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Smart Attendance System: An Internet of Things (IoT)-Enabled Concept

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Abstract

Schools and colleges must effectively handle attendance data to ensure the attendance of all students. We created a portable smart attendance system (SAS) to solve typical problems with conventional attendance systems, such as their inadequacy for dynamic educational situations, susceptibility to mistakes, and time consumption. SAS creates a reliable and effective biometric attendance solution by combining complex components such as the ESP32 microcontroller, R307 fingerprint sensor, and 11.44-inch thin-film transistor organic light-emitting diode display. SAS provides a reliable and efficient means of documenting attendance by using fingerprint biometrics for personal identity and authorization. The R307 sensor accurately scans and validates student fingerprints, while the ESP32 microcontroller analyzes verified attendance data. This data is then saved on a XAMPP server via the internet of things. Furthermore, SAS interacts with Twilio, allowing teachers to send attendance information to parents via SMS. This strategy enhances communication between educational institutions and parents, ensuring early notifications and enabling quick responses to irregular attendance. The suggested approach was field-tested with 20 students for 7 days and achieved a 100% accuracy rate.

Categories: IoT Applications, IoT Applications and Use Cases, IoT Devices and Hardware
Keywords: iot, fingerprint-based attendance system, esp32, twilio, xampp, tft oled, sms

Introduction

Considering today's education system, effective attendance management is essential for both institutional accountability and academic performance. Traditional methods for monitoring attendance, which frequently depend on manual procedures, are time-consuming, prone to mistakes, and inappropriate for the rapidly changing environment of educational institutions. Adopting innovative approaches is essential to efficiently simplifying attendance management as advances in technology. A complete solution for effectively controlling student attendance and giving parents real-time notifications is the smart attendance system (SAS).

To address the problem of manual attendance system, various solutions based on punch card, barcode tag, radio-frequency identification (RFID) tag, speech recognition, face recognition, fingerprint recognition, multimodal system, etc., have been provided by researchers. Fingerprint-based attendance system has the advantages such as being non-invasive, highly reliable, highly accurate, socially acceptable, and low cost compared to other biometric sensors [1].

The Internet of Things (IoT) connects everyday objects to the internet, enabling them to send and receive data [2]. By integrating sensors, software, and communication technology, IoT facilitates remote monitoring, automation, and data-driven decision-making across various domains, from smart homes and cities to industrial processes and healthcare systems.

This paper suggests creating and implementing a portable SAS using IoT to address issues of traditional attendance system. It does this by utilizing innovative parts such as the ESP32 microcontroller, fingerprint sensor R307, 1.44-inch organic light-emitting diode (OLED) display, and Twilio platform. By merging these cutting-edge technologies, SAS aims to overcome the limitations of traditional attendance systems and create a more effective, accurate, and fascinating means of monitoring attendance. The ESP32 microcontroller, which is well known for its versatility and networking capabilities, serves as the system's brain. The SAS has a solid basis owing to its seamless integration, which enables real-time data processing, wireless connectivity, and interoperability with a wide range of sensors and modules. Using the fingerprint sensor R307 makes it safer and more accurate to keep track of attendance. This sensor guarantees unique identification by blocking proxy attendance and enabling biometric authentication, which promotes student accountability and attendance record integrity.

The structure of the remaining paper is as follows: The Materials and Methods section describes the creation and deployment of SAS using IoT, as well as provides a literature evaluation of current attendance systems. The Results section presents a visual representation of the proposed system, the results of the conducted tests, and a comparison with existing methods. The Discussion section discusses

the established system, while the Conclusions section summarizes and identifies future areas for investigation.

Materials And Methods

Manual attendance systems suffer from various shortcomings including inaccuracies due to human error, time inefficiency in recording and processing data, susceptibility to falsification or buddy punching, and limited scalability for large organizations. Additionally, manual systems lack real-time monitoring capabilities and cannot provide insightful data analysis compared to automated solutions.

To address the issues of traditional attendance systems, different researchers provide different solutions based on tag/card or biometric sensors or multimodal systems. The current attendance system is roughly classified into biometric-based attendance system and non-biometric-based attendance system [3,4]. Non-biometric-based attendance systems can use punch card, RFID tags, barcode tags, or Bluetooth-based electronic tags as authentication methods. Biometric-based attendance systems can use face, fingerprint, eye, or speech as authentication methods [5,6]. Table *1* compares the work of different researchers on parameters such as authentication method used, processor- or microcontroller-based system, availability of short message service (SMS) facility, wired or wireless data feeding facility, IoT- or non-IoT-based system, and portability of system. According to Table *1*, it is found that most of the researchers use fingerprint biometric authentication techniques, but SMS sending facility is not available, and database data are not accessible worldwide. This indicates that there are still research issues in the existing system. The proposed system suggests a fingerprint-based attendance system with SMS facilities, where the data can be accessed worldwide, in order to address the issues present in the previous attendance systems.

