

Smart Lock System for Optical Distribution Cabinet Using RFID and Hydraulic Mechanism

Lisda Asdianty, Uke Kurniawan Usman, Akhmad Hambali

Telkom University, Indonesia

Email: lisdaasdianty@student.telkomuniversity.ac.id, ukeusman@telkomuniversity.ac.id,
ahambali@telkomuniversity.ac.id

ARTICLE INFO		ABSTRACT
Keywords:	Optical Distribution Cabinet; Radio Frequency Identification; Smart Lock; Hydraulic Mechanism	Optical Distribution Cabinet (ODC) is a critical component in fiber optic network infrastructure, often located in public places and vulnerable to unauthorized access and vandalism. Traditional mechanical locking systems have limitations in terms of security and operational efficiency. This research presents a Radio Frequency Identification (RFID)-based smart lock system integrated with a hydraulic mechanism to improve security and access efficiency at ODCs. The system utilizes an Arduino Uno microcontroller as the main controller unit, MFRC522 RFID module for user authentication, a hydraulic actuator as the door opening mechanism, and status indicators in the form of buzzer and LED. When a valid RFID card is detected, the system activates the solenoid to unlock, and the hydraulic actuator automatically opens the ODC door. A green LED lights up to indicate access is accepted, while a red LED lights up and a buzzer sounds if access is denied. The test results show that the system is able to respond to RFID input with an optimal distance of up to 4 cm and successfully open the ODC door automatically using the hydraulic actuator. The implementation of this system is expected to replace conventional locking methods and improve operational efficiency in managing fiber optic network infrastructure.

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Introduction

Optical Distribution Cabinet (ODC) is one of the main components in fiber optic network infrastructure that functions as a termination point between feeder cables and distribution cables (Safrianti et al., 2018; Takai & Yamauchi, 2009). ODC is made of special material that contains connectors, splitters and connections. ODCs are usually used in passive optical access networks (PON) and are capable of supporting installations of up to 1.536 active customer connections (Asril et al., 2023). The existence of ODC has a very important role because it stores active optical connections that support the availability and quality of network services. However, research by Saputra (2022) identified that ODCs scattered in public areas are often the target of acts of vandalism and unauthorized access.

The use of conventional key systems has several disadvantages, such as less practical access because it takes time to enter the key. In addition, user negligence is also common, such as forgetting to put, leaving behind, or even losing the key (Wijaksana et al., 2019). To overcome these challenges, a more modern and efficient locking system is needed. This system should be able to limit access to authorized parties only, as well as increase efficiency in operations. With the development of technology, the implementation of electronic-based systems is a reliable alternative to replace conventional mechanical locking systems.

One innovation that can be applied is the use of a microcontroller-based automatic lock system. A microcontroller is a small computer packaged in the form of an IC (Integrated Circuit) chip that functions as a control center that can manage the user authentication process and control mechanical devices to open doors automatically (Junaedi et al., 2021). With this technology, the level of physical security can be increased, while making it easier for technicians to access devices in the field without having to use manual keys. Radio Frequency Identification (RFID) technology is the main component in this system. RFID is an automatic identification technology that uses tags and readers to capture data wirelessly (Yusup, 2022). RFID allows the process of verifying user identity to be carried out quickly and accurately through wireless communication between the RFID card and the reader. Only users carrying authenticated RFID cards can gain access to the ODC, thereby reducing the potential for illegal access.

Previous studies have explored the potential of modern technologies for security systems. For instance, Soni et al. (2021) demonstrated that RFID-based locks enhance security but face challenges like signal interference. Junaedi et al. (2021) showcased the adaptability of microcontrollers in automation, though their application in ODCs remains limited. Additionally, Kumar et al. (2021) and Achmady et al. (2024) highlighted the reliability of hydraulic actuators and the rapid response of solenoid locks, respectively. Despite these advancements, RFID and microcontroller technologies have seen limited adoption in ODCs due to high costs, technical complexity, and a lack of customized solutions.

