

# *Smart Greenhouse Coffee Dryer with Fuzzy Algorithm on Internet of Things Platform*

Dodit Suprianto<sup>1</sup>, Muhammad Taufik Prayitno<sup>2</sup>, Luqman Affandi<sup>3</sup>

<sup>1,2,3</sup>*Information Technology, Informatics Engineering, State Polytechnic of Malang, Indonesia*

<sup>1</sup>dodit.suprianto@polinema.ac.id (\*)

<sup>2</sup>taufikprayitno16@gmail.com, <sup>3</sup>laffandi@polinema.ac.id

Received: 2021-09-04; Accepted: 2021-12-24; Published: 2022-01-07

**Abstract**— Coffee is a major commodity of the Indonesian plantation industry. One of Indonesia's lack of competitiveness in the international market is the low quality of coffee beans. This is because traditional farmers still use conventional methods for drying. The undried coffee cherries can damage the quality of coffee beans. Based on these problems, the researchers made a Smart Greenhouse dryer using the Internet of Things Platform. The Internet of Things is used to allow it to be monitored remotely in real-time. Temperature and humidity data in the greenhouse will be analyzed using a fuzzy algorithm. Actuators use the fuzzy output results to control the temperature and humidity of the greenhouse to reach the ideal drying conditions. The perfect drying temperature enables coffee cherries to achieve a moisture content of 12.55% within 14 days. Data on average temperature and humidity per day will be recorded and calculated to determine when the coffee cherries are ready for the next stage. The system can also calculate estimated days based on moisture content. With this, the drying of coffee cherries will be optimal and get the water content of the Indonesian National Standard to increase the quality and selling price of the coffee beans. The results show that Smart Greenhouse can be controlled remotely via the website. The integrated Sugeno Fuzzy algorithm keeps the greenhouse at the ideal drying temperature. Test results show that Smart Greenhouse can reduce the water content of coffee cherries 7.4 days more efficiently than conventional drying methods.

**Keywords**— Internet of Things, Coffee Beans Dryer, Fuzzy Sugeno, Smart Greenhouse, NodeMCU.

## I. INTRODUCTION

Coffee is one mainstay commodity that plays an essential role in the Indonesian economy through export or import activities. Coffee commodities can increase farmers' income, increase state income, support industrial raw materials, and expand employment opportunities.[1].

In 2004, foreign exchange earnings for coffee generated exports of US\$ 251 million, accounting for 10.1% of all agricultural exports, 0.5% of non-oil and gas exports, and 0.4% of total exports. [2]. Currently, Indonesia's total area of coffee plantations is around 1.3 million hectares. More than 90% of farms are cultivated by small-scale farmers with a plantation area of about 1-2 hectares, making it difficult to maintain production and quality stability, affecting Indonesia's less intense competitiveness in the international market.

The drying stage is one of the crucial processes informing the taste and quality of coffee beans. Generally, freshly harvested coffee cherries in either Robusta or Arabica have a 45-50% [3]. After harvesting, the coffee cherries will be dried to have a moisture content of 12.55%, according to the Indonesian National Standard number 01-2907-2008 [4]. The poor quality of coffee is caused by the high water content that triggers the growth of mold to affect the taste and selling price [5]. This problem occurs because traditional farmers use conventional methods in the drying process, namely drying coffee cherries in the sun with tarpaulin mats. The drying of the coffee cherries is not optimal because some coffee cherries are still not completely dry [6]. Uncertain climate change also has

a negative effect; namely, it can reduce the productivity of coffee plants [7].

The traditional process of drying coffee that is less effective can be overcome by using the greenhouse method[8]. In 2014 Sukrisno Widyotomo conducted a study on translucent buildings (greenhouses) for the coffee drying process at the Indonesian Coffee and Cocoa Research Center. The use of greenhouses for the drying process of coffee beans is proven to improve the quality of coffee beans according to Indonesian National Standard number 01-2907-2008, which is 12% water content. On the other hand, the greenhouse technique in drying coffee beans still has drawbacks. Farmers have to come to the greenhouse daily to monitor the coffee cherries' water content and manually record the temperature and humidity. Temperature and humidity in greenhouses tend to be challenging to control because they depend on weather conditions and the sun's heat.

The utilization of Internet of Things technology will help increase the efficiency and effectiveness of greenhouse work systems. The instruments are built through the operation control system, observation, analysis, data transmission, and back access control [9].

This study designs a Smart Greenhouse Coffee Dryer that utilizes the Internet of Things to control temperature and humidity, and monitor conditions in the greenhouse room in real-time, making it easier for coffee farmers in the coffee bean drying process. The temperature and humidity data in the greenhouse will be analyzed using a fuzzy algorithm, while the output is in the form of lamp and fan actuators.

The target of the fuzzy algorithm is to maintain the temperature and humidity of the greenhouse to reach the ideal drying conditions so that the coffee beans get a moisture content of 12.55% in less than 14 days as recommended by the Indonesian National Standardization Agency and to improve the quality and selling price of coffee beans.

