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Portable Biometric Attendance Management System Using ESP32

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Abstract:
This paper presents a compact and portable biometric attendance system built on the ESP32 microcontroller platform. The system incorporates a DY50 fingerprint sensor and an OLED display for user interaction, operating in two distinct modes: enrollment and attendance. Designed for mobility, the device is battery-powered and rechargeable, eliminating dependency on fixed infrastructure. Attendance records are securely stored in a MySQL database hosted on XAMPP via Wi-Fi connectivity. This project aims to offer a reliable and tamper-proof solution to traditional attendance methods, suitable for field operations, educational settings, and temporary installations.

1. Introduction
Traditional attendance systems often rely on manual entry or RFID technologies, which are prone to errors, proxy attendance, and lack mobility. The integration of biometric systems improves accuracy, but most solutions require stationary setups. This project introduces a portable and standalone biometric attendance system that utilizes the ESP32 microcontroller, a DY50 fingerprint module, and an OLED display for ease of use. With built-in battery support and Wi-Fi-based database connectivity, it can be deployed in dynamic or remote environments.

2. Problem Definition
Accurate and secure attendance tracking is a persistent challenge across various sectors, especially in educational institutions, construction sites, field teams, and temporary or mobile workspaces. Conventional attendance methods, such as manual roll calls or RFID card systems, are not only time-consuming but also vulnerable to manipulation and proxy attendance. Additionally, these systems often depend on fixed infrastructure like computers, power sources, and LAN networks, limiting their usability in remote or dynamic environments.
There is a growing demand for a solution that is not only reliable and tamper-proof but also portable, easy to use, and independent of constant power or wired network connections. This research addresses the need for a compact, biometric-based attendance system that operates efficiently on limited hardware, ensures data security, and is capable of functioning in real-time via wireless communication. The proposed system intends to fill this gap by introducing a self-contained, battery-operated device that uses fingerprint recognition to manage attendance data and store it securely in an online database through local server integration.

3. Objectives
The primary objective of this project is to design and develop a portable biometric attendance management system using the ESP32 microcontroller that addresses the limitations of traditional attendance systems.

The system is expected to provide a seamless, accurate, and secure way to record and manage attendance data in real-time.

Key objectives include:

- To implement a fingerprint-based authentication mechanism using the DY50 sensor for secure user identification.
- To build a compact and battery-powered device capable of functioning without dependence on fixed infrastructure.
- To develop two operational modes: one for enrolling new users and the other for logging attendance.
- To integrate an OLED display for user feedback and status display.
- To connect the system wirelessly to a local MySQL database hosted on XAMPP for storage and management of attendance data.
- To ensure the system is cost-effective, user-friendly, and deployable in a variety of field and institutional settings.

4. Methodology

The development of the portable biometric attendance management system was carried out through a structured and modular approach. The methodology involved both hardware and software integration, with an emphasis on portability, reliability, and user-friendly interaction.

4.1 Hardware Design:

At the core of the system is the ESP32 microcontroller, chosen for its dual-core processing capability, built-in Wi-Fi, low power consumption, and compatibility with IoT applications. The DY50 fingerprint sensor is used for capturing biometric data, as it provides reliable fingerprint recognition with onboard storage capabilities. An OLED display (typically 0.96-inch I²C-based) was incorporated to display prompts, status messages, and feedback to the user in real-time.

To ensure portability, the system is powered by a rechargeable lithium-ion battery, with a charging module integrated into the circuit. The compact design of the components allows the device to be handheld or mounted in mobile setups.

4.2 Software Development:

The firmware for the ESP32 was developed using the Arduino IDE, leveraging libraries for fingerprint scanning, OLED display management, and Wi-Fi communication. The system is programmed to operate in two modes:

- Enrollment Mode: New fingerprints can be registered through the sensor. Once a fingerprint is successfully enrolled, the data (including a unique ID and timestamp) is transmitted via Wi-Fi and stored in a MySQL database hosted on XAMPP.
- Attendance Mode: When a user places their finger on the sensor, the system matches it against enrolled fingerprints. If a match is found, it records the user's ID and timestamp in the database, and a confirmation message is shown on the OLED display. Failed attempts also generate feedback.

The ESP32 communicates with the MySQL database over Wi-Fi using HTTP or TCP protocols through a PHP script hosted on the local XAMPP server. This allows the system to store and retrieve data without needing external cloud services, ensuring low cost and offline operability when needed.