In addition to RFID-based authentication, the system also integrates mechanical actuators to optimize operational performance. Hydraulic actuators are chosen as door movers because they are capable of providing large torque and fast response, so that the ODC doors can open automatically after a successful verification process. Meanwhile, in this system, the solenoid serves as an electromagnetic locking mechanism that ensures the door remains securely locked when the system is inactive. To provide feedback to the user, the system is equipped with LEDs as visual indicators and buzzers as audio alerts. By combining RFID technology, hydraulic actuators, solenoids, LED indicators, buzzers, and Arduino Uno microcontrollers, this system is expected to improve security and operational efficiency in ODC management.

This research addresses these gaps by proposing an innovative smart lock system that integrates RFID authentication with a hydraulic mechanism, controlled by an Arduino microcontroller. The system aims to enhance security by restricting access to authorized personnel while improving operational efficiency through automated door control. By combining these technologies, the study offers a tailored solution for ODCs, overcoming the limitations of traditional locks and previous electronic systems. The objectives include designing a reliable prototype, evaluating its performance, and demonstrating its potential to replace conventional methods. The expected benefits include stronger security, reduced manual intervention, and a scalable model for broader network infrastructure applications. This research contributes a practical and forward-looking solution to the challenges of ODC security and management.

Research methods

Research Planning

The planning in this research aims to produce an effective and efficient automatic lock solution on the Optical Distribution Cabinet (ODC) based on Arduino and RFID. The planning stages are arranged systematically, starting from problem identification, needs formulation, system design and implementation, testing, troubleshooting, to evaluating the final results. To describe the workflow of the entire design process, it can be seen in the flowchart in Figure 1 below.

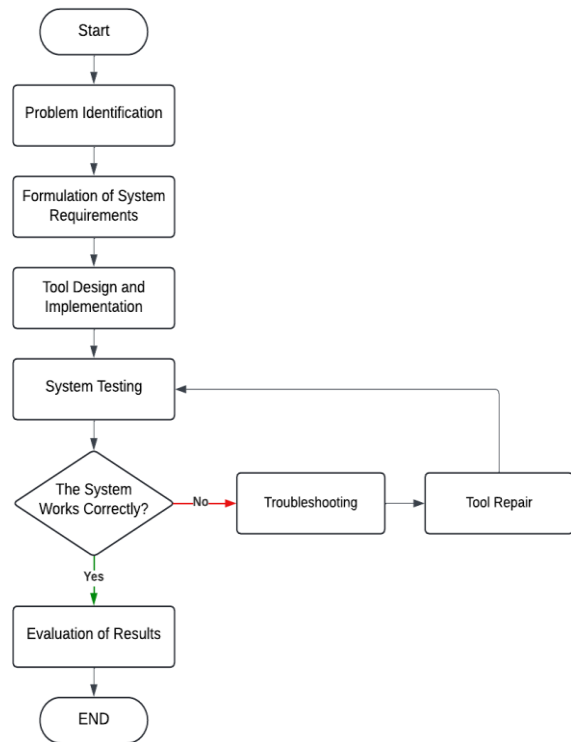


Figure 1. Research Planning Flow
Source: Developed by the author (2025)

System Architecture

The system architecture is designed to manage the authentication and opening of ODC doors automatically and securely, by combining RFID technology and hydraulic actuators. The entire process is controlled by an Arduino Uno microcontroller as the control center.

The system uses two separate types of power sources designed to provide the appropriate power supply for each component:

- 1) A 9V battery supplies power for the Arduino Uno, RFID, LED, and buzzer. On this line, there is a switch button to manually turn the system on and off.
- 2) 14.8V Li-ion battery as power supply for the solenoid as it requires higher current and voltage.

In the ODC smart lock system architecture, the RFID module reads the UID for the authentication process. If valid, the Arduino activates the relay that triggers the solenoid, and the LED and buzzer provide access status feedback. The relationship between components such as RFID, Arduino, relays, hydraulic actuators, and two power supplies is depicted in the block diagram in Figure 2.

