxy attendance, where a student records presence on behalf of another, undermines accuracy and the credibility of institutional records. Recent approaches, such as GPS-based mobile tracking, offer innovation but remain limited by vulnerabilities like location spoofing and reliance on stable network connections. These limitations highlight the necessity for a secure, reliable, and efficient system.

The present study addresses this need by integrating biometric authentication with real-time monitoring to enhance both reliability and usability in classroom settings [18]. Hence, there is a pressing requirement for an automated yet scalable solution that can reduce administrative workload while simultaneously improving precision and security [1], [2].

Recent developments in biometrics, especially fingerprint recognition, provide promising opportunities for enhancing attendance accuracy. Fingerprint-based verification ensures high levels of security since it relies on unique identifiers that are extremely difficult to duplicate. Nevertheless, the adoption of such systems in schools and universities is still limited, primarily because of concerns about costs, technical complexity, and integration issues. Future advancements should focus on enhancing scalability, improving fingerprint-matching accuracy, and combining multiple biometric methods for greater reliability [3], [4].

Alongside fingerprint recognition, facial recognition has also gained momentum due to its practicality and security benefits [5]. Still, widespread implementation of fingerprint-based systems faces challenges linked to infrastructure and expenses [6]. Importantly, fingerprint verification significantly reduces risks such as proxy attendance and delivers dependable authentication [7].

Scholars further highlight the role of the Internet of Things (IoT) in strengthening biometric attendance systems. IoT provides a flexible platform for connecting various biometric sensors into centralized, real-time networks that capture and process attendance data efficiently [8], [9].

Therefore, this research is dedicated to creating a fingerprint-based attendance system built on Arduino technology. Its core objective is to design an economical and user-friendly platform that automatically records attendance in real-time. Hence, addressing issues of human error and fraudulent sign-ins. All attendance data is stored in a database, simplifying record management and reporting.

With this approach, institutions can achieve more secure and reliable attendance records while reducing manual workload. Furthermore, this proposed system can be scaled for both small classrooms and larger lecture halls, making it adaptable across diverse educational environments.

Related Work

This section reviews existing literature on attendance monitoring solutions, with a particular focus on biometric authentication and IoT-driven approaches. Prior research is analyzed to identify the techniques, hardware, and system frameworks used, as well as their respective strengths and drawbacks. These insights form the basis for designing a secure and efficient attendance solution built with Arduino ESP8266 and fingerprint recognition technology.

Several researchers have explored diverse techniques for automating attendance, making use of technologies like facial recognition, QR codes, RFID, and other biometric solutions. Examples from prior studies include Real-Time Attendance Entry through Face Detection and Recognition [3], a QR Code-Based Student Attendance System [1], the Development of an IoT-enabled Attendance Monitoring System [4], and a Smart Face Biometric Verification–based Attendance Handling framework [10].

A. QR Code-Based Student Attendance System

An alternative approach utilized a QR code attendance One study proposed a QR code-based attendance system combined with facial verification to reduce impersonation. The design used a server–mobile application structure where students scanned codes containing class details, which were verified against a central database. While effective in preventing some fraud, the approach required smartphones and continuous internet access, limiting scalability [1].

B. Development of Attendance Monitoring System Using IoT Technology

Another approach used RFID technology with a Raspberry Pi microcontroller to record attendance in real time [4]. Each student carried an RFID tag linked to a database, and the system supported notifications for absenteeism. While efficient, the method relied on physical cards that could be lost or forgotten, reducing reliability.

C. Real-Time Attendance Entry Using Face Detection and Recognition

A real-time attendance system using facial recognition was implemented with machine learning models such as SVM and LBPH [3]. It automatically marked attendance from classroom video streams, reducing manual teacher involvement. However, the system required high-quality images and was sensitive to lighting and angle variations, limiting reliability.

D. Smart Face Biometric Verification Oriented Attendance Handling System Using Artificial Intelligence

An AI-based face biometric verification (AIFBV) system was developed to recognize multiple faces in real time, even under different lighting conditions [10]. Using Haar-Cascade classifiers and machine learning models, it achieved reliable detection and automated attendance logging. However, the approach was computationally intensive and highly dependent on training datasets.

E. Facial Recognition Attendance Tracking: An Intelligent Monitoring Approach

Another study proposed a cloud-integrated attendance system combining IoT, RFID, and facial recognition with AI-based models [14]. It improved accuracy and enabled real-time monitoring with remote access. However, the approach required significant computing resources and cloud infrastructure, raising concerns about scalability, cost, and data privacy.

F. Utilizing QR Codes for Smart and Low-cost Student Attendance Acquisition and Monitoring System

Research has shown a strong positive relationship between student attendance and academic performance [15]. This highlights the importance of reliable, automated systems that reduce absenteeism and support better learning outcomes.

G. Photographic Attendance Tracking System Online (PATSO)

The Photographic Attendance Tracking System Online (PATSO) applied facial recognition with Support Vector Machines to record attendance [16]. It achieved accuracy above 90% and showed stable performance across tests, though it still depended on proper lighting and clear facial features.

H. Critical Review and Justification

Table I provides a summary of the main findings and limitations from prior studies, highlighting the research gaps that this research aims to address.

Table I. Critical Review and Justification

Related Works/ Research Title	Technology Used	Key Features	Limitations
QR Code-Based Student Attendance System. [1]	QR Code + Facial Verification	Multi-factor authentication, GPS tracking	Requires smartphone, potential privacy issues
Development of Attendance Monitoring System Using IoT Technology. [4]	RFID + IoT	Real-time tracking, auto -notifications	Dependency on RFID cards, risk of loss
Real-Time Attendance Entry Using Face Detection and Recognition. [3]	Facial Recognition (SVM, LBPH)	Automated attendance, multi-angle recognition	Requires high-quality camera, privacy concerns
A Smart Face Biometric Verification Oriented Attendance Handling System Using Artificial Intelligence. [10]	AI-based Face Recognition	Multi-face detection, robust to lighting	Computationally intensive, dataset dependent
Cloud-Enabled Fingerprint and Face Attendance Management System in Educational Institutions [14]	RFID + Facial Recognition (LBPH, Haar Cascade) + AWS Cloud + IoT (Raspberry Pi)	Real-time attendance, cloud dashboard, dual verification (RFID + face)	Needs internet, cloud cost, limited by Raspberry Pi
Utilizing QR Codes for Smart and Low-cost Student Attendance Acquisition and Monitoring System [15]	QR Code + Raspberry Pi + Web Server	QR code for attendance, Web-based tracking	Needs phone to scan, needs internet, can be misused
Photographic Attendance Tracking System Online (PATSO) [16]	Face recognition (Face recognition library), Machine learning (SVM), Python backend + Angular frontend	Uploads group/individual images for attendance, accurate face matching (90%+), Auto CSV report generation, Option to notify parents via SMS	Needs good lighting & proper face angle, dependent on quality of dataset, requires internet access and training time
Fingerprint Attendance System Using Arduino (Proposed)	Biometric attendance,Fingerprint recognitionArduino, ESP32	Unique biometric identification, Impossible to proxy, Cost-effective	Physical contact required

Previous studies show that while QR code and face recognition-based systems are convenient, they often struggle with challenges such as privacy concerns, reliance on external devices, and sensitivity to environmental conditions. RFID-based solutions improve efficiency but remain dependent on physical cards, which can easily be misplaced or forgotten.

