Design of temperature control system for broiler cage using IoT-based fuzzy logic method

Astriyani Magdalena Siregar [1], Grace Leta Tesalonika Sihotang [1], Iman Fahruzi [1]

[1] Teknologi Rekayasa Elektronika, Jurusan Teknik Elektro, Politeknik Negeri Batam, Batam, INDONESIA

*Corresponding Author, email : Iman@polibatam.ac.id

Abstract

Many broiler farms in Indonesia still use conventional methods in managing cage temperature, which can have a negative impact on productivity and chicken welfare. Unstable temperatures can cause stress in chickens, reduce feed efficiency, and lower production yields. To overcome this problem, this research develops an Internet of Things (IoT)-based cage temperature control system with Fuzzy Logic method. The system uses DHT22 sensors to measure temperature and humidity, which are then processed by the NodeMCU ESP32 microcontroller. Based on the Fuzzy Logic method, the system automatically adjusts the intensity of the heating lamp and fan speed to maintain the cage temperature in optimal conditions. The test results show that the system is able to maintain the cage temperature within the optimal range with an average sensor error of 1,36%. In addition, comparison with application proves high accuracy in temperature control. With the integration of IoT technology through the Thingspeak platform, this system enables real-time temperature monitoring and control, thereby improving the efficiency of pedaging farm management.

Keywords: Temperature control, Fuzzy Logic, IoT, broiler chicken

1. Introduction

Agriculture, especially the livestock sector, plays a vital role in the Indonesian economy as it absorbs a lot of labor and contributes greatly to the national economy. One of the leading commodities in this subsector is chicken meat, which accounts for around 60% of the total national meat consumption. With the increasing population, chicken meat consumption is expected to continue to rise globally, including in developing countries such as Indonesia. This creates a great opportunity for the chicken farming industry to increase production and efficiency[1]. With population growth continuing to increase, it is estimated that the level of poultry meat consumption will also continue to increase. By 2030, it is estimated that the global poultry meat consumption rate will increase to 17.2 kg per individual from 13.8 kg in 2015. This means that poultry meat consumption is expected to increase from about 33% to about 38%. [2] However, most small to medium-scale chicken farms in Indonesia still use conventional methods in cage management, including temperature regulation which is done manually [3] Whereas, optimal ambient temperature greatly affects broiler growth, feed use efficiency, and livestock productivity [4]. One solution to improve the efficiency of cage management is the application of Internet of Things (IoT) technology that allows monitoring and controlling cage conditions automatically. One method that can be used in IoT-based cage temperature regulation is fuzzy logic, which is able to produce optimal decisions in maintaining temperature stability [5].

This research aims to improve the broiler cage temperature control system by applying the IoT-based fuzzy logic method. The main difference of this research compared to previous research is in the use of sensors and microcontrollers and temperature control approaches. Previous research by Audia Faris Trinaldi in 2022, namely "Development of a Cage Temperature and Humidity Monitoring System to Improve the Performance of Arduini-based Breeders" using DHT11 sensors and Arduino microcontrollers [2], while our research uses DHT22 sensors which have a higher level of accuracy in measuring temperature and humidity. Then in research by A. Khoiru Nurdina in 2023 using DHT 11 sensor and NodeMCU ESP8266 microcontroller. In addition, this research also explores further the application of the Mamdani fuzzy method compared to the Sugeno method in optimizing temperature control systems, as well as broader system integration to improve the operational efficiency of broiler farms.

Therefore, to solve the problem, we propose research with the title Designing a Broiler Cage Temperature Control System Using IoT-Based Fuzzy Logic Method. Thus it is hoped that this research can contribute to increasing the productivity and efficiency of broiler farms in Indonesia and provide technology-based solutions that can be applied by small to medium scale farmers.

2. Material and methods

This research employed an experimental research method, which involved the design and implementation of both hardware and software components to achieve the desired system performance. The purpose of the design process was to determine the appropriate components and ensure that the developed system could operate effectively according to expectations.

2.1 Electrical Design

This electrical diagram shows the IoT-based control system with NodeMCU ESP32 as the main controller. The system consists of a DHT22 sensor, L298N motor driver, incandescent lamp, AC light dimmer, DC fan, and DC adapter. The DHT22 sensor reads the temperature and humidity, sending the data to the NodeMCU for processing. Based on fuzzy logic, the NodeMCU controls the dimmer to control the brightness level of the lamp connected to the 220V AC PLN, as well as regulates the speed of the DC fan through the driver module. The fan and lamp work to maintain optimal temperature and humidity conditions automatically.

