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IoT-based Automatic Environmental Monitoring and Regulation System for Medicine Storage with Integration of Temperature, Humidity, and Air Quality Sensors

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Abstract

Due to unmaintained environmental conditions, such as temperature, humidity, and air quality, drug storage rooms are prone to damage. This research develops an automated environmental monitoring and regulation system for drug storage rooms using Internet of Things (IoT) technology. The system integrates temperature (DHT22), humidity, and dust (GP2YX1014AU0F) sensors connected to NodeMCU ESP8266 microcontroller and Blynk application for real-time monitoring and control. The sensors are controlled through NodeMCU ESP8266 as the microcontroller. System testing shows that the temperature and humidity sensors have high accuracy, with an average of 96% temperature and 86% humidity. The system can detect changes in temperature and humidity quickly with a response time between 4 to 7 seconds. The test results also show that the system can control devices, such as fans and humidifiers, to maintain the environmental conditions of drug storage following the standards. This research supports previous theories regarding the use of IoT in environmental monitoring. It extends the application by adding air quality (dust) measurements, contributing to managing drug storage rooms. This research's main contribution is integrating air quality (dust) measurements into IoT-based monitoring, which is rarely applied to similar systems. The system offers a practical solution for automatically optimizing drug storage and can be implemented in the pharmaceutical sector and other environments that require real-time condition monitoring.

Keywords: IoT, medicine storage room, temperature sensor, humidity, air quality.

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I. INTRODUCTION

A drug storage room is a critical area used to store various types of medical drugs, which are highly susceptible to damage due to inadequate environmental conditions. To guarantee the quality of medicines stored for a long period, it is important to consider ideal conditions that meet established storage standards. According to the Ministry of Health of the Republic of Indonesia regulation in 2007, good air circulation is a major factor affecting the quality of medicine storage [1], [2]. Air circulation changes can impact various forms of medicine, such as tablets, liquids, and injections. For example, lack of supervision of the storage space can cause problems with the stability of air circulation. In addition, lighting factors, especially direct light exposure, can also affect the condition of drugs. The Indonesian Ministry of Health's Standard Regulation No. 5 of 2014 stipulates that drug storage temperatures should be between 15-30°C and that humidity should not exceed 73% [3]. Another study showed that the ideal drug storage room temperature standard is 25°C with a relative humidity of around 25% [4], while another study indicated an optimal temperature of around 18°C and 65% humidity [5].

Problems in the storage of pharmaceutical products, especially in pharmacies, are a major concern because they can affect the quality of the product until it reaches the consumer [6]. Factors such as temperature, humidity, cleanliness, lighting, and ventilation play an important role in maintaining the physical integrity of drugs and are critical aspects of storage conditions [2], [6], [7], [8]. Nonetheless, conventional temperature and humidity monitoring methods often face obstacles, including delays in recording and a lack of data accuracy [9]. Applying Internet of Things (IoT) technology using microcontroller control devices and temperature, humidity, and air quality sensors integrated into the IoT system is an innovative step in overcoming these obstacles. Applying IoT raises the need for continuous monitoring of the temperature and humidity of the drug storage room to prevent the risk of drug degradation [10], [11].

Several studies have developed solutions to temperature and humidity problems based on Internet of Things (IoT) technology, including a research [12] Warehouse Management System (WMS) to improve the operational efficiency of pharmaceutical warehouses with an integrated temperature and humidity monitoring system. As for research [13], they are implementing flexible and optical-based sensors for in situ temperature and humidity measurements in various settings, including electrochemical cells. Research [14] explored modeling and controlling temperature and humidity in heating, Ventilating, and Air Conditioning (HVAC) systems to optimize humidity control in hot and humid climatic environments. In addition, IoT solutions using devices such as microcontrollers like Arduino and the Blynk IoT cloud enable real-time monitoring and control of temperature and humidity in storage rooms to maintain optimal temperature and humidity to reduce the risk of drug degradation [15], [16], [17]. In terms of the use of sensors and control devices, generally using DHT11, DHT22, and SHT30 sensors, with NodeMCU ESP8266 controllers as in the results of research [6], [18] showed an average temperature measurement error factor of 0.043ºC with an accuracy of 99.76%, which confirms the reliability of the system. Other research, such as in [9], shows that conventional approaches to monitoring temperature and humidity still face significant obstacles, such as delays in recording and lack of data accuracy. The results achieved from implementing the IoT-based temperature and humidity monitoring system with high accuracy reached 98.49% for temperature and 87.78% for humidity. In addition, the need to monitor the temperature and humidity of drug storage rooms is becoming increasingly apparent, especially in the context of the standard temperature not exceeding 25°C and humidity not exceeding 60% [10].