I. Proposed Solution

To address the limitations of earlier QR code, RFID, and face recognition methods, this research proposes a fingerprint-based attendance system. Fingerprint biometrics provide secure, reliable verification and significantly reduce fraudulent practices [11]. The framework integrates an ESP32 microcontroller with an AS608 fingerprint sensor, Node-RED for real-time data processing, and MySQL for data storage. Unlike mobile- or card-based systems, this design enhances both security and usability by enabling direct biometric authentication without reliance on external devices.

METHODOLOGY

A. Research Design

The Fingerprint Attendance System followed the Rapid Application Development (RAD) framework, which is a model particularly suited for research that require iterative cycles and active user participation.

RAD emphasizes minimal upfront planning and rapid prototyping to shorten development timelines. Its iterative nature allows for continuous refinement, ensuring that the final system can adapt to evolving requirements efficiently [12].

The RAD approach consists of several stages: requirements planning, user design, prototyping, construction, and testing. These stages are executed systematically to enable accelerated and iterative system development [13].

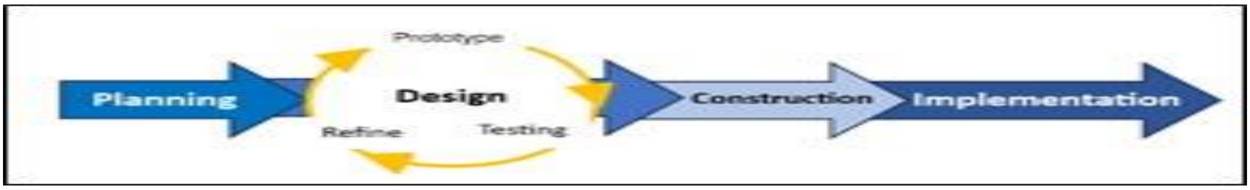

Figure 1. Stages of the RAD methodology

Figure 1 above shows all phases of the RAD methodology [12]. The methodology is divided into multiple phases, which are identified as requirements planning, user design, prototyping, construction, and testing. Each phase is systematically implemented to facilitate an accelerated and iterative development process [13].

Requirements Planning

The initial phase focused on collecting all system requirements prior to development. Both hardware and software resources were specified to ensure proper functionality and dependability. Key hardware components included the ESP32-WROOM-32 microcontroller, the AS608 fingerprint sensor, and a 16x2 I2C LCD display, each selected for their compatibility with the system. On the software side, Node-RED was utilized for flow-based programming, while MySQL was selected for database management. The required functions of each component were outlined, together with their interconnections and methods for handling data.

User Design

This phase concentrated on designing the user interface and workflows. It covered the fingerprint enrollment process, attendance logging procedures, and the web-based reporting interface. Workflows were planned to ensure straightforward use for both students and lecturers. During this stage, the system architecture was also defined to confirm that all components would operate together seamlessly.

Prototyping

In this stage, preliminary prototypes of the system were created according to the design specifications. The ESP32 microcontroller uses the Arduino IDE, functioning as the system's core processor. The AS608

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fingerprint sensor was connected to the microcontroller to capture biometric inputs, while Node-RED handled communication between the sensor, ESP32, and MySQL database. Prototype testing was conducted to validate hardware–software integration and identify potential issues early for resolution.

Construction

This phase involved the complete assembly and implementation of the attendance system. The ESP32 microcontroller was integrated with the AS608 fingerprint sensor, and all components were mounted on a breadboard. Using the Arduino IDE, the required code was uploaded to the ESP32, enabling the system to capture fingerprints, verify them against the enrolled database, and log attendance in real time. MySQL was configured to store attendance records, while Node-RED was employed to handle the data flow between the fingerprint sensor, ESP32, and database. A web interface was also developed to provide administrators and lecturers with access to real-time attendance data. Each component was connected in line with the system design and programmed to operate cohesively.

Testing and Cutover

The last stage consisted of end-to-end testing to ensure the system's reliability. Functional testing was carried out on each component, including the ESP32 microcontroller, fingerprint sensor, and MySQL database, to confirm proper operation. The system was assessed for its accuracy in fingerprint recognition, attendance logging, and database updating. Any detected issues were corrected. After verifying full functionality, the research entered the cutover phase, where the complete setup was finalized and readied for deployment in a live environment.

B. System Architecture

The fingerprint attendance system architecture consists of three main components: hardware configuration, software integration, and data management, as illustrated in Figure 2.

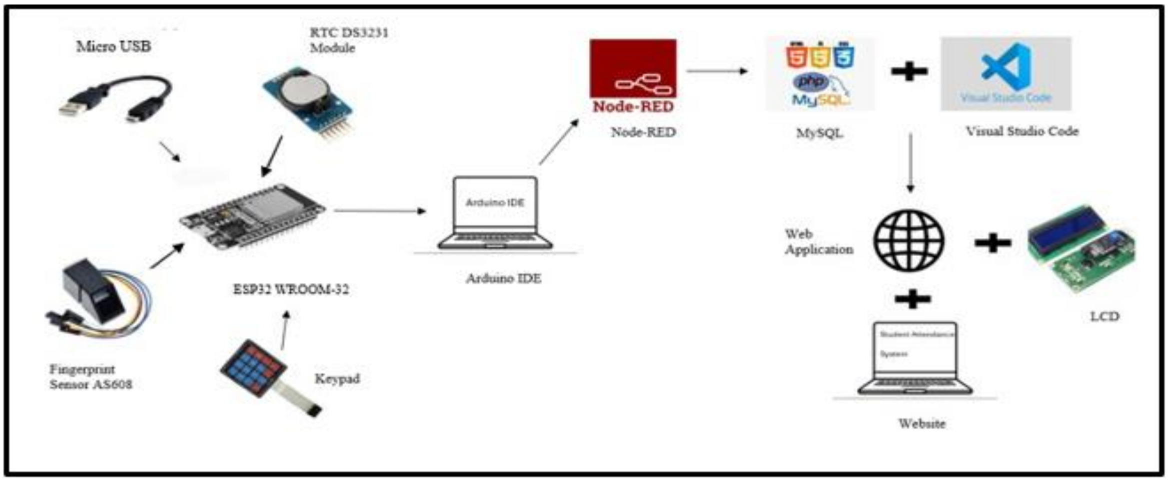

Figure 2. System Architecture

The hardware configuration includes:

1. ESP32 WROOM-32 microcontroller
2. AS608 fingerprint sensor
3. I2C 16x2 LCD display
4. RTC DS3231 module for accurate timekeeping
5. 4x4 keypad for user input
6. Breadboard and connecting wires

The software components include:

1. Arduino IDE for programming the ESP32
2. Node-RED for data flow management
3. MySQL database for data storage
4. Web interface for attendance reporting.