## II. RESEARCH METHODOLOGY

The methodology of this study refers to the flow system shown in Figure 1.

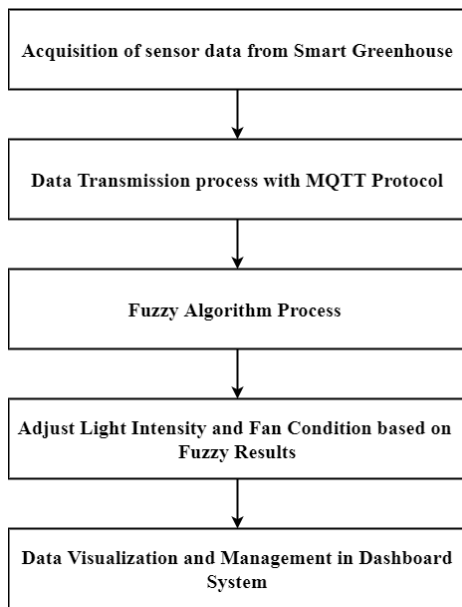


Figure 1. Smart Greenhouse System Workflow

The flow that occurs in this system starts from inputting temperature and humidity data obtained from the acquisition of the dht11 sensor data in the greenhouse to the microcontroller and then enters the next stage where the data will be sent to the cloud with the MQTT protocol. Data that enters the cloud will be processed using the Sugeno fuzzy algorithm to determine the output value of the actuator so that the ideal drying temperature can be achieved. At the same time, the cloud will forward data on temperature, humidity, and actuator conditions to the monitoring dashboard so that the user can monitor it in real-time.

### A. Internet of Things (IoT) and Message Queuing Telemetry Transport (MQTT)

The smart greenhouse system in this study was designed using the Internet of Things concept in Figure 2. In general, the idea of IoT works by connecting several devices and communicating with each other via the internet [10]. This embedded system utilizes the NodeMCU ESP8266-12E as the central controller. This device has several advantages: low cost, integration with Wi-Fi module, the small board size, and low power consumption.[11][12].

Figure 2 is a general picture of a smart greenhouse; this picture has already applied the IoT concept. The Smart

Greenhouse contains a microcontroller, sensors, and actuators. Furthermore, the smart greenhouse is connected to the cloud, which processes and transmits data. Finally, the end-user app contains a dashboard and web-based monitoring system. The communication and data transmission process in a smart greenhouse utilizes the MQTT protocol. The MQTT protocol is used because it is a standard protocol for machine-to-machine or IoT communication with low overhead data packets and low power consumption [13][14].

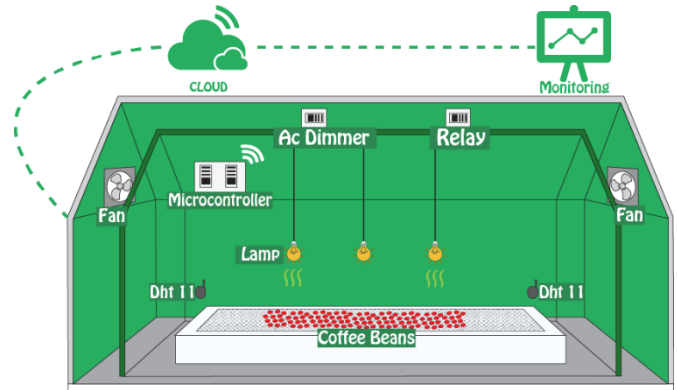


Figure 2. Smart Greenhouse Overview

### B. System Concepts

The NodeMCU ESP8266-12E controls the temperature and humidity in the Smart Greenhouse Coffee Dryer by controlling fan speed and lamp brightness. The setting technique uses the Sugeno fuzzy method so that the temperature and humidity of the room can be maintained as targeted. Figure 3 shows the architecture of the system being built.

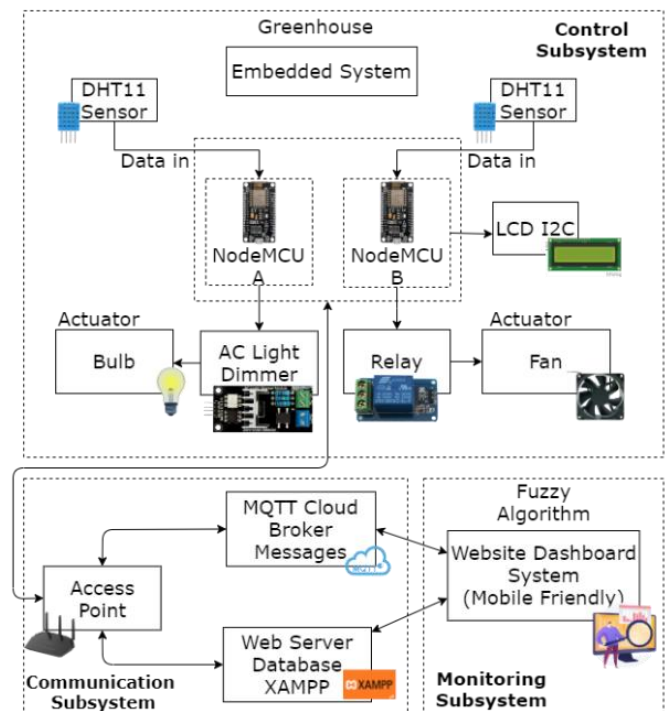


Figure 3. Smart Greenhouse System Architecture

The system architecture in Figure 3 consists of three subsystems as follows:

