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Smart Laboratory Using Radio Frequency Identification (RFID) Based on The Internet of Things

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A B S T R A C T

In Indonesia, traditional methods are still commonly used for managing laboratories. This has resulted in various issues, such as the loss of keys, and has hindered the efficiency of these laboratories. However, the integration of technology has the potential to improve laboratory management by up to 33%. A modernized laboratory system, known as an "Innovative Laboratory", combines technology with traditional management techniques. The proposed Internet of Things-based tool aims to assist laboratories in improving their management services, including a registration system, a locker system, and a desk system. This tool utilizes a Keypad 4x4 and PCF8574 to select desks and lockers, Node MCU as a microcontroller to publish identification data from an MQTT broker, and RFID technology to access and activate electronic locks and sockets. To ensure that data is successfully transferred and the selected locker and desk are available, the system requires a certain delivery time for a maximum of 251 bytes of data that can be sent at different signal strengths. Only registered users with valid identification are able to access the locker and desk systems, and users must unregister before switching to a new locker or desk. The goal of this system is to streamline and improve the management of laboratories.

A R T I C L E   I N F O

1. INTRODUCTION

The incorporation of RFID technology into a laboratory enables real-time asset tracking and the automation of multiple processes, including inventory management and data collection. It can also improve the laboratory's safety and productivity by eliminating the need for manual tracking and minimizing the risk of human error.

By providing a platform for the integration and management of RFID data with other systems and devices, the IoT plays a vital role in a smart laboratory employing RFID technology. The Internet of Things enables the monitoring and analysis of RFID tag data in real-time, as well as the automation of processes based on this data [1].

Overall, a smart laboratory utilizing RFID technology based on the Internet of Things can significantly improve the laboratory's efficiency, productivity, safety, and accuracy.

For the management, learning, and research activities in the laboratory to run well, the development of a good laboratory management and management system can increase the effectiveness of learning by up to ±33% [2][3].

In the past few years, the development of information technology has proliferated, allowing automation systems to be applied in laboratories, or what we can call Smart Laboratory [4][5].

Therefore, to minimize unwanted things, as well as with existing technological advances, a more modern laboratory management system is needed using the Internet of Things. In this study, a system will be made which has three parts registers, locker devices, and tablet devices. The data from each Smart Laboratory user will be displayed on the MQTT Box so that it is expected to facilitate the monitoring process for each Smart Laboratory us

2. METHODS

We split this research into three stages: the first stage is Literature Review, the second stage is System Development, and the last stage is System Testing.

2.1   Literature Review

We need to explain some material, system environment, and related terms we used in this research as the first stage. Then, the system and some materials are described in the following items.

2.1.1   Smart Laboratory

The laboratory is a closed or open room designed according to the needs to carry out activities related to education, research, and community service [6]. Nowadays, the laboratory is evolving, as described in some research. *Smart Laboratory* is a method that combines laboratory elements with technological advances, which include several factors related to management and information systems, to create a more productive and conducive work environment [7][8].

2.1.2   Internet of Things

A wireless communication technology widely used and growing rapidly is called the Internet of Things (IoT); the Control and monitoring equipment to support human needs is based on Internet technology [9][10].

