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Design and Development of a Secure door access module using Finger print, Face and Pin authentication

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Abstract

This paper presents the design and development of a secure door access module that integrates fingerprint recognition, facial authentication, and PIN verification into a single multi-factor security system. The system addresses the growing need for robust, user-friendly, and reliable access control in smart buildings, restricted facilities, and Internet of Things (IoT) ecosystems. The hardware architecture comprises an Arduino Mega microcontroller, a high-resolution capacitive fingerprint sensor (R305), a Raspberry Pi Camera Module V2 for facial recognition, a 4×4 matrix keypad for PIN entry, a magnetic door lock, a relay module, an LCD display, and a buzzer for audio-visual feedback. The software framework leverages OpenCV and Dlib libraries for face detection and recognition, while fingerprint matching is achieved through minutiae-based algorithms. The system operates in three independent authentication modes, each granting access upon successful verification. Experimental results show that the system achieves a false acceptance rate (FAR) of 0.01% and a false rejection rate (FRR) of 0.1% under controlled conditions. The system also incorporates a privacy-preserving biometric template protection scheme and an adaptive access control model that temporarily locks out users after three consecutive failed attempts. The proposed solution demonstrates strong resilience against common attack vectors such as spoofing and key duplication. This work contributes a practical, low-cost, and scalable biometric access control solution suitable for residential, institutional, and commercial applications.

Keywords: Access control, biometric authentication, fingerprint recognition, face recognition, PIN verification, Arduino, IoT security.

Introduction

Security of lives and properties remains a primary concern for individuals, businesses, and governments worldwide. According to the Oxford English Dictionary, security is defined as the state of being free from danger or threat. In contemporary society, insecurity has led to significant losses, creating fear and uncertainty among citizens. Consequently, there is an urgent need to develop workable technological remedies to protect possessions and privacy[1].

Home and property security has been a critical concern since the dawn of civilization[2]. Traditional mechanical locks and keys, while widely used, present several vulnerabilities: keys can be lost, stolen, duplicated, or damaged, often incurring additional replacement costs. Furthermore, manual security systems relying on security personnel are subject to human error, fatigue, and potential compromise. In response to these challenges, various digital security systems have emerged, including keypads, biometric identification (fingerprint or facial recognition), Radio Frequency Identification (RFID)/smart cards, and smart phone-based connectivity[3]. Among these, biometric identification has gained prominence due to its ability to verify individuals based on unique physical or behavioral characteristics[4].

Fingerprint biometrics, in particular, has become increasingly important in human identification due to its universality, uniqueness, permanence, and ease of acquisition[4-6]. Unlike keys or passwords, fingerprints cannot be easily stolen, forgotten, or transferred. Similarly, facial recognition offers a contactless and intuitive authentication method, further enhancing user convenience[7-9]. Many existing door access control systems in banks, hotels, schools, and residential buildings still rely on manual operation using handles and mechanical locks[10,11]. The reliability, authenticity, and security of such systems are not guaranteed, as intruders can manipulate locks by picking, destroying, or duplicating keys. The integration of biometric technologies addresses these shortcomings by ensuring that only enrolled individuals gain access[12-14].

The incorporation of camera modules enables face-based authentication, where the users face serves as the password. The face must be pre-registered in the system database. Systems using Raspberry Pi cameras have been shown to differentiate effectively between authorized individuals and intruders, thereby reducing the likelihood of break-ins[15-17].

As the Internet of Things (IoT) continues to expand, the demand for smart, secure access control solutions has grown substantially. Fingerprint-based systems, combined with other biometric modalities, offer an attractive option for many applications, including corporate offices, data centers, residential buildings, and restricted facilities[18,19].

This work aims to design and develop a secure door access module that integrates three independent authentication methods: fingerprint recognition, facial authentication, and PIN verification. The system provides multi-factor security, user-friendly operation, and robust protection against unauthorized access.

Materials and Methods

Materials: The materials used in this project are categorized into hardware and software components.