Study	Authentication Method	Processor/Microcontroller Based	SMS Facility	Wireless/Wired Communication for Data Feeding	IoT-/Non-IoT-Based System	Portable/Non-portable
[7]	Fingerprint based	8051 Microcontroller based	No	Wired	Non-IoT	Portable
[8]	Fingerprint and mobile MAC address based	Processor	No	Wireless	Non-IoT	Portable
[9]	Mobile-based face recognition	Processor	No	Wireless	IoT	Portable
[10]	Bluetooth-based electronic tag	Mobile processor	No	Wired	Non-IoT	Portable
[11]	Speech biometric based	Mobile processor and server processor	No	Wireless	Non-IoT	Portable
[12]	Face recognition based	Processor	No	Wired	Non-IoT	Non-portable
[13]	Face recognition using deep learning	Processor	No	Wired	Non-IoT	Non-portable
[14]	Fingerprint based	Microcontroller based	No	Wired	Non-IoT	Non-portable
[1]	RFID and face recognition based	----	No	----	Non-IoT	Non-portable
[4]	RFID based	Microcontroller based	No	Wireless	Non-IoT	Portable
[15]	Passive RFID tags and frequency distribution algorithm	COTS RFID device	No	Wired	Non-IoT	Non-portable
[3]	Barcode based	Processor	No	Wireless	Non-IoT	Portable
[16]	Fingerprint based	Microcontroller based	No	Wired	Non-IoT	Portable

TABLE 1: Comparison of the work of different researchers on attendance systems

COTS: commercial off-the-shelf; MAC: medium access control

Methodology

The proposed system is developed in two phases. In the first phase, hardware is developed using a controller and sensors, and in the second phase, software is developed for the portable module as well as the server's frontend and backend. The block diagram of the proposed system is shown in Figure *1*. It consists of an ESP32 module, a fingerprint sensor, an OLED display, and a power supply section. The description of the hardware and software components is as follows:

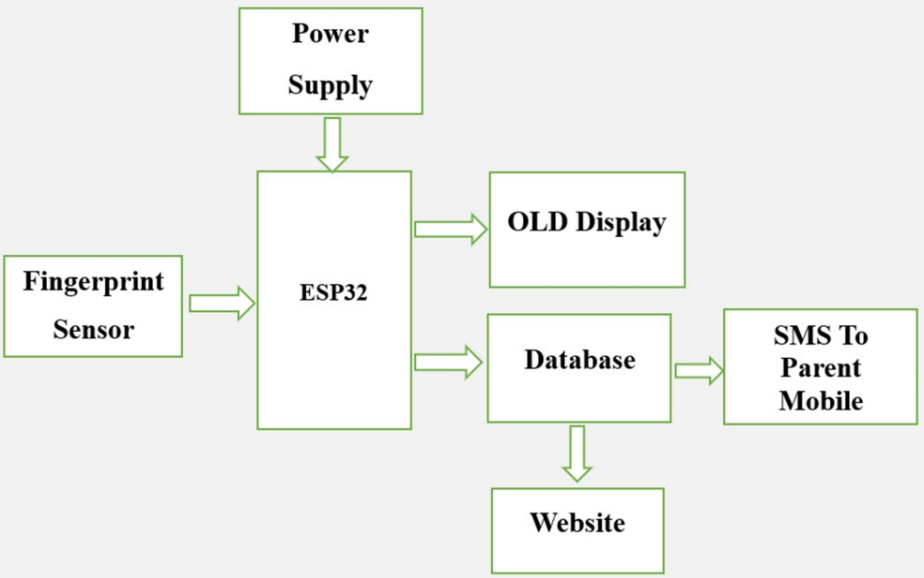

FIGURE 1: Proposed smart attendance system block diagram

Hardware Description

In today's fast-paced world, effective attendance management is critical for enterprises of all sizes. The introduction of technology has transformed old attendance tracking methods, creating the method for advanced systems that provide accuracy, dependability, and ease. This hardware description describes the components and features of SAS intended to streamline attendance management processes.

ESP32: Espressif Systems create the powerful and flexible ESP32 microprocessor board for IoT applications [17]. It comes with a dual-core Tensilica LX6 processor that can be clocked up to 240 MHz and Wi-Fi and Bluetooth connections. The board includes a rich set of peripherals such as analog to digital converters (ADCs), digital to analog converters (DACs), universal asynchronous receiver-transmitter (UART), serial peripheral interface (SPI), inter-integrated circuit (I2C), and pulse width modulation (PWM). It also supports encryption and safe boot. The ESP32 is ideal for battery-powered projects because it can work with a wide range of voltages and has low-power modes. The ESP32 works with a number of development platforms, such as the Arduino Integrated Development Environment and the Espressif IoT Development Framework. The ESP32 board has a Tensilica LX6 CPU with two cores that can run at up to 240 MHz, Bluetooth 4.2, and Wi-Fi (IEEE 802.11 b/g/n) connection. The RAM is 520 KB, and the ROM is 448 KB. The SRAM is for data storage. There are 34 general-purpose input/output (GPIO) pins, eighteen 12-bit ADC channels, and two 8-bit DAC channels on the board. Communication methods like UART, SPI, I2C, integrated inter-IC sound bus, controller area network, Ethernet MAC, and secure digital/secure digital input output/MultiMediaCard can be used with it. The ESP32 also incorporates support for PWM. Figure *2* shows the ESP32 board with its pin numbers.