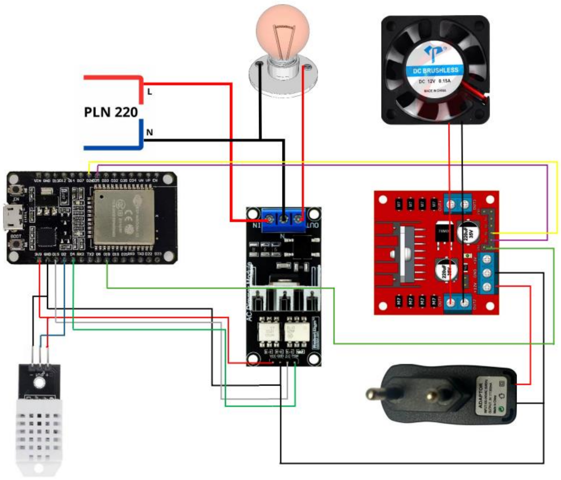


Figure 1 . Electrical Design

2.2 Mechanical Design

Mechanical design in the form of mechanical design. The size of the broiler cage temperature control tool is 100cm x 100cm x 100cm. The door we put in front because to facilitate and remove the chicken, there is acrylic on the door so that users can see inside without opening the door. The door can be closed tightly to maintain the temperature. In front of the tool there are 2 vents to function in and out of Co2 and O2 or as air circulation. There are 2 lights at the top and 2 fans on the left and right that function to regulate and control automatically. Wooden boards as the main material for building the main structure of this tool. Wooden boards were chosen because they are easy to process and lightweight.

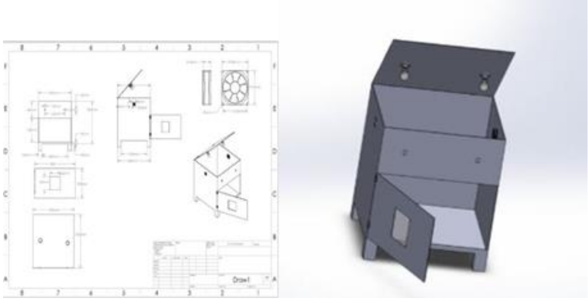


Figure 2. 3D Mechanical

2.3 Software Design

For the software aspect, the system starts with sensor initialization, where the DHT22 temperature sensor will be set to start the measurement. After sensor initialization, the sensor will send data to ESP32 then the data is inputted and sent to thingspeak to be displayed on thingspeak as remote monitoring.

The system will read the temperature data from the DHT22 sensor. This temperature data will then be processed using the Fuzzy Logic method to determine the next step. First of all, the system will evaluate whether the measured temperature falls into the low medium or high temperature category. If the system detects a low temperature, it will send a signal to increase the light intensity of the incandescent lamp and decrease the fan speed in the cage. This step aims to provide additional heating in the cage so that the temperature can rise and reach the desired level.

Conversely, if the temperature is detected to be high, the system will signal to increase the fan speed. The fan will work to increase the air circulation inside the cage, helping to lower the temperature efficiently by removing hot air from the cage. Once the appropriate steps are taken based on the measured temperature conditions, the system will continue to monitor the temperature conditions inside the enclosure continuously. This process will continue to ensure that the temperature inside the coop remains within a safe and comfortable range for broilers. The system flowchart can be seen in Figure 3.