Hardware Components

ESP32-WROOM-32

The ESP32-WROOM-32 (Figure 3) acts as the main controller of the system. It provides Wi-Fi and Bluetooth connectivity while processing fingerprint data and coordinating communication with other components.

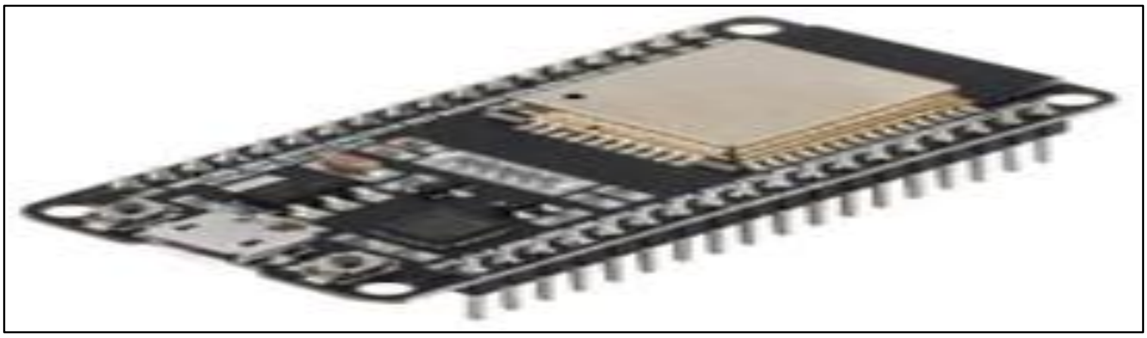

Figure 3. ESP32 WROOM-32

AS608 Fingerprint Sensor

The AS608 fingerprint sensor, shown in Figure 4, captures and verifies fingerprints, providing secure biometric authentication for the attendance system.

Figure 4. AS608 Fingerprint Sensor

I2C 16x2 LCD Display

The I2C 16x2 LCD, shown in Figure 5, displays real-time system messages such as fingerprint enrollment and attendance status.

Figure 5. *I2C 16x2 LCD Display*

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RTC DS3231 Module

The RTC DS3231 module, shown in Figure 6, ensures accurate timekeeping for attendance logs, even during power interruption.

Figure 6. RTC DS3231 Module

Other Components

1. 4x4 Keypad: For user input, particularly student ID entry
2. Breadboard: Provides a platform for connecting electronic components without soldering
3. Micro USB cable: Powers the ESP32 and enables code upload from a computer

D. Software Components

Arduino IDE

The Arduino IDE is used to program the ESP32 microcontroller.

Node-RED

Node-RED manages the data flow between the ESP32 and the MySQL database, enabling real-time communication.

MySQL

MySQL stores student information and attendance records for reporting and analysis.

E. Implementation Process

The system implementation was carried out in a structured sequence to ensure functionality and reliability. First, the hardware components ESP32 microcontroller, AS608 fingerprint sensor, I2C LCD display, RTC module, and keypad were assembled and connected according to the system architecture. The software configuration involved programming the ESP32 using the Arduino IDE to interface with the fingerprint sensor and peripheral devices.

Subsequently, a MySQL database was designed to store student information and attendance records. To enable real-time communication, Node-RED flows were developed to handle data transfer between the ESP32 and the database. A web interface was then created to provide lecturers and administrators with an accessible platform for viewing and managing attendance records.

Finally, all components were integrated into a unified system, and comprehensive testing was conducted to validate fingerprint recognition, data logging, and reporting functionalities. This systematic process ensured seamless interaction between hardware and software while delivering a reliable biometric attendance solution.

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FINDINGS & ANALYSIS

A. Hardware Implementation

The hardware components were successfully integrated as shown in Figure 7, with the ESP32-WROOM-32 serving as the central processing unit. The AS608 fingerprint sensor, I2C 16x2 LCD display, RTC DS3231 module, and 4x4 keypad were connected to the ESP32 through appropriate pins. The external setup view is shown in Figure 8.

Figure 7. Hardware Development Setup (internal view)

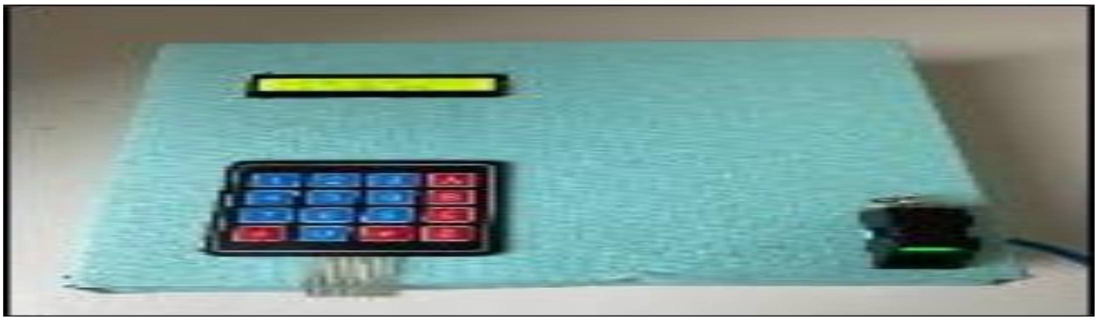

Figure 8. Hardware Development Setup (external view)

B. Software Implementation

The software implementation involved programming the ESP32 using Arduino IDE, setting up the Node-RED flow, and creating the MySQL database for data storage. Figure 9 shows the Node-RED flow configuration for data transfer between the ESP32 and MySQL database.