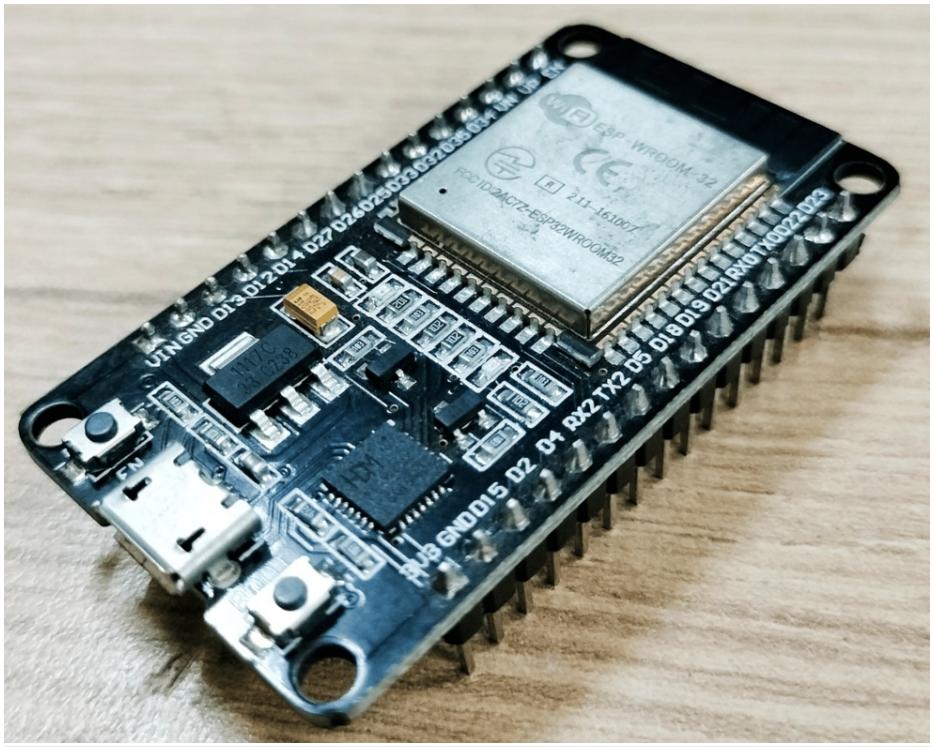

FIGURE 2: ESP32 board with its pin numbers

R307 fingerprint sensor module: The R307 module integrates a fingerprint reader, a CPU, and a storage unit to provide a complete fingerprint recognition system [18]. The R307 fingerprint sensor is reliable and efficient, capable of identifying and storing fingerprints. A high-speed digital signal processor (DSP) equips it, enabling fast and precise fingerprint detection, collection, and matching. The sensor can store up to 1,000 fingerprints and features numerous communication interfaces like UART and USB, making it simple to integrate with microcontrollers and PCs. The device's compact dimensions and consistent functionality make it well suited for use in security systems, time attendance systems, and access control applications. Figure *3* shows the R307 fingerprint sensor module.

This module has an optical fingerprint reader with a high resolution of 500 DPI, ensuring that a high-quality fingerprint image is acquired. The UART transfer link facilitates the connection between microcontrollers and other devices. This device's operation necessitates a power supply with a voltage range of 3.6 V to 6.0 V. In order to get distinct fingerprint images, it is recommended that the image size be set to 256 × 288 pixels. Processing and matching typically take less than a second. The R307 functions optimally within a temperature range of -20°C to +50°C and has a configurable baud rate ranging from 9,600 to 1,15,200 bps. The dimensions of its tiny size are around 55 mm in length, 32 mm in width, and 21.5 mm in height. Moreover, it is compatible with Arduino libraries, which simplifies the process of development.

FIGURE 3: R307 fingerprint sensor module

OLED display: OLED is an advanced display technology known for its vibrant colors, profound black levels, and high energy efficiency. OLEDs differ from ordinary LCDs in that they do not need a backlight. Instead, each pixel produces its own light, leading to improved contrast and reduced screen sizes. This system utilizes a 1.44-inch OLED, which is sometimes known as a 1.44-inch thin-film transistor LCD. This small screen boasts a pixel resolution of 128 × 128, ensuring sharp and intricate visuals. The device uses a serial peripheral interface to establish contact with microcontrollers and provides excellent visibility from many viewing points, often within a range of 160 degrees or less. The display is capable of reproducing a wide spectrum of colors, has a built-in backlight for use in low-light environments, and has minimal energy consumption, making it ideal for devices that run on batteries. The compact size of this device makes it well suited for portable and wearable applications. Additionally, it is often compatible with widely used programming platforms like Arduino and Raspberry Pi. Figure *4* displays the 1.44-inch OLED along with its corresponding pin numbers.

FIGURE 4: OLED display with a 1.44-inch screen

Software Description

The software description entails the integration of hardware components with software solutions to create an effective attendance management system. This system utilizes the ESP32 microcontroller, R307 fingerprint sensor, XAMPP software, Twilio API, and IoT technology. The ESP32 firmware connects to the R307 fingerprint sensor, establishes an internet connection, gathers fingerprint data, and communicates with the server to record attendance. The ESP32 uses its Wi-Fi capabilities to transmit fingerprint data to the XAMPP server for processing. XAMPP is a widely used web server that allows developers to efficiently construct and test their applications on a server that is installed on their own computer [19]. It comes with MySQL for database administration, PHP for server-side scripting, and Apache for hosting web applications. XAMPP manages the attendance database and offers a platform for accessing and modifying data.