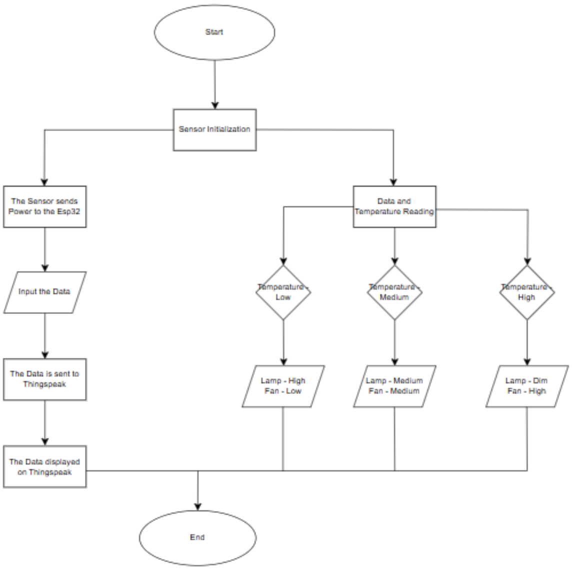


Figure 3. Flowchart System

2.4 Fuzzy System Design

Fuzzy in language means “fuzzy” or “uncertain”, allowing a value to have a degree of membership between 0 and 1, not limited to yes/no (1/0) as in a strict set. This concept describes levels of grayness in linguistics such as “a little”, ‘quite’, and “very”. Fuzzy logic comes from the concept of Fuzzy Set introduced by Prof. Lotfi Zadeh in 1965, a professor at the University of California, Berkeley. In his paper “Fuzzy Set”, he explains the basic concepts of fuzzy sets that result in more flexible and stable applications than conventional systems. The Mamdani (Min-Max) method of fuzzy inference, introduced by Ebrahim H. Mamdani in 1975, works by determining the minimum value of each rule and the maximum value of the combined consequences. This method is popular because it is intuitive, has many applications, is suitable for environmental analysis, and is able to produce outputs that match human input [6].

The process of applying the Mamdani method consists of four main stages, namely fuzzification, inference, rule composition, and defuzzification. In the fuzzification stage, data is converted into fuzzy variables so that membership functions are obtained for each fuzzy set in the temperature and output variables [7].

At the fuzzification stage, the membership function of the fuzzy set of each variable is obtained. In fuzzy logic theory, a fuzzy set is a grouping of things based on linguistic variables, which are expressed in a membership function.

Based on [8] the good temperature for broiler chickens is 27 ° C - 29 ° C. This data is a reference for defining the “Medium” fuzzy set at temperature.

Table 1. Input Linguistic Variable

Input	**Linguistik Variables**	***Numerical Term***
Temperature	Low	[20 20 24 26]
	Medium	[24 26 28 29]
	High	[28 29 30 30]

In this study, the membership function is represented using a trapezoidal curve. The description of the membership function for the input is presented in graphical form as shown in Figure 4.

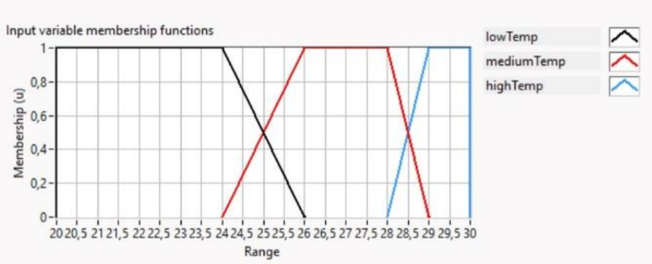


Figure 4. Temperature Membership Function Graph

In Graphical form As shown in Figure 4, the input variable temperature is represented by three trapezoidal curves covering a range of 20°C to 30°C. Each curve indicates a different temperature category: Low, medium, and high. These membership functions are used to determine how much a temperature value belongs to each category based on equations (1), (2), and (3).

$$\mu\, Low(x) \quad = \begin{cases} 1 & 20 \leq x \leq 24 \\ \frac{26-x}{2} & 24 \leq x \leq 26 \\ 0 & x \geq 26 \end{cases} \tag{1}$$

$$\mu\, Medium(x) = \begin{cases} 0 & x \leq 24 \;\&\; x \geq 29 \\ \frac{x-24}{2} & 20 \leq x \leq 30 \\ \frac{29-x}{1} & 28 \leq x \leq 29 \\ 1 & 26 \leq x \leq 28 \end{cases} \tag{2}$$

$$\mu\, High(x) \quad = \begin{cases} 0 & x \leq 28 \\ \frac{x-28}{1} & 28 \leq x \leq 29 \\ 1 & 29 \leq x \leq 30 \end{cases} \tag{3}$$

Table 2. Output Linguistic Variable

Output	**Linguistik Variables**	***Numerical Term***
Lamp	Dim	[0 10 30 40]
	Medium	[30 40 60 75]
	Bright	[60 75 100 100]
Fan	Low	[0 0 40 50]
	Medium	[40 75 160 200]
	High	[160 200 255 255]

In this study, the membership function is represented using a trapezoidal curve. The description of the membership function for the output is presented in graphical form as shown in Figures 5 and 6.