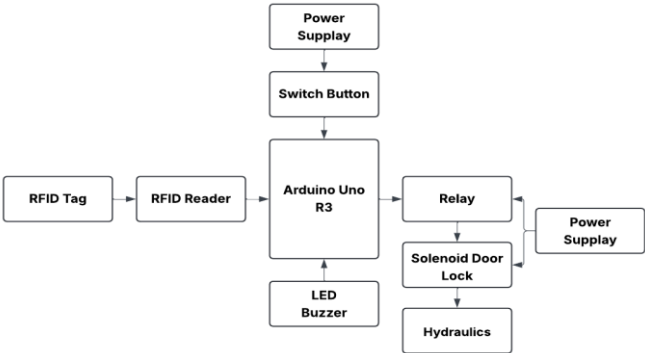


Figure 2. System Architecture Block Diagram
Source: Adaptation of Arduino-based system design by Hartini et al. (2022)

Hardware Design

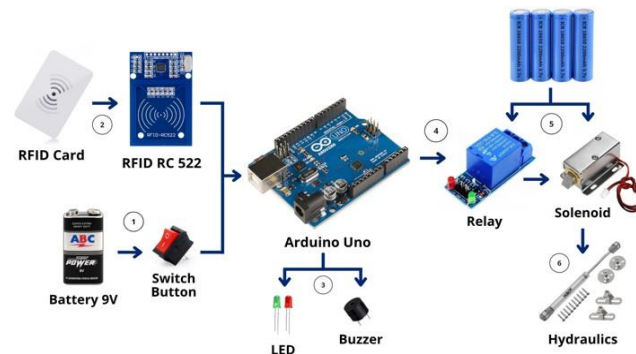


Figure 3. Auto Lock System Architecture

Source: Author's prototype documentation, inspired by the design of the solenoid lock by ElectronicWings (2025)

The main components in this system include RFID authentication module, Arduino Uno microcontroller, actuator system (solenoid lock and hydraulic actuator), and output devices such as LED and buzzer. Each component is connected to the Arduino to be controlled based on the embedded programming logic. An overview of the relationship between components is shown in Figure 3.

The system consists of several main blocks, namely:

- 1) **Arduino Uno:** Arduino Uno acts as the main controller of the system. This module receives input from the RFID and controls the output to relays, solenoids, LEDs, and buzzers.
- 2) **Switch Button:** The switch button is installed on the Arduino power supply line, used to manually enable or disable the system.
- 3) **RC522 RFID Module:** This module functions as a UID reader from an RFID card. Communication between RFID and Arduino is done through the SPI (Serial Peripheral Interface) interface, which consists of MOSI, MISO, SCK, SDA and GND pins .
- 4) **Indicator LED and Buzzer:** The system is equipped with two LEDs (red and green) and a buzzer as authentication status indicators. When the card is valid, the green LED lights up, while if it is invalid, the red LED and buzzer will activate simultaneously to signal rejection.
- 5) **Relay and Solenoid Lock:** Relay is used to connect and disconnect electricity to the solenoid lock which works on electromagnetic principles. When the UID is verified, the Arduino will activate the relay, so that the solenoid opens and allows the ODC door to be opened.
- 6) **Hydraulic Actuator:** A hydraulic actuator is a device that converts hydraulic energy into mechanical energy. It generally consists of a cylinder or fluid motor driven by hydraulic pressure to perform mechanical operations . In this system, the actuator is used to open the ODC door vertically after the solenoid opens.
- 7) **Power Supply System:** The system uses two separate power supplies to maintain stability and efficiency. A 9V battery supplies the Arduino and digital control circuit, while a 14.8V battery is dedicated to the solenoid which requires high power. This separation prevents interference between voltage lines when the solenoid is active.

The connection circuit of all components is shown in schematic form in Figure 4, created using Fritzing for easy visualization of data paths and power distribution. The schematic shows the connections between the Arduino and components such as relays, LEDs, buzzers, and RFID.