2.1.3   RFID MFRC522

RFID MFRC522 is a wireless technology that reads objects via radio waves using an SPI connection [11-14]. The MFRC522 RFID module can be seen in **Figure 1.**
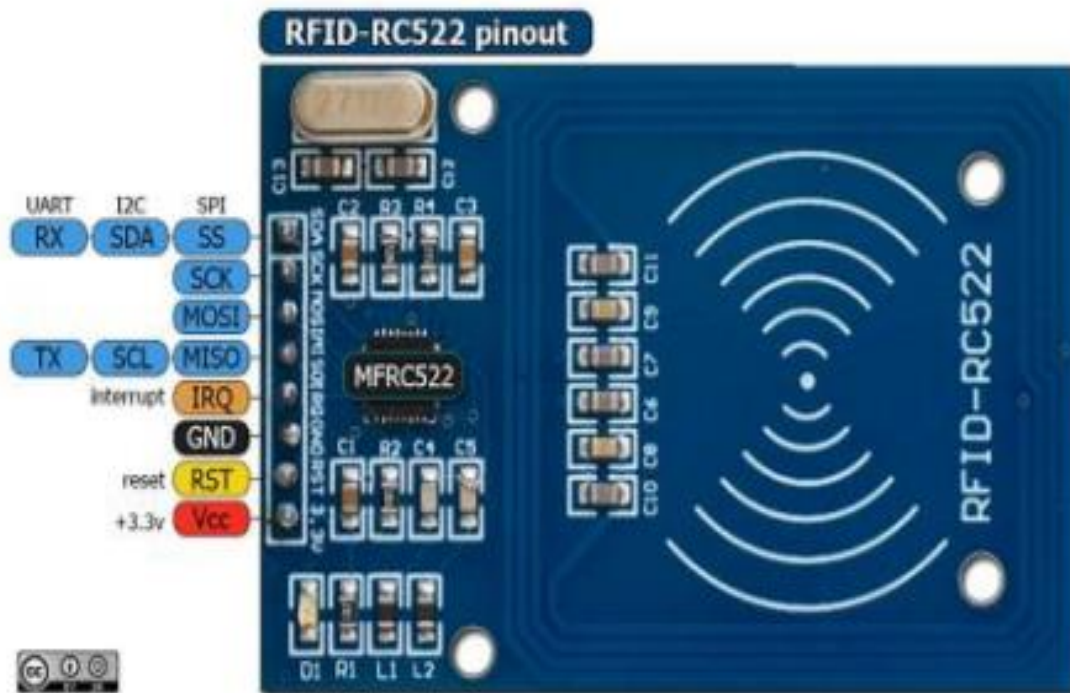

Figure 1. Illustration of module of RFID MFRC522.

2.1.4   Keypad 4x4

It is a common interface device in the form of a push button switch which is arranged in a matrix and functions to input data [15][16], as shown in **Figure 2.**

2.1.5   BJPCF8574 GPIO extender

PCF8574 is an extender for additional pins on the microcontroller [17]. This module works with I2C communication. With eight digital I/O pins each and three input addresses, as shown in **Figure 3.**

2.1.6   Solenoid Door Lock (SDL)

It is an electric lock in the form of an actuator capable of performing linear movements. In this solenoid, there is a coil of wire which, when current flows, creates a magnetic field to push the iron core [18]. As in **Figure 4**

Figure 2. Illustration of module of keypad 4x4.

Figure 3. Illustration of PCF8574 module.

Figure 4. Illustration of solenoid door lock.

2.1.7   LCD 20x4

LCD is an electronic component that functions as a data viewer in the form of characters or letters available in the form of an LCD display module along with supporting circuitry such as data pins, power supply control, and contrast control [19], as shown in **Figure 5.**

Figure. 5 Illustration of LCD 20x4.

2.2 Flowchart

Figure 6a. show a flowchart of the registration system that explains how the registration flow is in using SmartLab. **Figure 6b.** show a flowchart of the system on the locker and table that explains the workflow of the system when it receives data from the MQTT broker.
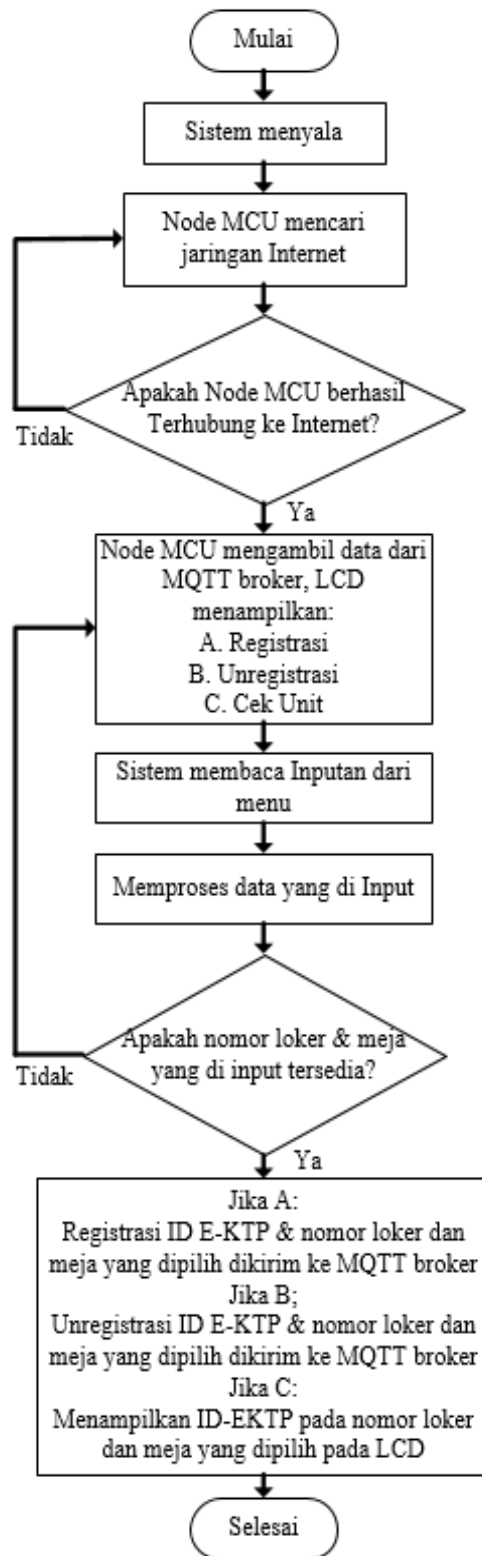

