Implementation Internet of Things (IoT) in Fire and LPG Leakage Detection System Based on Esp32 with Multiuser Notification

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Abstract – The community's late realization of the fire is often a cause of the delayed handling of fires. Therefore, a fire detection system that can be monitored remotely is needed to overcome the delay in handling fires. This study aims to create a fire and LPG leak detection system based on ESP32 with multiuser notification through IoT implementation in a Prototype. The system is installed in a miniature room measuring 30cm x 30cm x 30cm. The fire detection system uses KY-026 sensors, the LPG leak detection system uses MQ-6 sensors, and multiuser notification uses Telegram. The study's result showed that the fire detection system can detect fire up to a distance of 820cm, has 100% detection accuracy, and uses two sensors can reduce blind spots. The LPG leak detection system can detect small gas leaks up to a distance of 18cm in a miniature room, has 100% detection accuracy, and uses two MQ-6 sensors can speed up the detection. For sending multiuser notifications via Telegram, it has 100% accuracy and a throughput of 22,785 notifications per minute but has a high jitter of 1,238 seconds and a notification delay of between 1,842 and 1,905 seconds.

Keywords: Internet of Things, ESP32, Fire, LPG Leaks, Multiuser Notifications

I. INTRODUCTION

Fire is one of the disasters that threatens life and the source of life for the community. The impacts caused by fire include loss of life, damage to the surrounding environment, loss of property, and psychological effects on humans. Fires can be caused by several factors, such as natural factors, non-natural factors, and human factors themselves [1]. Fires due to non-natural factors generally occur due to electrical short circuits and leaks in LPG gas pipes [2]. For example, based on data released by the Central Statistics Agency (BPS) of West Jakarta City, from 2015 to 2022, electricity and gas almost always occupy the highest position as causes of fires [3].

The delay in the community in realizing that a fire has occurred in a place is often a problem in handling fires. According to East Java statistical data in 2018, there were 98 cases of fire with material losses reaching more than 100 million rupiah due to delays in handling. The difficulty of firefighters reaching the location of the fire was the cause [4]. When a house or building is uninhabited, a house abandoned by its owner can also cause delays in handling fires. Indoor fire safety systems usually only use APAR (Light Fire Extinguishers), while a fire indication detection system has not yet been implemented, so fires are only discovered when they have spread and cannot be controlled by APAR [5]. Therefore, a fire indication detection system that can also be monitored remotely is needed to overcome delays in handling fires. Under these circumstances, integrating the Internet of Things (IoT) with a fire detection system can be an effective solution.

IoT is a technology that controls and communicates with various other devices using the internet. Through IoT, different electronic devices can be easily connected via the internet so that the internet can meet the needs for addressing and connectivity [6]. These devices are connected to a mesh network and can send information signals [7]. Therefore, IoT can be an effective solution for remote control and monitoring systems, especially in urban areas, because various devices can communicate with each other and exchange information as long as they are connected to the internet network.

Several researchers have previously researched IoT-based fire detection. Rizaldy conducted research and designed a fire early warning system using a hybrid fire sensor and MQ-2. The microcontroller used is Arduino and uses the Wi-Fi module ¬ESP8266. The results of the sensor readings will be sent to the smartphone in the form of notifications and sensor measurement data [8]. Meanwhile, the research conducted by Laksmana and

Ikbar is entitled Design and Construction of Fire Handling and Control Tools Based on Arduino Nano with IoT System. In this study, two microcontroller boards were used, namely Arduino Nano as the system's main controller and Wemos D1 mini for the internet connection. The designed system will provide notifications via Android as a warning indication of fire detection [9].

The results of these studies indicate that IoT can help in delivering early warnings of fires or indications of the cause of fires when the occupants of the house are outside, thereby reducing delays in handling fires. However, these studies have shortcomings, namely, the use of microcontrollers and Wi-Fi modules are still separate. This is due to the limitations of GPIO (General Purpose Input/Output) on the Wi-Fi module used. In addition, the fire warning notification sent is only directed to one user or device, so if the user is negligent, such as being busy, or the device is off, the warning notification is not delivered.

Based on the background that has been described, this study will implement the Internet of Things (IoT) on the ESP32-based fire and LPG gas leak detection system with multiuser notification delivery. ESP32 functions as a microcontroller for the system as well as a Wi-Fi module so that the system becomes more compact and economical. ESP32 also has more GPIOs so that it can be used to integrate more sensors and actuators [10]. Notifications of fire or LPG gas leaks will be sent to several users or multiple users via the Telegram application. This research hopes to provide a more effective fire-handling solution and reduce the community's delay in realizing the occurrence of a fire.

Research Problem

- How can the Internet of Things (IoT) be implemented on an ESP32-based LPG gas leak and fire detection system with multiuser notification delivery?
- What are the results of the performance analysis of the ESP32-based LPG gas leak and fire detection system with multiuser notification delivery in terms of delay, accuracy, throughput, and jitter?

II. METHODS

Figure 1 shows a research flow diagram relating to the methods used by the authors to obtain the required data. The research stage begins with a literature review. In this stage, the author reviews several studies and study journals to identify studies that require further development. The data that has been obtained becomes the basis for researchers to choose a research topic and then formulate the problem.

