Implementation of Finite State Machine on Cluster Housing Security System Based on LoRa with Telegram Notification

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***Abstract*— Cluster housing is a residential area with a single access gate system that is widely applied in urban areas. Although equipped with security officers, theft cases in cluster housing still often occur due to the limitations of the system in providing warnings quickly. This study aims to design a home security system that is able to detect suspicious activity and send warnings from home to the security post via LoRa communication. This system uses a magnetic switch sensor to detect door conditions and a PIR sensor to detect movement around the house. The test results show that the magnetic switch sensor can detect an open door when the distance between the magnet and the reed switch exceeds 20 mm, while the PIR sensor is effective in detecting movement up to 5 meters from angles of 0°, 45°, and 90°. Notifications to Telegram are sent with an average delay time of 2-13 seconds. LoRa communication range testing shows that the system is able to send data stably up to a distance of 120 meters in Line of Sight (LoS) and Non-Line of Sight (NLoS) conditions. With the ability to detect threats directly and a wide communication range, the system is expected to improve security in residential areas well.**

Keywords*— *Cluster Housing, Home Security, LoRa, Magnetic Switch, PIR Sensor

I. INTRODUCTION

Cluster housing is a closed residential area that relies on a one-gate system as the main exit and entrance. In addition to providing residential facilities, this type of housing is generally equipped with commercial areas, sports facilities, and parks to support the comfort of residents. Security aspects are an important concern in cluster housing, which are usually guarded by security officers at the access gate to monitor the entry and exit of residents and guests [1],[2],[3].

However, this conventional security system has not been able to completely prevent crime. Based on data from the National Police Criminal Investigation Unit in 2024, there were 414,468 cases of crime in Indonesia, with 637 cases occurring in residential areas in East Java [4,5]. Cases of theft and housebreaking are quite dominant incidents, indicating that the presence of security officers and patrol systems are not yet effective enough in providing maximum protection [6,7].

The need for a more modern and responsive security system is important, especially because of the increasingly mobile lifestyle of society. Several theft incidents as reported by MutiaraindoTV.com and Surya.co.id prove that crime still occurs even though conventional security systems have been implemented [8,9]. Therefore, the use of sensor-based technology and automation systems is a relevant solution to increase the effectiveness of supervision [10,11,12].

This study aims to design a home security system that is able to detect suspicious activity and provide warnings quickly and automatically. The system developed combines a PIR sensor to detect movement and a magnetic switch sensor to monitor door conditions. Threat detection will be forwarded via LoRa communication from the house to the security post, where the warning will be displayed on the LCD and accompanied by a buzzer sound. Notifications are also sent via the Telegram application to speed up the response of security officers to threats [13,14].

With the application of Finite State Machine (FSM) technology in the system logic settings, as well as the use of LoRa as a long-distance communication medium, this system is expected to be an effective solution in improving security in cluster housing environments [15].

II. METHOD

A. Method FSM (Finite State Machine)

The Finite State Machine (FSM) method is used to organize the transition logic between system states based on input from sensors. FSM provides a structured framework in responding to events in a step-by-step and logical manner, from monitoring normal conditions to detecting threats and sending notifications. The following is a table that presents the FSM in this study.

TABLE I
FSM TRANSITION

Current State	Event	Next State	Action
Idle	Sensors do not detect threats	Idle	No action
Idle	Sensor detects threat	Threat Detection	Process sensor data
Threat Detection	Invalid data (threat not detected)	Idle	Return to Idle state
Threat Detection	Valid data (threat detected)	Send Notification	Send notification to the security post
Send Notification	Notification Sent	Idle	Displays status on LCD and buzzer on

Validation is done based on the condition of the sensors. If only one of the sensors is active or the data is invalid, the system does not proceed to the notification process. The validation criteria are summarized in the following table:

TABLE II
THREAT VALIDATION

Sensor	Condition Without Threat	Condition With Threat
Magnetic Switch	Door closed, circuit active	Door open, circuit disconnected
PIR Sensor	No movement detected	Movement detected in sensor area

B. *FSM Flowchart*

The following figure shows the system workflow based on Finite State Machine (FSM) logic. The system starts at the Idle state, where the device continuously monitors the inputs from the sensors. If no threat is detected, the system remains in the Idle state. When the sensors detect a potential threat, the system moves to the validation process. If the threat is confirmed valid, the system sends a notification to the security post and activates the local indicator. If invalid, the system returns to the Idle state.