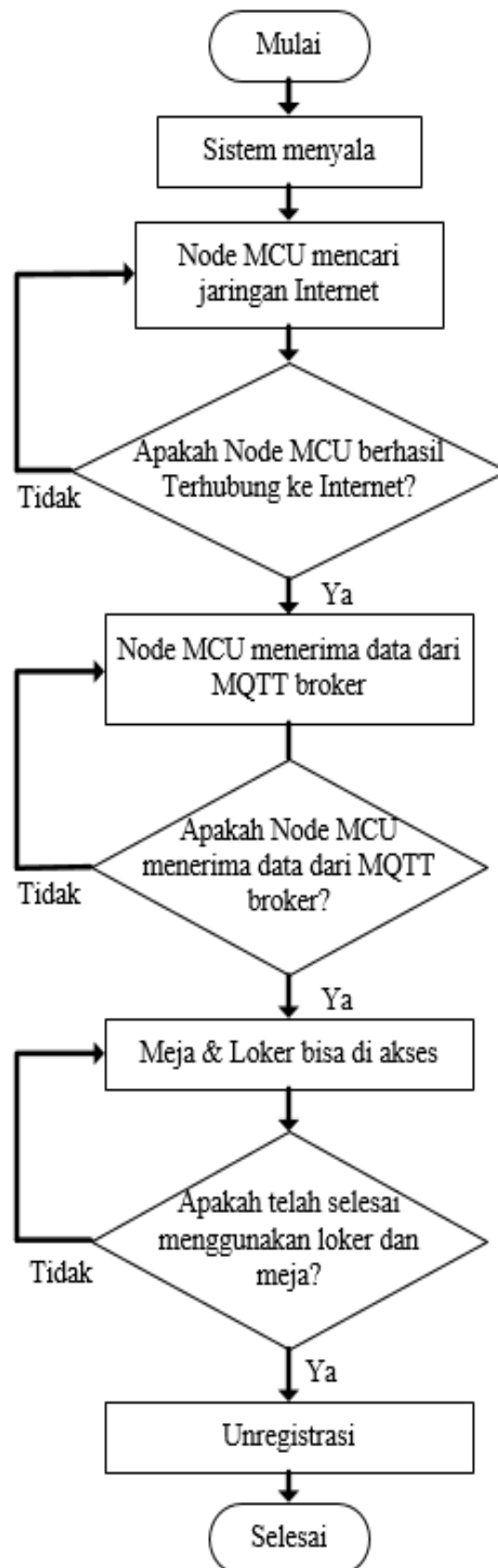**Figure 6a.** registration system flowchart.

Figure 6b. System flowchart on lockers and desks.