4.3 Database and Server Integration:

The backend database is created using MySQL, and the server is managed using XAMPP, which bundles Apache, MySQL, and PHP in one environment. A set of PHP scripts handles data insertion, retrieval, and user validation. The database includes tables for enrolled users and attendance logs, each entry timestamped and associated with a fingerprint ID.

5. Implementation.

By integrating hardware components and software modules, the portable biometric attendance system was developed into a functional prototype. During various stages, the system was tested extensively to ensure it met the design objectives of portability and reliability as well as accuracy.

5.1. Hardware Setup:

The system is based on the following:
- ESP32.
The Dev Board functions as the primary controller, handling data processing, fingerprint sensor interfacing, Wi-Fi communication, and display updates.
- DY50.
Fingerprint Detector: Used for taking photographs and verifying fingerprint data. It communicates with the ESP32 via UART serial communication.
The OLED Display (0.96 " I2C) offers user feedback for fingerprint scans, displaying messages such as "Place Finger," "Matched," and "Unmatched," along with the words "Saved."
The device's Lithium-ion Battery (18650 or 3.7V pack) provides energy and can be charged using the onboard TP4056 charging module.
All components were combined in a custom case to make the system easy to carry and transport.

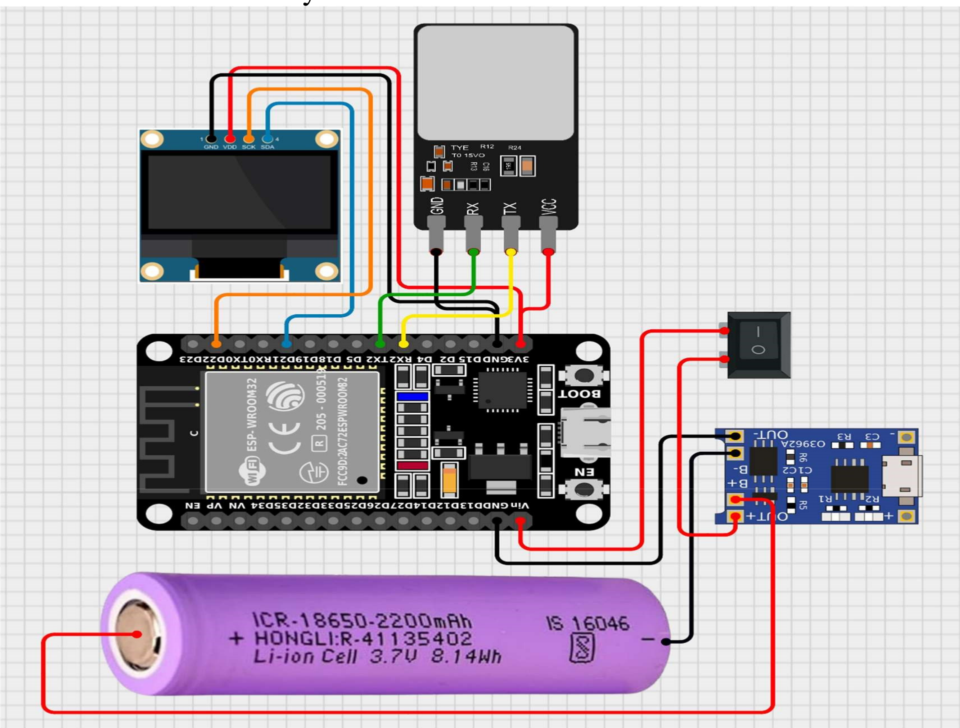
5.2. Software and System Logic:

The software was created using the Arduino IDE and comprises various libraries:
To connect with the DY50 sensor, use Adafruit_Fingerprint instead.
Adafruit_SSD1306 and Adalfruit GFX controllers are utilized to manage the OLED display. Additionally,
The use of WiFi.h and HTTPClient.j enables communication between the XAMPP server and the network.
The firmware workflow comprises of the subsequent stages:
A pre-established Wi-Fi network is connected to the system when it starts up on its initial startup.
Users are prompted to select their enrollment or attendance mode by using buttons or a toggle.
The system sends the user ID to the database and in Enrollment Mode, it creates a new template fingerprint on the DY50's onboard memory. This is done automatically.
A scanned fingerprint is linked to saved templates in Attendance Mode.
When matching, a log of attendance (with ID and timestamp) is sent to the server stored in the MySQL database on XAMPP.
The XAMPP server handle contains PHP scripts:
- Compiling fresh records into the tables of registered users and attendance statistics.
Online attendance records for easy retrieval.

5.3. Testing and Deployment:

It was tested in a controlled environment with multiple registered fingerprints. Successive attendance logging, the rejection of unregistered fingerprints, and the prevention of duplicate entries within a specified period are among the test cases.
Results showed:
- Relatively accurate fingerprint identification.
- Quick processing and recording (within 2-3 seconds).