Twilio is a cloud-based communication platform that offers an application programming interface (API) for sending and receiving SMS messages, making phone calls, and performing other related functions [20]. This proposed system utilizes Twilio to dispatch SMS messages to parents on their children's attendance status or updates. The ESP32 establishes communication with the server via Wi-Fi protocols in order to upload attendance data, hence facilitating remote monitoring and system control.

Working

A fingerprint-based attendance system operates in numerous interrelated phases, including enrollment, attendance logging, data transmission, database management, notification, and remote monitoring and management. The procedure for enrolling a user and assigning a unique code follows these steps: 1) The user begins the registration process by selecting the "enrollment" option in the system. The system then

prompts the user to enter a unique identification (ID) number associated with this particular fingerprint. This ID allows the system to distinguish the fingerprint from others stored in the sensor's memory. Users enter the ID through the web-based interface, which is crucial for identifying them in subsequent actions. 2) To ensure accurate fingerprint capture, the system requires two independent scans of the same finger. First, the system prompts the user to place their finger on the sensor. The R307 sensor then captures the fingerprint image, temporarily storing it in buffer 1. The user is then instructed to remove their finger and reposition it on the sensor. The system collects and saves the second scan in buffer 2. This dual-scan strategy reduces errors and increases fingerprint matching accuracy by enabling the system to check for consistency between the two images. 3) After capturing both images, the system analyzes the data to generate a fingerprint template, which is a digital representation of the fingerprint based on distinguishing characteristics such as ridges and minutiae points. If the two scans match closely, the system accepts the fingerprint as legitimate. The R307 sensor then links the template with the user's ID and saves it in its memory. The ESP32 microcontroller then connects to the R307 sensor, which processes and stores the fingerprint templates locally. When a user places their finger on the R307 sensor during the attendance logging phase, the sensor captures their fingerprint image. The ESP32 verifies the user's identity by comparing the collected fingerprint to the saved templates. Following successful verification, the ESP32 stores the attendance data and user information, such as the ID and timestamp, locally. During the data transmission phase, the ESP32 connects to the internet via WiFi protocols and transfers attendance data to the XAMPP server via HTTP. The ESP32 sends the attendance data to the XAMPP server, which is equipped with Apache, MySQL, and PHP, during the server-side processing phase. PHP scripts analyze the incoming data and populate the MySQL database with the latest attendance records. During the database management phase, the MySQL database in XAMPP holds attendance records, including user IDs, timestamps, and attendance status (e.g., present or absent).

The alerts phase uses Twilio's SMS API to send attendance alerts to selected contacts, such as parents. Notifications for events like late arrivals or absences are manually generated and sent to recipients via SMS. Finally, during the remote monitoring and management phase, administrators may access the attendance system through the XAMPP web interface. They are able to monitor attendance in real time, track attendance patterns, and manage user profiles. Figure *5* shows the functioning of the proposed system, while Figure *6* depicts the SMS sending mechanism for a single student or a group of students' parents.