Hardware Design

This study uses two KY-026 fire sensors and two MQ-6 gas sensors that act as input. The data obtained from these sensors will be processed by the ESP32, which acts as a microcontroller. The results of the sensor readings are processed using programming so that they can be read by humans. The data processed by the ESP32 is the output that will later be sent to the specified smartphone user via the internet network. The output produced is in the form of a warning notification that a fire or LPG gas leak has been detected.

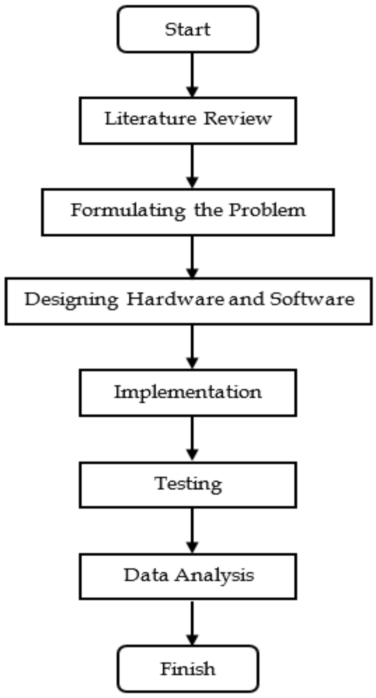


Figure 1. Research Flowchart

Software Design

IoT programming for ESP32-based fire and LPG gas leak detection systems is done using Arduino IDE software. The first program created is a program to read fire and gas sensor data and then display the data on the Arduino IDE serial monitor in analog read form to determine the condition of the surrounding environment. After getting the sensor reading value, the threshold value is determined between normal conditions and fire conditions. For gas sensors, the reading value will be converted into ppm units for measuring LPG gas concentration.

The next program is to send notifications to several smartphone users via the Telegram application. Notifications are sent when a condition occurs where fire or LPG gas leaks are detected. Notifications will be sent repeatedly within a certain time interval until no fire or gas leaks are detected. Smartphone users who receive notifications are only predetermined users.

Implementation

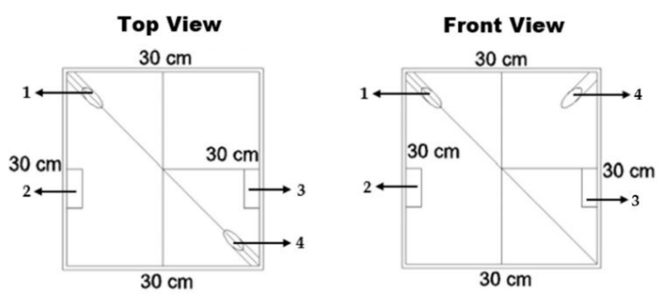


Figure 2. Miniature Room Design

The next stage after completing the hardware and software design is implementation. In this study, the form of implementation of the fire and LPG gas leak detection system is a prototype in a miniature room. In the prototype research for fire detection, it is necessary to adjust the severity and scale of the fire represented in the prototype. Meanwhile, for LPG gas leak detection, adjustments involve the size of the area that can be covered by the sensor and the gas used as a representation of LPG gas leaks. The design of the miniature room is shown in Figure 2.

Caption for Figure 2:

1. KY-026 1
2. MQ-6 1
3. MQ-6 2
4. KY-026 2

Testing

Testing ensures the system's performance and whether it functions properly according to the desired design. The tests that will be carried out are as follows.

- Fire Detection System Testing

The fire detection system test is related to the KY-026 fire sensor. In the KY-026 sensor test, the threshold method is used to determine the analog reading value from the sensor as a condition for detecting fire. The test begins by observing the sensor reading value when there is no fire and continues with the fire condition at different distances from the sensor. The fire position is tested both directly in front of the sensor and at a 45° angle to simulate various detection scenarios. The fire used for the test is a fire from a candle flame. In addition, other fire test media are also used to represent the severity of the fire, such as mosquito coil fire for low-level fires and tissue burning fire for high-level fires. This test will determine the maximum distance the sensor can detect fire.

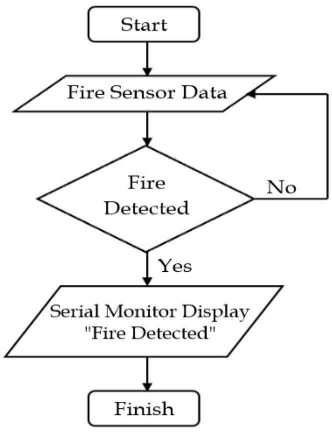


Figure 3. Fire Detection System Testing Flowchart

The next test is to determine the percentage of sensor success in detecting fire by conducting 30 trials. The number 30 is taken because it is often used as a practical standard in experiments [11]. The threshold value obtained from the results of observations in the previous test is used as a reference to determine the condition of the presence or absence of fire. The Arduino IDE serial monitor will display the words "Fire Detected" if the fire is detected. The flow diagram for accuracy testing is shown in Figure 3.

Next, a blind spot test of the sensor is carried out because the prototype of the fire detection system that was made used two fire sensors placed in different positions and directions in a miniature room. This test was carried out to determine whether the sensor has a blind spot in detecting fire with the position and direction as shown in Figure 2. The test was carried out by placing a fire source at several points specified in the miniature room and observing whether each sensor detected a fire. There are 16 test points in the miniature room shown in Figure 4.