Guaranteed stable battery life of 5+ hours.



Connections:

1. ESP32. Board Pin Connections.

Fingerprint Sensor (DY50 or similar)

ESP32 Can Connect a Fingerprint Sensor Pin.
VCC 3V3.
GND GND.
TX D2 (GPIO4)
RX D3 (GPIO0)
The TX sensor of ESP32 is connected to the receiver by way of reverse.

OLED Display (I2C - SSD1306. 128x64)

OLED Pin Connected To ESP32. Pin.
GND GND.
VCC 3V3.
SCL D1 (GPIO22)
SDA D2 (GPIO21)
Check if your OLED can be used with the I2C address of 0x3C. Note:

2. Power System.

Slide Switch.

The TP4056 module input is connected to the Battery (+)
The circuit is turned ON or OFF by hand.
TP4056. Charging Module (with protection)
TP4056. Pin Connection.
B+ Battery with a red wire from 18650

A black wire from 18650 can be used to charge a B- Battery.
OUT+ ESP32. 3V3 input (via switch)
OUT- ESP32. GND.
The TP4056 is capable of charging the 18650 battery and driving the ESP32 through its output terminals.

3. 18650. Li-ion Battery.
Battery Terminal Connected To.
Positive (+) B+ on TP4056.
Battery Terminal Connected To.
Negative (–) B– on TP4056.

Power Notes.
The ESP32 is powered directly by the TP4056, which provides between 3.7 and 4.2V output. This is advantageous.
To prevent a battery from over-charging, use TP4056 module that is protected.

6. Future Enhancements.
The portable biometric attendance management system's core objectives are achieved through its portability, biometry accuracy, and real-time data logging, but there is room for future improvements and user experience enhancements.

6.1. Integration of Mobile and Web Dashboards:
Afterwards, the next iteration could feature either a mobile app or e-commerce web dashboard that permits administrators to view attendance data anywhere, anytime, anywhere for future export and management. This would eliminate the need for the local XAMPP server and make the system more accessible for remote monitoring.

6.2. Offline Data Storage and Syncing:
Offline data caching could be used to improve performance in areas that are not accessible to Wi-Fi. Onboard memory or an SD card can be used by the ESP32 to temporarily store attendance logs, which can then be synced with the database after reconnecting Wi-Fi.

6.3. Enhanced Security Features:
The addition of security features like fingerprint encryption during transmission and secure authentication mechanisms (such as password-protected admin access) can enhance security. The outcome would be more personal information and a checkbox, which would prevent any unintentional changes to the system.
6.4. Battery Optimization and Solar Charging:
Even though the current battery provides enough backup, future versions may incorporate a power management system for improved energy efficiency and solar charging modules to make it more practical in outdoor or remote areas.

6.5. Development of facial recognition or multi-modal biometrics:
A camera module or combination of both with RFID or keypad-based verification could be used to expand the system's functionality and improve its compatibility with user authentication, while also improving its ability to recognize facial recognition and other user preferences and security measures.

6.6. Scalability for Larger Organizations:

At present, the system is geared towards small to medium-sized groups, but it can be expanded to accommodate numerous users through the use of a unified cloud server and database, making it suitable for educational institutions, government agencies, or large corporations.

6.7. Real-time Notifications and Alerts:

The system may be configured to send SMS or email alerts to supervisors or administrators when a user is not attending. How this functionality is used? Real-time monitoring and accountability could be improved by this.

7. Conclusion

This research presents a practical and efficient solution for managing attendance through a portable biometric system built on the ESP32 microcontroller. By combining fingerprint recognition using the DY50 sensor with a user-friendly OLED interface and rechargeable battery support, the system achieves both mobility and security — making it suitable for dynamic and decentralized environments.

The implementation demonstrates that a low-cost, standalone device can effectively eliminate issues such as proxy attendance, manual errors, and infrastructure dependency. With seamless integration to a local MySQL database via XAMPP, the system ensures real-time data logging and provides a reliable digital attendance trail.

Beyond its current capabilities, the system holds promise for further advancements, including mobile connectivity, cloud integration, and enhanced user interfaces. Its modular architecture makes it adaptable to various domains like schools, construction sites, NGOs, and even disaster relief operations.

In conclusion, the project successfully bridges the gap between traditional attendance systems and modern, IoT-based biometric solutions. It sets a foundation for future research in portable identity verification systems that are affordable, scalable, and ready for deployment in real-world scenarios.

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