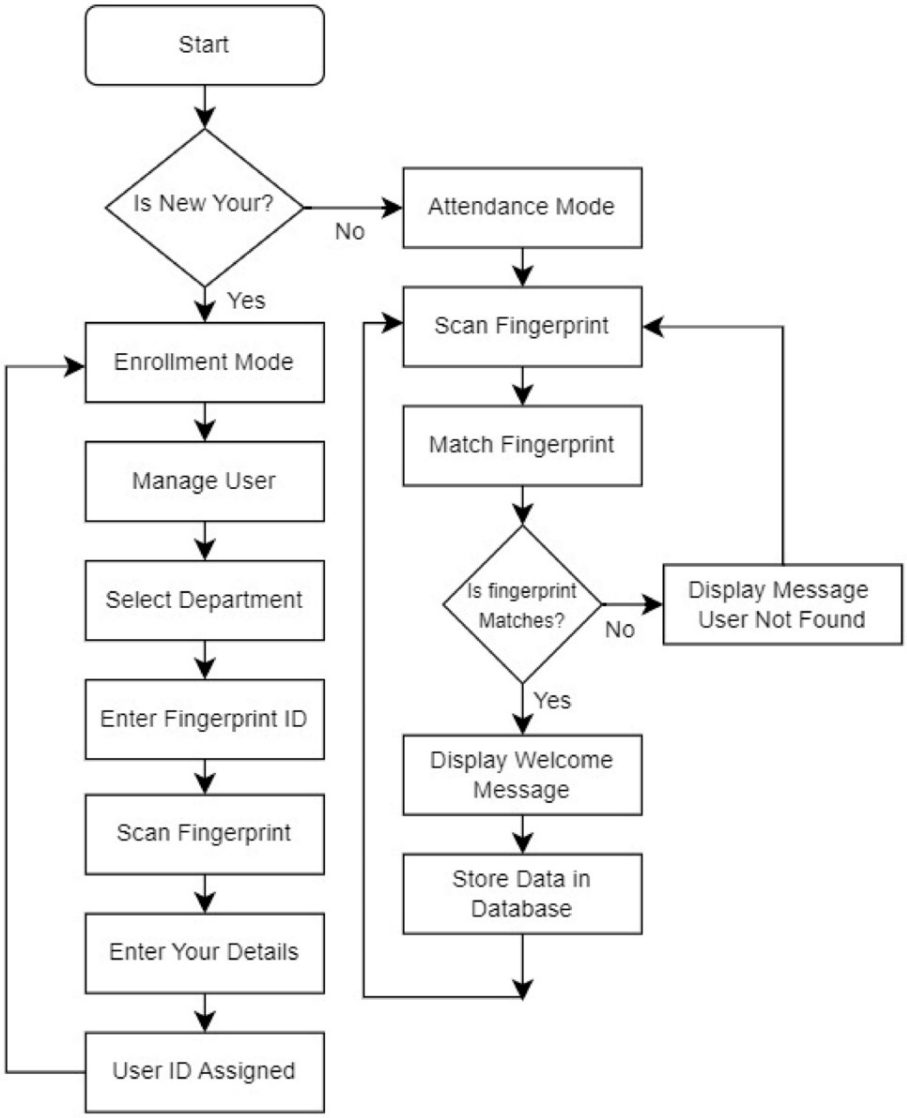

FIGURE 5: Flowchart of the proposed system workflow

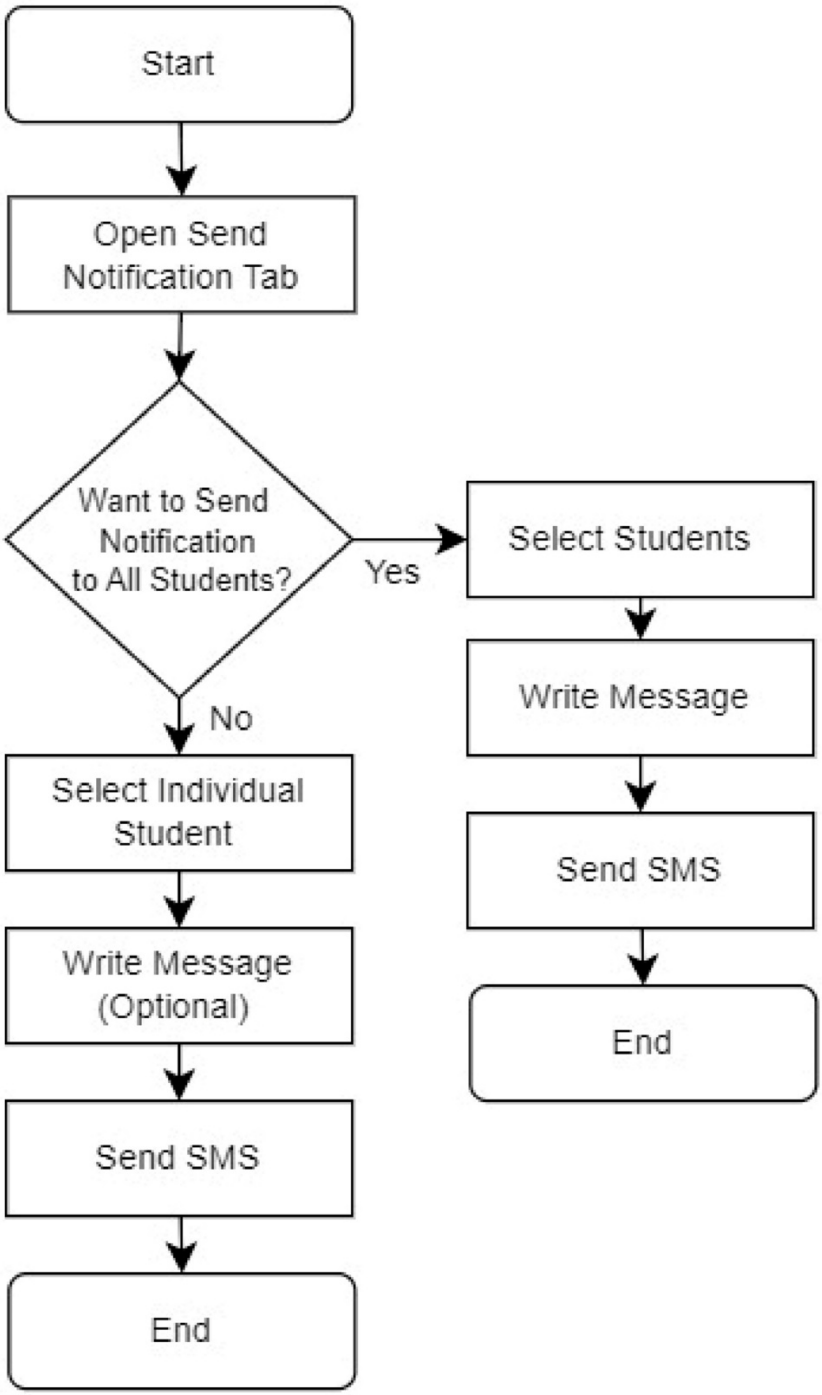

FIGURE 6: Flowchart of SMS sending procedure

Results

This system aims to automate portable attendance tracking using biometric identification via fingerprint scanning. The ESP32 microcontroller serves as the main controller, interfacing with the R307 fingerprint sensor to capture and verify fingerprint data. Upon successful verification, the attendance data is sent to a centralized database hosted on a local server using XAMPP. The attendance records can then be accessed and managed through a web-based interface.