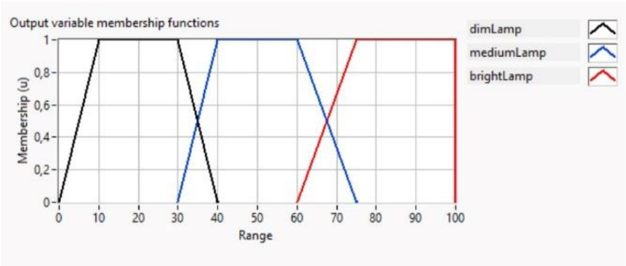


Figure 5. Lamp Membership Function Graph

In graphical form as shown in Figure 5, the variable light output is depicted with three curves showing the percent value of light intensity in the range of 0 to 100. The microcontroller controls the brightness of the lamp through the dimmer. The three curves represent low, medium, and high light conditions, respectively, which are generated based on specific membership values.

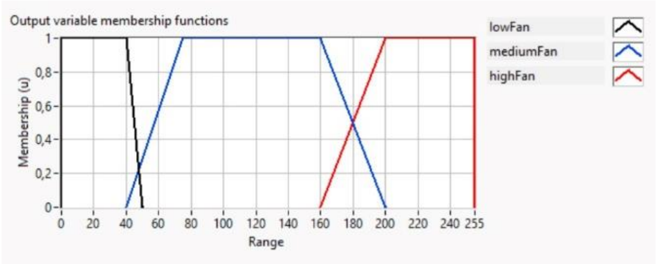


Figure 6. Fan Membership Function Graph

In the graph as shown in Figure 6, the fan output variable is represented by three curves showing Pulse Width Modulation (PWM) values in the range of 0 to 255. The microcontroller uses these PWM values to regulate the fan speed. The three curves represent three levels of fan speed, namely low, medium, and high.

In the Mamdani method, after determining the input and output variables, the next step is to set the implication function. The implication function used in this method is MIN, which is formulated in the following equation. (4).

$$\mu_{A\cap B} = min(\mu A\,[x], \mu B[x]) \tag{4}$$

The results of the fuzzification process are adjusted using predefined fuzzy rules, to adjust the output to the design. The process carried out to obtain the output value of the fuzzy rule is the inference process. This fuzzy rule will be a guide in the deffuzification process [9]. The following are fuzzy rules that have been determined based on input variables and output variables.

Table 3. Mamdani Fuzzy Rules

OUTPUT	INPUT	
TEMPERATURE	**LAMP**	**FAN**
LOW	BRIGHT	LOW
MEDIUM	MEDIUM	MEDIUM
HIGH	DIM	HIGH

In this study, fuzzy rules consist of fuzzy logic statements or fuzzy statements in the form of IF-THEN rules. In the Mamdani method, the rule composition used is the Max method, where the fuzzy set solution is obtained by taking the highest value of each rule applied. This maximum value is then used to modify the fuzzy area and applied to the output using the OR (combined) operator [10] The Max method equation can be explained as follows:

$$\mu sf\ [X_i] \leftarrow\ max\ (\mu sf\ [X_i], \mu kf\ [X_i]) \tag{5}$$

The last process in the fuzzy system is defuzzification. The defuzzification process applies the centroid method, where the crisp solution is obtained by determining the center point Z* of the fuzzy output region. Thus, when given a fuzzy set in a certain range, one specific crisp value can be determined as the output result [11].

$$defuzzifikasi\ (Z^*)\ = \frac{\int_a^b Z\ .U(z)\ dz}{\int_a^b\ U(z)\ dz} \tag{6}$$

2.5 IoT-based Monitoring System Design

IoT technology with the Thingspeak platform is used to monitor and regulate the temperature of the broiler coop in real-time. The DHT22 temperature sensor sends data to the cloud, while actuators such as heating lamps and fans are regulated based on the temperature data. HTTP protocol is used for communication between IoT devices and Thingspeak.