This research was conducted based on several studies related to the critical role of pharmaceutical product storage in maintaining its quality until it reaches consumers [19], focusing on monitoring the temperature and humidity of drug storage rooms through IoT technology and improving the accuracy of temperature and humidity monitoring and control systems in drug storage environments. Based on the above-related research, measurements of air cleanliness levels, such as dust levels, should be added. So, this study created an IoT system to monitor temperature and humidity in the drug storage room and measure air quality through room dust. This research uses DHT 22 sensors for temperature, humidity, and dust using GP2YX1014AU0F sensor, control with NodeMCU ESP8266 microcontroller. It monitors the room's temperature, humidity, and dust with limit values. In addition, this monitoring system controller displays information in a 16x2 LCD, red and green LEDs, and a buzzer. The difference in this research is that in addition to adding a dust sensor, this system is equipped with a DC Fan and humidifier on/off to mitigate rising temperature and humidity. With significant accuracy values from the results of this study, it is expected to make a valuable contribution to improving the quality and safety of drug storage in various environments and providing a solid foundation for developing IoT-based temperature and humidity monitoring technology in the future.

The organization of this paper is as follows: Section 2 discusses the research methodology used, followed by Section 3 which describes the results and discussion in detail covering the system performance analysis. Finally, conclusions and recommendations for further development are described in Section 5.

II. RESEARCH METHOD

This research adopts an experimental approach with design and development to design and implement an automated environmental monitoring and regulation system using Internet of Things (IoT) technology. The research method is divided into several interrelated stages, as in Figure 1.

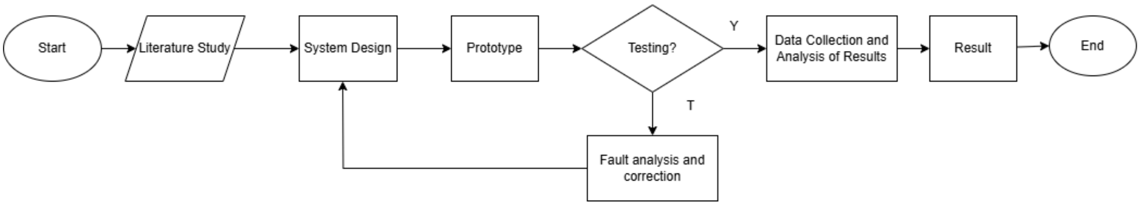


Fig. 1. Research Method Flow

A. Literature Study

The initial stage of this research involved collecting and analyzing literature related to environmental monitoring systems, IoT technology, and drug storage standards. The information obtained was used to formulate an effective system design that meets the needs of drug storage. This literature study resulted in functional requirements and system specifications.

Table I. FUNCTIONAL REQUIREMENTS AND SYSTEM SPECIFICATIONS

No	Functional Requirements	System Specifications
1	The system should be able to monitor the temperature and humidity in the medicine storage room in real-time using the installed sensors.	• Temperature and Humidity using DHT22 Sensor with Temperature Range: -40°C to 125°C, Humidity Range: 0% to 100% RH, Accuracy: ±0.5°C for temperature and ±2% RH for humidity. • Optical Dust Sensor using GP2YX1014AU0F sensor, Can detect particles with a size of 0.5 µm to 10 µm. Effective detection distance: 1 m to 5 m, depending on particle concentration.
2	The data collected should be displayed directly	LCD 16x2
3	The system should be able to automatically adjust the cooling device based on the data obtained from the sensors to keep the temperature and humidity within the specified range.	The NodeMCU ESP8266 Microcontroller and Actuator uses a Relay to control the cooling device, Allowing control of devices with power up to 10A.
4	The system should notify the user if the temperature or humidity exceeds the preset limits on the mobile application.	Cloud IoT Blynk
5	An alarm should sound or alert the mobile app when environmental conditions are at risk.	Buzzer

B. System Design

Based on the literature study, the system design considers the main components required, such as temperature and humidity sensors, actuators for ventilation and cooling settings, and communication modules to transmit data in real-time. A system architecture diagram will illustrate the relationship between these components.

