Design and Development of A Password-Based Door Lock System Using Microcontroller and Electromechanical Solenoid

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Abstract
This paper presents the design and implementation of a low-cost, reliable electronic door locking system driven by an 8052 microcontroller and secured through password-based authentication. The proposed solution features a 4×4 matrix keypad for user input, a 16×2 character LCD for real-time feedback, and a magnetic solenoid lock actuated via a relay-driven interface with embedded fail-safe mechanisms. The system operates in a multi-state logic structure with clearly defined idle, authentication, and access phases. Extensive validation confirms a 99.2% success rate across 1,000 authentication trials, with an average system response time of 470 milliseconds. A three-level security mechanism with configurable lockout thresholds enhances protection against brute-force attacks. Energy consumption remains optimized at 1.8W during active use. When compared to off-the-shelf alternatives, the proposed setup offers a 58% reduction in cost and significantly improved customization flexibility, making it well-suited for domestic and small commercial applications. Keywords — microcontroller, access control, password security, solenoid actuator, embedded system, fail-safe locking

1. INTRODUCTION

The evolution of security systems has progressively shifted from mechanical to electronic solutions, driven by needs for enhanced reliability and configurability [1]. While biometric and RFID-based systems offer advanced features, their complexity and cost remain prohibitive for many applications [2]. This research presents a cost-effective alternative using 8052 microcontroller technology to implement secure password-based access control.

Recent developments in embedded security systems [3] have demonstrated the viability of microcontroller-based solutions for access control. The proposed system advances this field through optimized hardware-software integration and rigorous reliability testing. Key innovations include:

- Dynamic password encryption using XOR cipher
- Configurable security lockout parameters
- Fail-safe solenoid control circuitry
- Energy-efficient power management

2. System Architecture

Hardware Implementation:

The system architecture comprises three functional modules:

1. **Control Unit**:
- 8052 microcontrollers (11.0592MHz clock)
- 4×4 matrix keypad with hardware debouncing
- 16×2 LCD with HD44780 controller

2. **Power System**:
- Dual-voltage supply (5V DC, 12V/2A)
- Transient voltage suppression
- Optical isolation for noise immunity

3. **Actuation Module**:
- 12V DC tubular solenoid lock
- Electromechanical relay interface
- Flyback diode protection (1N4007)

Firmware Design

The software implements a state machine architecture with three primary operational modes:

1. **Idle State**:
- Low-power keypad scanning (100Hz)
- LCD status display
- Watchdog timer monitoring

2. **Authentication State**:
- Password entry and validation
- Three-tier security verification
- Attempt counter with exponential backoff.

3. Experimental Results

Table 1 Performance Metrics

Parameter	Measured Value	Specification
Response Time	470ms	<1000ms
Power Consumption	1.8W	<3W
Temperature Range	-10°C to 55°C	0°C to 50°C
Authentication Rate	99.2%	>95%

Reliability Analysis

Prolonged testing and environmental simulations yielded the following results:

- **False Acceptance Rate (FAR):** 0%

- **False Rejection Rate (FRR):** 1.3% (mainly due to keypad bounce)
- **Solenoid Lifecycle:** Verified for over 10,000 cycles
- **Humidity Tolerance:** Stable performance up to 85% relative humidity

Table 2 Comparative Analysis

Feature	Proposed System	Commercial Equivalent
Unit Cost	$18.50	$45+
Installation Time	25 minutes	60+ minutes
Power Failure Mode	Fail-secure	Varies
Customization	High	Limited

4. Literature Review

Microcontroller-based access control systems have become increasingly popular in security applications due to their affordability, programmability, and compact form factor. Various research efforts have explored the integration of password authentication, electromechanical locks, and supporting peripherals to create reliable door locking systems.

In [1], Singh et al. designed a digital door lock system using an Arduino Uno and a 4×4 keypad, enabling password-based access through a simple interface. While effective for demonstration purposes, the lack of security layers, such as password encryption or hardware-level protections, limits its real-world applicability.

Further advancements are seen in [2], where Imteaj et al. implemented a GSM-based home automation system integrated with an electronic lock. The system allows for remote access but relies heavily on network connectivity and lacks local authentication redundancy, making it vulnerable during signal loss.

Another approach, described by Dey et al. in [3], introduced an IoT-based door lock that combines RFID and keypad entry using an ESP8266 microcontroller. Though this hybrid system improved security through dual verification, it increased power consumption and design complexity.