**Step 1:** The control subsystem block is the central control system for control and publishes the acquisition data sensors of the greenhouse. The control subsystem receives fuzzy results to determine the actuator, and these results are used to regulate the PWM signal, which controls the heat of the bulb and the flame of the fan. The control subsystem has two microcontrollers, two dht11 sensors, an ac light dimmer, relay, fan, and lamp. The average temperature and humidity data will also be duplicated on the LCD so that the greenhouse temperature can constantly be monitored offline.

**Step 2:** The communication subsystem block is an essential component in data exchange and device communication. With the access point as a gateway, the transmission process uses MQTT in the communication protocol. MQTT is a perfect protocol for machine-to-machine and IoT communication concepts with low power and resource consumption. The time interval used to transmit sensor data to the monitoring subsystem is every 2 seconds for real-time data. The interval used to analyze the data with the fuzzy algorithm is every 2 minutes, so in a day or 24 hours, 720 analyses will be done.

**Step 3:** The monitoring subsystem block is the last system directly connected to the user. The sensing data from the microcontroller will be presented in a dashboard containing data on temperature, humidity, and real-time conditions of the greenhouse. This data will also be processed using a fuzzy algorithm; the results will be published to determine the PWM value of the lamp and fan conditions in the control subsystem. Data on average temperature and humidity per day will be recorded and calculated according to the date of entry of the coffee cherries to find out when the coffee cherries are ready to be taken for processing at the next stage. All of this information can be monitored from PC and Android platforms.

*C. Fuzzy Sugeno Method*

The method used to control the smart greenhouse is the Sugeno fuzzy algorithm—determination of linguistic values. Linguistic values are numerical intervals with linguistic values whose semantics can be defined by the membership function. The linguistic values in this study can be seen in Table I.

TABLE I  
 LINGUISTIC VALUE

Variable Value	Linguistic Value
Temperature	Cold, Normal, Hot
Humidity	Dry, Normal, Wet
Heat Lamp	Normal, Hot, Very Hot
Fan State	On, Off

The main reason for dividing the minimum number of memberships is computational efficiency. Since this method applies to hardware-related IoT systems like microcontrollers, computer efficiency should be considered. In research from D Ismawati about the effect of the number of memberships on the fuzzy output. It can be concluded that the difference in the

number of memberships of 3, 5, 7 affects the time to achieve ideal conditions. With a difference of only 1 second, the authors prioritize computational efficiency on the system above time speed to achieve ideal conditions [15]. Fuzzification is used to change information from sensor data input to linguistic fuzzy set data.

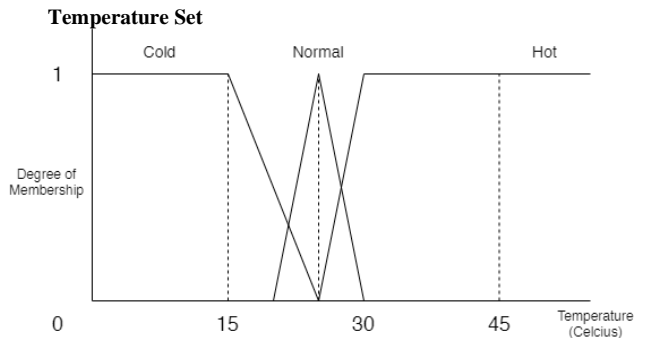


Figure 4. Temperature membership degree

Figure 4 shows the variable temperature conditions in the greenhouse are divided into three parts: cold, normal, and hot where the universe of discussion on the greenhouse temperature variable is 10° to 50°, with fuzzy set domain in degrees Celsius: Cold (15°-25°), Normal (20°-30°), Hot (20°-45°).

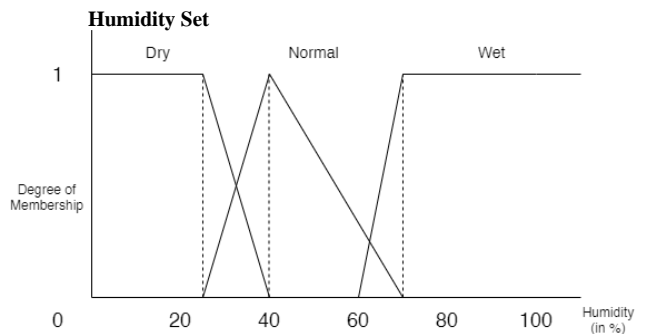


Figure 5. Humidity membership degree

Figure 5 shows the variable humidity conditions in greenhouse are divided into three parts, namely Dry (25% - 40%), Normal (25% - 70%), Wet (60% - 100%).