2.3   System Architecture

In **Figure 7.** Is a System Architecture which consists of 3 parts. The Registration System section is for registering the user's EKTP card, monitoring existing units, and unregistering as explained in [20]. If the user card has been registered, the data will be sent to the System on the Locker and the System on the available Desk, where the registered card can activate the relay on the Locker Node to move the solenoid and the relay on the Desk Node to activate the contact box.
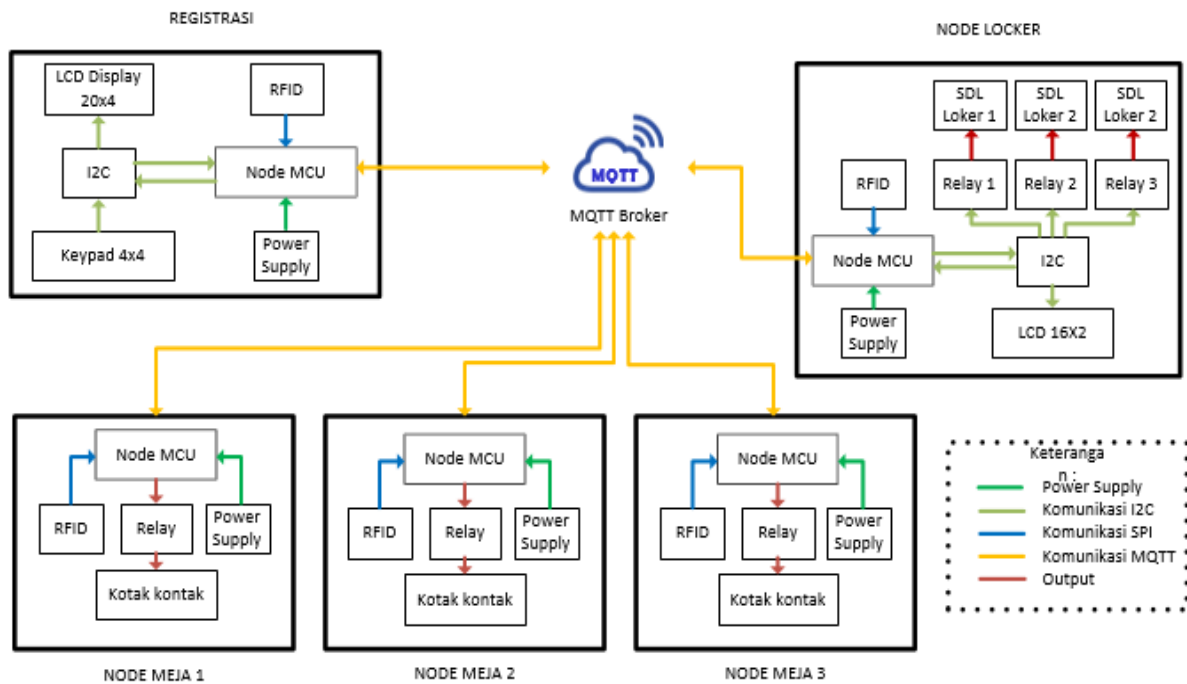
Figure 7. System architecture.

2.4   System Wiring Diagram

In system planning there is a Registration System section as shown in **Figure 8.**, System Diagram on Locker in **Figure 9.** and the System Diagram on the Table in **Figure 10.**
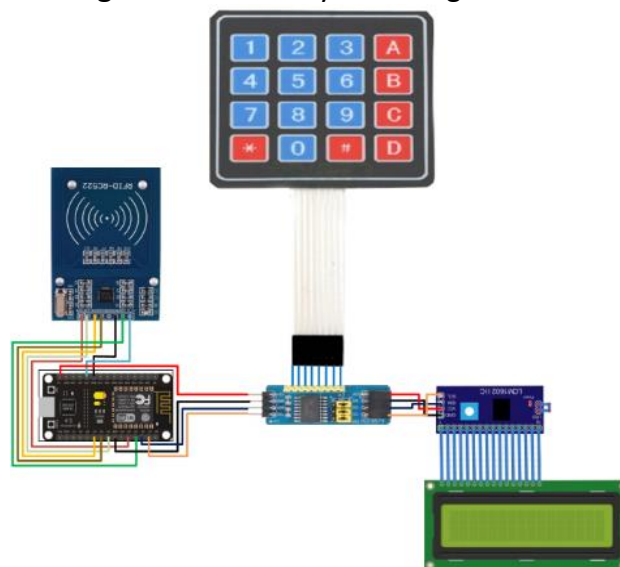
Figure 8. Wiring system registration.