In Figure 1, we can see the Finite State Machine (FSM) flowchart that represents the logical behavior of the proposed security system. The diagram illustrates how the system operates through a sequence of defined states, starting from the Idle state, transitioning to Threat Detection when sensor activity is detected, and moving to the Send Notification state once a valid threat is confirmed.

The FSM structure shown in Figure 1 ensures that the system responds systematically to sensor inputs rather than reacting randomly. By separating system behavior into distinct states, the logic becomes easier to manage, verify, and modify. This approach also reduces false alarms, since sensor data must pass a validation process before the system proceeds to the notification stage.

Furthermore, Figure 1 highlights how the FSM allows the system to return to the Idle state after completing the notification process. This looping mechanism enables continuous monitoring without requiring manual system resets. As a result, the FSM-based design improves system reliability, efficiency, and consistency in handling security events in the cluster housing environment.

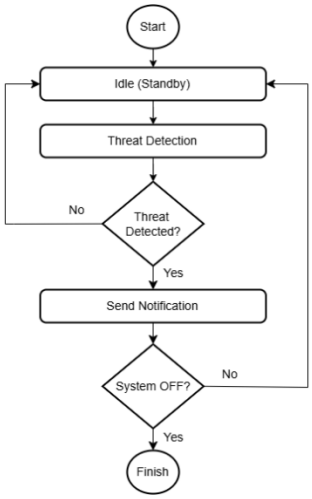

Figure 1. FSM Flowchart

C. *Block Diagram of Sending System (Home)*

The system block diagram illustrates the workflow of the home security device which consists of three main stages: input, process, and output. In the input stage, the system uses two main sensors, namely a magnetic switch to detect the condition of the door (open or closed) and a PIR sensor to detect human movement around the house. The data from these two sensors is then processed by the ESP8266 microcontroller, which serves as the control center to process the signals and determine the threat status. If a threat is detected, the data is sent through the LoRa module as a remote wireless communication medium. At the output stage, the data is received by the LoRa Master Node device at the security post, which will activate the buzzer, display information on the LCD, and send an automatic notification to the Telegram application so that security officers can respond quickly.

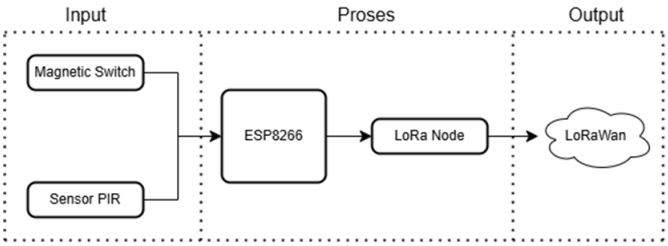

Figure 2. Block Diagram of Sending System (Home)

D. *Receiver Block Diagram (Security Post)*

The block diagram of the receiving device illustrates the process of receiving and processing data from the house to the security post. The system receives data from LoRa Nodes 1, 2, and 3, each representing sending devices in different homes. Each node sends sensor data through the LoRaWAN network to the LoRa Master Node at the security post. Next, the data is forwarded to the ESP32 microcontroller for processing. The ESP32 connects to the WiFi network in order to send real-time

notifications to the Telegram application. In addition, the ESP32 also activates the buzzer as a sound alert and displays security status information on the LCD to make it easier for officers to monitor the condition of each house directly.