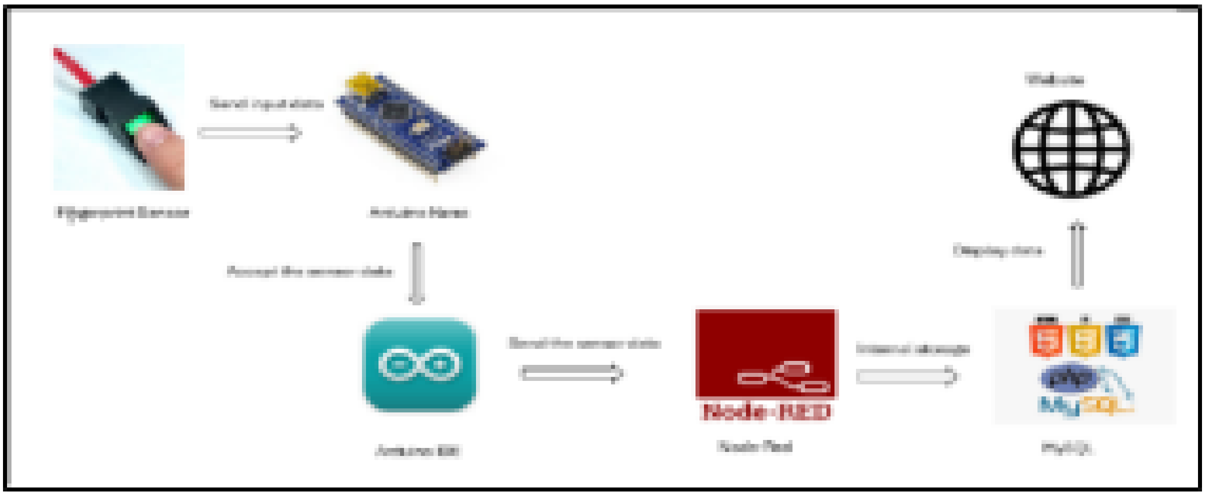

Figure 9. Node-RED Flow Configuration

The database structure was designed to store student information and attendance records efficiently, as shown in Figure 10.

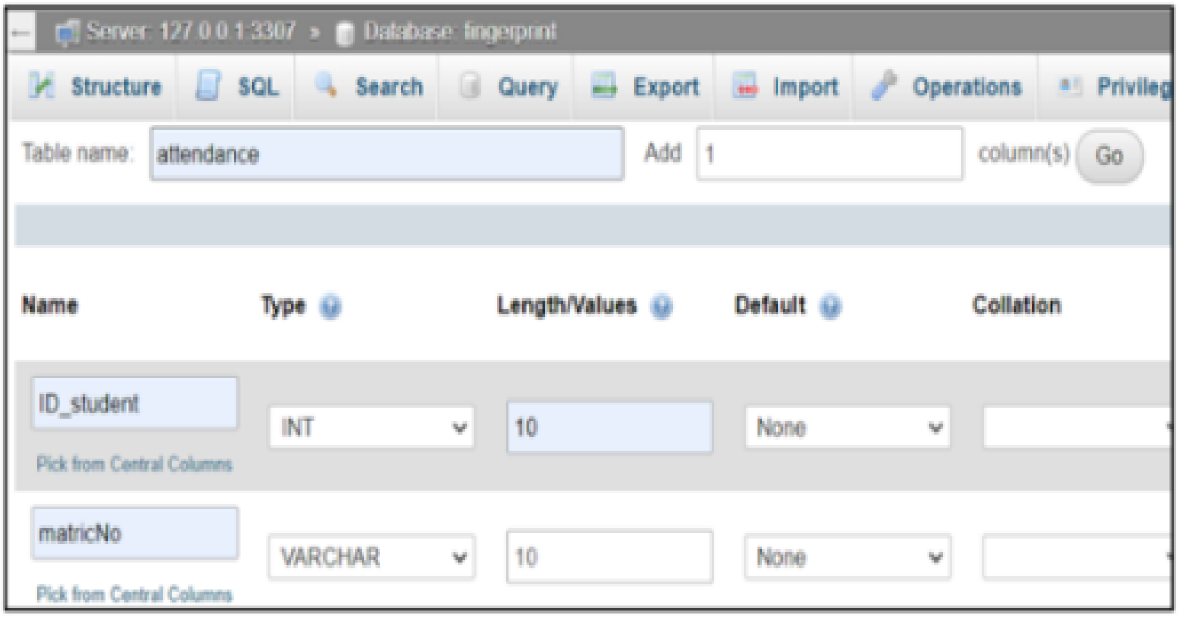

Figure 10. MySQL Database Structure

C. System Testing

Comprehensive testing was conducted to verify the functionality of the fingerprint attendance system. Tests were performed on individual components as well as the integrated system.

D. User Interface

The system provides user interfaces for both hardware interaction and web-based attendance management.

Login Screen

Figure 11 depicts the login screen, which provides fields for entering username and password. This step ensures that only authorized users can access the system. A 'Login' button is included to submit credentials, and an error message is displayed if the login details are incorrect.