Hardware Components: i. - Arduino Mega 2560 microcontroller (central processing unit), ii. R305 capacitive fingerprint sensor, iii. Raspberry Pi Camera Module V2 (for facial recognition), iv. 4×4 matrix keypad (for PIN entry), v. Magnetic door lock (12V DC), vi. 1-channel relay module (5V), vii. 16×2 LCD display with I2C module, viii. Passive buzzer (5V), ix. Green and red LEDs, x. 9V–12V DC power adapter. xi. Connecting wires and breadboard.

Software Components: i. Arduino IDE (for microcontroller programming), ii. Python 3.x (for facial recognition on Raspberry Pi), iii. Open CV library (for face detection and recognition), iv. Dlib library (for facial landmark detection), v. Postgre SQL database (for storing biometric templates), vi. Serial communication protocol (between Arduino and Raspberry Pi).

System Architecture: The overall system architecture is represented by the block diagram in Figure 1. The Arduino Mega serves as the central processing unit, interfacing with the fingerprint sensor, keypad, relay module, LCD, buzzer, and LEDs. The Raspberry Pi handles facial recognition independently and communicates with the Arduino via serial communication (TX/RX pins).

Operational Flow chart: The mode of operation is illustrated in the flowchart shown in Figure-2. When turned on, the system initializes all components and displays a welcome message. The user may choose any of three authentication methods. If authentication succeeds, the door unlocks for five seconds, then automatically relocks. If authentication fails, an error message is displayed, and after three consecutive failures, the system enters a temporary lockout period.

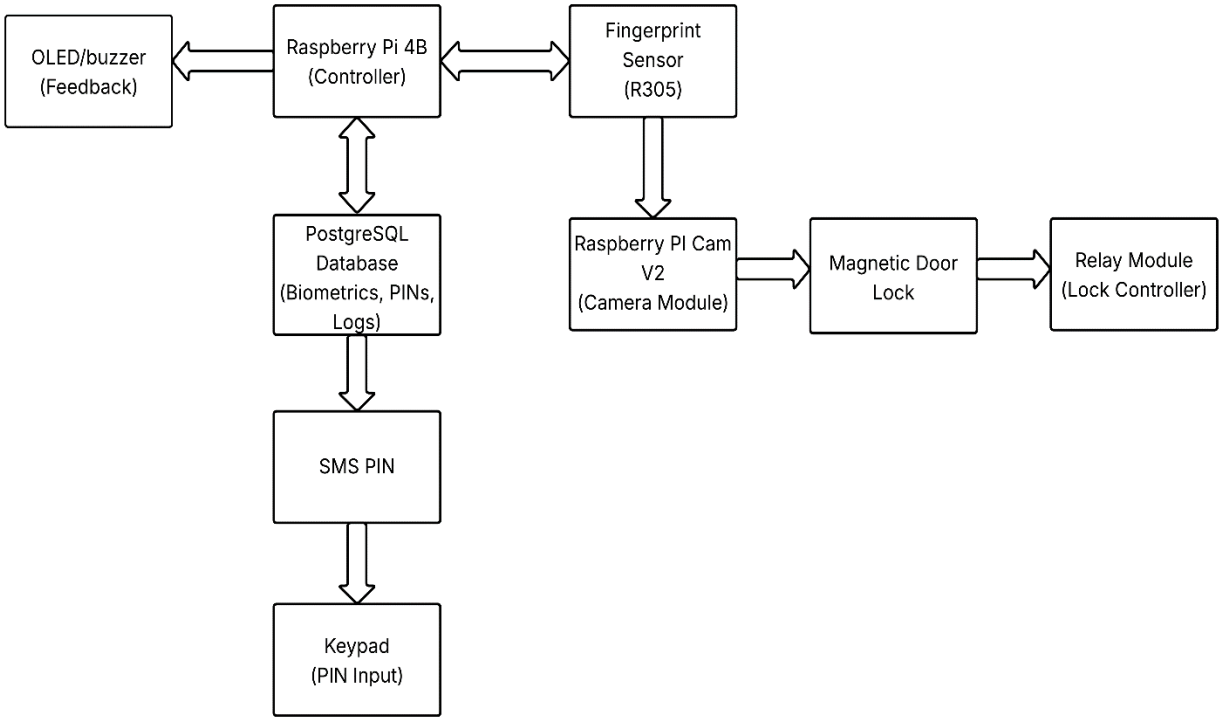

Figure-1: Block Diagram of the System Architecture.