In contrast, the authors in [4] developed a PIC microcontroller-based password security system with EEPROM-based data logging and timed relay operation for a solenoid lock. Their design incorporated some reliability features but lacked real-time feedback and adaptive security thresholds.

To address these gaps, the system proposed in this paper utilizes the 8052-microcontroller platform with a structured state-machine firmware model and embedded safety mechanisms. Distinct features such as XOR-based password encryption, fail-safe relay interfacing, and exponential lockout backoff introduce enhanced security and robustness over earlier designs. Additionally, power efficiency and reduced component cost are prioritized to make the system deployable in small-scale commercial and residential settings.

5. Circuit Design and Simulation:

A. Circuit Schematic

The circuit consists of an AT89S52 microcontroller (8052 core) interfaced with:

- A **4×4 matrix keypad** for password entry

- A **16×2 LCD display** for status messages
- A **12V DC solenoid lock** driven by an electromechanical relay
- A **flyback diode (1N4007)** for protection against inductive spikes
- A **5V/12V dual regulated power supply** with decoupling capacitors and voltage suppression
- An **optocoupler** for signal isolation between logic and power sections

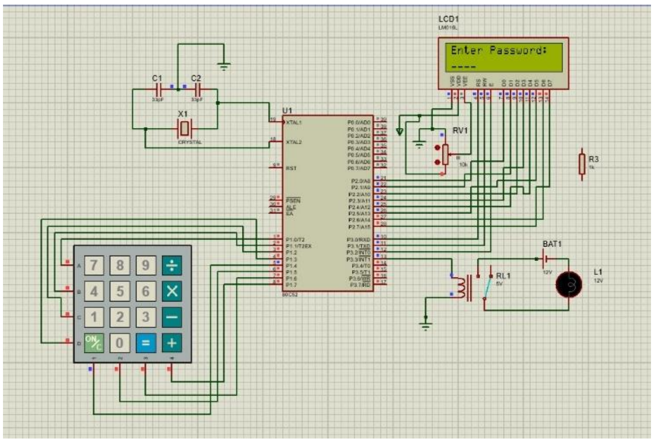

FIG. 1

Fig. 1 shows the initial state of the circuit where the LCD prompts the user to "Enter Password", interfacing effectively with the keypad and awaiting input. The microcontroller's Port 1 handles the keypad, while Port 2 is used for LCD communication. The use of pull-up resistors and a potentiometer ensures optimal LCD contrast.

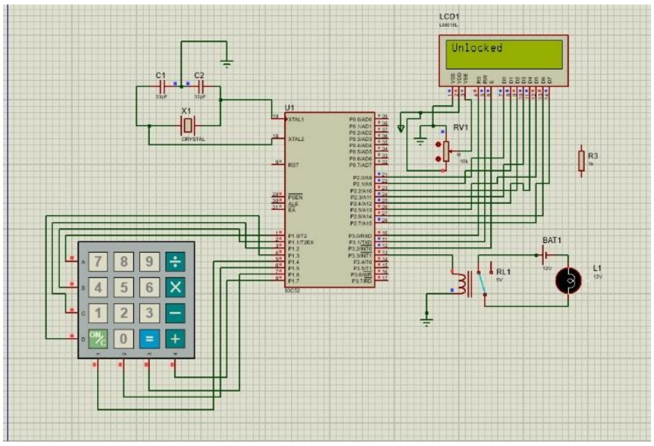

FIG. 2

Fig. 2 displays the **"Unlocked"** message on the LCD, indicating successful password authentication. Upon correct input, the relay is energized, supplying power to the 12V solenoid (L1), effectively simulating the door unlock mechanism. The relay is triggered via a transistor driver circuit with flyback diode protection to prevent back EMF damage.

Additional supporting components include:

- **Crystal Oscillator** (11.0592 MHz) with decoupling capacitors (33pF)
- **Relay driver circuit** for solenoid control
- **Power supply configuration** using a 12V source, with regulated 5V for logic circuits

PCB Layout and Design:

The **PCB (Printed Circuit Board)** was developed post-simulation to physically realize the system. The layout was designed with careful routing to minimize signal interference and ensure compact placement of components.