The registration system uses the Node MCU ESP8266 as a microcontroller, RFID, keypad and PCF8574 as input and LCD as display.

Figure 9. Wiring system on locker.

In the existing system, the locker uses Node MCU ESP8266 as a microcontroller, RFID as input, PCF8574 as I/O pin extender, Relay as output to activate Solenoid Door Lock and LCD as data viewer.

Figure 10. Wiring system on table.

The system on the table uses the Node MCU ESP8266 as a microcontroller, RFID as input, LED as an indicator, Relay as output to activate the contact box.
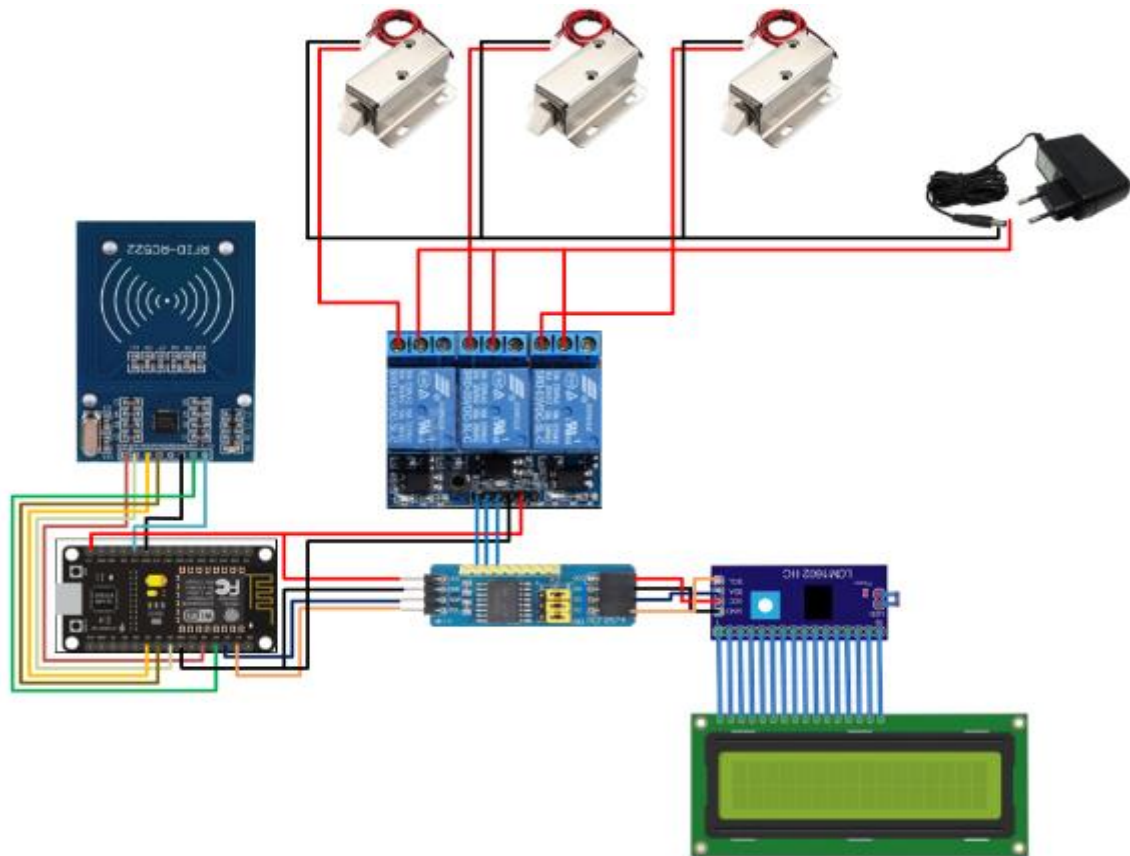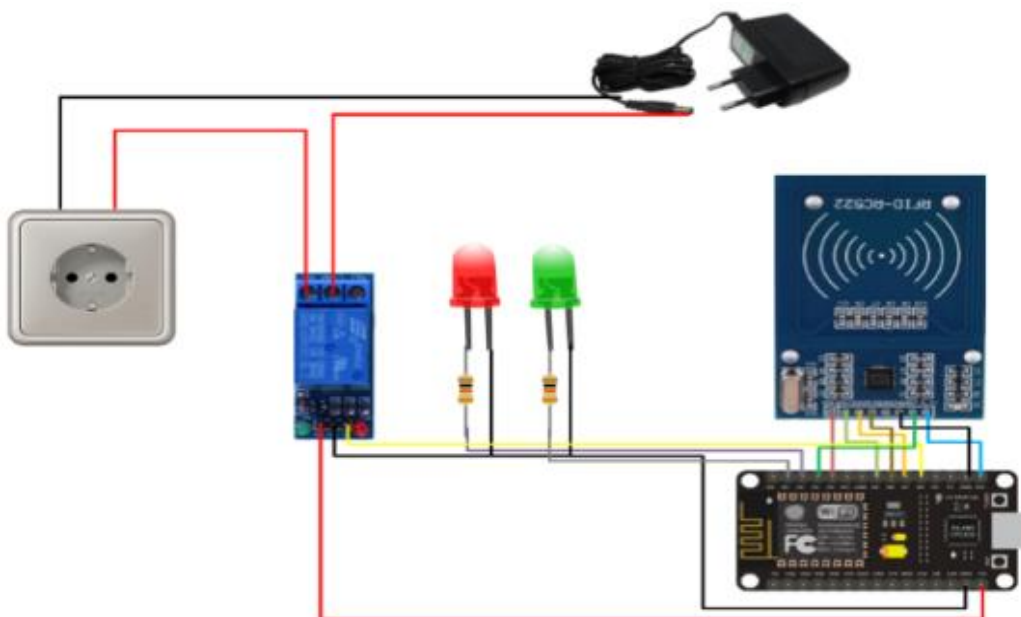
3. RESULTS AND DISCUSSION