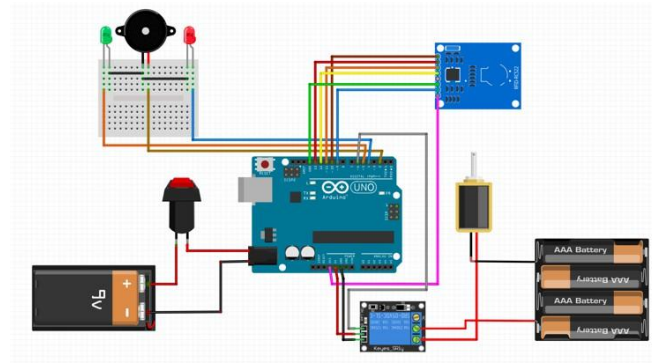


Figure 4. Auto Lock System Circuit Schematic

Source: Designed using Fritzing by the author

Software Design

The system was developed using the Arduino IDE as the main programming platform. Arduino IDE is used to write, edit, and upload programs to the Arduino Uno microcontroller [15]. Arduino IDE is made from JAVA programming language, which is equipped with C/C++ library (wiring) to facilitate input/output operations. In this system, several libraries are used such as MFRC522.h for communication with RFID reader and SPI.h for communication between Arduino and RFID RC522.

The programming logic is designed to detect the RFID card, verify the UID, activate the relay to open the solenoid lock, and activate the green and red LEDs and buzzer as an indicator of access status. To facilitate understanding of the system workflow, the program logic flowchart is shown in Figure 5.

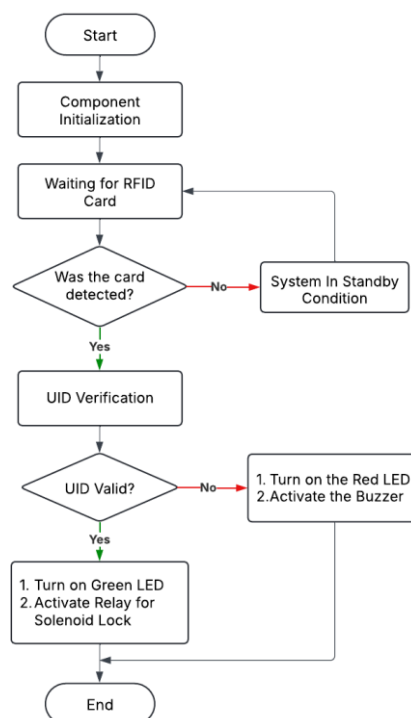


Figure 5. System Programming Flow

Source: The programming logic flow was developed by the author using the MFRC522.h and SPI.h libraries

Results and Discussion

Prototype Implementation

System implementation was carried out on a prototype Optical Distribution Cabinet (ODC), with modular testing and integration of each component to ensure functionality. Once all components were functioning properly, the system was then installed into the prototype ODC in stages.

1) Integration of Arduino and RFID Module

The initial step in the system implementation is to integrate the RC522 RFID module with the Arduino Uno through the SPI communication line as shown in Figure 6. After the integration is successful and the system is able to detect the card properly, the RFID module is installed on the front of the ODC prototype to facilitate the authentication process.



Figure 6. Integration of Arduino and RFID Module

Source: Photo of prototype integration by the author, referring to the SPI communication guide (Hartini et al., 2022)

2) Integration of Indicator LED and Buzzer

The next step is to connect the green LED, red LED, and buzzer to the Arduino output pin as an indicator of the authentication result. The green LED lights up when access is accepted, while the red LED and buzzer activate when access is denied. These components, as shown in Figure 7.

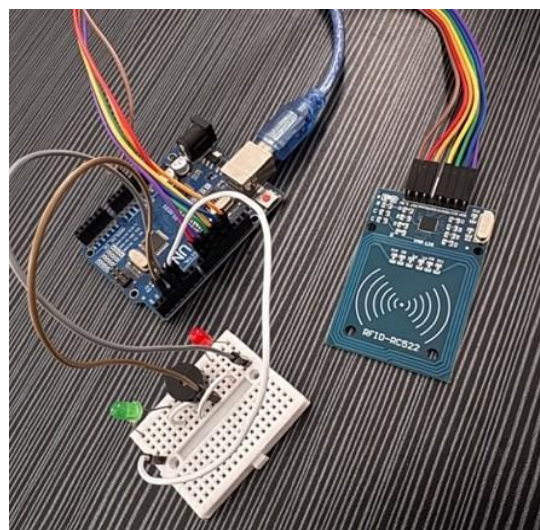


Figure 7. Integration of Indicator LED and Buzzer

Source: Documentation of the author's experiment, with pin configuration following the Arduino datasheet (Arduino S.r.l., 2025)

3) Integration of Relay and Solenoid Lock

In the integration of relay and solenoid, the relay is used as an electronic switch that connects the Arduino to the solenoid lock. When a valid card is detected, the relay delivers 14.8V current to the solenoid to unlock. Figure 8 shows the initial configuration of this circuit.