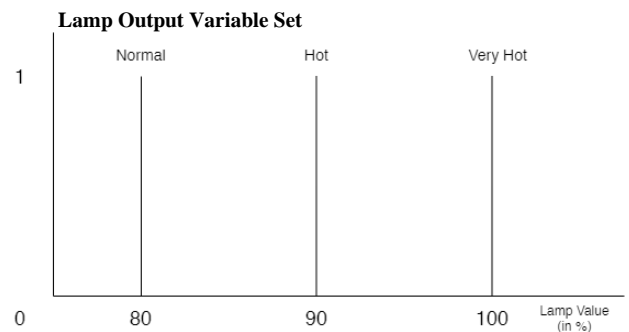


Figure 6. Lamp output variable set

In the use of fuzzy Sugeno, the output is constant or linear value and divided into normal (80%), hot (90%), and very hot

(100%) for lamp output, that shown in Figure 6. Meanwhile, the AC Light Dimmer module regulates the heat generated by the lamp.

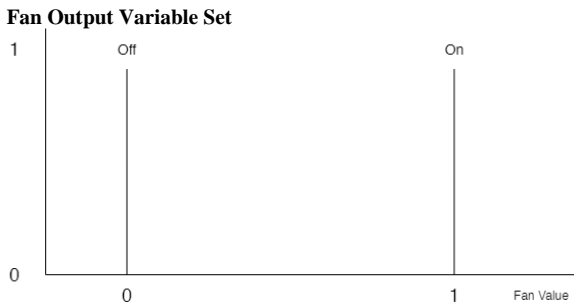


Figure 7. Fan output variable set

Figure 7 shows the fan output variable set is divided into two parts: On (1) and Off (0). We control the fan by using relay components.

The formation of a fuzzy rule base contains many fuzzy rules that determine the fuzzy input value to the fuzzy output value [16]. This rule is often expressed in the IF-THEN format. The basic rules that have been made are as follows in Table II:

TABLE II  
 FUZZY RULE TABLE

IF	Temp.	Rh	Output	
			Heat Lamp	Fan
R1	Cold	Dry	Very Hot	Off
R2	Cold	Normal	Very Hot	On
R3	Cold	Wet	Very Hot	On
R4	Normal	Dry	Hot	Off
R5	Normal	Normal	Hot	On
R6	Normal	Wet	Very Hot	On
R7	Hot	Dry	Normal	Off
R8	Hot	Normal	Normal	On
R9	Hot	Wet	Normal	On

Fuzzy inference, this implication process is carried out after all membership values are known from the input temperature and humidity. The implication function uses the minimum (MIN) formula.

Defuzzification, after knowing all the implication values of each rule for each  $\alpha$  and  $z$  values. Next to the stage of defuzzification. At this stage, calculations will be carried out using the average method with the following Equation (1). To get the output value of the fan ( $Z_k$ ) and heating lamp ( $Z_p$ ).

$$Z = \frac{\sum \alpha_i z_i}{\sum \alpha_i} \quad (1)$$

### III. RESULT AND DISCUSSION

The analysis is carried out by implementing Sugeno fuzzy calculations to find the output of lights and fans in regulating actuators in the greenhouse. The following is a breakdown of the Sugeno fuzzy calculation flow with the assumption that the data obtained by the DHT11 sensor is a temperature of 28°C and air humidity of 75%.

**Step 1:** Temperature Fuzzification Process: The temperature of 28°C is included in the intersection of the set between normal and heat. So that the following values are obtained using Equation (2).

$$\mu_{Cold} = \begin{cases} 1; & x \leq 15 \\ \frac{25-x}{25-15}; & 15 < x \leq 25 \\ 0; & x > 25 \end{cases}$$

$$\mu_{Normal} = \begin{cases} 0; & x \leq 20 \text{ or } x \geq 30 \\ \frac{x-20}{25-25}; & 20 < x \leq 25 \\ \frac{30-x}{30-25}; & 25 < x < 30 \end{cases} \quad (2)$$

$$\mu_{Hot} = \begin{cases} 0; & x \leq 25 \\ \frac{x-25}{45-25}; & 25 < x \leq 45 \\ 1; & x > 45 \end{cases}$$

Then the results of the temperature fuzzification are obtained as follows:

$$\mu_{Cold}[28] = 0; \mu_{Normal}[28] = 0.4; \mu_{Hot}[28] = 0.15$$

**Step 2:** Humidity Fuzzification Process: The humidity value of 75% is included in the wet set, so the following values are obtained using Equation (3).

$$\mu_{Dry} = \begin{cases} 1; & x \leq 15 \\ \frac{40-x}{40-15}; & 15 < x \leq 40 \\ 0; & x > 40 \end{cases}$$

$$\mu_{Normal} = \begin{cases} 0; & x \leq 20 \text{ or } x \geq 70 \\ \frac{x-20}{40-20}; & 20 < x \leq 40 \\ \frac{70-x}{70-40}; & 40 < x < 70 \end{cases} \quad (3)$$

$$\mu_{Hot} = \begin{cases} 0; & x \leq 25 \\ \frac{x-25}{45-25}; & 25 < x \leq 45 \\ 1; & x > 45 \end{cases}$$

Then the results of the temperature fuzzification are obtained as follows:

$$\mu_{Dry}[75] = 0; \mu_{Normal}[75] = 0; \mu_{Wet}[75] = 0.75$$

**Step 3:** Implication function process: In the fuzzy Sugeno method, the output value is constant, so the condition value is determined in Table III.