3.1 Unit Test

In unit testing, it aims to find out whether the unit can work according to its function, so that it can be used on the system, there are several components being tested.

The first test is done by connecting the MCU Node to an internet connection, the LED will light up, and when not connected to the internet the LED will turn off. From **Table 1.**, it can be concluded that the unit has been functioning properly.

Table 1. MCU node connection test with LED.

Number of Testing	Node MCU ESP8266				Description
	Connected to Internet	LED ON	Not Connected to Internet	LED OFF	
1	Yes	Yes	Yes	Yes	Good
2	Yes	Yes	Yes	Yes	Good
3	Yes	Yes	Yes	Yes	Good
4	Yes	Yes	Yes	Yes	Good
5	Yes	Yes	Yes	Yes	Good
6	Yes	Yes	Yes	Yes	Good
7	Yes	Yes	Yes	Yes	Good
8	Yes	Yes	Yes	Yes	Good
9	Yes	Yes	Yes	Yes	Good
10	Yes	Yes	Yes	Yes	Good

Other test is carried out by testing the effect of the signal on the amount of data sent, from 3 signal conditions, with various data sizes. From **Table 2.**, it can be concluded that the signal strength does not affect data transmission, but the maximum amount of data that can be sent from the MCU node is 251 bytes.

Another test is carried out by providing input voltages of 1V, 3V, 5V, 10V and 15V on the Solenoid. From **Table 3.**, it can be concluded that Solenoid can be actively unlocked at a voltage of 10V and 15V.

Table 3. Solenoid door lock test.

No	Voltage (v)	Results
1	1 V	Not Open
2	3 V	Not Open
3	5 V	Not Open
4	10V	Open
5	15 V	Open

Another test is done by providing a program on the LCD to display characters in the form of letters and numbers. From **Table 4.**, we can say LCD can function properly.

Table 2. Testing the influence of the signal on the amount of data.

No	Low Signal (RSSI Range 0-33)					
	75 byte	**125 byte**	**251 byte**	**252 byte**	**260 byte**	**300 byte**
1	Yes	Yes	Yes	No	No	No
2	Yes	Yes	Yes	No	No	No
3	Yes	Yes	Yes	No	No	No
4	Yes	Yes	Yes	No	No	No
5	Yes	Yes	Yes	No	No	No
-	**Medium Signal (RSSI Range 34-67)**					
1	Yes	Yes	Yes	No	No	No
2	Yes	Yes	Yes	No	No	No
3	Yes	Yes	Yes	No	No	No
4	Yes	Yes	Yes	No	No	No
5	Yes	Yes	Yes	No	No	No
-	**Strong Signal (RSSI Range 68-100)**					
1	Yes	Yes	Yes	No	No	No
2	Yes	Yes	Yes	No	No	No
3	Yes	Yes	Yes	No	No	No
4	Yes	Yes	Yes	No	No	No
5	Yes	Yes	Yes	No	No	No
5	Yes	Yes	Yes	No	No	No

Another test is done by reading the ID of the E-KTP card with an ordinary RFID card. From **Table 5.**, it can be concluded that the E-KTP card has a 14-digit ID, while an ordinary RFID card has an 8-digit ID.