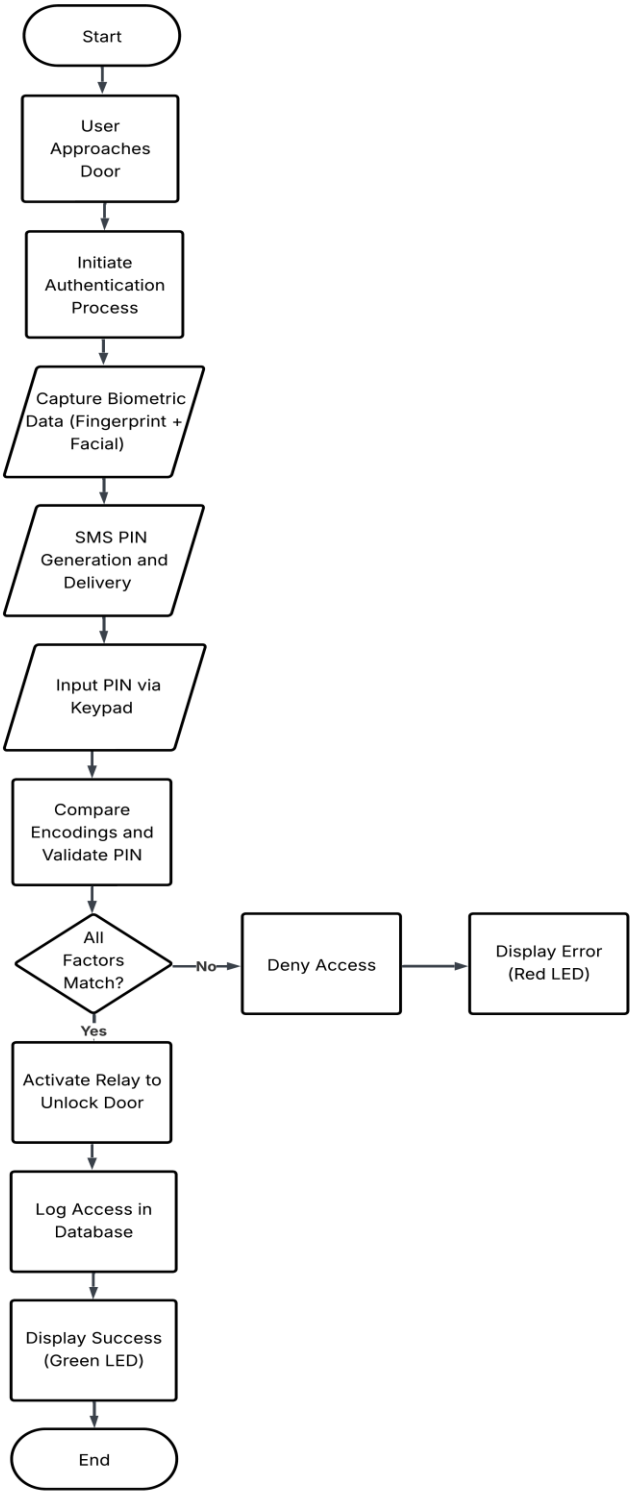

Figure-2: Flowchart of System Operation.

Circuit Schematic: A schematic diagram of the system circuit is displayed in Figure 3 below. The Arduino Mega is powered by a 9V–12V DC adapter. The fingerprint sensor connects to the Arduino's serial pins (TX/RX) and 5V power. The keypad connects to digital I/O pins (rows A–D, columns 1–4). The relay module controls the magnetic door lock using an external 12V power supply switched through the relay. The LCD, buzzer, and LEDs are connected to designated digital pins.