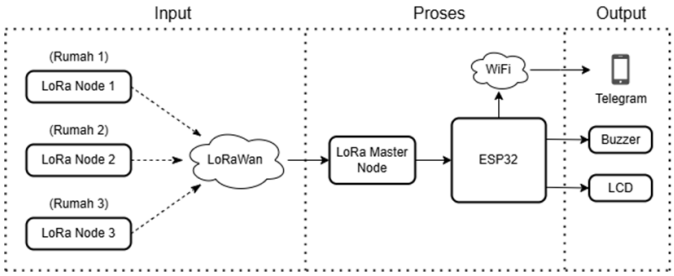

Figure 3. Block Diagram of Sending System (Home)

E. System Flowchart

The following figure shows the workflow of the home security system as a whole, starting from the initialization process until the notification is sent to the security post. The ESP8266 device first initializes the sensor to ensure all components are ready to work. After that, the system enters Idle mode and waits for a signal from the sensor. If the PIR sensor detects movement or the magnetic switch detects an open door (disconnected circuit), the system will send data to the LoRa Master Node at the security post via the LoRa network. Next, the device at the security post will process the received data, then send a notification via Telegram, activate the buzzer as an alarm, and display status information on the LCD. After all actions are taken, the system returns to idle.

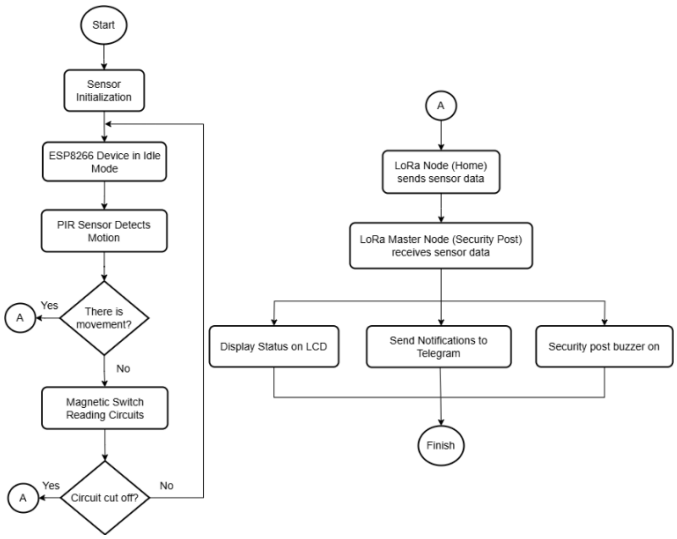

Figure 4. System Flowchart

III. RESULTS AND DISCUSSION

A. Device Design Sending Device (Home)

The sending device is designed in the form of a box measuring 10×7.8 cm and is installed in the home area. Inside the box is an ESP8266 microcontroller that serves as the main controller for the entire system operation. Data communication is done using the LoRa RA-02 module, which connects the sending device with the receiving device at the security post. The system obtains its power supply from an external source directly connected to the circuit. On the outside of the box, a magnetic switch sensor is installed to detect the condition of the door (open or closed), as well as a PIR sensor to detect human movement, especially when someone enters without going through the main door access.

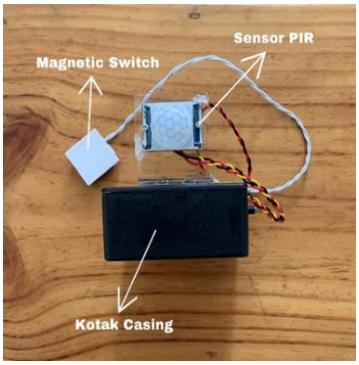

Figure 5. Sending device outside view

In Figure 5, the external appearance of the sending device is shown. The figure highlights the physical placement of the magnetic switch sensor on the door and the PIR sensor positioned to monitor movement around the house entrance area.

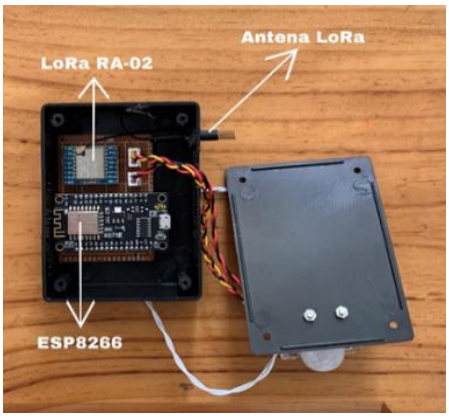

Figure 6. Sending device inside view

Figure 6 provides an internal view of the sending device, where the arrangement of the ESP8266 microcontroller, LoRa RA-02 module, power supply, and sensor connections can be observed. This configuration supports stable data acquisition and wireless transmission.