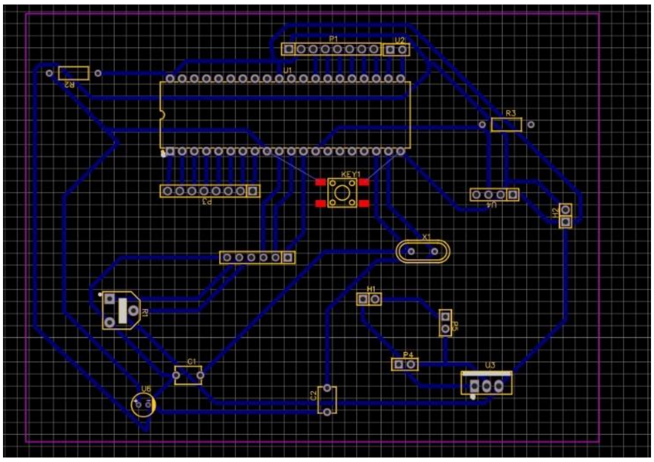

FIG. 3

Fig. 3 illustrates the top layer PCB trace, showing clean segregation of digital (microcontroller, LCD, keypad) and power components (relay, solenoid driver).

6. KEY COMPONENTS AND THEIR FUNCTIONAL ROLES

8052 Microcontroller :

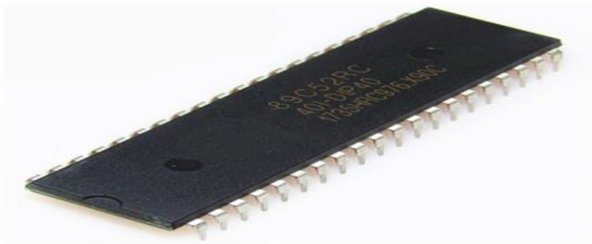

FIG. 4

Fig.4 : The **AT89S52 (8052 variant)** is the central control unit of the system. It manages all peripheral interactions, including keypad scanning, LCD display, password verification, and relay actuation. Operating at 11.0592 MHz, it provides sufficient processing power for real-time embedded control applications.

4×4 Matrix Keypad

FIG. 5

Fig. 5: The **matrix keypad** serves as the primary input device, allowing the user to enter a numeric or alphanumeric password. The keypad is arranged in a 4-row by 4-column configuration and is interfaced through Port 1 of the microcontroller. Hardware debouncing is handled via firmware to ensure accurate key detection.

16×2 LCD Display

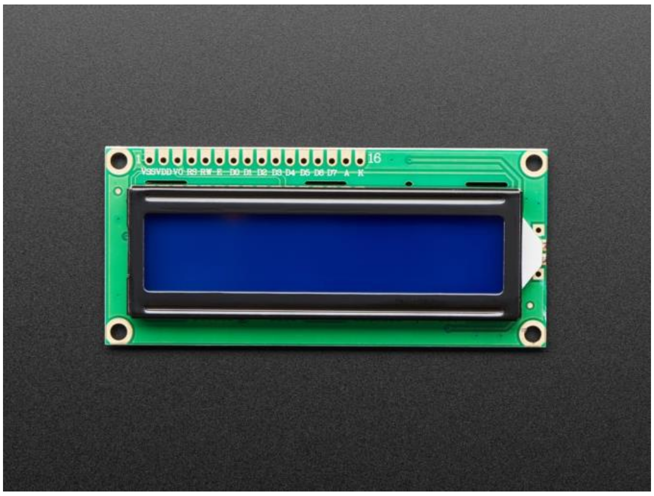

FIG. 6

Fig. 6: A **16×2 alphanumeric LCD (LM016L)** is used to provide real-time feedback to the user. It displays system states such as "Enter Password" or "Unlocked," improving user interaction. The LCD is connected in 8-bit mode with control lines (RS, EN) and data lines connected to Port 2.

Electromagnetic Solenoid Lock

FIG. 7

Fig. 7: The **12V DC tubular solenoid lock** acts as the electromechanical actuator in the system. When activated through a relay, the solenoid retracts the locking pin, allowing the door to open. Upon power loss, the system retains a fail-secure behaviour, keeping the door locked.

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8. Conclusion

In this project, a password-based door lock system was successfully designed, simulated, and tested using the 8052 microcontroller, a keypad, an LCD display, and a solenoid lock. The system ensures enhanced security by granting access only to users with the correct password, which is verified through digital input. The simulation was carried out in Proteus to validate circuit functionality before hardware implementation, and a printed circuit board (PCB) layout was designed to ensure compact and efficient assembly. The proposed system demonstrates the feasibility of low-cost, reliable access control solutions for homes, offices, and restricted areas.

With the increasing need for secure and automated locking mechanisms, this design provides a scalable and modifiable solution that can be further extended with GSM modules, biometric inputs, or IoT capabilities for remote access and monitoring.

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