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Fuzzy Logic and IoT for Aeroponic Temperature and Humidity Control

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Abstract*— Aeroponic cultivation is a modern farming technique in which plant roots are suspended in the air and sprayed with a nutrient solution, proper control of temperature and humidity is essential to ensure optimal growth of aeroponic plants. This research aims to design and implement an air temperature and humidity control system in an aeroponic cultivation chamber This system utilizes a ESP8266 microcontroller integrated with a DHT22 sensor to detect air temperature and humidity in real-time. The data obtained from the sensors is used to control the output devices, i.e. pumps and fans, which are operated through the L298N Motor Driver. The results of the study showed that the developed system was able to maintain optimal temperature and humidity for lettuce growth with an accuracy rate of temperature readings of 98.35% and humidity of 98.45%. The system can work automatically based on Fuzzy Logic's algorithm, but it can also be monitored in real-time through the Blynk app connected to the internet network. Overall, the implementation of this system shows a significant improvement in the growth and development of lettuce plants compared to manual methods, making it an efficient and effective solution for modern aeroponic cultivation.

***Keywords*— Aeroponic, ESP8266, Fuzzy Logic, Internet of Things, L298N, Sensor DHT-22.**

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I. INTRODUCTION

Indonesia is an agrarian country that relies on the agricultural sector as a source of livelihood and as a support for development in Indonesia. However, in the current era, land for farming is decreasing because the population is increasing so that agricultural land is used as residential land. To allow people to continue to be able to grow crops, especially in urban areas, they can cultivate plants with aeroponics. The rapid growth of lettuce requires the right environmental conditions, including optimal temperature and humidity. Significant variations in temperature or humidity can result in stress on the plant, affecting the growth and quality of the crop. Therefore, the management of the agricultural environment is the key to achieving optimal results in lettuce cultivation [1]. The Aeroponic System is a modern technique for growing agricultural crops without soil or water as a planting medium by letting plant roots hang in the air [2]. Aeroponic cultivation techniques are suitable for urban communities or for those who want to cultivate plants that live in high-temperature areas or do not have enough land, because these aeroponic systems are space- and water-efficient. The Aeroponic method can be used to grow vegetables of the type of plants. One of them is in lettuce plants.

Manual environmental management in aeroponic systems requires great attention and precision. Errors in environmental settings can lead to a decrease in production quality and quantity. Therefore, a control system is needed that is able to monitor and control environmental conditions automatically and in real-time, in order to maintain the stability of temperature, humidity, and nutrient distribution in the lettuce cultivation room [3].

Research on Aeroponics is not the first research carried out, but has been researched by several researchers, including M. Fadhil, B. D. Argo, & Y. Hendrawan et al, with the title Design and Construction of Prototype Automatic Sprinkler with RTC Timer System DCS1307 Based on Atmega Microcontroller in Aeroponic Plants [2]. This study explains the use of prototypes to water plants automatically, but has not yet used a network. By using an Internet of Things-based system, farmers can reduce operational costs and risks in lettuce cultivation. This system can reduce the need for human labor to manually monitor and regulate temperature and humidity. In addition, by monitoring the environment in real-time, farmers can detect unwanted changes or potential problems quickly, so they can take the necessary actions to prevent losses [4].

Next is the research entitled Designing a Temperature and Humidity Monitoring System in an Internet of Things Based Aeroponic System [5], this system only monitors temperature and humidity, but does not discuss temperature and humidity control. In this regard, the author designed a tool that can control the temperature and humidity of the cultivation room and can also be monitored using a network (IoT) with the title "Air Temperature and Humidity Control System in Aeroponic Cultivation Rooms Using IoT-Based Fuzzy Logic Method."

II. RESEARCH METHOD

A. System Architecture

The system architecture on this tool consists of several main parts that are interconnected. The DHT22 sensor is used to read the temperature and humidity values of the air inside the aeroponic cultivation chamber. The data obtained from the sensor is then processed by the microcontroller ESP8266 as the central control of the system. Furthermore, ESP8266 process the data using the fuzzy logic method to determine the actions that must be taken. The results of this processing are used to control the fan and water pump through the L298N motor driver so that the temperature and humidity remain at the appropriate conditions [6]. In addition to working automatically, the system is also connected to the internet so that temperature and humidity values can be monitored in real-time through the Blynk app.