B. Receiver Device Tool Design (Security Post)

The receiving device placed at the security post is assembled in a box measuring 10×5 cm. On the outside of the box, an I2C LCD screen is installed to display the security status information of each house. Inside the box, the system is controlled by an ESP32 microcontroller that acts as the central controller. Data communication is done through the LoRa RA-02 module which receives signals from the sending device using the LoRa network. In addition, the device is also

equipped with a buzzer as a sound indicator when a threat is detected. The entire circuit obtains power supply from an external power supply that is directly connected to the system.

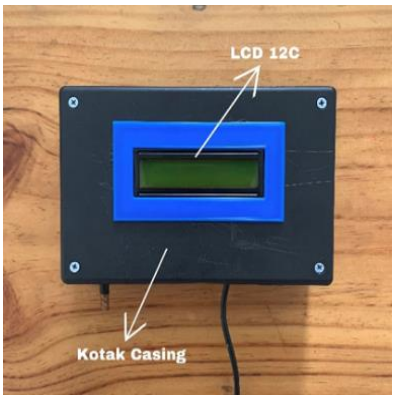

Figure 7. Receiving device outside view

Figure 7 shows the external view of the receiving device located at the security post. The figure emphasizes the LCD interface used to present security status information from each monitored house.

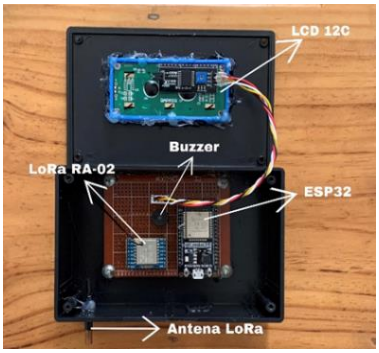

Figure 8. Receiving device intside view

As depicted in Figure 8, the internal configuration of the receiving device consists of an ESP32 microcontroller, a LoRa module, a buzzer, and supporting electronic components.

C. Testing the Magnetic Switch Sensor

Magnetic switch sensor testing is done to determine the maximum distance between the magnet and reed switch that can still be detected. The sensor was tested with distance variations of 5 mm, 10 mm, 15 mm, 20 mm, and more than 20 mm. Each test was conducted five times to ensure the accuracy of the sensor response.

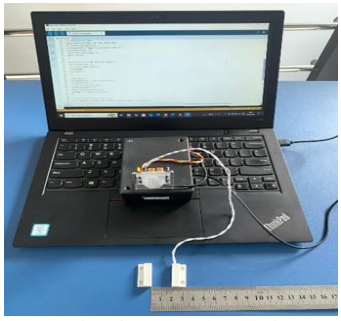

Figure 9. Testing the magnetic switch sensor

The test data that has been obtained is then compiled in Table III to show how effectively the sensor detects changes in distance.

TABLE III
MAGNETIC SWITCH SENSOR TEST RESULT DATA

Test To-	Distance (mm)	Logic Output	Sensor Detection Status
1	5	LOW (0)	Inactive
2	10	LOW (0)	Inactive
3	15	LOW (0)	Inactive
4	20	HIGH (1)	Active Sensor
5	>20	HIGH (1)	Active Sensor

Based on the test results, the magnetic switch sensor shows a LOW output at a distance of 5-15 mm, and turns HIGH when the distance reaches 20 mm or more. This indicates that the sensor's sensitivity limit is in the range of 20 mm, where the door is considered open.

D. Testing the PIR Sensor

PIR sensor tests were conducted to measure the effectiveness of motion detection at various distances and angles. Tests were conducted with human movement from a distance of 1 to 5 meters at three different angles, namely 0°, 45°, and 90°. Each combination of distance and angle was tested once, resulting in a total of 15 test scenarios.