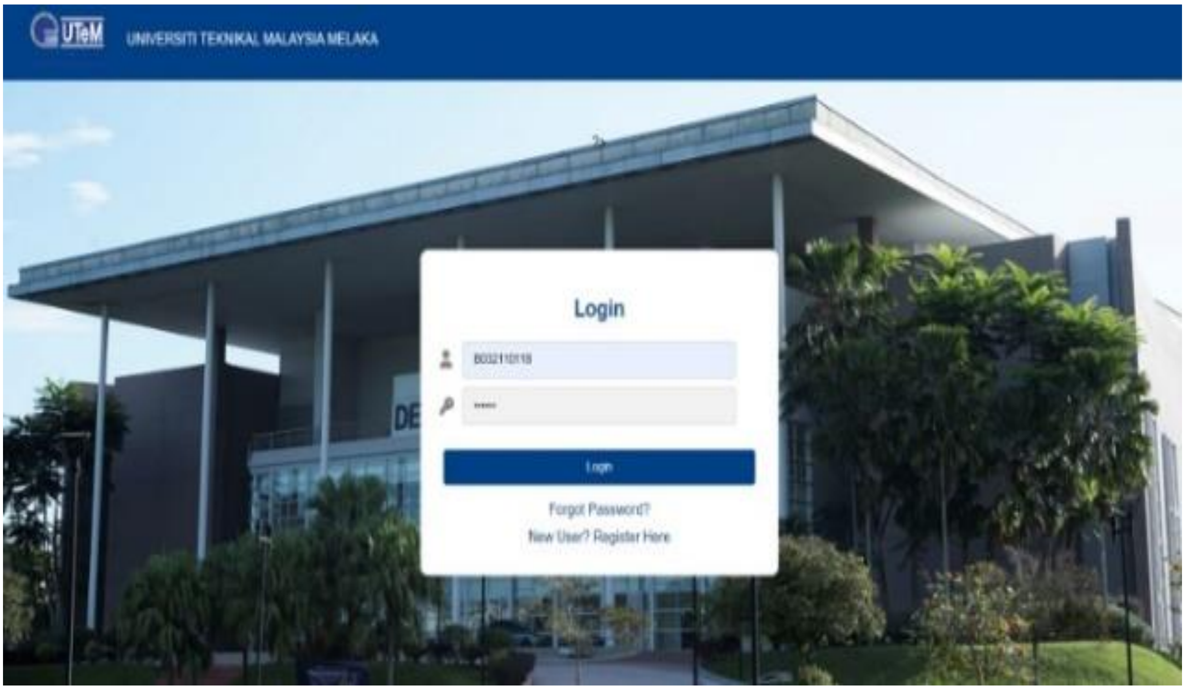

Figure 11. Login Screen

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Dashboard

After login, both lecturers and students are directed to a personalized dashboard (Figure 12), which serves as the main interface of the system. The dashboard provides access to key functions such as managing student data, recording and viewing attendance, and accessing personal or academic information. Its design is simple and user-friendly, with clearly displayed menus and navigation tabs tailored to the user role.

Figure 12. Dashboard

Attendance Checking

Students can view their attendance records through this feature, as shown in Figure 13. The interface typically displays details such as date, time, subject, and attendance status, helping students keep track of their participation in lectures and lab sessions.

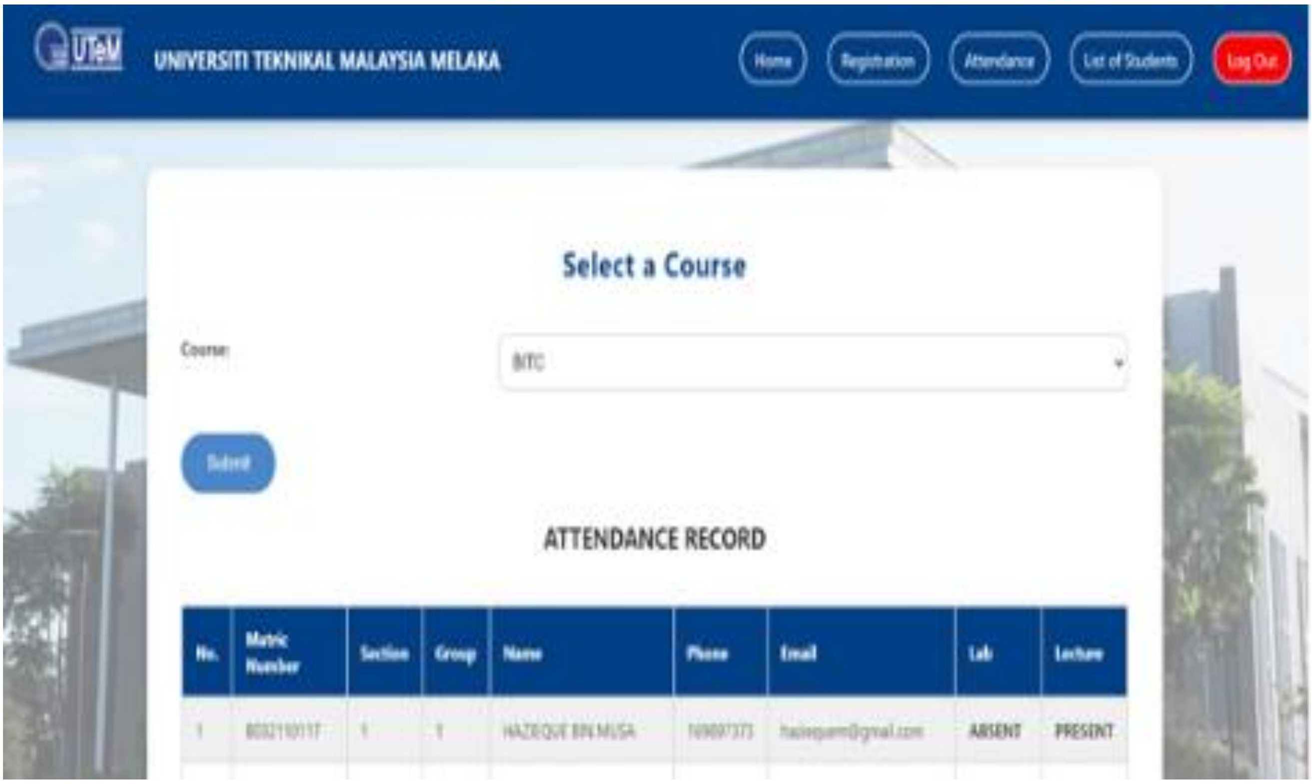

Figure 13. Attendance Checking Feature

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Attendance List

Figure 14 below show the feature that allows lecturers to generate and view a comprehensive list of attendance records for both laboratory and lecture sessions. This helps lecturers monitor student consistency, identify absences, and prepare reports when required.

Figure 14. Attendance List

Hardware Interface

The I2C 16x2 LCD display provides feedback during fingerprint enrolment and attendance recording processes, as shown in Figures 15 and 16.

Figure 15. LCD Message for Fingerprint Scanning

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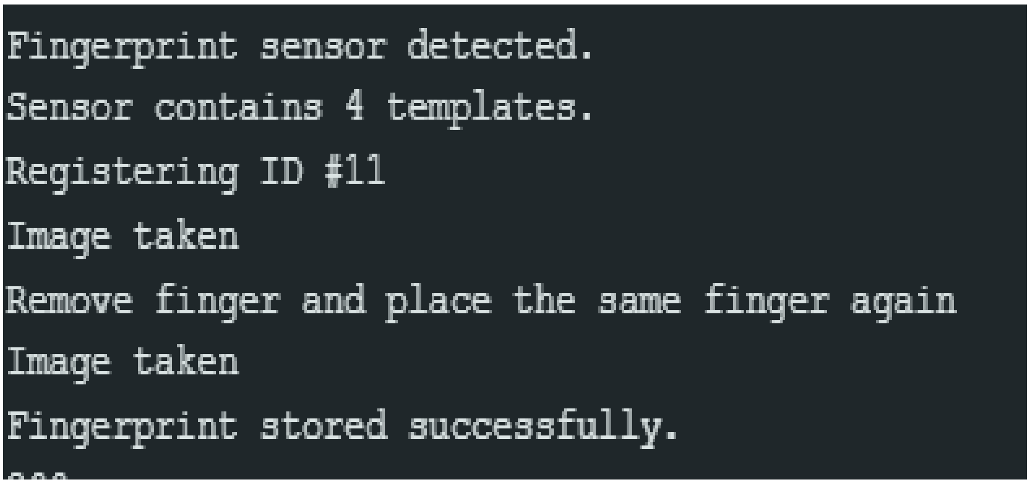

Figure 16. Successful Fingerprint Enrollment Message

E. System Performance Comparison

Lecturer Perspective (Ease of Use)

Figure 17 below shows the graph illustrating the shift in lecturers' perceptions regarding system usability. Before implementation, responses were mostly concentrated in the lower and neutral ranges, reflecting hesitation and difficulty of use. After adoption, the responses shifted significantly toward 'Agree' and 'Strongly Agree', indicating a clear improvement in perceived ease of use.