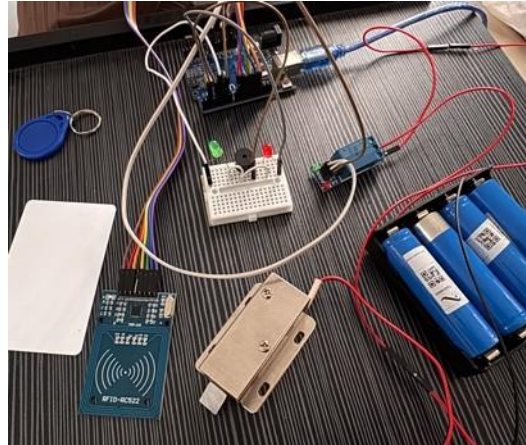


Figure 8. Integration of Relay and Solenoid Lock

Source: Solenoid testing by the author, referring to the power specification of ElectronicWings (ElectronicWings, 2025).

4) Hydraulic Actuator Installation

The final stage is the integration of a hydraulic actuator that lifts the ODC door automatically. This actuator works mechanically without the need for a power supply. As shown in Figure 9, the actuator is mounted on the inner side of the ODC prototype.



Figure 9. Hydraulic Actuator Installation

Source: Implementation of hydraulic actors by the author, with reference to mechanical design from Senthil Kumar et al. (2021)

5) Implementation of Auto Lock System Prototype on ODC Prototype

The final results of the prototype assembly show that all components-including the RFID, LED, buzzer, relay, and solenoid-are well integrated and work in sync, from authentication to automatic door opening using the hydraulic actuator. Figure 10 shows the final appearance of the fully assembled prototype.



Figure 10. Implementation of Auto Lock System Prototype on ODC Prototype

Source: Final prototype assembled by the author (2025).

System Testing

Tests were conducted in several scenarios to test the system's response and operational effectiveness.

1) RFID Sensor Testing

This RFID sensor test aims to determine the effectiveness of reading RFID cards by the RC522 module from various distances. Each experiment measures the response time and card reading status. The test results can be seen in Table 1.

Table 1. RFID Sensor Testing

No	Distance (cm)	Reading Status
1.	1	Detected
2.	2	Detected
3.	3	Detected
4.	4	Detected
5.	5	Not Detected
6.	6	Not Detected

Source: Data from empirical testing results by the author (2025)

2) RFID Card Testing

This test was conducted using five RFID cards, consisting of three valid UIDs and two invalid UIDs. The system was tested to verify whether only the registered cards could unlock the lock. The test results are shown in Table 2.

Table 2. RFID Card Testing

No	Card UID	UID Status	System Access	Indicator
1.	03E32B29	Valid	Accepted	Green LED
2.	03C04627	Valid	Accepted	Green LED
3.	8A741254	Valid	Accepted	Green LED
4.	53E67313	Invalid	Rejected	Red LED + Buzzer
5.	B4A917BA	Invalid	Rejected	Red LED + Buzzer

Source: UID validation experiment by the author, with reference to authentication techniques from Prity et al. (2021)

3) Solenoid Lock Testings

This test is focused on the accuracy of the solenoid in opening the lock after receiving a signal from the Arduino. Tests were carried out in valid and invalid UID conditions. The test result data is shown in Table III.

Table 3. Solenoid Lock Testing

No	Scenario	Switch Button	Solenoid Response
1.	Valid UID	On	Open
2.	Invalid UID	Off	Stay Locked

Source: Solenoid lock test by the author, referring to the electromagnetic response of the datasheet

4) Hydraulic Actuator Testing

Hydraulic actuator testing was conducted to evaluate the mechanical performance of the system. This testing process ensures that the actuator is able to provide sufficient thrust to open the ODC door. The test results are shown in Table IV.