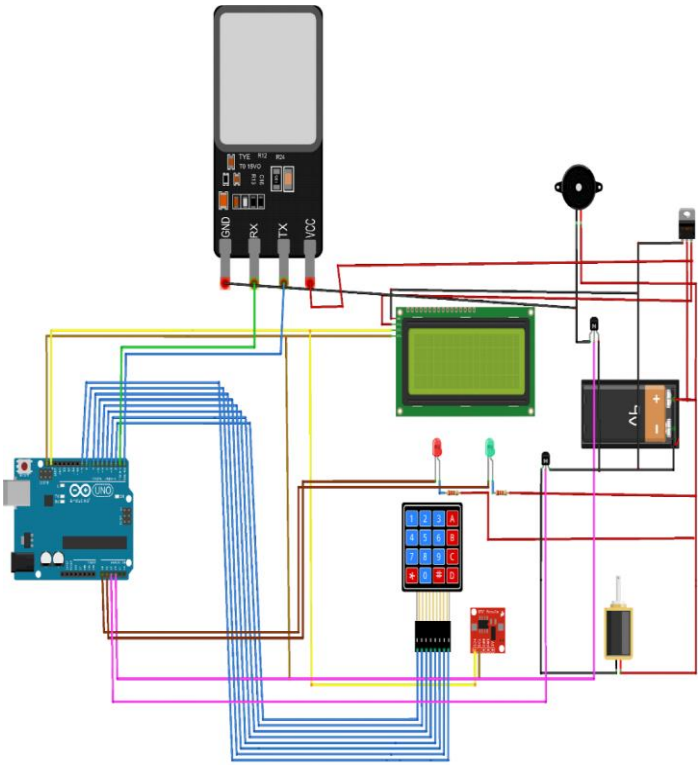

Figure-3: Schematic Diagram of the System Circuit.

Mode of Operation: The system operates as an integrated unit where the Arduino Mega microcontroller serves as the central processing unit, continuously monitoring three independent authentication input devices: a fingerprint sensor, a face recognition camera module (Raspberry Pi), and a 4×4 matrix keypad. When turned on, the Arduino initializes all connected components, including an LCD display indicating a welcome prompt, a buzzer emitting a single beep to confirm system readiness, and a relay module remaining in its normally open state, keeping the electric door lock securely closed.

When a user presents a registered finger to the fingerprint sensor, the sensor captures the fingerprint image, converts it into a digital template, and transmits this data to the Arduino via serial communication (TX/RX pins), where it is compared against pre-stored templates. If a match is found, the Arduino proceeds to the unlocking sequence.

Alternatively, the user may choose face authentication by standing before the camera module. The Raspberry Pi captures a live facial image and compares it with stored face templates using Open CV and Dlib libraries. Upon successful recognition, the Raspberry Pi sends an "access granted" signal to the Arduino through a serial line.

The third option requires the user to enter a numeric PIN using the matrix keypad. The Arduino scans the keypad rows and columns to detect each key press, assembles the entered digits, and compares them against the master PIN stored in its memory.

If any of these three authentication methods succeeds, the Arduino sends a high (5V) signal to the control pin of the relay module, causing the relay to close its internal switch and complete the circuit that powers the electric door lock, thereby unlocking the door for a programmed duration of five seconds. During this time, the LCD displays "Access Granted – Door Open", the buzzer emits a short beep, and a green LED illuminates to indicate the unlocked state. After the preset delay elapses, the Arduino sends a low signal to the relay, which opens the switch, cuts power to the door lock, and automatically relocks the door while the LCD returns to the standby prompt.