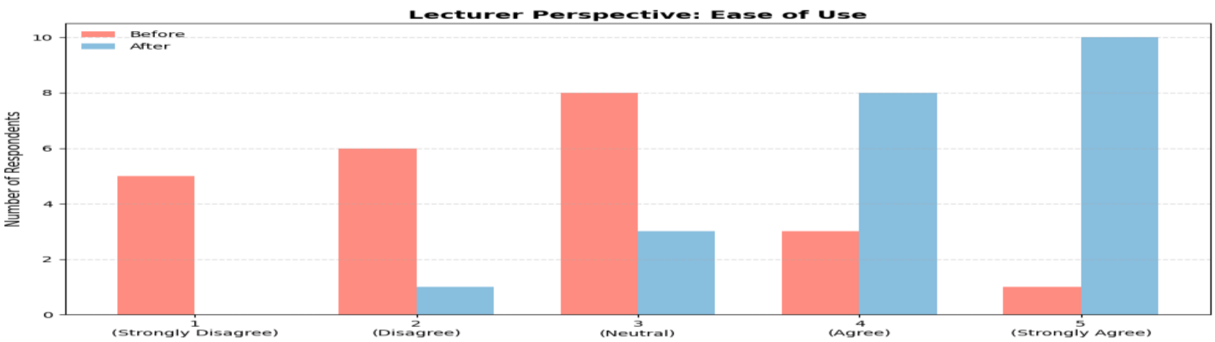

Figure 17. Lecturer Perspective (Ease of Use)

Lecturer Perspective (Accuracy)

Figure 18 below shows the graph illustrating lecturers' evaluation of system accuracy. Before system implementation, responses were spread across 'Disagree' and 'Neutral', indicating doubts about reliability. After implementation, most responses shifted to 'Agree' and 'Strongly Agree', demonstrating improved confidence in data accuracy.

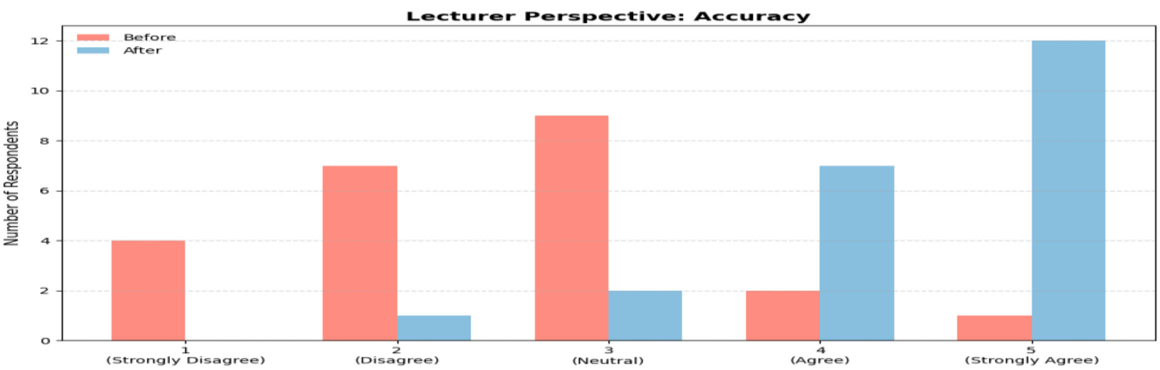

Figure 18. Lecturer Perspective (Accuracy)

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Lecturer Perspective (Time Efficiency)

Figure 19 below shows the graph comparing lecturers' perceptions of time efficiency before and after system implementation. Previously, many responses were concentrated in 'Neutral' or 'Disagree', reflecting inefficiencies in the manual process. After implementation, responses shifted strongly toward 'Agree' and 'Strongly Agree', highlighting significant time savings and improved process efficiency.

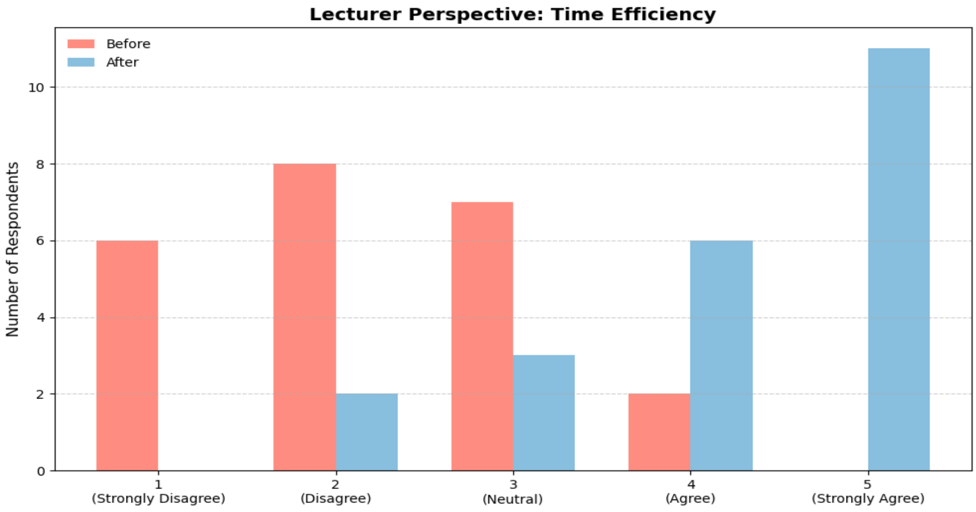

Figure 19. Lecturer Perspective (Time Efficiency)

Student Perspective (Ease of Use)

Figure 20 below shows the graph illustrating students' perception of system usability. Initially, many responses clustered around 'Neutral', suggesting uncertainty. After implementation, most responses shifted to 'Agree' and 'Strongly Agree', indicating positive user experience and smoother adoption among students.