TABLE III  
 FUZZY OUTPUT VALUE

Condition Variable	Value
Very Hot	100
Hot	90
Normal	80
On	1
Off	0

The implication function uses the minimum calculation (MIN) by taking the smallest temperature and humidity fuzzification results using Equation (4).

$$\alpha_i = \mu_{A_i}(X) \cap \mu_{B_i}(X) = \text{MIN} \{ \mu_{A_i}(X), \mu_{B_i}(X) \} \quad (4)$$

Determination of this status output using the Zero Order Fuzzy Sugeno Method using Equation (5).

$$\text{IF}(X_1 \text{ is } A_1), (X_2 \text{ is } A_2), (X_3 \text{ is } A_3), (X_4 \text{ is } A_4) \dots \\ (X_n \text{ is } A_n) \text{ THEN } z = k \quad (5)$$

Where  $X_n$  variable is the input variable, and  $A_n$  variable is the membership set. The following is the implementation of the rule base to determine the lamp and fan output:

- [R1] IF Cold Temperature AND Dry Humidity THEN S-Heat Lamp, Fan Off =  $\text{MIN}(0;0) = 0$
- [R2] IF Cold Temperature AND Normal Humidity THEN S-Heat Lamp, Fan On =  $\text{MIN}(0;0) = 0$
- [R3] IF Cold Temperature AND Wet Humidity THEN S-Heat Lamp, Fan On =  $\text{MIN}(0;0.75) = 0$
- [R4] IF Normal Temperature AND Dry Humidity THEN Heat Lamp, Fan Off =  $\text{MIN}(0.4;0) = 0$
- [R5] IF Normal Temperature AND Normal Humidity THEN Heat Lamp, Fan On =  $\text{MIN}(0.4;0) = 0$
- [R6] IF Normal Temperature AND Wet Humidity THEN S-Heat Lamp, Fan On =  $\text{MIN}(0.4;0.75) = 0.4$
- [R7] IF Hot Temperature AND Dry Humidity THEN Light Normal, Fan Off =  $\text{MIN}(0.15;0) = 0$
- [R8] IF Normal Temperature AND Humidity THEN Normal Lamp, Fan On =  $\text{MIN}(0.15;0) = 0$
- [R9] IF Hot Temperature AND Wet Humidity THEN Normal Lamp, Fan On =  $\text{MIN}(0.15;0.75) = 0.15$

**Step 4: Defuzzification Process:** The defuzzification process aims to produce firm values using the following weighted average using Equation (6) and (7).

Lamp output defuzzification:

$$Z_l = \frac{(0.4 \times 100) + (0.15 \times 80)}{0.4 + 0.15} \quad (6)$$

$$Z_l = \frac{52}{0.55}$$

$$Z_l = 94,5$$

Fan output defuzzification

$$Z_k = \frac{(0.4 \times 1) + (0.15 \times 1)}{0.4 + 0.15} \quad (7)$$

$$Z_k = \frac{0.55}{0.55}$$

$$Z_k = 1.00$$

Based on the results of manual calculations using the Fuzzy Sugeno Method with an input temperature of 28°C and a humidity of 75%, it produces a lamp output value of 94.5 and a fan output value of 1. This output value will regulate the condition of the actuator logic in the control system.

#### A. Result of the Implementation of the Greenhouse Prototype

The prototype used to simulate drying coffee beans is a mini greenhouse with 70x60x50cm made of fiber and a pipe frame with a net as the base. Models and shapes are produced as closely as possible to the original greenhouse scheme without

changing its primary function. The results of the prototype greenhouse are shown in Figure 8 and Figure 9

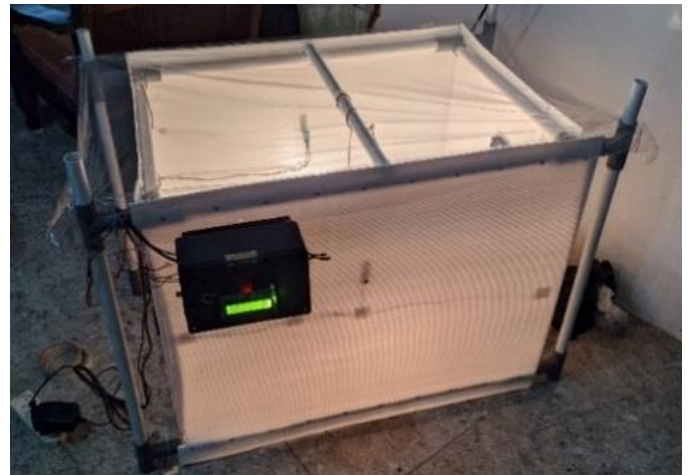


Figure 8. Greenhouse Prototype front view



Figure 9. Greenhouse Prototype top view

#### B. Smart Greenhouse Dashboard and Monitoring

In this section, the researcher created a website-based dashboard and monitoring system. This system is directly connected to the prototype greenhouse in the MQTT protocol. The dashboard system consists of 5 pages.