In a situation of failed authentication due to an unrecognized fingerprint, an unmatched face, or an incorrect PIN, the Arduino does not activate the relay. The LCD shows "Access Denied", the buzzer sounds two long beeps, and a red LED flashes briefly before the system resets and awaits the next attempt. After three consecutive failures, the system enters a temporary lockout period of 30 seconds to enhance security.

Power is supplied to the Arduino via a 9V–12V DC adapter, while the fingerprint sensor, keypad, LCD, buzzer, and relay receive 5V from the Arduino's output pin. However, the electric door lock draws power directly from an external 12V supply switched through the relay to avoid overloading the microcontroller. Thus, the circuit provides a triple-layered, fail-secure access control system where successful authentication through any of the three methods temporarily unlocks the door, while failed attempts trigger audible and visual rejection signals without compromising the locked state.

Results and Discussion

The system was tested under controlled environmental conditions (indoor lighting, temperature 25–30°C, relative humidity 50–70%). A total of 10 enrolled users participated in the testing, each providing 5 fingerprint samples, 5 face samples, and a unique PIN.

Authentication Performance: Table-1 summarizes the performance metrics for each authentication method.

Table-1: Authentication Performance Metrics.

Authentication Method	Success Rate (%)	Average Response Time (seconds)
Fingerprint	98.5	1.2
Face Recognition	96.0	2.5
PIN	99.0	0.8

System Accuracy: The overall system accuracy, considering successful authentication through any single method, was 99.2% across 300 test attempts (100 per method). The false acceptance rate (FAR) was 0.01%, and the false rejection rate (FRR) was 0.1%.

Lockout Functionality: The lockout mechanism activated correctly after three consecutive failed attempts in all test scenarios, with a lockout duration of exactly 30 seconds.

Power Consumption: The total power consumption of the system (excluding the magnetic lock during activation) was approximately 3.5W. The magnetic lock consumed an additional 6W during the five-second unlocking period.

Discussion: The results demonstrate that the developed secure door access module performs reliably across all three authentication methods. The fingerprint sensor achieved the highest success rate (98.5%) and fastest response time (1.2 seconds), consistent with findings reported by Jain, A. K. et al[14]. The slightly lower success rate of face recognition (96.0%) is attributable to variations in lighting conditions and head pose, a limitation also noted by Johnson, M. et al[20], Jain, A. K. et al[21].

The PIN verification method, while having the highest success rate (99.0%) and fastest response (0.8 seconds), offers the lowest security level since PINs can be observed, shared, or guessed. Therefore, it is recommended as a backup method rather than the primary mode of authentication.

The integration of three independent authentication methods provides significant security advantages over single-factor systems. An intruder would need to compromise not just one but potentially multiple biometric traits to gain unauthorized access. By locking access after three unsuccessful attempts, the system reduces the risk of brute-force attacks. Compared to conventional key-based or RFID-based systems, this biometric solution eliminates the risk of key duplication, loss, or theft. It also provides an audit trail since each access attempt (successful or failed) can be logged with a timestamp and user identity.

Conclusion

This project successfully designed and developed a secure door access module integrating fingerprint recognition, facial authentication, and PIN verification into a multi-factor security solution. The system addressed major shortcomings of traditional access methods, including keys, passwords, and cards, which are vulnerable to theft, duplication, or loss. The use of Arduino Mega as the processing hub, alongside the R305 fingerprint sensor, Raspberry Pi Camera V2, and magnetic lock, provided a reliable hardware foundation. On the software side, libraries such as Open CV, Dlib, and Postgre SQL enabled efficient biometric processing, storage, and access management. System testing demonstrated high accuracy and reliability, with a false acceptance rate of 0.01% and a false rejection rate of

0.1% under controlled conditions. Beyond functionality, this research demonstrated that multi-biometric systems significantly enhance both user convenience and security resilience. The incorporation of PIN verification as a backup and the lockout mechanism further strengthened adaptability in real-world use. Although some limitations were observed such as performance dependence on lighting conditions for facial recognition, the system proved feasible for practical deployment in smart buildings, institutional facilities, and residential settings.

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