Figure 10. Testing the PIR sensor

The results of testing the PIR sensor against various combinations of distance and angle are then recorded and summarized in Table IV below.

TABLE IV
PIR SENSOR TEST RESULT DATA

No	Test Distance	Face Angle (°)	Motion Detection
1	1 meters	0°	Detected
		45°	Detected
		90°	Detected
2	2 meters	0°	Detected
		45°	Detected
		90°	Detected
3	3 meters	0°	Detected
		45°	Detected
		90°	Detected
4	4 meters	0°	Detected
		45°	Detected
		90°	Detected

		0°	Detected
5	5 meters	45°	Not Detected
		90°	Detected

E. LoRa Communication Testing of Sender and Receiver Devices

Based on the data in Table V, all LoRa sending devices in the three houses successfully transmitted data to the receiving device at the security post without any data loss. The buzzer response is active whenever the PIR sensor or magnetic switch detects activity (logic 1), and is inactive when there is no detection (logic 0). The test was conducted three times for each house, and the results showed that all data was received correctly and the buzzer was active according to the sensor conditions. This shows that the LoRa communication system works well and the system responds accurately to the sensors. The success rate of data transmission during the test has been recorded thoroughly. A summary of the results can be seen in Table V below.

TABLE V
LORA COMMUNICATION TEST RESULT DATA

Home Name	Sensor Status		Delivery Status	Buzzer Response
	Magnetic Switch	PIR Sensor		
Home 1	1	0	Success	Active
	0	1	Success	Active
	1	1	Success	Active
	0	0	Success	Active
Home 2	1	0	Success	Active
	0	1	Success	Active
	1	1	Success	Active
	0	0	Success	Active
Home 3	1	0	Success	Active
	0	1	Success	Active
	1	1	Success	Active
	0	0	Success	Active

F. Testing System Control Commands via Telegram

Tests were conducted to ensure the system could respond appropriately to commands sent via the Telegram app. The tested commands include activation and deactivation of the system in each house using formats such as /ON1 and /OFF1, as well as system status requests. The test results show that all commands are successfully executed with appropriate responses, indicating that communication between the user and the system via Telegram is running well and stable.

In Figure 11, the Telegram application interface used for system control commands is presented. This figure shows how users, particularly security officers, can interact with the system remotely by sending predefined commands such as activation, deactivation, and status checking for each house. The interface provides a simple and intuitive command structure, allowing the system to be controlled without requiring physical access to the security post equipment.

The control mechanism illustrated in Figure 11 demonstrates the integration between the IoT system and cloud-based messaging platforms. By utilizing Telegram as the control interface, the system enables real-time interaction and flexibility, ensuring that security personnel can manage the system efficiently even when they are not physically present at the monitoring location.

Figure 11. Telegram app view

The results of testing control commands via Telegram are presented in Table VI to show the system response to each command sent.

TABLE VI
TELEGRAM CONTROL COMMAND TEST RESULTS

No	Telegram Commad	Function Command	Response System	Status
1	/OFF1	Disable home system 1	Home 1 Disabled	Success
2	/ON1	Activate home system 1	Home 1 activated	Success
3	/OFF2	Disable home system 2	Home 2 Disabled	Success
4	/ON2	Activate home system 2	Home 2 activated	Success
5	/OFF3	Disable home system 3	Home 3 Disabled	Success
6	/ON3	Activate home system 3	Home 3 activated	Success
7	/status	Checking the status of the entire system	Display system status	Success

G. Telegram App Notification Testing

This test aims to ensure the system can automatically send notifications to the Telegram application when the sensor detects suspicious activity. Such activity includes movement from a PIR sensor or an open door from a magnetic switch sensor. Each notification was tested to assess the speed and accuracy of the message received. As a result, the system successfully sent alert messages that matched the conditions detected at home.