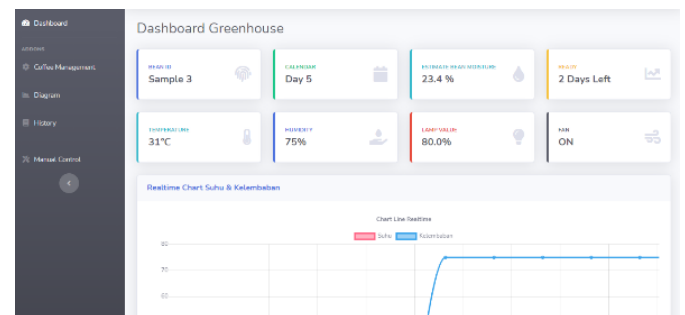


Figure 10. Dashboard Home Page

The dashboard page shown in Figure 10 contains information on temperature, humidity, fan, and light conditions in the greenhouse. In addition, there is also information about coffee beans that are being dried, including data on days,

estimated moisture content, and when the coffee beans are ready to be taken for processing to the next stage. At the bottom position, there is a real-time chart of temperature and humidity to find out changes in data in specific time intervals.

The second page in Figure 11 is the coffee management menu; there are several input forms: coffee id, initial water content, and type of coffee. The data obtained from this input will later start the drying process and predict the water content of the coffee beans. When coffee beans are being dried, the information from the form will be disabled.

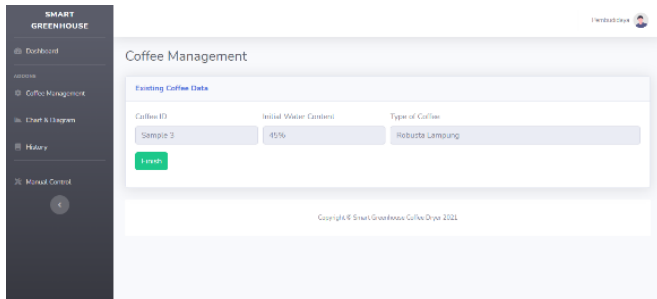


Figure 11. Coffee Management Menu

The third page is the chart & diagram menu, containing the daily average temperature data, which will be visualized in a chart to monitor changes from day today, shown in Figure 12.

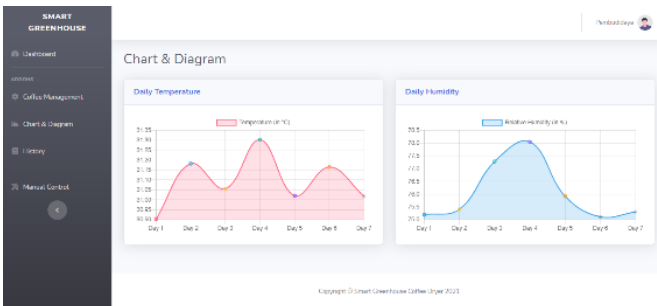


Figure 12. Chart and Diagram Menu

The fourth page is the history menu containing historical data on coffee beans that have been dried in a smart greenhouse, shown in Figure 13.

Coffee ID	Initial Water Content	Type	Date In	Date Out
Sample 5	55	Arabica Arjuna	13 June 2021	15 June 2021
Sample 5	12	Robusta Lampung	13 June 2021	15 June 2021
Sample 1	50	Robusta Lampung	09 June 2021	16 June 2021
Sample 2	45	Robusta Lampung	13 June 2021	14 June 2021
Sample 3	40	Pondok Bajak	13 June 2021	14 June 2021
Sample 6	60	Robusta Lampung	13 June 2021	13 June 2021

Figure 13. History Menu

The last page is the manual control menu in Figure 14. In case of an urgent situation, the other menu allows the user to

control the greenhouse manually. The user can adjust the fan condition and the lamp's intensity in this menu.

After the overall system is built, testing is carried out to determine whether the system is running as expected? The testing refers to the actuator conditions and temperature conditions obtained from the greenhouse. The test pays attention to the initial temperature transfer time to the ideal temperature at a particular time after the system is turned on. The test results are stated in Table IV.