As can be seen in Figure 1, the system uses a power supply that converts 220V AC into 5V DC to supply stable power to all components. At the system's center is an ESP8266 microcontroller that serves as the device's data processor and controller. This microcontroller collects information from two main sensors: the DHT22 sensor, which measures temperature and humidity, and the GP2YX1014AU0F sensor, which detects the presence of dust particles in the air. The data obtained from these sensors is displayed on a 16x2 LCD, providing real-time information to the user about the environmental conditions. In addition, the system is equipped with indicator LEDs and a buzzer that provides a warning if the environmental parameters are outside the set limits.

Environmental regulation is done through relays that control the fan and humidifier; the fan increases air circulation and lowers the temperature, while the humidifier keeps the humidity at an optimal level. The system is also connected to an IoT cloud platform, which enables remote monitoring and control via a smartphone app. With this design, the system is expected to provide an effective and responsive solution to maintain the quality and safety of drugs during the storage process and provide convenience in monitoring and controlling the required environmental conditions.

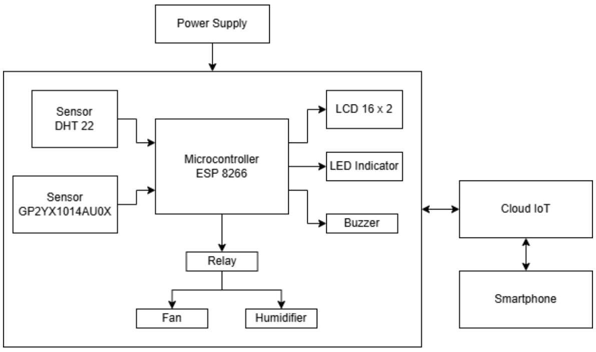


Fig. 2. Architecture of the proposed IoT System

C. *Prototyping*

The development of the prototype automated environmental monitoring and regulation system began with the selection of appropriate components, including the NodeMCU ESP8266 microcontroller, DHT22 temperature and humidity sensor, and GP2YX1014AU0F dust sensor, which was chosen for their respective capabilities and high accuracy in monitoring environmental conditions. After selection, the hardware was installed based on the designed schematics, ensuring all components were connected properly. Next, software was developed using the C++ programming language in the Arduino IDE, which includes logic to read data from sensors, control relays for fans and humidifiers, and transmit data to the cloud server using the MQTT protocol. The prototype of the device can be seen in Figure 3.

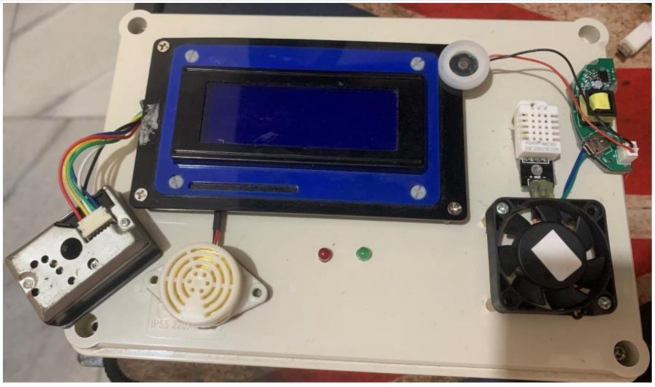


Fig. 3. Hardware Prototype

D. *Testing*

Testing of the prototype automatic environmental monitoring and regulation system is carried out to evaluate the performance and effectiveness of the system in maintaining the ideal drug storage conditions. The testing process includes several stages: Functional, Responsive, and Accuracy Testing. Functional testing aims to ensure that all system components function as expected. This includes individual testing of each sensor (DHT22 and GP2YX1014AU0F) to verify their ability to measure temperature, humidity, and dust content. Furthermore, the functions of the NodeMCU microcontroller are tested to ensure that it can read the data from the sensors and control the relays for the fan and humidifier correctly. Each implemented function, such as data display on the LCD, notification from the buzzer, and device control via the IoT cloud, was tested to ensure that they work according to the set specifications. After functional testing, responsive testing was conducted to evaluate the speed and accuracy of the system in responding to changes in environmental conditions. This responsive test aims to measure the sensor response timesensor's response time to a given rapid change in temperature or humidity. In this stage, the temperature and humidity conditions are changed gradually, and the system is monitored to see how quickly and accurately new data is obtained and the control actions taken by the system. For example, when the temperature exceeds a predetermined threshold, the system's activating fan response should be recorded. The results of this test give an idea of how well the system can maintain the desired storage conditions. Accuracy testing using equation (1) aims to determine how precise the measurements taken by the sensor are under different conditions. The DHT22 sensor is tested by comparing the temperature and humidity readings against a calibrated standard gauge. The dust level measurement accuracy of the GP2YX1014AU0F sensor was also tested to ensure reliable data. The results of these tests were calculated in terms of average measurement error and percentage accuracy, giving a clear indication of the sensor's performance in the context of drug storage.