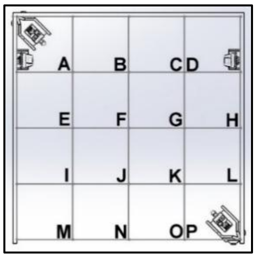


Figure 4. Top View of 16-Point Division on Miniature Room

- LPG Leak Detection System Testing

The LPG gas leak detection system testing is related to the MQ-6 gas sensor. Sensor testing begins by observing the sensor reading value in clean air room conditions to obtain the Ro value (sensor resistance in clean air). The Ro value is needed to measure gas levels in ppm (parts per million) by converting the ADC value of the sensor reading. The equation used to obtain the ppm of gas is as follows [12].

$$Rs = \left(\frac{V_{CC}}{V_{RL}} - 1\right) \times R_L \qquad (1)$$

R_L (Resistance Load) is a 0.93 k Ohm resistor, according to the MQ-6 module.

$$Ro = \frac{Rs}{10} \qquad (2)$$

The value of 10 is obtained from the MQ-6 sensitivity graph based on the datasheet, shown in Figure 5, which is the Rs/Ro ratio in clean air.

$$ppm\ gas = 10^{\wedge}\left(\frac{log\left(\frac{Rs}{Ro}\right) - \log(17{,}1484)}{-0{,}4114}\right) \qquad (3)$$

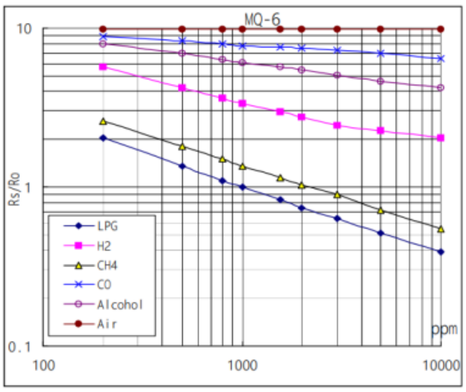


Figure 5. MQ-6 Sensor Sensitivity Characteristics Graph

Next, testing was carried out to determine the maximum distance and percentage of sensor success in detecting gas leaks by conducting 30 trials. The threshold method is used to determine the value of the ppm reading from the sensor as the limit of the detected gas leak condition. The gas leak used in the test comes from three lighters, sprayed for 5 seconds to simulate a leak condition. Observation of the ppm value begins when there is no gas leak and continues with the condition of a gas leak. The threshold value that has been obtained is a marker of LPG gas detected, the Arduino IDE serial monitor will display information on the LPG gas content. The flow diagram of the MQ-6 sensor success percentage test is shown in Figure 6.

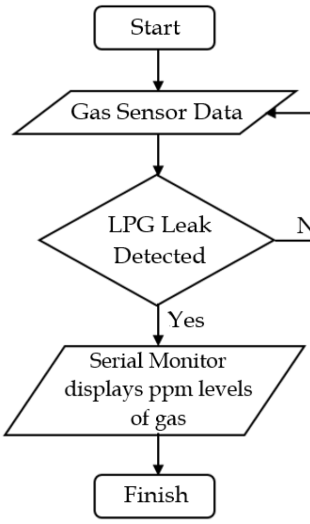


Figure 6. LPG Leak Detection System Testing Flowchart

Then, testing is carried out to determine the response time of the two gas sensors in detecting gas leaks. Testing is carried out by placing the source of the gas leak at several points defined in the miniature room, as shown in Figure 4, and observing the response time of each sensor to detect a gas leak.

- Testing Multiuser Notification Delivery via Telegram

Notification delivery testing is conducted to ensure that the system can send warning notifications when a fire or LPG gas leak is detected. Notification delivery testing includes delivery delay and the completeness of the number of notification recipients. The notification delivery time is calculated from the start of the system detecting a fire or LPG gas leak until the user receives the notification. Testing is also conducted to ensure that all predetermined users receive warning notifications. Three users will receive notifications as a representation of the home environment: the homeowner, immediate family, and neighbors. The flowchart for notification testing is shown in Figure 7.

In addition to the delay and completeness of the number of notification recipients, additional testing will be carried out to determine the performance of notification delivery. Tests carried out include to determine Throughput and Jitter. The throughput value shows how many notifications can be sent and received in one unit of time. If written in the form of an equation, it becomes,

$$Throughput = \frac{Number\ of\ Notifications\ Received}{Total\ Delivery\ Time} \quad (4)$$

Meanwhile, Jitter indicates the variation in delay in data transmission caused by the time difference in sending notifications [13]. If written in the form of an equation,

$$Jitter = \frac{1}{N-1}\sum_{i=1}^{N-1}\left|\Delta t_i - \Delta t_{avg}\right| \quad (5)$$

Δt_i is the time interval between receiving the i-th and (i + 1)-th notifications, while Δt_{avg} is the average of Δt_i. All notification delivery performance tests will be conducted in 30 trials.