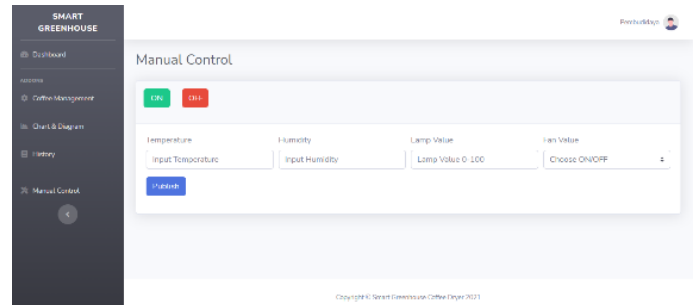


Figure 14. Manual Control Menu

TABLE IV  
OVERALL SYSTEM TEST RESULT

Time (Minutes)	Intensity Lamp(%)	Fan	DHT11	
			Temp.(°C)	Rh(%)
2	98.8	ON	26	84
2	97.1	ON	27	82
3	95	ON	28	80.5
5	90	ON	29	80.5
8	80	ON	30	78
10	80	ON	31	77
5	80	ON	32	75

The results of the study should be written clearly and densely. The discussion should describe the significance of the research results, not repeat them. Avoid using citations and excessive discussion of published literature.

### C. Drying Process Analysis

In this section, an analysis of the coffee bean drying process in a smart greenhouse is carried out. The drying process occurs by reducing the initial moisture content of the coffee beans slowly over a particular time and temperature. In this test process, a water content determination formula is used. The parameters used are the weight of the starting material, the weight of the final material, the temperature, and the drying duration. The purpose of this test is to determine the water content reduction at a specific temperature and time as a reference for predicting the water content in coffee beans. The process of determining the water content is expressed in the following Equation (8).





$$KA = \frac{Wb - Wk}{Wb} \times 100\% \quad (8)$$

Where  $KA$  variable is the water content of the material (%),  $Wb$  variable is the weight of material before drying (grams), and  $Wk$  variable is the weight of the material after drying (grams). Stages of calculating the water content of coffee beans:

- A sampling of coffee beans in a greenhouse assuming an initial moisture content of 45%.
- The sample is weighed to determine the weight of the starting material.
- The samples were dried at an average temperature of 31°C for a specific time.
- The sample is weighed again to determine the decrease in water content at a temperature of 31 °C in a specific time.

The calculation process is carried out in two tests to find accurate numbers. The calculation process in Table V.

TABLE V  
 DRYING PROCESS TEST

Initial Weight	Final Weight	Temp.	Time
61.3 gram 	61.1 gram 	31°C	1 minute
61.1 gram 	60.8 gram 	31°C	1,5 minutes

Based on the results in Table V, the mass of coffee beans has a constant decrease of 0.01 grams every 30 seconds at a temperature of 31°C. These results show that smart greenhouses can carry out the primary function of reducing the coffee beans' water content, which is marked by a reduction in the mass of the coffee beans at a specific temperature and time. From the drying process test results in Table 5, the moisture content can be determined using the following Equation (9).

$$\begin{aligned}
 Wb &= 61,3 \text{ gram.} \\
 Wk &= 61,1 \text{ gram.} \\
 KA &= \frac{61,3 - 61,1}{61,3} \times 100\% \\
 KA &= \frac{0,2}{61,3} \times 100\% \\
 KA &= 0,003\%
 \end{aligned}
 \tag{9}$$

The reduced water content during the 1-minute drying process at 31°C is 0.003%.

From the above calculation, it can be concluded that in 1 minute at an ideal temperature of 31°C, the water content of coffee beans can be reduced by 0.003% in the drying process. These calculations become the basis for the prediction function on the website with a simple analysis that in one day or 24 hours, the reduced water content is 4.32%.

In the quality standards of coffee beans listed in SNI, the maximum moisture content in post-drying coffee beans is 12.55-13%, while the moisture content of freshly harvested

coffee beans is 45-50% so that it can be calculated predictively with the Equation follows:

$$LP = \frac{KDA - KDT}{KA} \tag{10}$$

Where  $LP$  variable is drying time (minutes),  $KDA$  variable is initial moisture content (%),  $KDT$  variable is target moisture content (%), and  $KA$  variable is reduced water content/minute. Assuming the initial water content is 50%, the calculation process is as follows:

$$\begin{aligned}
 LP &= \frac{KDA - KDT}{KA} \\
 LP &= \frac{45 - 13}{0,003} \\
 LP &= \frac{32}{0,003} \\
 LP &= 10.666 \text{ minutes}
 \end{aligned}
 \tag{11}$$

From the above calculation, it can be concluded that the time needed to reduce coffee beans with an initial moisture content of 45% to 13% is 10,666 minutes or 7.4 days.

#### IV. CONCLUSION

Smart Greenhouse Coffee Dryer With Fuzzy Algorithm On Internet Of Things Platform can replace conventional methods with an alternative to the drying process. From the results of testing the drying process, the smart greenhouse reduced the initial water content of coffee beans by 45% to 13% within 7.4 days with an ideal drying temperature of 31°C. Using fuzzy algorithms in smart greenhouses with temperature and humidity data as parameters can produce output values as a reference for actuator logic responses to keep greenhouse conditions stable at the ideal drying temperature. The website-based dashboard and monitoring system functions as a supporter of the drying process and plays a vital role by presenting real-time greenhouse data, coffee bean management processes, predictive calculations of moisture content, and manual greenhouse control functions.