B. Sensors and Calibration

The sensor used in this system is a DHT22 sensor that functions to detect the temperature and humidity of the air in the aeroponic cultivation chamber. The DHT22 sensor was chosen because it has a digital data output, a fairly high level of accuracy, and is compatible with ESP8266 microcontrollers. This sensor reads the conditions of the surrounding environment and then sends temperature and humidity data to the microcontroller to be processed as the basis for system control.

Calibration of the DHT22 sensor is carried out by comparing the sensor reading results with reference measuring instruments in the form of a digital thermometer and hygrometer. Tests are performed on several different temperature and humidity conditions to determine the difference in reading values between the sensor and the reference measuring instrument. Based on the results of the test, the accuracy of temperature readings was 98.35% and the accuracy of humidity readings was 98.45% [7]. These results show that the DHT22 sensor has a good level of accuracy and is feasible to use as the main sensor in IoT-based air temperature and humidity control systems. For the calculation of errors and accuracy levels in the DHT22 sensor uses the following formula:

C. Blynk Planning

In this design, the blynk application is used as a user interface for temperature and humidity monitoring in the aeroponic cultivation room. Blynk is made using tools that are already available in the blynk application which is then arranged according to the needs of ESP8266 equipped with wifi and can then be displayed on the blynk web or on a smartphone.

D. Blynk Planning

The Fuzzy Logic method is used for fan control and condensation processes. The Fuzzy Logic Mamdani process consists of three main stages:

1. *Fuzzification*: Fuzzification is the initial stage that is recognized in the fuzzy logic method. This stage is carried out by the process of converting crisp (numerical) values into fuzzy sets using the membership function. In this design, the system uses 2 inputs, namely temperature (in °C) and fan activation and condensation/watering. For temperature, there are 3 sets, namely cold, medium, and hot with limits [6]. The following is a picture of the membership function of the variable
2. *Inference:* At this stage, each output of the fuzzification in the form of membership degrees and linguistic variables will be combined using a rule base. From the rule base, the variation in watering duration and fan duration will be known. The rules and functions of membership used in this study were obtained from previous research. Where there are 9 rules to determine the duration of the fan and watering.
3. *Defuzzifikasi:* In the defuzzification process, calculations are made to obtain the duration of watering. The decisions resulting from the reasoning process are still in fuzzy form, which is in the form of output variables. In this test 3 sets of outputs were used which are the duration of watering (in seconds) and 3 sets of outputs for the duration of the fan (in seconds) which are read from the temperature and humidity sensors [1]. The duration of the fan has a set of off, medium and long.

E. Platform IoT dan Website

The Internet of Things (IoT) platform used in this system is Blynk, which functions as a media for real-time monitoring of air temperature and humidity data. Blynk was chosen because it has a simple, easy-to-use interface, and supports direct integration with ESP8266 microcontrollers over the internet. With this platform, users can monitor the environmental conditions of aeroponic cultivation rooms without having to be on site directly.

The temperature and humidity data read by the DHT22 sensor is transmitted by the ESP8266 to the Blynk server via a WiFi connection. Furthermore, the data is displayed on the Blynk application in the form of numerical displays and indicators to make it easier for users to monitor changes in environmental conditions. This IoT platform is used only as a monitoring medium, while the temperature and humidity control process is carried out automatically by the system using the fuzzy logic method.

In addition to the IoT platform, this system can also be accessed through the Blynk Cloud website which functions as a web-based monitoring dashboard. This website displays the same temperature and humidity data as in the mobile application, so users can monitor using other devices such as laptops or computers. With this website, the flexibility in monitoring the system becomes higher and supports the concept of the Internet of Things as a whole.

III. RESULTS AND DISCUSSION

All paragraphs must be indented. All paragraphs must be justified, i.e., both left-justified and right-justified.

A. DHT22 Sensor Measurement Results

The temperature readings of the DHT-22 sensor were tested to determine the error rate by comparing them with a thermohygrometer as the reference. The testing was conducted over 20 trials. The comparison between the DHT-22 sensor readings and the thermohygrometer is presented in Table 1.