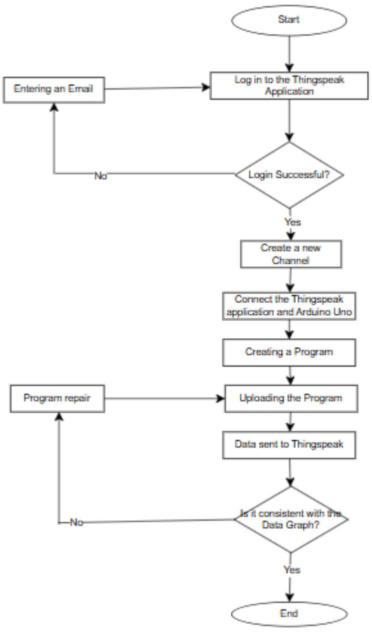


Figure 7. IoT Flowchart


BROILER CAGE TEMPERATURE MONITORING

Channel ID: 1955669

Access : Private

Temperature readings from DHT22 sensor using ESP32 microcontroller

Channel Stats

Created : last month

Last Entry : about a minute ago

Entries : 455

Figure 8. Web Design

3. Results and Discussion

This chapter discusses the results of the implementation and testing of an egg hatcher equipped with a Fuzzy logic-based temperature and humidity control system and IoT-based monitoring. The main objective of the testing is to evaluate the benefits of applying fuzzy logic in maintaining optimal environmental conditions for hatching eggs, as well as the convenience and efficiency offered by the remote monitoring system. The data collected during the test will be analyzed to quantify the system performance, identify potential improvements, and prove the superiority of the proposed approach over conventional methods. The egg hatching device is shown in Figure 9.

Figure 9. Chicken Coop Temperature Control Device

A. DHT 22 sensor testing

Testing of the DHT 22 sensor is carried out to assess the performance of the sensor in detecting and measuring temperature. This test uses the comparison method between the DHT 22 sensor readings processed by the microcontroller and the measurement data from the digital thermohygrometer. The following are the results of the comparison of the error rate between the SHT30 sensor and the digital thermohygrometer. Tests carried out based on table 4 with a total of 1 chicken, and table 5 with a total of 2 chickens, and table 6 with a total of 4 chickens. Testing with different numbers of chickens to find out if there is a difference in room temperature.

Table 4. Comparison of DHT 22 Temperature Reading With Thermohygrometer on 1 Chicken

Time	Temperature on DHT 22 (°C)	Temperature on Thermohygrometer (°C)	*Error* (%)
0 Minutes	23,97	24,00	0,12
5 Minutes	25,84	25,9	0,23
10 Minutes	25,99	26,4	1,55
15 Minutes	26,38	26,8	1,56
20 Minutes	26,46	26,9	1,63
25 Minutes	26,53	27,00	1,74
30 Minutes	26,53	27,00	1,74
Average *error*			**1,23**

Based on the data in Table 3, the error calculation for each data is done using the following formula:

$$Error = \frac{|\,Thermohygrometer\ Value\ -\ DHT\ 22\ Value|}{Thermohygrometer\ Value} \times 100\% \qquad (7)$$

Based on the data presented in Table 4, it can be concluded that the average comparison error between the DHT sensor 22 Thermohygrometer is 1.23%. Graphs illustrating the temperature data on the tool are shown in Figures 10 and 11.

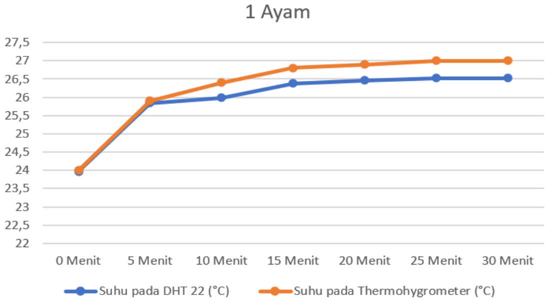


Figure 10. Comparison Chart of Temperature Readings on DHT 22 Sensor with Thermohygrometer on 1 Chicken

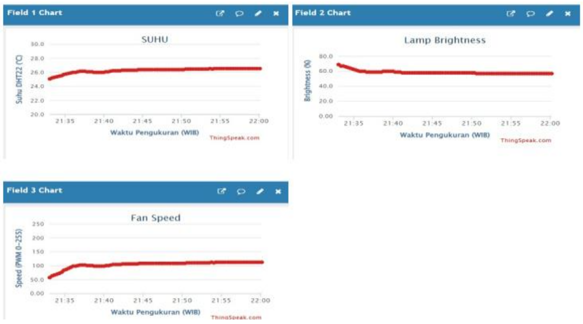


Figure 11. Graph on ThingSpeak Showing Real-Time Temperature Monitoring and Control of 1 Chicken.