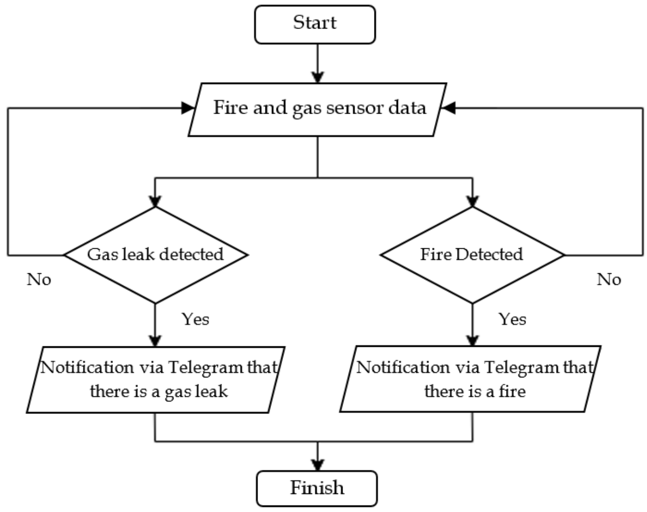


Figure 7. Notification Delivery Testing Flowchart

Data Analysis

The data obtained from testing and observation will then be analyzed. The calculation of the percentage of errors or failures is also carried out to determine the reliability and accuracy of the performance of the system that has been created. The percentage error can be found using the equation below [14].

$$\frac{\text{number of failed attempts}}{\text{total number of attempts}} \times 100\% \quad (6)$$

III. RESULT AND DISCUSSION

The fire detection system uses two KY-026 fire sensors as input, and the gas leak detection system uses two MQ-6 gas sensors as input. Data from the sensors is then processed by the Esp32 DevKit V1 30 Pin, which is connected to Wi-Fi and powered by 5V input from a USB micro cable. The output of the system is a notification of a fire or gas leak sent to the smartphone. Table 1 shows the sensor pinout wiring table with the Esp32 pinout.

After the Esp32 processes the sensor data and a fire or gas leak condition is detected, the system will notify the user's smartphone. The process of sending notifications via Telegram requires the help of a Bot. Telegram Bot creation is done through the BoTFather channel. Users can create new bots or set bots such as profiles, descriptions, and bot names through this channel. After the bot is successfully created, the BoTFather channel will provide a token to access the Telegram HTTP API so that it can be entered into the system program so that the bot can function as desired, namely as a notification distributor. In addition, a Telegram group ID is required that contains all users who have been determined to receive notifications from the Bot. The Telegram group ID can be found through the help of the IDBot channel on Telegram. The ID that has been obtained is then entered into the system program to ensure that the warning notification is sent to the destination.

Table 1. Wiring Sensor with Esp32

Sensor Pinout		Esp32 Pinout
KY-026 1	+	3V3
	-	GND
	A0	D32
KY-026 2	+	3V3
	-	GND
	A0	D33
MQ-6 1	VCC	VIN
	GND	GND
	A0	D34
MQ-6 2	VCC	VIN
	GND	GND
	A0	D35

Once all the system configuration and Telegram bot settings are complete, the next step is to test the system live to ensure that the sensors and notifications work as expected. Testing is done using a prototype designed to accurately simulate real-world conditions. The prototype of the fire and gas leak detection system is in the form of a miniature room measuring 30 cm x 30 cm x 30 cm. The material used for making the miniature room is plywood. The placement of the sensor in the miniature room is adjusted to the design shown in Figure 2. The results of making the prototype can be seen in Figure 8.

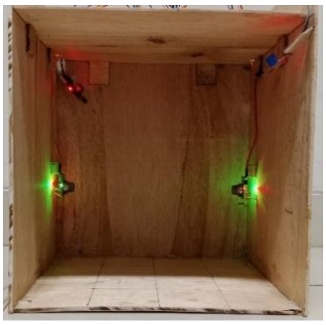


Figure 8. Results of Miniature Rooms Realizations

Fire Detection System Test Results

The observation results show that the ADC value of the KY-026 sensor when there is no fire is 4095, where this value is the largest ADC value of the ADC with a resolution of 10 bits. Furthermore, the results of observations of ADC values under conditions when there is fire are visualized in the form of graphs shown in Figure 9, Figure 10, and Figure 11. There are three types of fire media used, namely mosquito coils, candles, and tissue-burning fires. Mosquito coils as small fires, candle flames as medium fires, and tissue burning fires as large fires. Representation is based on the size of the flame. Mosquito coils do not have a flame but are only in the form of embers with a width x height of ±0.5 x 0.5 cm. Candle flames have a flame measuring ±1 x 3 cm, and tissue-burning fires have a flame measuring ±3 x 15 cm. Table 2 shows an illustration of the fire test media used and also the position of the fire in the maximum distance test of the KY-026 sensor.