#### REFERENCE

- [1] Direktorat Kajian Strategis dan kebijakan Pertanian, "Peran komoditas kopi bagi perekonomian Indonesia," vol. 13, 2017.
- [2] R. Kustiari, "Perkembangan Pasar Kopi Dunia dan Implikasinya bagi Indonesia," *Forum Penelit. Agro Ekon.*, vol. 25, no. 1, p. 43, 2016, doi: 10.21082/fae.v25n1.2007.43-55.
- [3] P. Ghosh and N. Venkatachalapathy, "Processing and Drying of Coffee - A review," *Int. J. Eng. Res. Technol.*, vol. 3, no. 12, pp. 784-794, 2014.
- [4] W. M. Kurniawan and K. Hastuti, "Penentuan Kualitas Biji Kopi Arabika Dengan Menggunakan Analytical Hierarchy Process (Studi Kasus Pada Perkebunan Kopi Lereng Gunung Kelir Jambu Semarang)," *Simetris J. Tek. Mesin, Elektro dan Ilmu Komput.*, vol. 8, no. 2, p. 519, 2017, doi: 10.24176/simet.v8i2.1358.
- [5] A. Sulistyningtyas, "Prosiding Seminar Nasional Publikasi Hasil-Hasil Penelitian dan Pengabdian Masyarakat 'Implementasi Penelitian dan Pengabdian Masyarakat Untuk Peningkatan Kekayaan Intelektual' PENTINGNYA PENGOLAHAN BASAH (WET PROCESSING) BUAH KOPI ROBUSTA (Coffea robusta)," *Pentingnya Pengolah. basah (Wet Process. Buah kopi Robusta (Coffea var. robusta) untuk menurunkan resiko kecacatan biji hijau saat coffe grading*, pp. 90-94, 2017.

- [6] W. Sutrisno, N. Amiralmahti, and B. Wibowo, "Pembuatan Alat Penjemur Kopi," *Jattec*, vol. 1, no. 2, pp. 100–103, 2020.
- [7] S. B. Prasetyo, N. Aini, and M. D. Maghfoer, "Dampak Perubahan Iklim Terhadap Produktivitas Kopi Robusta (Coffea Robusta) di Kabupaten Malang," *J. Produksi Tanam.*, vol. 5, no. 5, pp. 805–811, 2017.
- [8] F. Wijayanti and S. Hariani, "Pengaruh Pengeringan Biji Kopi dengan Metode Rumah Kaca dan Penyinaran Sinar Matahari Terhadap Kadar Air Biji Kopi Robusta (Coffea Robusta)," *Pros. Semin. Nas. Sains Dan Teknol. Vol. 2. No. 1*, 2019.
- [9] A. N. A. Syah, T. Nuryawati, and W. S. Litananda, "Pengembangan Smart Greenhouse Untuk Budidaya Holtikultura," *Semin. Nas. PERTETA 2018*, no. 2010, pp. 1–10, 2018, [Online]. Available: <http://www.ccw.ir/content/92/default.aspx>.
- [10] L. K. Ramasamy and S. Kadry, "Internet of things (IoT)," *Blockchain Ind. Internet Things*, 2021, doi: 10.1088/978-0-7503-3663-5ch1.
- [11] Dodit Suprianto, Vipkas Al Hadid, Rini Agustina, *Microcontroller Arduino Untuk Pemula*, 1st ed. Jakarta: Jasakom, 2019.
- [12] D. Suprianto, N. Noprianto, and R. Agustina, "IoT DEVELOPMENT BOARD DSP-TECH," *Internet of Things*, 2021. <https://iotboard.dsptech.info/internet-of-things/>.
- [13] H. R. A. Ameer and H. M. Hasan, "Enhanced MQTT Protocol by Smart Gateway," *Iraqi J. Comput. Commun. Control Syst. Eng.*, no. October, pp. 53–67, 2020, doi: 10.33103/uot.ijccce.20.1.6.
- [14] T. Yokotani, S. Ohno, H. Mukai, and K. Ishibashi, "IoT Platform with Distributed Broker MQTT," *Int. J. Futur. Comput. Commun.*, vol. 10, no. 1, pp. 7–12, 2021, doi: 10.18178/ijfcc.2021.10.1.572.
- [15] D. Ismawati, D. Syauqy, and B. H. Prasetyo, "Perbandingan Jumlah Membership Dan Model Fuzzy Terhadap Perubahan Suhu Pada Inkubator Penetas Telur," *J. Pengemb. Teknol. Inf. dan Ilmu Komput.*, vol. 1, no. 6, pp. 476–485, 2017, [Online]. Available: <https://j-ptiik.ub.ac.id/index.php/j-ptiik/article/view/139>.
- [16] A. Firdausi, I. R. F. Arif, and G. P. N. Hakim, "Time Control Nebulizer Operation Using Fuzzy Sugeno Method," *J. Robot. Control*, vol. 2, no. 2, 2021, doi: 10.18196/jrc.2259.

This is an open access article under the [CC-BY-SA](https://creativecommons.org/licenses/by-sa/4.0/) license.