The proposed system was tested using a sample of 20 students over 7 days. Out of the 20 students, only 18 were registered in the system, while the remaining 2 were non-registered students. It was found that both the false acceptance rate and false rejection rate were zero, indicating that the proposed system achieved 100% accuracy.

Table 2 shows a comparison of the proposed method with other existing methods with respect to authentication method, accuracy, SMS facility, and system portability. From the analysis, it is found that the proposed method achieves 100% accuracy, with SMS sending facility and portability, which are not available in the other methods.

Authentication Method	Accuracy	SMS Facility	Portability	Study
RFID and face recognition based	99%	No	Non-portable	[1]
Passive RFID tags and frequency distribution algorithm	92%	No	Non-portable	[15]
Face recognition using deep learning	95.85%	No	Non-portable	[13]
Mobile-based face recognition	95.8%	No	Portable	[9]
Finger print based	100%	Yes	Portable	Proposed system

TABLE 2: Comparison of the proposed method with other existing methods

Figures 7-11 show the visual appearance of the user login page, user registration page, administrator page, notification page for sending SMS, and the front view of the developed portable SAS, respectively.

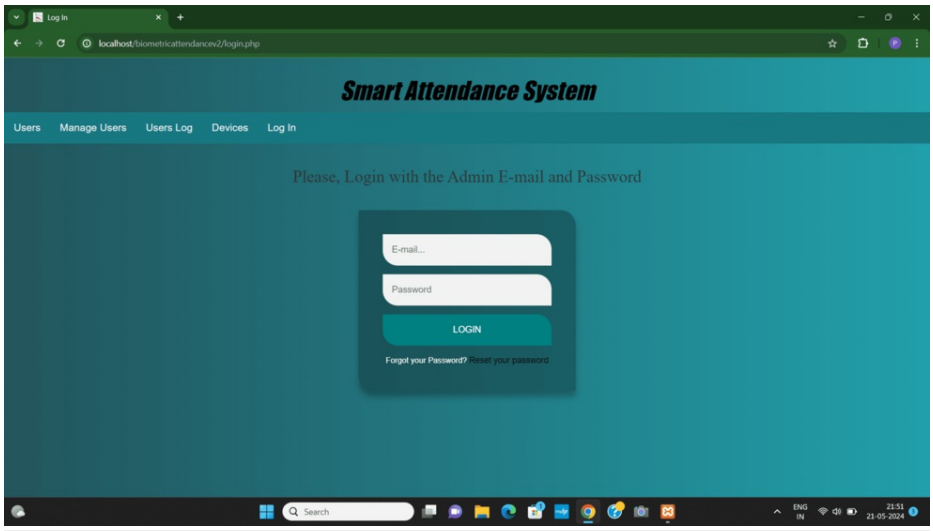

FIGURE 7: User login page

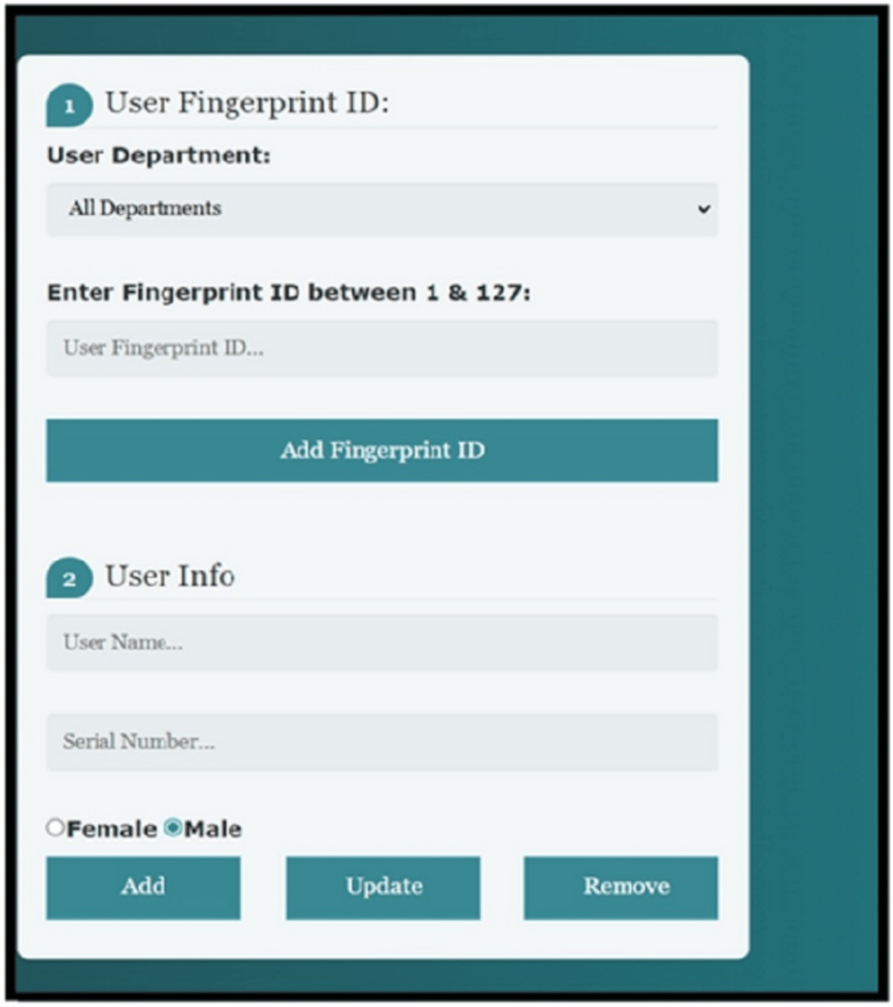

FIGURE 8: User registration page

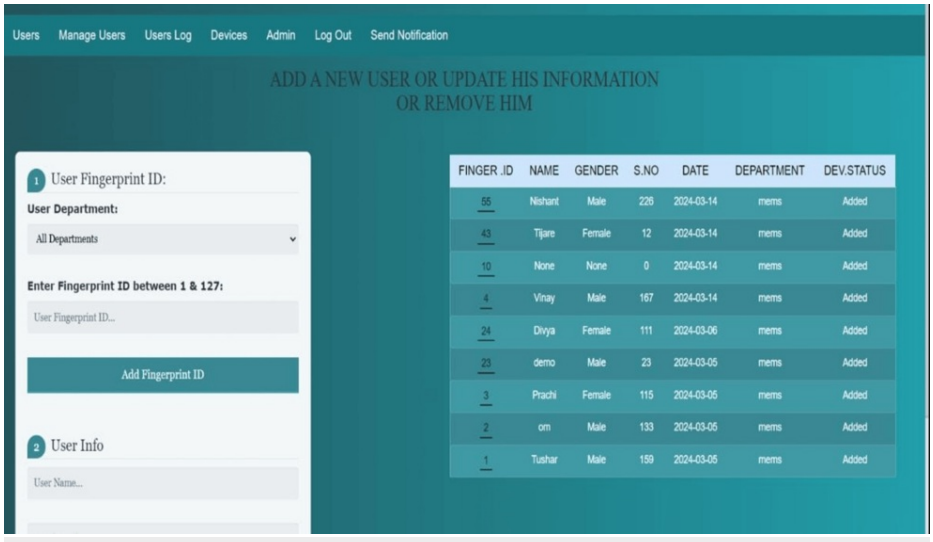

FIGURE 9: Administrator page

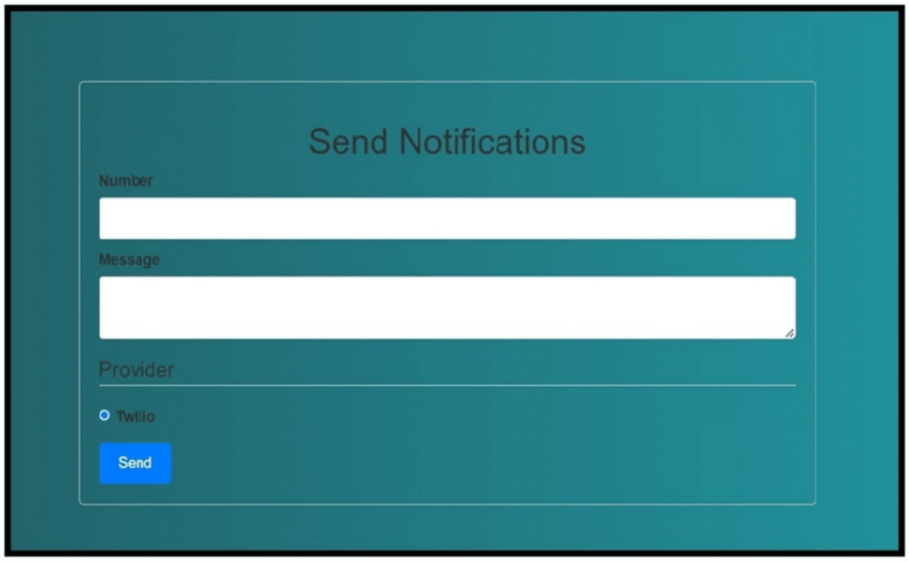

FIGURE 10: Notification page

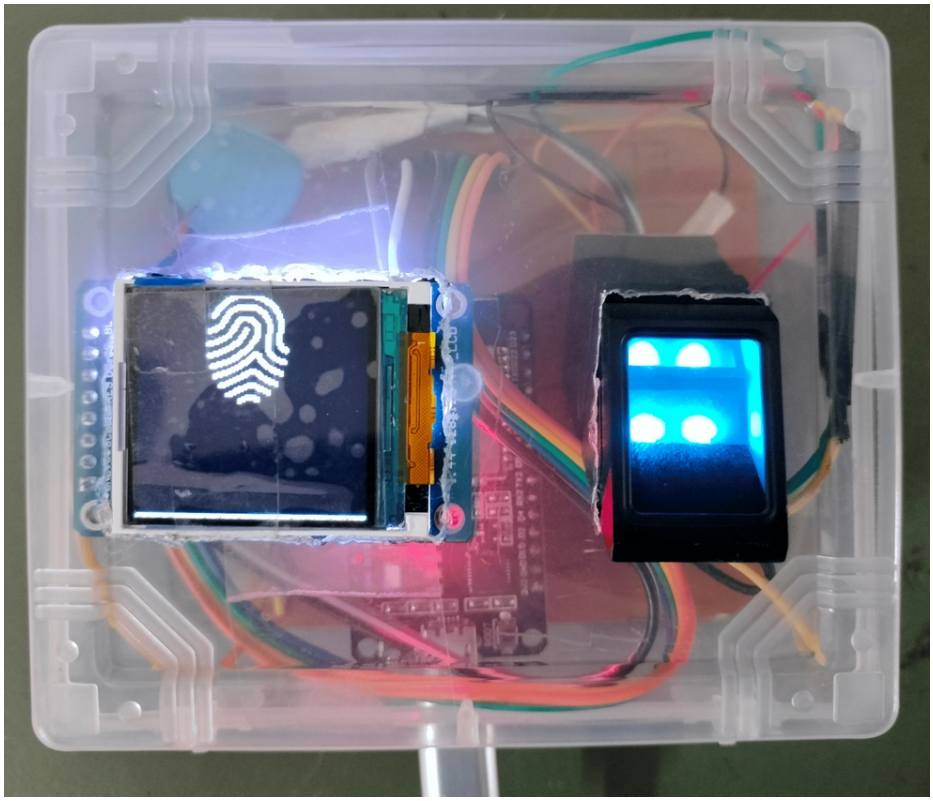

FIGURE 11: Front view of the developed portable smart attendance system

Discussion

In the proposed system, a fingerprint sensor is used instead of face biometric identification due to the following advantages: 1) fingerprint sensors generally provide higher accuracy rates compared to face recognition sensors [1], 2) fingerprint authentication tends to be faster than face recognition, 3) fingerprint

sensors are generally more resilient to environmental factors such as dust, dirt, and moisture than face recognition sensors, 4) fingerprint authentication has been widely adopted and accepted by users for several years, and 5) human fingerprints are persistent.