$$Accuracy = \left(1 - \frac{|\Delta|}{\mathrm{R}}\right) x\ 100\% \tag{1}$$

Dimana:
Δ = difference value
R= Reference Measurement Value

III. RESULTS AND DISCUSSION

In this study, a prototype of an automatic environmental monitoring and regulation system for drug storage rooms was successfully built and tested.

1. *Temperature and Humidity Sensor Testing Results*

Functional, responsive, and accurate testing on the DHT 22 sensor resulted in the system functioning properly. This test is done by comparison measurement using a Hygrometer as a reference value. The DHT22 sensor successfully accurately measured temperature and humidity, while the GP2YX1014AU0F sensor provided consistent dust level readings. The test was conducted for 20 measurements.

The temperature test results in Table II show that the temperature measurement device performs quite well, with an average accuracy of about 96%. The difference between the reading value and the reference value is 1% to 1.6%, indicating a relatively small deviation. Although there were slight variations, the temperature reading values that were higher than the reference value in each measurement remained within the accepted tolerance limits. Although some measurements showed a slightly lower accuracy at 94.67%, most of the measurement results showed an accuracy higher than 95%, which confirms the reliability of this measurement system in monitoring temperature with good enough accuracy. Overall, the system is reliable for applications that require precise temperature monitoring.

Table II. TEMPERATURE MEASUREMENT REUSLT

No Measurement	Reading Value (ºC)	Reference Value (ºC)	Difference (ºC)	Accuracy (%)
1	31.6	30	1.6	95
2	31.7	30.4	1.3	96
3	31.9	30.9	1	97
4	32	30.8	1.2	96
5	31.8	30.7	1.1	96
6	31.9	30.7	1.2	96
7	32	30.7	1.3	96
8	32	30.8	1.2	96
9	32	30.7	1.3	96
10	32	30.8	1.2	96
11	32.1	30.8	1.3	96
12	32	30.8	1.2	96
13	32.2	30.9	1.3	96
14	32.2	30.8	1.4	95
15	32.1	30.7	1.4	95
16	32.2	30.9	1.3	96

No Measurement	Reading Value (ºC)	Reference Value (ºC)	Difference (ºC)	Accuracy (%)
17	32.2	30.8	1.4	95
18	32.3	30.9	1.4	95
19	32.2	30.9	1.3	96
20	32.3	30.9	1.4	95
Average				**96**

The graph in Figure 4 displays the temperature measurement results by comparing the reading value of the sensor and the reference value. The blue line shows the sensor reading value, while the green line shows the reference value used as a standard. The difference between the two values is represented by the accuracy level visualized through orange bars. Overall, the accuracy ranges from 95% to 97%, averaging 96%. Each accuracy point is labeled for straightforward visual interpretation. This graph shows that the sensor has a consistent and reliable performance in measuring temperature with high precision.