Based on the graphs in Figure 11, three graphs from ThingSpeak are displayed showing real-time temperature control. The first graph shows a temperature change of 24°C - 26°C with fluctuations before stabilizing. The second graph shows that the light intensity has a slight decrease at the beginning of the measurement, then stabilizes at around 60, indicating that the system adjusts the lighting to maintain thermal balance. The third graph shows an increase in fan speed from around 50 to 100 PWM, helping the cooling process. Overall, the system works by automatically adjusting the lights and fans to keep the temperature stable.

Table 5. Comparison of DHT22 Temperature Readings with Thermohygrometer on 2 Chickens

Time	Temperature on DHT 22	Temperature on Thermohygrometer (°C)	*Error* (%)
0 Minutes	23,97	24,00	0,12
5 Minutes	25,84	26,00	0,61
10 Minutes	26,22	26,5	1,05
15 Minutes	26,30	26,8	1,86
20 Minutes	26,46	26,9	1,63
25 Minutes	26,53	27,00	1,74
30 Minutes	26,69	27,2	1,87
Average *error*			**1,27**

Based on the data presented in Table 4, it can be concluded that the average comparison error between the DHT 22 sensor and Thermohyrometer is 1.27%. Graphs illustrating the temperature data on the tool are shown in Figures 12 and 13.

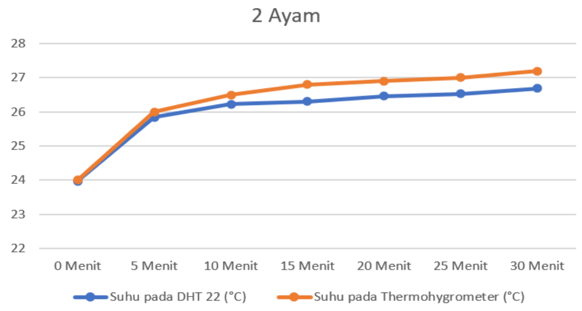


Figure 12. Comparison Chart of Temperature Readings on DHT 22 Sensor with Thermohygrometer on 2 Chickens

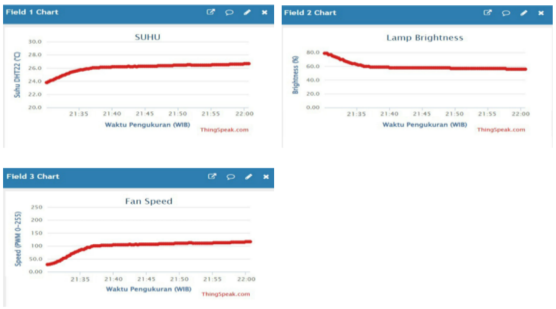


Figure 13. Graph on ThingSpeak Showing Real-Time Temperature Monitoring and Control on 2 chickens.

Based on the graphs in Figure 13, it displays three graphs from ThingSpeak that illustrate the automatic temperature control system. The first graph shows the temperature rising from 24°C to 26°C with little fluctuation. The second graph shows a decrease in light intensity from 80 - 60 indicating the system reduces lighting as the temperature rises. The third graph shows an increase in fan speed from 50 - 100 PWM, aiding the cooling process. Overall, the system works by automatically adjusting the lights and fans to keep the temperature stable.

Table 6. Comparison of DHT22 Temperature Readings with Thermohygrometer on 4 Chickens

Time	Temperature on DHT 22 (°C)	Temperature on Thermohygrometer (°C)	*Error* (%)
0 Minutes	23,97	24,00	0,12
5 Minutes	25,84	26,00	0,61
10 Minutes	26,38	26,7	1,20
15 Minutes	26,46	27,00	2,00
20 Minutes	26,61	27,1	1,80
25 Minutes	26,69	27,2	1,87
30 Minutes	26,69	27,2	1,87
Average *error*			**1,36**

Then the data in table 5, it can be concluded that the average comparison error between the DHT 22 sensor and Thermohyrometer is 1.36%. Graphs illustrating the temperature data on the device are shown in Figures 14 and 15.