The ESP32 and NodeMCU are both popular microcontroller platforms used in IoT and embedded projects. In the proposed system, the ESP32 is used because of its advantages over others, such as 1) it has various low-power modes, allowing it to conserve energy and extend battery life in battery-powered applications, 2) it features a dual-core Tensilica LX6 processor, offering better multitasking capabilities and performance compared to the single-core processor in the NodeMCU, 3) it provides more GPIO pins compared to the NodeMCU, 4) it operates at higher clock speeds, up to 240 MHz, compared to the NodeMCU, which typically operates at 80 MHz, and 5) it includes built-in security features such as secure boot, flash encryption, and cryptographic hardware acceleration, providing improved security for IoT applications compared to the NodeMCU.

XAMPP is used in the proposed system for the development and deployment of web servers and web applications. The advantages of using XAMPP to develop a server are as follows: 1) it is compatible with multiple operating systems, such as Windows, macOS, and Linux, 2) it bundles together essential server components, such as Apache (web server), MySQL (database management system), PHP (server-side scripting language), and Perl, simplifying the setup process and ensuring compatibility between components, 3) it enables developers to create and test web applications locally on their computers before deploying them to a production server, 4) it facilitates rapid development and debugging without the need for an internet connection, and 5) it is distributed under an open-source license, making it free to download, use, and modify.

In the proposed system, Twilio is used instead of a GSM module for sending SMS to parents. Twilio offers numerous advantages over traditional GSM modules, including scalability, reliability, ease of integration, feature-rich APIs, flexibility, and cost-effectiveness.

Conclusions