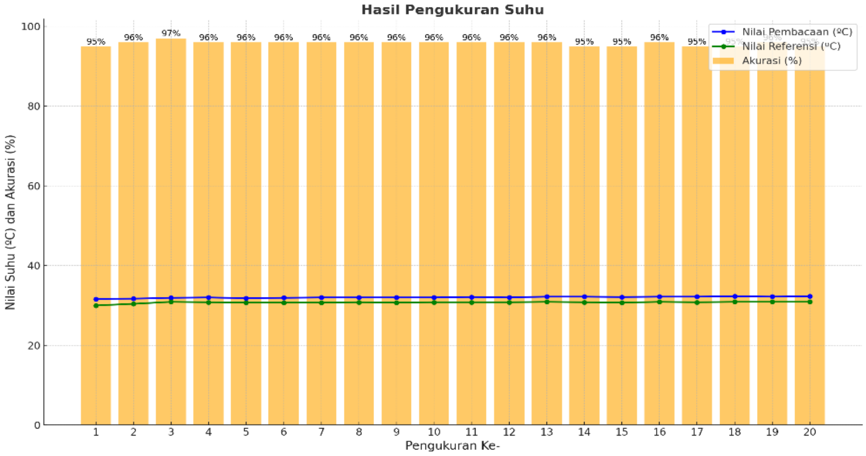


Fig. 4. Humidity Measurement Chart

Table III shows the test results for humidity measured at various time points, where the humidity reading value is compared with the reference value. Based on the results, the humidity reading values show variations between 69% and 82%, with the average accuracy fluctuating between 80% and 90%. The difference between the readout and reference values ranges from 8% to 13.7%, indicating that this humidity measurement system significantly differs from the reference value at some measurement points. Although some points had lower accuracy (around 80%), most of the measurement results showed acceptable accuracy of around 83% to 90%. This shows that although the humidity measurement can be affected by various factors, the system still provides fairly reliable results in the measured humidity in the tested storage room.

Table III. HUMIDITY MEASUREMENT RESULT

No Measurement	Reading Value (%)	Reference Value (ºC)	Difference (%)	Accuracy (%)
1	82	90	8	90
2	69	82,7	13,7	80
3	70	82,6	12,6	82
4	70	82,4	12,4	82
5	70	81,4	11,4	84
6	71	81,8	10,8	85
7	71	81,7	10,7	85
8	71	81,3	10,3	85
9	70	80,8	10,8	85
10	70	81,2	11,2	84
11	71	80,7	9,7	86
12	71	81,6	10,6	85
13	71	80,8	9,8	86
14	71	79,2	8,2	88
15	70	79,5	9,5	86

No Measurement	Reading Value (%)	Reference Value (ºC)	Difference (%)	Accuracy (%)
16	70	79,3	9,3	87
17	70	78,3	8,3	88
18	69	77,3	8,3	88
19	69	76,3	7,3	89
20	69	76,2	7,2	90
Average				**86**

The graph in Figure 6 depicts the humidity measurement results of the drug storage room, showing the relationship between the sensor reading value, the reference value, and the system's accuracy. The blue line represents the reading value of the humidity sensor, while the green line reflects the reference value used as the standard. The graph shows that the reading value tends to be below the reference value, with the difference getting smaller at the final measurement. This indicates a gradual increase in accuracy. The orange bars on the graph reflect the system's accuracy for each measurement, with accuracy values ranging from 80% to 90%. The highest accuracy is achieved at the 20th measurement with a value of 90%, indicating that the system can perform well in humidity measurement. The average accuracy of 86% shows that despite some variations, the system is quite reliable in reading the humidity conditions of the medicine storage room. This visualization provides a clear picture of the system's reliability while helping to identify areas for further improvement.

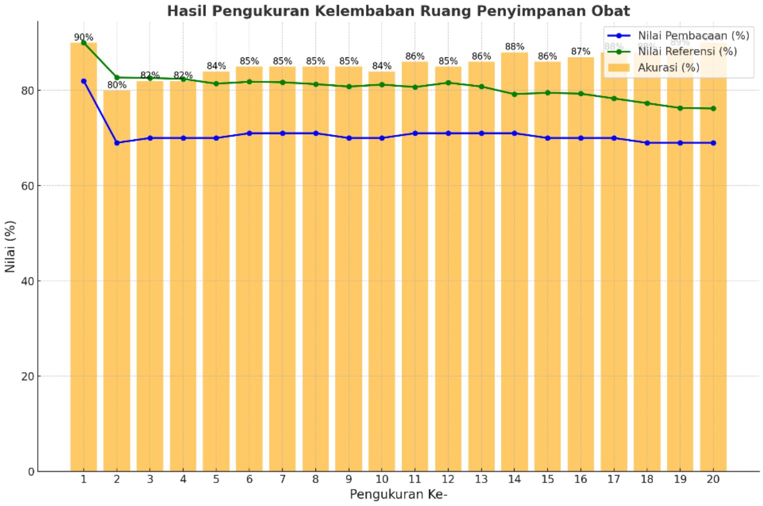


Fig. 5. Humidity sensor Measurement

For testing the responsiveness of the DHT22 sensor, simulated changes in temperature or humidity in the environment are carried out. Then, the sensor can be monitored to determine how quickly it can detect these changes and provide accurate readings. Responsive testing of DHT 22 can be seen in Table IV. Based on the responsive test results in Table IV, the DHT22 sensor shows a reasonably fast response time to changes in temperature and humidity. The average response time for temperature is about 5 seconds, while for humidity, the average response time is about 5.5 seconds. This shows that the DHT22 sensor can detect changes in temperature and humidity in a short time, making it a somewhat effective system for applications that require real-time monitoring of environmental conditions.