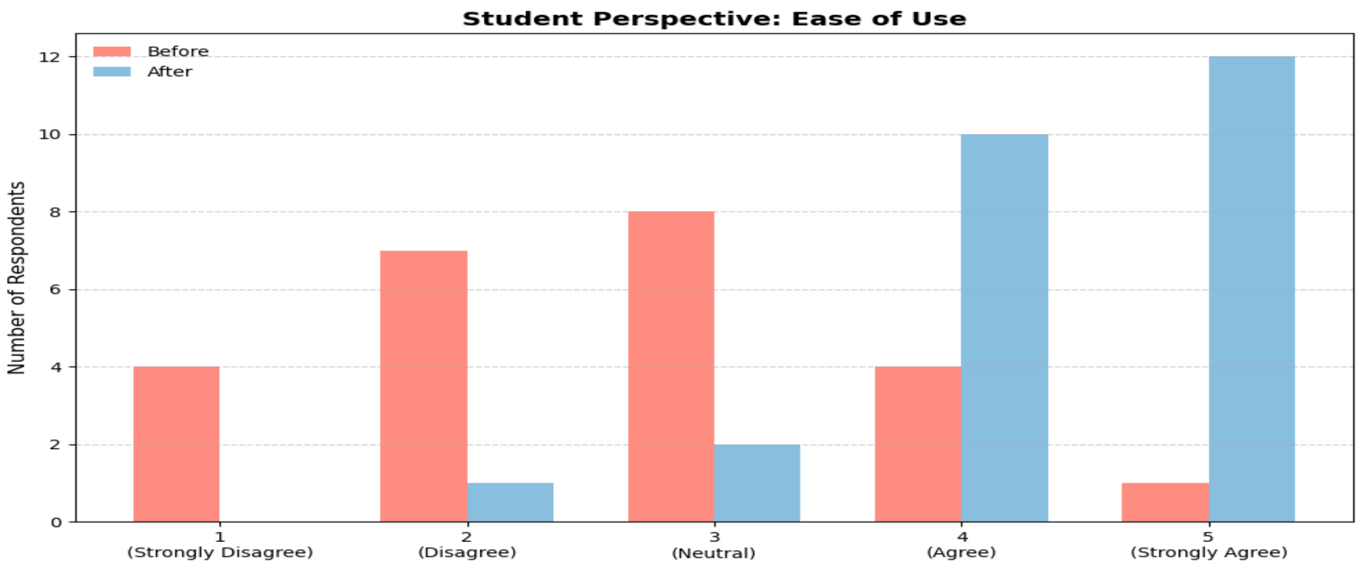

Figure 20. Student Perspective (Ease of Use)

Student Perspective (Accuracy)

Figure 21 below shows the graph illustrating students' evaluation of system accuracy. Before implementation, most responses were concentrated around 'Neutral', reflecting doubts or lack of clarity regarding data reliability. After implementation, responses shifted predominantly toward 'Agree' and 'Strongly Agree', indicating improved student trust in the accuracy of attendance and related information.

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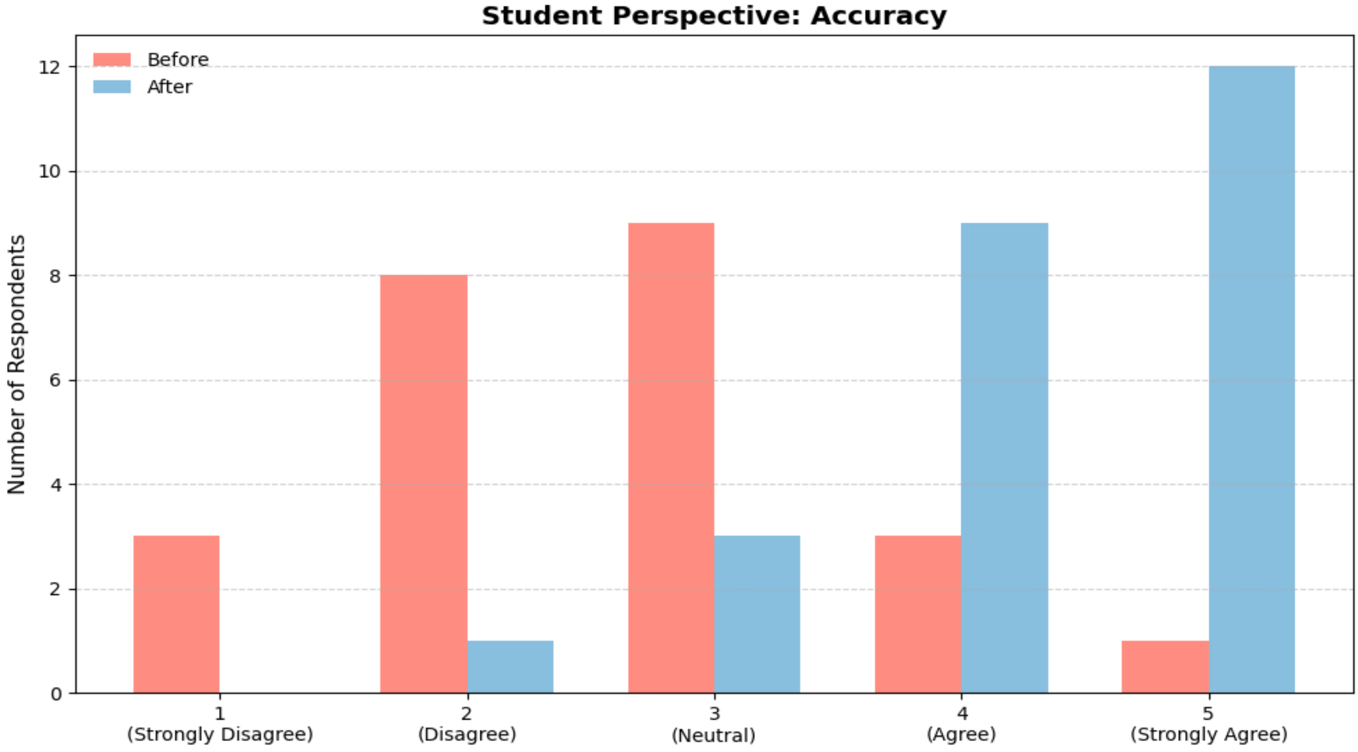

Figure 21. Student Perspective (Accuracy)

Student Perspective (Time Efficiency)

Figure 22 depicts the graph highlighting students' perception of time efficiency. Before system adoption, many responses leaned toward 'Neutral' and 'Disagree', indicating delays in manual processes. After implementation, most responses shifted to 'Agree' and 'Strongly Agree', signifying that students experienced faster and more efficient attendance management.