The proposed portable attendance tracking system utilizes biometric identification through fingerprint scanning for automation. The ESP32 microcontroller, interfacing with the R307 fingerprint sensor, captures and verifies fingerprint data. Upon successful verification, attendance records are transmitted to a centralized database hosted on a local server using XAMPP, accessible via a web-based interface. Fingerprint sensors are chosen over face recognition due to their higher accuracy, speed, durability, user acceptance, and persistence. The ESP32 is preferred over NodeMCU for its low-power modes, dual-core processor, GPIO count, clock speed, and built-in security. XAMPP aids web server and app development with cross-platform compatibility, bundled essential components, local testing, and open-source accessibility. Twilio replaces GSM modules for SMS to parents, offering scalability, reliability, integration ease, feature-rich APIs, flexibility, and cost-effectiveness. This integrated approach optimizes attendance management while leveraging the strengths of each component. With the help of biometric verification, real-time notifications, and an easy-to-use user interface, this technology facilitates smooth communication between schools/colleges and parents while guaranteeing precise attendance tracking. This technology represents a substantial breakthrough in attendance tracking as it improves security measures, operational efficiency, accountability, and transparency. It offers organizations a dependable, effective, and user-friendly solution that is customized to meet their needs. The proposed system was field-tested on 20 students over a 7-day period, and a 100% accuracy rate was attained. It is interesting to investigate how system will work if internet connection is terminated for some time.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

Concept and design: Vishal V. Panchbhai, Prachi D. Tijare

Acquisition, analysis, or interpretation of data: Vishal V. Panchbhai, Om D. Waghmare, Mahesh H. Bhoyar, Vinay Patle

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Supervision: Vishal V. Panchbhai

Critical review of the manuscript for important intellectual content: Om D. Waghmare, Mahesh H. Bhoyar, Vinay Patle

Disclosures

Human subjects: All authors have confirmed that this study did not involve human participants or tissue. **Animal subjects:** All authors have confirmed that this study did not involve animal subjects or tissue. **Conflicts of interest:** In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

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