In addition, the sensor also provides accurate readings after a change in conditions. For example, after the temperature changed from 25°C to 28°C, the DHT22 sensor detected the change accurately, showing a final reading of 28.0°C after a response time of 5 seconds. Similarly, with humidity, the change from 50% to 60% was successfully detected within 6 seconds, and the humidity reading value also matched the applied change.

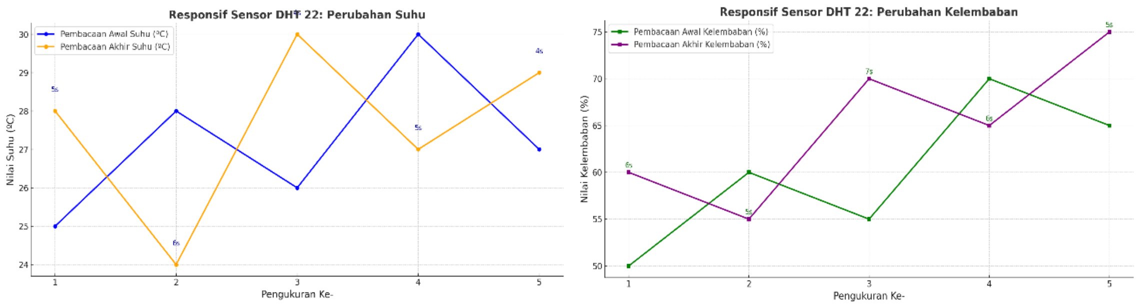
Overall, these test results show that the DHT22 sensor has good, responsive performance, fast response time, and sufficient accuracy, so it can be used for temperature and humidity monitoring applications where speed and accuracy are required.

Figure 7(a) shows each measurement's total and final temperature changes, with the temperature response time marked above the final reading line. The temperature response time ranges from 4 to 6 seconds, demonstrating the sensor's ability to respond quickly to temperature changes. The graph in Figure 7(b) shows each measurement's initial and final humidity changes, with the humidity response time plotted above the final readout line. The humidity response time is 5 to 7 seconds, demonstrating the sensor's ability to detect changes in humidity accurately.

Table IV. HASIL PENGUJIAN RESPONSIF DHT 22

No Measurement	Temperature Change (ºC)	Response Time (Seconds)	Initial reading (ºC)	Final Reading (ºC)	Humidity Change (ºC)	Response Time (Seconds)	Initial reading (%)	Final Reading (%)
1	25 - 28	5	25	28	50% → 60%	6	50%	60%
2	28°C → 24°C	6	28.0	24.0	60% → 55%	5	60%	55%
3	26°C → 30°C	4	26.0	30.0	55% → 70%	7	55%	70%
4	30°C → 27°C	5	30.0	27.0	70% → 65%	6	70%	65%
5	27°C → 29°C	4	27.0	29.0	65% → 75%	5	65%	75%

The graph in figure 6 presents the test results of the DHT 22 sensor in a cleaner and easier-to-understand manner. Blue and orange lines show the initial and final temperature changes for each measurement, while green and purple lines show the initial and final humidity changes. Response time labels for temperature and humidity were added at each endpoint to provide additional information visually. Overall, the temperature response time ranges from 4 to 6 seconds, while the humidity response time ranges from 5 to 7 seconds. This simple display is designed to make it easy for readers to understand the relationship between changes in temperature, humidity, and sensor response time.