Figure 12 shows the Telegram notification interface that displays alert messages generated automatically by the security system. This figure illustrates how warning messages are delivered to users when suspicious activity is detected, including notifications for door opening, motion detection, or simultaneous activation of both sensors. The notification content is designed to be clear and informative, enabling quick understanding of the threat condition.

Figure 12. Telegram app view

The results of this test are summarized in Table VII which displays the system response time and the content of the notification message received through the Telegram application.

TABLE VII
TELEGRAM NOTIFICATION TEST RESULTS

Home Name	Sensor Status		Delay (sec)	Message Sent to Telegram
	Magnetic Switch	PIR Sensor		
Home 1	1	0	02.70	WARNING! Home 1 : - Door Open!!!
	0	1	10.48	WARNING! Home 1 : - Movement Detected!!!
	1	1	03.95	WARNING! Home 1: DANGER! Both sensors detected a threat!
	0	0	-	No notification
Home 2	1	0	03,20	WARNING! Home 2 : - Door Open!!!
	0	1	13.49	WARNING! Home 2 : - Movement Detected!!!
	1	1	06.23	WARNING! Home 2: DANGER! Both sensors detected a threat!
	0	0	-	No notification
Home 3	1	0	07.53	WARNING! Home 3 : - Door Open!!!
	0	1	08.50	WARNING! Home 3 : - Movement Detected!!!
	1	1	06.87	WARNING! Home 3: DANGER! Both sensors detected a threat!
	0	0	-	No notification

Based on the results in Table VII, the system successfully sends messages according to the sensor conditions. If the magnetic switch sensor is active, the message "Door Open!!!" is sent; if the PIR sensor detects movement, the message "Movement Detected" is sent; and if both are active, the message "DANGER! Both sensors detect threat" is sent. Conversely, if there is no activity (sensor is 0), no message is sent. The sending time (delay) ranges from 2.7 to 13.49 seconds, depending on network conditions and connection to the Telegram server.

H. Testing LoRa Non Line of Sight (NLoS) Conditions

LoRa transmission testing in Non-Line of Sight (NLoS) conditions is carried out to determine the effective distance of data transmission when there are physical obstacles. The test uses the LoRa RA-02 module at a frequency of 433 MHz, 3 dBi antenna, spreading factor 7, and 125 kHz bandwidth. The test conditions involved obstructions such as buildings and trees, with the distance between the sender and receiver varied from 10 to 120 meters.

TABLE VIII
TEST RESULT DATA ON HOME 1

Trial To-	Distance (m)	RSSI (dBm)	SNR (dB)
1	10	-63	9.25
2	20	-83	9.25
3	30	-86	8.25
4	40	-90	3.50
5	50	-90	3.25
6	60	-94	-4.75
7	70	-95	-5.25
8	80	-99	-9.50
9	90	-100	-2.00
10	100	-100	-11.50
11	110	-99	-2.00
12	120	-102	-7.50

Table VIII presents the results of LoRa communication testing under Non-Line of Sight (NLoS) conditions for Home 1. The table shows a gradual decrease in RSSI and SNR values as distance increases, reflecting signal attenuation caused by physical obstacles.

TABLE IX
TEST RESULT DATA ON HOME 2

Trial To-	Distance (m)	RSSI (dBm)	SNR (dB)
1	10	-61	9.50
2	20	-79	9.25
3	30	-86	9.00
4	40	-87	7.50
5	50	-91	1.75
6	60	-91	-4.50
7	70	-95	-9.25
8	80	-98	-8.50
9	90	-99	-6.25
10	100	-100	-8.75
11	110	-100	-6.50
12	120	-103	-8.00

Table IX shows the LoRa communication test results under NLoS conditions for Home 2. Similar to Table VIII, the data indicate signal degradation with increasing distance, although data transmission remains successful up to 120 meters.