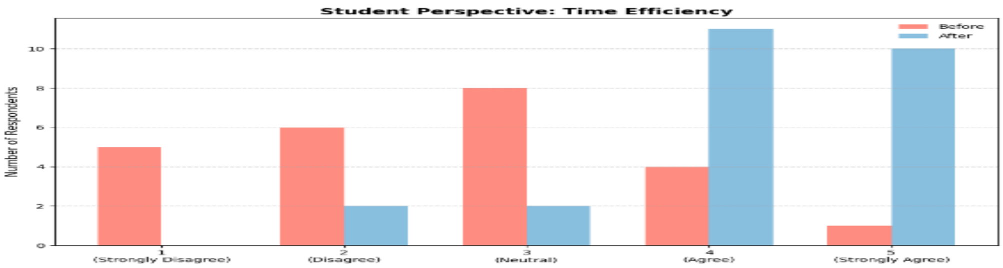

Figure 22. Student Perspective (Time Efficiency)

DISCUSSION

A. System Strengths and Limitations

Based on the implementation and testing results, the system's strengths and limitations were identified, as shown in Table II.

TABLE II. SYSTEM STRENGTHS AND LIMITATIONS

Strength	Limitations
Provides accurate and secure attendance tracking.	Fingerprint recognition may fail with dirty or damaged fingers.
Records attendance with precise timestamps.	System functionality depends on hardware that may

	require regular maintenance.
Facilitates easy online access and management of records.	Initial installation and configuration can be time-consuming and technically demanding.
Ensures reliable attendance tracking by using unique biometric identifiers, which prevents fraudulent practices such as buddy punching.	The storage of biometric information can lead to privacy and data security concerns.
Automates the entire attendance process.	Scalability may be limited for large classes or multiple locations.

B. Comparison with Existing System

The fingerprint attendance system demonstrates several advantages compared to previously reviewed systems. From a security perspective, fingerprints cannot be easily shared or duplicated, unlike QR code-based systems [1] or RFID-based systems [4], thereby significantly reducing the risk of fraudulent attendance. In terms of accuracy, fingerprint recognition achieves results comparable to facial recognition systems [3], [10] but with lower computational requirements, making it more efficient for classroom deployment. Furthermore, the system is cost-effective, as it relies on affordable hardware components rather than high-quality cameras and processors required for facial recognition technologies. Finally, the solution ensures reliability, since fingerprint recognition is less influenced by external environmental factors such as lighting conditions or camera angles.

The implementation of such a system has notable implications for educational institutions. Automating attendance tracking reduces administrative workload and minimizes human error, thereby increasing administrative efficiency. The use of biometric verification also promotes student accountability, as precise timestamped records encourage punctuality and consistent attendance. Additionally, the availability of comprehensive attendance data supports data-driven decision making, enabling educators to identify attendance trends and intervene with students at risk of poor participation. This system also contributes to resource optimization, allowing lecturers to dedicate more time to teaching rather than manual record-keeping, thereby enhancing educational quality. A relevant example is the Attend swift Hub system proposed [17], which integrates Arduino UNO, fingerprint modules, Wi-Fi connectivity, and a Telegram bot to deliver real-time attendance notifications to both faculty and parents. While this system prioritizes real-time communication and ease of classroom use, the proposed system emphasizes broader analytics and IoT-based integration, making it more suitable for long-term monitoring and performance evaluation [17].

C. Implications for Educational Institutions

The deployment of the fingerprint attendance system brings several advantages for educational institutions. Firstly, it streamlines administrative processes by automating attendance tracking, which reduces lecturers' workload and minimizes errors commonly associated with manual entry. Secondly, it encourages student responsibility, as precise time-stamped records motivate learners to attend classes consistently and punctually. The availability of accurate data also supports evidence-based decision making, enabling institutions to identify attendance trends and implement targeted interventions for students with low participation. As highlighted in [20], fingerprint-based solutions further enhance the credibility of attendance monitoring by eliminating proxy attendance and ensuring that only authorized individuals are validated. Lastly, the system aids in resource optimization by allowing lecturers to concentrate more on teaching activities rather than administrative duties, thereby improving the overall quality of education delivery.

D. Privacy and Ethical Considerations

The findings in [19] demonstrate that such a system significantly reduces errors, prevents proxy attendance, and streamlines the overall management process. While the fingerprint attendance system provides substantial benefits, several privacy and ethical considerations must be carefully addressed to ensure responsible adoption. Institutions are required to implement robust biometric data protection mechanisms to safeguard stored fingerprint information against unauthorized access or misuse. Equally important is the principle of informed consent, whereby students must be clearly informed about the purpose, storage, and usage of their biometric data prior to participation. To uphold inclusivity, institutions should also provide alternative attendance methods for individuals who are unable or unwilling to use fingerprint recognition due to medical, cultural, or personal reasons. Well-defined data retention policies are also essential to determine how long biometric records will be stored and to ensure their secure deletion once they are no longer required.

In addition to these ethical measures, technical safeguards should be implemented to reinforce security. Fingerprint templates should not be stored as raw images but instead as encrypted feature vectors using secure algorithms such as AES-256 or SHA-256 hashing. Data exchanges between the ESP32 microcontroller, Node-RED, and the MySQL database should be secured with SSL/TLS protocols to prevent interception. Access to the database must be controlled through role-based authentication and supported by regular audit logs, ensuring that only authorized administrators can retrieve or modify records. Backup files should also be encrypted and stored in secure locations. By combining ethical principles with encryption, secure communication, and strict access control, the system can ensure that biometric data remains confidential, tamper-resistant, and compliant with data protection regulations.

SUMMARY OF DISCUSSION

This research demonstrates that the fingerprint-based attendance system significantly improves efficiency and reliability in academic institutions. Lecturer and student feedback demonstrated ease of use, accuracy, and time efficiency, reducing workload, minimizing errors, and preventing proxy sign-ins. From the lecturer's perspective, post-implementation feedback indicated approximately 60-70% improvement across these key performance metrics, while students reported comparable enhancements, suggesting widespread user acceptance and satisfaction. These performance gains imply that the system successfully reduces administrative workload, minimizes human error, and mitigates fraudulent attendance practices such as proxy sign-ins. The system is cost-effective, using ESP32 and AS608 components, and ensures real-time data synchronization through Node-RED and MySQL. These features make it scalable and dependable, though long-term sustainability requires regular maintenance and strong data protection. To address privacy concerns, biometric data should be encrypted and supported by clear consent protocols. Future work will focus on multi-campus scalability, cloud integration, and the adoption of multi-modal biometrics and machine learning to improve inclusiveness and accuracy.

CONCLUSION

Real-time synchronization through Node-RED and MySQL enhances system dependability and supports future expansion, including cloud integration and multi-site deployment. Sustainable operation, however, requires regular maintenance and strict data privacy measures, such as encryption and informed consent. Future improvements should focus on scalability for larger populations, multi-modal biometrics to increase inclusivity, and advanced algorithms to improve matching speed and accuracy. Edge computing can also be adopted to reduce latency and strengthen system resilience.

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