(a) (b)

Fig. 6. Hasil Pengujian Sensor DHT 22: (a) Suhu dan (b) Kelembaban

2. *Air Quality Testing Results*

Measurement of air quality of the GP2YX1014AU0F Sensor is by testing when the sensor detects air quality by taking comparative measurements using the JSM131 Detector—functional, responsive, and accurate testing on the GP2YX1014AU0F sensor results in correctly functioning. The GP2YX1014AU0F sensor performance test results show that this sensor can accurately detect dust concentration. The sensor's measurement accuracy ranges from 96.67% to 98.89%, indicating that the sensor can provide readings very close to the calibrated reference value. Although there is a slight deviation of about 1-3%, these results are still within acceptable tolerance limits for air quality monitoring applications.

In addition, the sensor response time is also very fast, with an average response time of about 1.4 seconds. This shows that the GP2YX1014AU0F sensor is quite responsive in detecting changes in dust levels, which is essential for real-time air monitoring applications. These results indicate that the sensor is suitable for use in applications that require fast and accurate dust detection, such as in drug storage rooms or areas that require constant air quality monitoring. Overall, the GP2YX1014AU0F sensor performed well in accuracy, response time, and consistency, making it a reliable choice for dust and air quality monitoring applications.

Table V. FUNCTIONAL, RESPONSIVE AND QUANTITATIVE TESTING RESULTS OF AIR QUALITY SENSOR

No Measurement	Dust Concentration (µg/m³)	Sensor Reading (µg/m³)	Reference Value (µg/m³)	Diffrence (%)	Accuracy (%)	Response Time (Seconds)
1	30	31	30	3.33	96.67	1.5
2	60	61	60	1.67	98.33	1.3
3	120	118	120	1.67	98.33	1.2
4	180	178	180	1.11	98.89	1.4
5	250	245	250	2.00	98.00	1.5

Infografik pada gambar 6 menunjukkan hasil pengujian fungsi, responsivitas, dan akurasi sensor kualitas udara menggunakan sensor GP2YX1014AU0F. Grafik garis biru, hijau, dan oranye masing-masing merepresentasikan nilai Konsentrasi Debu, Pembacaan Sensor, dan Nilai Referensi dalam satuan mikrogram per meter kubik (µg/m³). Secara umum, nilai pembacaan sensor menunjukkan kesesuaian yang sangat baik dengan nilai referensi pada setiap pengukuran. Batang ungu menggambarkan tingkat Akurasi (%), yang berkisar antara 96,67% hingga 98,89%, mencerminkan keandalan tinggi sensor. Label di atas batang menunjukkan waktu respons untuk masing-masing pengukuran, yang berkisar antara 1,2 hingga 1,5 detik. Waktu respons yang cepat ini menunjukkan kemampuan sensor untuk mendeteksi perubahan konsentrasi debu secara real-time, menjadikannya alat yang andal dan efisien untuk pengukuran kualitas udara.

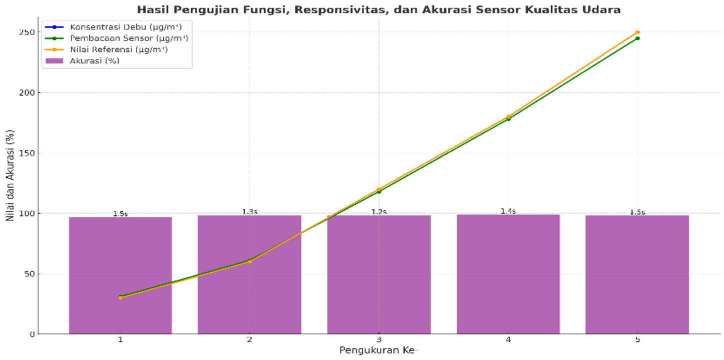
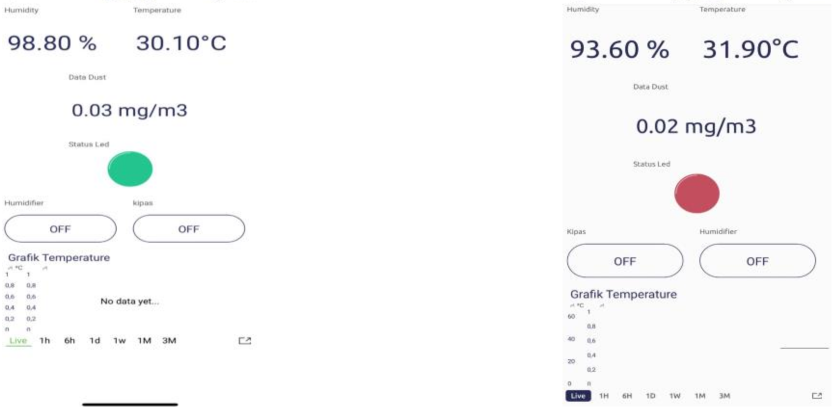