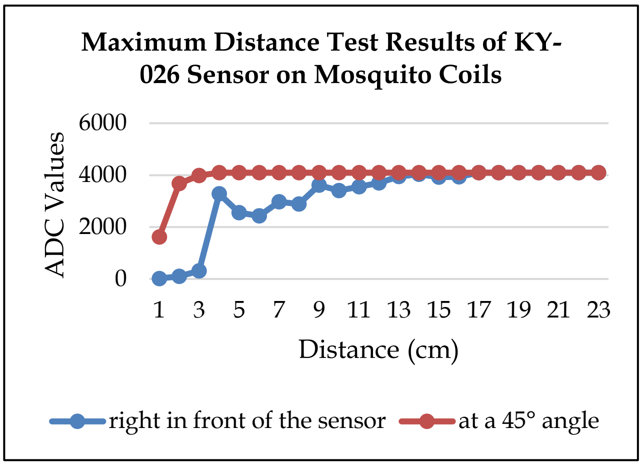


Figure 9. Graph of Distance Test Results on Mosquito Coil

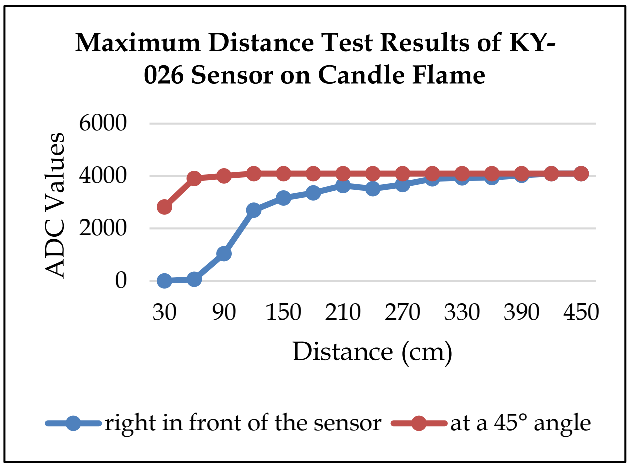


Figure 10. Graph of Distance Test Results on Candle Flame

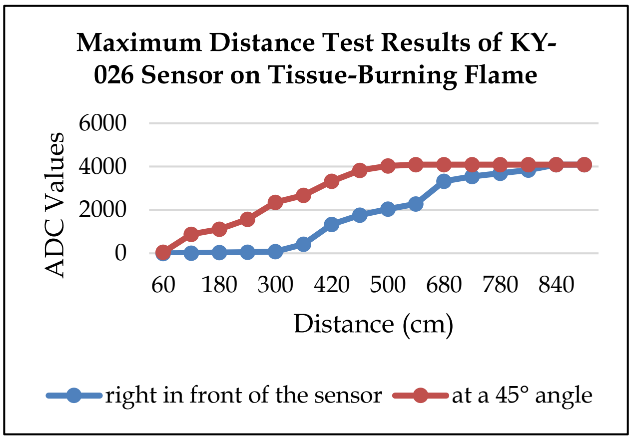
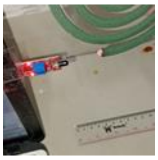
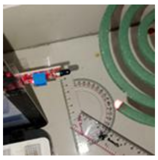


Figure 11. Graph of Distance Test Results on Tissue-Burning Flame

Table 2. Illustration of Maximum Distance Testing of KY-026 Sensor

No.	Fire Test Media	Fire Position	
		Right in front of the sensor	**at a 45° angle**
1	Mosquito Coil 		
2	Candle Flame 		
3	Tissue-Burning Flame 		

From the graphic data in Figure 9, Figure 10, and Figure 11, it can be seen that the maximum distance of fire detection by the sensor is observed by observing the last distance where the ADC value changes from the value when there is no fire. This is because the sensitivity of the sensor to infrared light produced by fire affects the sensor output voltage, which has an impact on changes in the ADC value. The stronger the infrared intensity received by the sensor, the smaller the ADC value. Based on Figure 9, the KY-026 sensor can only detect a mosquito coil fire up to a distance of 16 cm when its position is in front of the sensor and at a distance of 3 cm when its position is 45° from the sensor. This shows that the sensor will not detect mosquito coil fire or cigarette fire as a fire condition if the sensor is placed no less than 16 cm from the fire source. Meanwhile, from Figure 10, it is found that the KY-026 sensor can detect a candle fire up to a distance of 4 m when the fire is directly in front of the sensor and a distance of 1 m when the fire is 45° from the sensor. Then, Figure 11 shows that the KY-026 sensor can detect a tissue-burning fire up to a distance of 8.2 m when the fire position is right in front of the sensor and a distance of 5 m when the fire position is 45° from the sensor. So, in real implementation, the sensor can be placed at a distance of more than 5 meters from the fire source so that the sensor does not detect candle flames or stove flames as a fire condition.

Furthermore, based on the results of the accuracy test, the percentage of the KY-026 fire sensor detection accuracy can be seen from the number of successful sensor detections of fire in 30 trials. Because the system is only installed in a miniature room, the threshold value is taken from the sensor ADC value when detecting a medium-scale fire with a position of 45° from the sensor at a distance of 30 cm. Based on the results of previous tests, the ADC value read in these conditions was 2822. An illustration of the sensor accuracy test is shown in Figure 12. The accuracy test results showed that the KY-026 fire sensor successfully detected a fire 30 times in 30 trials. In addition, the ADC value read on the serial monitor never exceeded the threshold value, meaning there was no error in the program execution. Thus, by using equation (6), it can be said that the KY-026 sensor has an error percentage of

$$\frac{0}{30} \times 100\% = 0\%$$

which also means it has a success percentage of 100%. The accuracy percentage of 100% indicates that the sensor accuracy is excellent in detecting fire.

Figure 12. Illustration of KY-026 sensor detection accuracy test

Next are the results of the blind spot test from the use of two KY-026 sensors placed in different positions and directions in the miniature room. An illustration of the test to determine the sensor blind spot is shown in Figure 13. Of the total 16 fire points, each sensor successfully detected the presence of fire at all test points. This shows that if something blocks one of the sensor's views, the other sensor can still be used to detect the presence of fire so that the fire detection system can still function properly. So, it can be said that the use of two KY-026 fire sensors with a 45° angle installation in opposite corners of the room has no blind spots, thus increasing the reliability of the fire detection system.