TABLE I
DHT-22 Sensor temperature reading test

Experiment to-	Sensor DHT-22 (◦C)	Thermo-hygrometer (◦C)	Measurement Difference	Error (%)
1	30.3	30.1	0.2	0.66
2	30.3	30.2	0.1	0.33
3	27.8	28	0.2	0.71
4	23.8	24	0.2	0.83
5	32	32.4	0.4	1.23
6	33.6	34	0.4	1.17
7	31.8	32.3	0.5	1.54
8	23.4	24	0.6	2.5
9	25.1	26	0.9	3.46
10	27.9	26.4	1.5	5.68
11	27.5	28.1	0.6	2.13
12	28.7	29	0.3	1.03
13	27.8	29	1.2	4.13
14	28.7	29.1	0.4	1.37
15	28.9	30	1.1	3.66
16	29.7	30	0.3	1
17	28.9	29	0.1	0.34
18	24.3	24.5	0.2	0.81
19	24.5	24.4	0.1	0.4
20	29	29	0	0

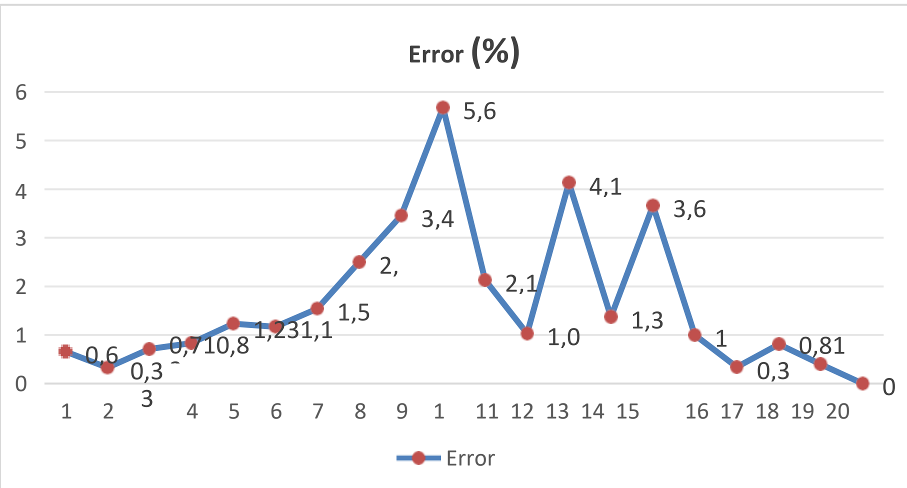


FIGURE 1. Effect of series resistances on the (a) I-V and (b) P-V characteristic

B. Communication Performance with Blynk

This test is performed to measure latency from the device to the Blynk app. Latency is the time lag between the request to send data and the receipt of that data, or in other words a delay in network communication. The test was carried out 10 times. The test is performed by giving the device an on/off treatment and calculating the reading time lag using a stopwatch, and converting the time to milliseconds (ms). The experimental data can be seen in Table 2.

TABLE II
DHT-22 Blynk Communication Table

Experiment to-	Time	Latency
1	3.44 pm	4180
2	4.03 pm	5320
3	5.10 am	1190
4	6.13 am	3920
5	6.26 am	4100
6	7.00 am	4130
7	7.15 am	2150
8	1.45 am	6420
9	2.25 am	6170
10	11.10 am	2110
Average		3969

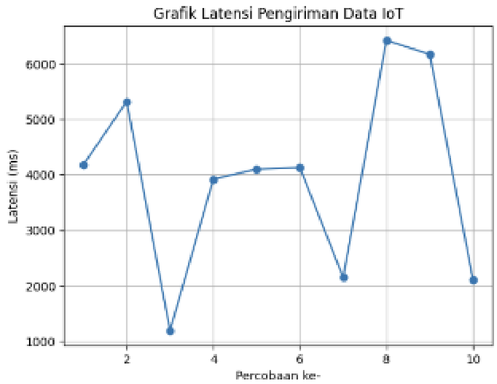


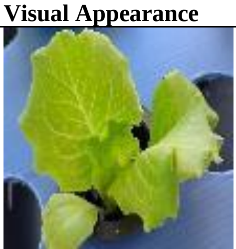
FIGURE 2. Blynk Communicatin Graph

From the experimental data in Table 2, the longest data transmission occurred on the clock 13:45 (noon) with a latency of 6420 ms, and the fastest DAT delivery occurred at 05:10 (morning). This indicates significant latency variance depending on the time and number of network users. The average latency of the above 10 attempts was 3969 ms.