Table 5. MFRC522 RFID testing.

No	MRFC522 RFID Testing				Results
	E-KTP		**Non E-KTP**		
	ID Detected	**Digit**	**ID Detected**	**Digit**	
1	04 67 4B AA AB 4F 80	14	D6 D9 6C D9	8	Baik
2	04 67 4B AA AB 4F 80	14	D6 D9 6C D9	8	Baik
3	04 67 4B AA AB 4F 80	14	D6 D9 6C D9	8	Baik
4	04 67 4B AA AB 4F 80	14	D6 D9 6C D9	8	Baik
5	04 67 4B AA AB 4F 80	14	D6 D9 6C D9	8	Baik

3.2   System Test

In system testing, a test is carried out which aims to ensure whether all components that have been combined previously can work according to their functions or not. Overall system testing is carried out in several ways, including:

a. Testing the input of the locker and table numbers available in the registration system against the system at the lockers and desks, when the lockers and desks are still empty.

b. Test the input of locker and table numbers that are not available in the registration system against the existing system at lockers and desks, when lockers and tables are still empty.

c. Testing the input of locker and table numbers available in the registration system against the system at lockers and desks, when lockers and tables are filled.

d. Test the input of locker and table numbers that are not available in the registration system against the existing system at lockers and desks, when lockers and tables are filled.

e. Tests input from unregistered cards on the system on lockers and desks.

f. PCF8574 test results with a matrix concept to produce 16 different outputs so that they can be active according to the given input

The following **Table 6.** show the results of system testing:

Table 6. Testing the input of available and unavailable locker numbers when the initial state of the locker is still empty.

Number of Testing	Initial Status	Registration			Relay on Locker						Results
		ID E-KTP	Status	Input	Before Tapping			After Tapping			
					1	32	64	1	32	64	
1	Still Empty	05-8B-B0-75-6B-D1-00	Sent	1	TA	TA	TA	A	TA	TA	Match
2	Still Empty	04-72-28-E2-EB-2E-80	Sent	32	TA	TA	TA	TA	A	TA	Match
3	Still Empty	04-16-46-3A-02-2C-80	Sent	64	TA	TA	TA	TA	TA	A	Match
4	Still Empty	05-8B-B0-75-6B-D1-00	Not Sent	65	TT	TT	TT	TT	TT	TT	Match
5	Still Empty	04-67-4B-AA-AB-4F-80	Unregistered	1	TA	TA	TA	TA	TA	TA	Match

Description: A = Active, TA = Inactive, TT = not available   *Conclusion: Good*

After testing, entering the available and unavailable locker and table numbers when the initial state of the lockers and tables are still empty in **Tables 6.** and **Table 7.**, the system will only be active if tapped using a registered E-KTP, and will not be active if tapped using Unregistered E-KTP, while in testing the input of available and unavailable locker and table numbers when the initial state of the lockers and desks have been filled in **Tables 8.** and **Tables 9.**, the system cannot receive new E-KTP data before unregistering the locker and the table. And last **Table 10.** show testing result produce 16 outputs.