TABLE X
TEST RESULT DATA ON HOME 3

Trial To-	Distance (m)	RSSI (dBm)	SNR (dB)
1	10	-68	9.75
2	20	-86	8.50
3	30	-85	7.75
4	40	-98	-7.25
5	50	-96	-6.00
6	60	-94	-7.50
7	70	-98	-8.25
8	80	-99	-9.75
9	90	-99	-2.50
10	100	-101	-10.25
11	110	-101	-8.25
12	120	-102	-9.75

The test results show that all houses experience a decrease in signal quality as the distance increases. In House 1, the RSSI dropped from -63 dBm to -102 dBm, and the SNR from 9.25 dB to -7.50 dB. House 2 shows a decrease from -61 dBm and 9.50 dB to -103 dBm and -8.00 dB, while House 3 from -68 dBm and 9.75 dB to -102 dBm and -9.75 dB. The decrease in SNR to negative began to appear after a distance of 50 to 60 meters, indicating signal degradation due to physical obstacles. Even so, data can still be received up to 120 meters away, proving that LoRa RA-02 remains reliable even in non-ideal environmental conditions.

I. Testing LoRa Line of Sight (LoS) Conditions

LoRa transmission testing in Line of Sight (LoS) conditions is carried out to evaluate the performance of the LoRa RA-02 module when there are no obstacles between the sender and receiver. The signal is sent through an open path without physical interference such as buildings or trees. The test uses a frequency of 433 MHz, a 3 dBi antenna, a spreading factor of 7, and a bandwidth of 125 kHz. Measured parameters include RSSI and SNR at a distance of 10 to 120 meters.

TABLE XI
TEST RESULT DATA ON HOME 1

Trial To-	Distance (m)	RSSI (dBm)	SNR (dB)
1	10	-71	9.75
2	20	-76	9.50
3	30	-80	9.00
4	40	-82	9.25
5	50	-88	8.00
6	60	-91	6.50
7	70	-94	4.75
8	80	-96	3.25
9	90	-92	4.00
10	100	-100	-2.75
11	110	-102	-8.50
12	120	-103	-10.25

Table XI presents the LoRa communication test results under Line of Sight (LoS) conditions for Home 1. The table shows stronger and more stable RSSI and SNR values compared to NLoS conditions, especially at distances below 60 meters.

TABLE XII
TEST RESULT DATA ON HOME 2

Trial To-	Distance (m)	RSSI (dBm)	SNR (dB)
1	10	-71	10.25
2	20	-76	10.00
3	30	-81	9.50
4	40	-84	9.25
5	50	-87	7.75
6	60	-93	4.75
7	70	-90	7.00
8	80	-95	5.25
9	90	-92	5.75
10	100	-96	3.00
11	110	-100	-4.00
12	120	-101	-5.25

Table XII shows the LoRa communication test results under LoS conditions for Home 2. The table indicates reliable signal strength and quality over increasing distances, with gradual degradation occurring at longer ranges

TABLE XIII
TEST RESULT DATA ON HOME 3

Trial To-	Distance (m)	RSSI (dBm)	SNR (dB)
1	10	-79	9.75
2	20	-82	9.25
3	30	-84	9.00
4	40	-85	9.50
5	50	-87	8.50
6	60	-94	4.00
7	70	-94	5.25
8	80	-95	4.25
9	90	-96	2.50
10	100	-99	-0.75
11	110	-100	-6.00
12	120	-104	-10.00

Test results at all three houses showed strong and stable signals up to 50 meters, with RSSI between -71 to -88 dBm and SNR of 8-10 dB. At distances above 60 meters, the signal began to weaken as the RSSI decreased to -104 dBm and the SNR became negative, especially above 100 meters. Despite the degradation, the LoRa module is still able to transmit data well up to 120 meters under LoS conditions.

IV. CONCLUSION

The results show that the LoRa based security system and Telegram notifications can function effectively. The magnetic switch sensor is able to accurately detect an open door when the magnetic distance exceeds 20 mm, while the PIR sensor effectively recognizes movement up to 5 meters from various angles. The system successfully sends data from the house to the security post up to 120 meters away in both LoS and NLoS conditions. Notifications to Telegram are sent with an average delay of 2-13 seconds and control commands such as activation, deactivation, and status checking can be executed properly. Overall, the system is proven to be able to improve response and security in a cluster housing environment.

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