Figure 13. Blind Spot Testing Illustration from Using Two KY-026 Sensors

LPG Leak Detection System Test Results

The results of the Ro value reading are displayed on the Arduino IDE serial monitor, and it is found that the Ro value for the sensor is 0.27. Equations (1) and (2) are used as the basis for creating a program to obtain the Ro value. The Ro value obtained is entered into equation (3) to convert the ADC value of the sensor reading into a ppm value. From observations, when there is no gas leak, it was found that the ppm value read was 3.12 ppm. The results of the test are visualized in the form of a graph shown in Figure 14. An illustration of testing for conditions where the sensor is in an open space (outside the miniature room) is shown in Figure 15, and where the sensor is in a closed space (inside the miniature room) is shown in Figure 16.

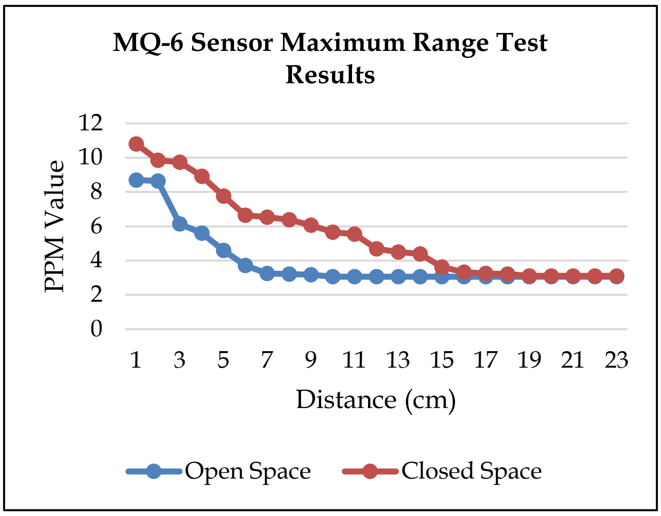


Figure 14. Graph of MQ-6 Sensor Maximum Distance Test Results

Figure 15. Illustration of MQ-6 Sensor Testing in an Open Space

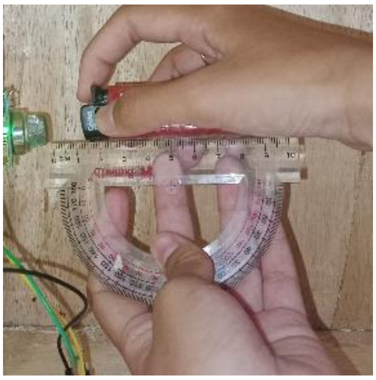


Figure 16. Illustration of MQ-6 Sensor Testing in a Closed Room

Based on the graphic data in Figure 14, it can be seen that the maximum distance of the sensor detects a gas leak by observing the last distance where the ppm value increases from the initial ppm value when there is no gas leak. This is due to the natural properties of gas that decomposes in the air. The further the source of the gas leak is from the sensor, the smaller the ppm value detected by the sensor because the gas decomposes in the air before reaching the sensor. So, it is obtained from Figure 14 that the MQ-6 gas sensor can detect gas leaks produced by three gas lighters to a distance of 9 cm in open spaces and 18 cm in closed spaces. The sensor coverage distance in open spaces is lower than in closed spaces because the gas is more easily decomposed in open spaces.

Next is the result of the sensor accuracy test in detecting gas leaks through 30 trials. In this test, the threshold value is taken from the ppm gas value in the closed room test because the system is only installed in a miniature room. Based on the data in Figure 14, the last ppm value indicating a gas leak is 3.21 at a distance of 18 cm. Meanwhile, the PPM value when the initial condition is no gas leak is 3.12. So, the threshold value is taken from the average value between 3.12 and 3.21, which is 3.16. The accuracy test is carried out by spraying gas from three matches for 5 seconds at a distance of 18 cm from the sensor. An illustration of the accuracy test is shown in Figure 17. After testing, it was found that out of 30 trials, the MQ-6 sensor successfully detected gas leaks 30 times with a range of ppm levels detected of 3.18 to 3.53 ppm within a time of 3 to 11 seconds. Thus, using equation (6), it can be said that the MQ-6 sensor has an error percentage of

$$\frac{0}{30} \times 100\% = 0\%$$

which means it has a success percentage of 100%. This shows that the sensor has very good accuracy in detecting gas leaks.

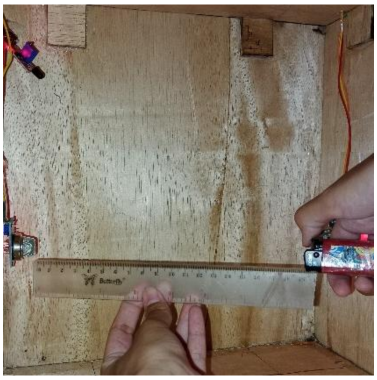


Figure 17. Illustration of MQ-6 Sensor Detection Accuracy Test

Next, to test the response time of two MQ-6 sensors, the lighter is directed as much as possible to both sensors so that the gas that comes out is not concentrated on one sensor only. Figure 18 illustrates the response time test of two MQ-6 sensors. The recording results for the sensor response time test are shown in Table 3.