C. Testing of the Control System for Lettuce Plants

The test was carried out from July 28, 2024 to August 8, 2024, in Rentan, Kapalo Koto, Pauh District. The plants tested on the tool were lettuce plants that were 15 days old, as many as 6 plant samples that had various lengths and number of leaves. To see the difference in more detail from plants, one plant was observed that was placed on a tool and one plant that was cultivated manually which was somewhat the same plant size. Both of these plants are not given any nutrients or fertilizers at all, so that the effect of the tool on the plant can be observed in detail. Then the lettuce leaves are measured using a ruler, the leaf measured is the main leaf (the oldest) of the plant. Table 3 shows a comparison of the growth and development of Lettuce plants over the course of a week.

TABLE III
DHT-22 Blynk Communication Table

Day to-	Using the Tool		Manual	
	Visual Appearance	**Growth Parameters**	**Visual Appearance**	**Growth Parameters**
1		Leaf length 4 cm Number of leaves 2 and 1 shoots		Leaf length 4 cm Number of leaves 3 and 1 shoot
3		Leaf length 4.7 cm Total leaves 4		Leaf length 4 cm Number of leaves 6 and 2 leaves yellow
5		Leaf length 6.5 cm Total leaves 5		Leaf length 4.5 cm Total leaves 4 and 1 shoot

D. Validation of Mamdani's Fuzzy Logic

To test the accuracy of the Mamdani fuzzy results processed by the microcontroller, the authors conducted a test by comparing the fuzzy results from the microcontroller (ESP8266) with the results obtained from the MATLAB software, which also uses the Mamdani fuzzy method. Fuzzy output using the microcontroller can be seen in Figure 3.

```
16:30:49.496 -> Temperature: 28.10 °C, Humidity: 79.50 %
16:30:49.589 -> Fan duration: 3.42, Pump duration: 0.00
16:31:00.558 -> Temperature: 28.10 °C, Humidity: 79.50 %
16:31:00.698 -> Fan duration: 3.42, Pump duration: 0.00
16:31:07.634 -> Pump auto-activation
16:31:13.139 -> Temperature: 28.10 °C, Humidity: 79.40 %
16:31:13.231 -> Fan duration: 3.43, Pump duration: 0.00
16:31:24.223 -> Temperature: 28.10 °C, Humidity: 79.40 %
16:31:24.317 -> Fan duration: 3.43, Pump duration: 0.00
16:31:35.306 -> Temperature: 28.10 °C, Humidity: 79.40 %
16:31:35.400 -> Fan duration: 3.43, Pump duration: 0.00
16:31:46.397 -> Temperature: 28.10 °C, Humidity: 79.40 %
16:31:46.537 -> Fan duration: 3.43, Pump duration: 0.00
16:31:57.521 -> Temperature: 28.10 °C, Humidity: 79.50 %
16:31:57.603 -> Fan duration: 3.42, Pump duration: 0.00
16:32:08.610 -> Temperature: 28.10 °C, Humidity: 79.60 %
```

FIGURE 3. Blynk Communicatin Graph

The test was carried out 12 times to ensure the accuracy of the results. Fuzzy output is duration in units (s). Here is a comparison of fuzzy output between microcontrollers (ESP8266) and MATLAB.

E. Pengujian Platform IoT

Testing of the Internet of Things (IoT) platform is carried out to ensure that the system is able to transmit and display real-time air temperature and humidity data through the Blynk app and website. The IoT platform was tested by connecting ESP8266 microcontroller to the internet network using a Wifi connection, then sending the data from the DHT22 sensor readings to the Blynk server.

The test begins with running the system and making sure ESP8266 successfully connect to the internet network. Once the connection is successful, the temperature and humidity data read by the sensor is displayed on a widget that has been created in the Blynk app. The data that appears on the application is then compared to the values displayed on the Arduino IDE monitor series to ensure that there are no data discrepancies.

In addition to the mobile application, the test was also carried out using the Blynk Cloud website. The temperature and humidity data displayed on the website are observed to ensure compatibility with the data that appears on the smartphone application. During testing, the system showed that data could be sent and updated periodically without significant communication interruptions.

Based on the results of the tests conducted, Blynk's IoT platform is able to display real-time temperature and humidity data with stable response. This proves that the integration of the system with the IoT platform is running well and can be used as a medium for monitoring the environmental conditions of aeroponic cultivation rooms.

F. Comparison with Previous Research

Based on the results of the research that has been conducted, the air temperature and humidity control system in the IoT-based aeroponic cultivation room has several similarities and differences with previous studies. In previous studies, generally the cultivation environmental control system still uses conventional or threshold-based control methods, so the system's response tends to be rigid and less adaptive to changes in environmental conditions.