Fig. 7. Grafik HASIL PENGUJIAN FUNGSIONAL, RESPONSIF DAN AKUARSI SENSOR KUALITAS UDARA

3. *Cloud IoT Testing Results*

The evaluation was conducted on the performance of a smartphone application in the form of Cloud IoT Blynk to monitor and control devices in real time, such as temperature, humidity, or dust sensors in the medicine storage room. In this test, the controller application can control connected devices like fans and humidifiers. The results of this test will provide an overview of the reliability and performance of the system in maintaining optimal conditions in the drug storage room, as well as the effectiveness of using IoT technology in monitoring and controlling the environment remotely. Cloud IoT test results are presented as a Blynk application display in Figure 7.



Humidity 98.80 %
Temperature 30.10°C
Data Dust 0.03 mg/m3
Humidifier OFF
kipas OFF
No data yet...

Humidity 93.60 %
Temperature 31.90°C
Data Dust 0.02 mg/m3
Kipas OFF
Humidifier OFF

(a) (b)

Fig. 8. Cloud IoT Testing Results: (a) Normal detected condition and (b) Abnormal detected condition

4. Comparison of Results with Related Research

Based on the comparison table above, this study shows competitive results in accuracy and performance compared to some related studies. In Rai's research (2022), although using the same sensors (DHT11 and DHT22), the accuracy of temperature and humidity is not mentioned in detail, making it difficult to compare the accuracy of the sensors directly. Meanwhile, in Santosa's research (2023), although the accuracy of the temperature and humidity sensors was perfect (98.49% and 87.78%), this research did not record the results of controlling further devices such as fans or humidifiers, which are the main focus in this research. In Sasono's (2020) research, the temperature and humidity sensors (DHT11, DHT22, and SHT30) showed higher accuracy, especially in temperature measurement (99.76%). However, the control system, which used AC and email or SMS-based notifications, showed a swift response (3 seconds). This shows the superiority of the system in terms of response time. However, this research is still limited to only controlling temperature with air conditioning. At the same time, this study focuses more on managing temperature, humidity, and air quality simultaneously with more comprehensive device control.

Overall, this research enriches the existing literature by adding air quality parameters (dust) as part of environmental monitoring, which contributes significantly to managing drug storage using IoT technology in terms of more comprehensive temperature and humidity monitoring and more flexible device control.

Table VI. COMPARISON OF RESEARCH RESULTS

Aspects	**This Work**	[18]	[9]	[6]
Sensor	DHT22 (Temperature dan Humidity), GP2YX1014AU0F (Air Quality)	DHT11, DHT22, SHT30	DHT11, DHT22	DHT11, DHT22, SHT30
MCUs	NodeMCU ESP8266	NodeMCU ESP8266	NodeMCU ESP8266	NodeMCU ESP8266
IoT Platform	Blynk	Blynk	Thinger.Io	Cayenne
Temperature Sensor Accuracy (%)	96%	Not mentioned	98.49%	99.76%
Humidity Sensor Accuracy (%)	86%	Not mentioned	87.78%	95.49%
Response Time	4-7 detik	Not mentioned	Not mentioned	3 seconds
Device Control	Fans and Humidifiers	Not mentioned	AC (relay)	AC (relay)

IV. CONCLUSION

Based on the research results, an automatic environmental monitoring and regulation system using IoT technology for drug storage rooms has been proven effective in measuring and controlling temperature, humidity, and air quality. Test results show that the temperature (DHT22) and humidity sensors have high accuracy, with an average accuracy of 96% for temperature and 86% for humidity. The system responded quickly to changing environmental conditions, with acceptable response times of 4 to 7 seconds. The results support the claim that IoT-based systems, particularly those integrating temperature, humidity, and dust sensors, can effectively monitor and control the environmental conditions of drug storage in real time, reducing the risk of drug damage. These results align with previous studies emphasizing the importance of IoT-based environmental monitoring. However, this study further develops the theory by adding air quality (dust) sensors for more comprehensive applications. Thus, this research enriches and expands the understanding of drug storage management and air quality and encourages future development in IoT-based monitoring technologies.

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