Table 3. MQ-6 Sensor Response Time Test Results

Gas Leak Point	MQ-6 1 Response Time (s)	MQ-6 2 Response Time (s)
A	17,89	5,31
B	11,07	4,51
C	9,57	2,37
D	16,49	1,69
E	14,51	4,49
F	6.31	14.26
G	5.94	11.83
H	4.01	4.01
I	4.14	16.27
J	5.38	12.28
K	5.78	13.03
L	6.09	9.40
M	5.57	17.22
N	4.27	13.08
O	7.42	14.69
P	12.25	9.24

Figure 18. Illustration of Response Time Testing of Two MQ-6 Sensors

Based on the data recorded in Table 3, the response time of each MQ-6 sensor can be seen. From a total of 16 test points, at each LPG gas leak position point, each sensor has a faster response time than the other sensors. This shows that using two MQ-6 gas sensors with different positions can help speed up the system in detecting LPG gas leaks, thereby increasing system reliability. In addition, based on Table 3, it is shown that the fastest detection response, which is under 3 seconds, occurs when the position of the gas leak source is at test points C and D which are 2 cm to 10 cm from the nearest sensor. So, in real implementation, the gas sensor can be placed close to the LPG, namely at a distance of no more than 10 cm, so that the system can detect gas leaks quickly.

Telegram Notification Delivery Test Results

30 delay and accuracy trials were conducted, divided into 10 fire notification trials, 10 LPG gas leak notification trials, and 10 fire and LPG gas leak notification trials. Figure 19 shows the results of notifications that were successfully sent to three users, and the results of the delay and accuracy test of notification delivery can be seen in Table 4, Table 5, and Table 6.

Table 4. Results of Fire Notification Delivery Testing

Trial No.	Serial Monitor Arduino IDE	Telegram Recipients			Delay (s)
		1	2	3	
1	Fire detected	✓	✓	✓	1.939
2	Fire detected	✓	✓	✓	1.675
3	Fire detected	✓	✓	✓	1.911
4	Fire detected	✓	✓	✓	1.814
5	Fire detected	✓	✓	✓	1.871
6	Fire detected	✓	✓	✓	1.885
7	Fire detected	✓	✓	✓	1.834
8	Fire detected	✓	✓	✓	1.698
9	Fire detected	✓	✓	✓	1.902
10	Fire detected	✓	✓	✓	1.894
Average Delay (s)					**1.842**

Table 5. Gas Leak Notification Delivery Test Results

Trial No.	Serial Monitor Arduino IDE	Telegram Recipients			Delay (s)
		1	2	3	
1	Gas Leak Detected	✓	✓	✓	1.900
2	Gas Leak Detected	✓	✓	✓	1.906
3	Gas Leak Detected	✓	✓	✓	1.902
4	Gas Leak Detected	✓	✓	✓	1.864
5	Gas Leak Detected	✓	✓	✓	1.814
6	Gas Leak Detected	✓	✓	✓	1.816
7	Gas Leak Detected	✓	✓	✓	2.001
8	Gas Leak Detected	✓	✓	✓	1.761
9	Gas Leak Detected	✓	✓	✓	1.898
10	Gas Leak Detected	✓	✓	✓	1.904
Average Delay (s)					**1.877**

Table 6. Fire and Gas Leak Notification Delivery Test Results

Trial No.	Serial Monitor Arduino IDE	Telegram Recipients			Delay (s)
		1	2	3	
1	Fire and Gas Leak Detected	✓	✓	✓	1.822
2	Fire and Gas Leak Detected	✓	✓	✓	1.904
3	Fire and Gas Leak Detected	✓	✓	✓	1.903
4	Fire and Gas Leak Detected	✓	✓	✓	1.905
5	Fire and Gas Leak Detected	✓	✓	✓	1.965
6	Fire and Gas Leak Detected	✓	✓	✓	1.759
7	Fire and Gas Leak Detected	✓	✓	✓	1.877
8	Fire and Gas Leak Detected	✓	✓	✓	2.014
9	Fire and Gas Leak Detected	✓	✓	✓	1.900
10	Fire and Gas Leak Detected	✓	✓	✓	1.997
Average Delay (s)					**1.905**

Figure 19. Results of Sending Notifications via Telegram

Based on Table 4, Table 5, and Table 6, the accuracy and delay of notification delivery can be seen. Table 4 shows that the average delay for sending fire notifications is 1.842 seconds. Table 5 shows the average delay for sending LPG gas leak notifications is 1.877 seconds, and Table 6 shows the average delay for sending fire and LPG gas leak notifications is 1.905 seconds. From the three sets of data, it can be seen that the fire notification with the fewest characters has the fastest delivery delay among other notifications. In addition, the three tables also show that the notification was successfully sent to all users 30 times out of 30 attempts, and the notification received by the user is equal to that displayed on the serial monitor. So, by using equation (6), it is found that the percentage of notification delivery failure is

$$\frac{0}{30} \times 100\% = 0\%$$

Which means it has a success or accuracy percentage of 100%. Every time a fire or LPG gas leak is detected, the notification is successfully sent to all recipients and is accurate with the actual conditions. Next, Table 7 shows the results of throughput and jitter testing carried out by creating conditions for fire and LPG gas leaks so that the system sends notification messages of fire and LPG gas leaks continuously with a time between notifications of 100 ms. This condition is maintained until 30 notifications are sent from the system.