Table 7. Testing the input of available and unavailable locker numbers when the initial state of the locker is filled.

| Number of Testing | Initial Status | Registration | | | Relay on Locker | | | | | | Results |
| | | ID E-KTP | Status | Input | Before Tapping | | | After Tapping | | | |
					1	32	64	1	32	64	
1	Already Filled	05-8B-B0-75-6B-D1-00	Not Sent	1	TA	TA	TA	TA	TA	TA	Match
2	Already Filled	04-72-28-E2-EB-2E-80	Not Sent	32	TA	TA	TA	TA	TA	TA	Match
3	Already Filled	04-16-46-3A-02-2C-80	Not Sent	64	TA	TA	TA	TA	TA	TA	Match
4	Already Filled	05-8B-B0-75-6B-D1-00	Not Sent	65	TT	TT	TT	TT	TT	TT	Match
5	Already Filled	04-67-4B-AA-AB-4F-80	Unregistered	1	TA	TA	TA	TA	TA	TA	Match

Description: A = Active, TA = Inactive, TT = not available   *Conclusion: Good*

Based on the test results in **Table 10.**, PCF8574 makes it possible to generate and manage 16 different outputs. Using the matrix concept to group the positive and negative poles into col and row. So that when providing input for locker 1 it will turn on led 1, and so on until locker 16 and led 16.

Table 8. Testing available and unavailable table number input when the initial table state is empty.

Number of Testing	Initial Status	Registration			Relay on Locker						Results
		ID E-KTP	Status	Input	Before Tapping			After Tapping			
					1	32	64	1	32	64	
1	Still Empty	05-8B-B0-75-6B-D1-00	Sent	1	TA	TA	TA	A	TA	TA	Match
2	Still Empty	04-72-28-E2-EB-2E-80	Sent	32	TA	TA	TA	TA	A	TA	Match
3	Still Empty	04-16-46-3A-02-2C-80	Sent	64	TA	TA	TA	TA	TA	A	Match
4	Still Empty	05-8B-B0-75-6B-D1-00	Not Sent	65	TT	TT	TT	TT	TT	TT	Match
5	Still Empty	04-67-4B-AA-AB-4F-80	Unregistered	1	TA	TA	TA	TA	TA	TA	Match

Description: A = Active, TA = Inactive, TT = not available   *Conclusion: Good*

Table 9. Testing of available and unavailable table number inputs when the initial state of the table is filled.

Number of Testing	Initial Status	Registration			Relay on Locker						Results
		ID E-KTP	Status	Input	Before Tapping			After Tapping			
					1	32	64	1	32	64	
1	Already Filled	05-8B-B0-75-6B-D1-00	Not Sent	1	TA	TA	TA	TA	TA	TA	Match
2	Already Filled	04-72-28-E2-EB-2E-80	Not Sent	32	TA	TA	TA	TA	TA	TA	Match
3	Already Filled	04-16-46-3A-02-2C-80	Not Sent	64	TA	TA	TA	TA	TA	TA	Match
4	Already Filled	05-8B-B0-75-6B-D1-00	Not Sent	65	TT	TT	TT	TT	TT	TT	Match
5	Already Filled	04-67-4B-AA-AB-4F-80	Unregistered	1	TA	TA	TA	TA	TA	TA	Match

Description: A = Active, TA = Inactive, TT = not available   *Conclusion: Good*

Table 10. PCF8574 test results using the matrix concept to produce 16 outputs.

No	Input	Output	Description
1	Locker 1	Led 1	Turn ON
2	Locker 2	Led 2	Turn ON
3	Locker 3	Led 3	Turn ON
4	Locker 4	Led 4	Turn ON
5	Locker 5	Led 5	Turn ON
6	Locker 6	Led 6	Turn ON
7	Locker 7	Led 7	Turn ON
8	Locker 8	Led 8	Turn ON
9	Locker 9	Led 9	Turn ON
10	Locker 10	Led 10	Turn ON
11	Locker 11	Led 11	Turn ON
12	Locker 12	Led 12	Turn ON
13	Locker 13	Led 13	Turn ON
14	Locker 14	Led 14	Turn ON
15	Locker 15	Led 15	Turn ON
16	Locker 16	Led 16	Turn ON

Conclusion: Working Good

4. CONCLUSION

Based on the results of research and discussions that have been carried out, it can be concluded that in registering the E-KTP card can only be processed when the available locker and table numbers are still empty. The system at the locker and at the table can only be accessed using a card that has been previously registered. The registration will not be successful if the designated locker and table numbers are not available, meaning that cards that have not or are not registered will not be able to access the available lockers and tables. Meanwhile, new users cannot register their E-KTP for already filled locker and table numbers, so unregistration must be carried out first before being registered for new users.

This system, of course, requires additional features in its refinement, for example, the loan feature, the room temperature and humidity monitoring feature and external memory for data storage.

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