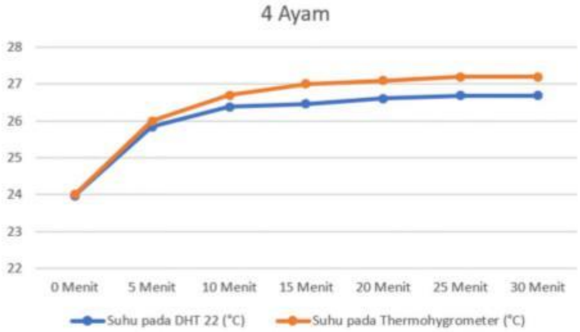


Figure 14. Comparison Chart of Temperature Readings on DHT 22 Sensor with Thermohygrometer on 4 Chickens

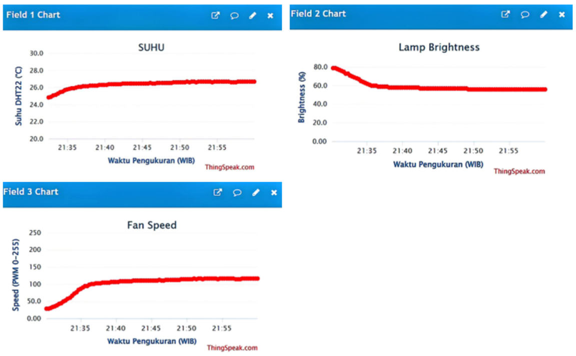


Figure 15. Graph on ThingSpeak Showing Real-Time Temperature Monitoring and Control on 4 chickens.

Based on the graphs in Figure 15, three graphs from ThingSpeak illustrate the automatic temperature control system. The first graph shows a gradual increase in temperature from 24°C - 26°C. The second graph shows a decrease in light intensity from 80 - 60, indicating the system reduces lighting as the temperature increases. The third graph shows an increase in fan speed from 50 - 100 PWM, which aids cooling. From these graphs, it can be seen that the system automatically adjusts the lights and fans to keep the temperature stable.

B. Fuzzy Testing and Discussion

Table 7. Fuzzy Output Results on Serial Monitor

Fuzzy Output Results on Serial Monitor																
Temp (°C)	Cold	Warm	Hot	Status	Lamp	Dim	Medium	Bright	Status Lamp	Fan	Low	Medium	High	Status Fan	Lamp Intensity	Fan Speed
20	1	0	0	Low	95	0	0	1	Bright	0	1	0	0	Low	95	0
21	1	0	0	Low	95	0	0	1	Bright	7	1	0	0	Low	95	7
22	1	0	0	Low	87	0	0	1	Bright	15	1	0	0	Low	87	15
23	1	0	0	Low	83	0	0	1	Bright	22	1	0	0	Low	83	22
24	1	0	0	Low	79	0	0	1	Bright	30	1	0	0	Low	79	30
25	0,5	0,5	0	Low	70	0	0,33	0,67	Bright	56	0	0,46	0	Medium	70	56
25,5	0,25	0,75	0	Medium	65	0	0,67	0,33	Medium	76	0	1	0	Medium	65	76

26	0	1	0	Medium	60	0	1	0	Medium	100	0	1	0	Medium	60	100
27	0	1	0	Medium	55	0	1	0	Medium	125	0	1	0	Medium	55	125
28	0	1	0	Medium	50	0	1	0	Medium	150	0	1	0	Medium	50	150
28,5	0	0,5	0,5	High	43	0	1	0	Medium	167	0	0,82	0,17	Medium	43	167
29	0	0	1	High	30	1	0	0	Dim	200	0	0	1	High	30	200
30	0	0	1	High	10	1	0	0	Dim	255	0	0	1	Medium	10	255

Based on Table 6, shows the results of the fuzzy system output displayed on the Serial Monitor, with the membership status and membership value of each input and output set based on temperature.

Table 8. Comparison of Fuzzy Output Results with Labview

Temperature (°C)	PWM Fan		PWM Lamp	
	Serial Monitor	Labview	Serial Monitor	Labview
20	0	0	95	95,2
21	7	7,4	91	91,3
22	15	15,2	87	87.3
23	22	22.8	83	83.7
24	30	30	79	78,9
25	56	56,9	70	70,3
25,50	76	76,2	65	65
26	100	99,9	60	60,2
27	125	125,2	55	55
28	150	151	50	50,8
28,50	167	167,6	43	42,7
29	200	199,8	30	30,9
30	255	254.5	10	9,7

Based on table 8, the output of the fuzzy system compared to the labview reading shows a very small difference. this proves that the fuzzy system is able to control fans and lights with high accuracy and consistency in regulating environmental parameters. in addition, the integration of the fuzzy system with labview goes well, ensuring optimal control.