Table 4. Hydraulic Actuator Testing

No	Testing Conditions	Actuator Response	Lifting Angle	Movement Stability
1.	Access Received	Lifting	90°	Stable
2.	Access Denied	Not Moving	-	-

Source: Analysis of hydraulic actuator performance by the author, with guidance from Simanjorang et al. (2021)

5) Indicator Testing

This indicator test aims to ensure that the system provides appropriate visual and audio feedback when access is accepted or denied. The green LED lights up if the UID is valid, while the red LED and buzzer activate if the UID is invalid. The results are presented in Table V.

Table 5. Indicator Testing

No	Scenario	Green LED	Red LED	Buzzer
1.	Valid UID	Lights on	Lights out	Off
2.	Invalid UID	Lights out	Lights on	On

Source: Visual/audio indicator testing data by the author (2025)

Power Consumption Analysis

A power consumption analysis was conducted to estimate how long the system can operate fully using two main power sources, a 9V battery for the Arduino Uno microcontroller and a 14.8V Li-ion battery to activate the lock solenoid. The purpose of this analysis is to ensure the system has appropriate power efficiency as well as estimating the operational time before recharging is required. The method used refers to the basic electrical formula, namely the equation (1) (Suwanda & Ivan, 2023):

$$P = V \times I \quad (1)$$

Where P is power (Watt), V is voltage (Volt), and I is current (Ampere).

1) Power Supply for Arduino

The Arduino Uno microcontroller and control components (LED, buzzer, RFID) are powered by one 9V battery. Based on data from the official datasheets of each component, the total current consumed by the Arduino and all control loads is 0.113 A (Arduino S.r.l., 2025; SunFounder, 2025). So to find out the total power, the following calculation is done:

$$P_{\text{Arduino}} = 9 \text{ V} \times 0.113 \text{ A} = 1.017 \text{ Watt}$$

The capacity of the 9V battery is 550 mAh (0.55 Ah), so the system operating time in the condition of all active components is 4.86 hours.

2) Power Supply for Solenoid

The solenoid is controlled via a relay and requires higher current. For the solenoid power supply in this system using four 3.7V Li-ion batteries (serialized to 14.8V) with a capacity of 1.5 Ah. The power used by the solenoid is 0.67 A (ElectronicWings, 2025). Then the total power of the solenoid can be calculated as follows:

$$P_{\text{Solenoid}} = 14.8 \text{ V} \times 0.67 \text{ A} = 9.92 \text{ Watt}$$

The estimated operational time for the solenoid is 2.24 hours. But in this system, the solenoid is only active for a few seconds when the authentication process is successful. Hence the actual usage is much more efficient.

The results showed that the RFID-based automatic lock system and hydraulic mechanism designed on the Optical Distribution Cabinet (ODC) can work well. The system is proven to be able to authenticate RFID cards in less than 1 second with an optimal reading distance of 1-4 cm, and is able to unlock via solenoid and lift the door automatically using a hydraulic actuator to an angle of 90°. The integration between the Arduino microcontroller, relays, and two separate power supply sources also successfully maintains the stability of the system when controlling different loads.

Testing valid and invalid UIDs shows that the system is able to reliably segregate access, with the support of LED indicators and buzzers as user feedback. However, the system is still offline and does not support logging or remote monitoring. Therefore, further development can be directed towards the integration of an Internet of Things (IoT)-based monitoring system to expand the functionality and scalability of the system. Overall, the system shows high potential to be implemented on fiber optic network infrastructure as an efficient and practical modern security solution in the field.

Conclusion

This study successfully achieved its objectives by designing and implementing a smart lock system for Optical Distribution Cabinets (ODCs) using RFID and hydraulic mechanisms, which enhances security and operational efficiency. The system demonstrated reliable performance in authenticating users, automating door access, and providing real-time feedback through visual and audio indicators. Future research could further improve this system by integrating IoT capabilities for remote monitoring and logging, optimizing power consumption for longer battery life, and exploring advanced authentication methods such as biometrics or

multi-factor verification to strengthen security. These developments would expand the system's applicability and scalability in modern network infrastructure management.

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