Table 7. Throughput and Jitter Test Results

i-th Notification	Delivery Time	Reception Time	Δt_i (s)	$\lvert\Delta t_i - \Delta t_{avg}\rvert$(s)
1	09:54:45.316	09:54:47.080	1.950	0.703
2	09:54:47.173	09:54:49.030	1.959	0.694
3	09:54:49.123	09:54:50.989	1.907	0.746
4	09:54:51.083	09:54:52.896	2.088	0.565
5	09:54:53.034	09:54:54.984	1.949	0.704
6	09:54:55.077	09:54:56.933	1.808	0.845
7	09:54:57.025	09:54:58.741	2.043	0.61
8	09:54:58.834	09:55:00.784	1.959	0.694
9	09:55:00.879	09:55:02.743	2.039	0.614
10	09:55:02.835	09:55:04.782	1.949	0.704
11	09:55:04.875	09:55:06.731	2.039	0.614
12	09:55:06.825	09:55:08.770	1.946	0.707
13	09:55:08.909	09:55:10.716	1.956	0.697
14	09:55:10.810	09:55:12.672	8.587	5.934
15	09:55:12.763	09:55:21.259	8.256	5.603
16	09:55:21.399	09:55:29.515	9.069	6.416
17	09:55:29.654	09:55:38.584	1.948	0.705
18	09:55:38.676	09:55:40.532	1.925	0.728
19	09:55:40.626	09:55:42.457	1.856	0.797
20	09:55:42.595	09:55:44.313	1.946	0.707
21	09:55:44.406	09:55:46.259	2.046	0.607
22	09:55:46.353	09:55:48.305	2.042	0.611
23	09:55:48.399	09:55:50.347	1.962	0.691
24	09:55:50.441	09:55:52.309	1.958	0.695
25	09:55:52.404	09:55:54.267	1.948	0.705
26	09:55:54.359	09:55:56.215	1.906	0.747
27	09:55:56.308	09:55:58.121	1.992	0.661
28	09:55:58.259	09:56:00.113	2.004	0.649
29	09:56:00.207	09:56:02.117	1.908	0.745
30	09:56:02.256	09:56:04.025	-	-
Average			**2.653**	**1.238**

Based on the test results shown in Table 7, it can be seen that from the first trial of sending notifications to the end of receiving notifications on the 30th trial, it took 1 minute 19 seconds or 79 seconds. So, by using equation (4) we get

$$Throughput = \frac{30}{79} = 0.379\ notifications/second$$

or 22.785 notifications/minute. The throughput of 22.785 notifications/minute for sending fire detection notifications and LPG gas leaks still shows high capacity. The system is still quite good at sending notifications in large quantities.

Next, Table 7 also shows the delay in receiving notifications on the i-th and i+1-th trials written in the Δti column. It can be seen that the average of Δt_i, or called Δt_{avg}, is 2.653 seconds. Then, each difference between Δti and Δtavg is written in the $\lvert\Delta t_i - \Delta t_{avg}\rvert$ column. So, according to equation (5), the Jitter value, which is the average of $\lvert\Delta t_i - \Delta t_{avg}\rvert$, is 1.238 seconds. A jitter of 1.238 seconds indicates that there is a significant difference between the delivery time of one notification and another, which can cause the notification to arrive too late. It can be seen in Table 7 that in the 15th to 17th trials, the notification delivery delay reached 9 seconds. This can happen because the delivery delay between notifications of 100 ms exceeds the rate limit of Telegram, which is 20 messages per minute [15]. Therefore, it is better to adjust the delay between notifications to reduce jitter.

IV. CONCLUSION

The conclusions of this study are as follows.

- The ESP32-based fire detection system and LPG gas leak detection system with multiuser notification delivery through the implementation of the Internet of Things (IoT) were successfully created using Telegram as an IoT platform. In the fire detection system, the KY-026 sensor is used, which is able to detect fire up to a distance of 8.2 m and has a detection success percentage of 100%. In addition, the use of two KY-026 sensors, with the sensors positioned 45° from the corner of the room and opposite each other, can increase the detection range so that the fire detection system has no blind spots. Meanwhile, in the LPG gas leak detection system, the MQ-6 sensor is used, which can detect 3 ppm of LPG gas at a distance of 10 cm and has a detection success percentage of 100%. In addition, the use of two MQ-6 sensors with different placements can help accelerate the detection of LPG gas leaks.
- The performance of sending multiuser notifications via Telegram for the ESP32-based fire and LPG gas leak detection system, namely,
    - The average notification delivery delay reached 1.905 seconds, indicating that the delivery time was relatively fast for each notification.
    - The accuracy of notification delivery success was 100%, so it is certain that all users receive notifications.
    - Throughput reached 22,785 notifications/minute.

This shows that the system's ability to deliver large numbers of notifications is still quite good.

- A jitter of 1.238 seconds indicates that there is a significant difference between the delivery times of one notification and another, which can result in notifications arriving too late.

Here are some suggestions for implementing this research in real conditions.

- The installation of the KY-026 sensor on the ceiling or upper wall corner with a 45° slope for optimal coverage with a distance of no more than 8 meters from the source of fire risk or no more than 5 meters for better detection of smaller fires.
- Placement of the MQ-6 sensor in the area around the LPG no more than 10 cm and a position higher than the LPG so that the system can detect gas leaks quickly.
- The system is made to have automatic calibration capabilities so that the system can determine the threshold value automatically when it is first used in a different environment.
- The delay between notifications is adjusted to the rate limit from Telegram to avoid instability in sending notifications.

Here are some suggestions for further research.

- Addition of a backup system for sending notifications via SMS if Wi-Fi is off.
- Develop a Machine Learning model with a sensor database to detect anomalous patterns before a fire occurs so that it can provide earlier warnings.

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