Testing is carried out, namely the output results of the fuzzy program compared to manual calculations and simulations using the labview application. For testing the data used at a temperature of 23 ° C. There are several steps that need to be taken in testing manual calculations, the first is determining the degree of membership of the fuzzy set.

Temperature membership degree of the normal set :

$$\mu_{normal}[23] = 1 \tag{8}$$

Based on the temperature data obtained, the membership function is then applied based on each fuzzy rule using the MIN operator. In this analysis, only rule 1 is applied and will be further discussed as follows:

Rules 1 **:** IF suhu is Low is bright then kipas is low also lampu is normal

$$\mu_{R1} = 1 \tag{9}$$

To evaluate and determine the PWM value of the fan using deffuzification.

$$\frac{\int_{40}^{50} \frac{50-z}{10} z\, dz + \int_{0}^{40} 1z\, dz}{\int_{40}^{50} \frac{50-z}{10}\, dz + \int_{0}^{40} 1\, dz} \tag{10}$$

PWM value of the fan $= 22{,}97$

To evaluate and determine the PWM value of the lamp using deffuzification.

$$\frac{\int_{60}^{75} \frac{z-60}{15} z\, dz + \int_{75}^{100} 1z\, dz}{\int_{60}^{75} \frac{z-60}{15}\, dz + \int_{75}^{100} 1\, dz} \tag{11}$$

PWM value of the lamp $= 83$

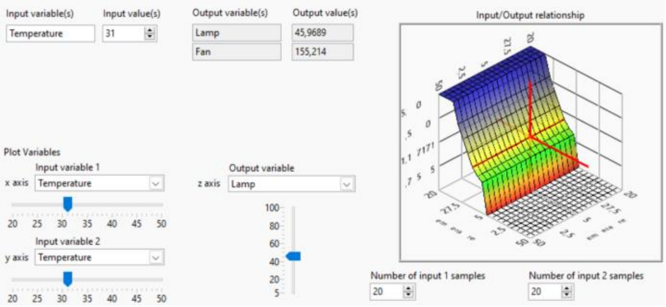
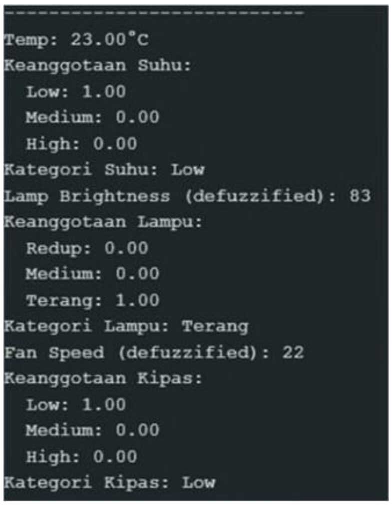

Input variable(s): Temperature
Input value(s): 31
Output variable(s): Lamp — Output value(s): 45,9689
Output variable(s): Fan — Output value(s): 155,214
x axis: Temperature
y axis: Temperature
z axis: Lamp
Number of input 1 samples: 20
Number of input 2 samples: 20

Figure 16. Fuzzy proving using labview

Proof using Arduino IDE for the PWM output results of fans and lights can be seen as shown in Figure 17.



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Temp: 23.00°C
Keanggotaan Suhu:
  Low: 1.00
  Medium: 0.00
  High: 0.00
Kategori Suhu: Low
Lamp Brightness (defuzzified): 83
Keanggotaan Lampu:
  Redup: 0.00
  Medium: 0.00
  Terang: 1.00
Kategori Lampu: Terang
Fan Speed (defuzzified): 22
Keanggotaan Kipas:
  Low: 1.00
  Medium: 0.00
  High: 0.00
Kategori Kipas: Low
```

Figure 17. Fuzzy proofing using serial monitor

4. Conclusion

This research shows that the IoT-based chicken coop temperature control system with Fuzzy Logic method can work automatically and accurately in maintaining the optimal temperature. The DHT22 sensor has an average error of up to 1.36%, which is still within the tolerance limit for this application. The system is able to adjust the intensity of the heating lamp and fan speed in real-time, ensuring stable cage conditions. Integration with the Thingspeak platform enables remote monitoring, making it easier for farmers to manage their cages. Test results prove that the system is effective in improving efficiency, reducing manual intervention, and supporting optimal broiler growth and health.

References

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