In this study, the Fuzzy Logic Mamdani method was used as a decision-making system in controlling fans and water pumps. The use of the fuzzy method provides an advantage over previous research because it is able to produce more flexible decisions and is closer to the human way of thinking in dealing with gradually changing temperature and humidity conditions.

In terms of hardware, this study uses a DHT22 sensor which has a better accuracy level than sensors commonly used in previous studies, such as DHT11. This is evidenced by the test results which showed an accuracy rate of temperature readings of 98.35% and humidity of 98.45%. In addition, the use of ESP8266 microcontroller allows the system to connect directly to the internet network without the need for additional modules.

In terms of monitoring, previous research generally only displayed data locally through LCD or computers. Meanwhile, in this study, the Internet of Things (IoT) platform was applied using the Blynk application and website, so that users can monitor temperature and humidity in real-time remotely. Thus, the system developed in this study has advantages in terms of monitoring flexibility, automation, and environmental control efficiency compared to previous research.

G. System Limitations

Although the developed system shows good performance, there are some limitations that need to be noted that the temperature and humidity control system in the IoT-based aeroponic cultivation chamber developed in this study has several limitations.

First, the system relies heavily on the availability of an internet connection. In the event of a network outage, the process of sending data to the IoT platform cannot be carried out, so remote monitoring through applications and websites is not optimal, even if the local control system is still running. The DHT22 sensor used is only capable of measuring the temperature and humidity of the air at a single measurement point. This causes the system to not be able to represent the overall environmental conditions if the cultivation space has a larger size or an uneven distribution of temperature and humidity. The system is only focused on controlling two environmental parameters, namely temperature and air humidity. Other parameters that also affect the growth of lettuce plants, such as light intensity, nutrient solution pH, and nutrient content, have not been integrated into the system. The Fuzzy Logic Mamdani method that is applied still uses a static rule base that is determined based on certain assumptions and references. The system does not yet have the ability to learn or automatically adapt to changes in environmental conditions in the long term. There is no automatic calibration mechanism for the sensor yet, so calibration must be done manually at regular intervals to maintain measurement accuracy

IV. CONCLUSION

Based on the design, implementation, testing, and analysis conducted in this study, it can be concluded that the IoT-based air temperature and humidity control system for aeroponic cultivation chambers has been successfully developed and operates in accordance with the expected objectives. The system is capable of monitoring and controlling environmental conditions automatically and in real time, which is crucial for supporting optimal lettuce plant growth in aeroponic cultivation systems.

The DHT22 sensor demonstrated a high level of measurement accuracy, with an average accuracy of 98.35% for temperature readings and 98.45% for humidity readings. These results indicate that the sensor is reliable and suitable for use as the primary data acquisition component in environmental monitoring and control applications. Accurate sensor readings play a critical role in ensuring that the control decisions made by the system are precise and effective.

The implementation of the Mamdani Fuzzy Logic method on the ESP8266 microcontroller proved to be effective in controlling the operation of the fan and water pump based on varying temperature and humidity conditions. Unlike conventional threshold-based control systems, the fuzzy logic approach provides smoother and more adaptive control behavior, closely resembling human decision-making. This allows the system to respond more flexibly to gradual changes in environmental conditions within the aeroponic cultivation chamber.

Furthermore, the integration of Internet of Things (IoT) technology through the Blynk platform enables real-time remote monitoring of temperature and humidity via both mobile applications and web-based dashboards. This feature significantly enhances user convenience, allowing farmers or system operators to monitor environmental conditions without being physically present at the cultivation site. The communication performance test showed that although network latency varies depending on network conditions, the system remains stable and functional for real-time monitoring purposes.

Experimental results on lettuce plant growth showed that plants cultivated using the developed control system experienced better growth performance compared to those grown under manual control. Lettuce plants grown with the automated system exhibited faster leaf growth, healthier leaf color, and a more stable development pattern. This confirms that maintaining stable temperature and humidity conditions has a positive impact on plant growth and overall crop quality.

Overall, the proposed system offers an effective, efficient, and practical solution for environmental control in aeroponic cultivation, particularly in urban or limited-land farming environments. Although the system still has limitations—such as dependence on internet connectivity, limited sensing points, and the absence of adaptive learning mechanisms—the results of this study demonstrate strong potential for further development. Future improvements may include the integration of additional environmental parameters, multi-point sensing, and intelligent adaptive algorithms to further enhance system performance and scalability

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