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	Chintya Tribhuana Utami	Institut Teknologi Telkom Surabaya, Indonesia	chintya@student.ittelkom-sby.ac.id		
	Helmy Widyantara	Institut Teknologi Telkom Surabaya, Indonesia	helmywid@ittelkom-sby.ac.id		
	Muhammad Adib Kamali	Institut Teknologi Telkom Surabaya, Indonesia	adibkamali@ittelkom-sby.ac.id		

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Light Intensity Control and Greenhouse Monitoring System for Melon Cultivation

Chintya Tribhuana Utami
Departement of Information Technology
Institut Teknologi Telkom Surabaya
Surabaya, Indonesia
chintya@student.ittelkom-sby.ac.id

Helmy Widyantara
Departement of Information Technology
Institut Teknologi Telkom Surabaya
Surabaya, Indonesia
helmywid@ittelkom-sby.ac.id

Muhammad Adib Kamali
Departement of Information Technology
Institut Teknologi Telkom Surabaya
Surabaya, Indonesia
adibkamali@ittelkom-sby.ac.id

***Abstract*— Melons fall into category C-3, where they require full exposure to light, and their main characteristic is low photosynthetic efficiency. Cultivating melon plants at the greenhouse of Institut Teknologi Telkom Surabaya is challenged by the fluctuating climate of Surabaya city, which can impact the received light intensity and result in a deficiency for required photosynthesis. In addition to the level of light intensity, the selection of light color for specific growth phases also influences plant development. Therefore, the purpose of this paper is to create a monitoring and light intensity control system in the greenhouse based on the color spectrum of the growth phases of melon plants, in order to support the growth and development of melon plants. The Fuzzy Mamdani method was chosen to establish rules for the percentage of light color based on light intensity and the growth phase of melon plants. The results show that the system's outcomes using the fuzzy method achieved an accuracy of 99.92% with a margin of error of 0.08% for the blue LED, 99.74% accuracy with a margin of error of 0.26% for the red LED, and 99.95% accuracy with a margin of error of 0.05% for the white LED, while the web-based monitoring system is capable of displaying light intensity data, plant growth phases, and lamp statuses.**

Keywords— Fuzzy, Light Intensity, Melon.

I. INTRODUCTION

According to the National Statistics Agency, melon fruit production in Indonesia decreased by 6.54% in 2021 compared to the previous year [1]. One of the factors contributing to the decline in melon fruit production is the unpredictable climate conditions, which have led melon farmers to experience losses and a decrease in fruit quality.

Based on the sectoral statistical report of Surabaya in 2021, the average sunlight exposure in the city reached 75% in 2020. The highest sunlight exposure was recorded in September at 93%, while the lowest was in December at 57% [2].

Melon falls under the C-3 category, which requires full sunlight exposure, and its main characteristic is low photosynthetic efficiency. Melon plants require a photosynthesis process ranging from 10 to 12 hours per day [3]

Light-Emitting Diodes (LEDs) have become one of the solutions used for plant lighting in greenhouses. Blue light is beneficial for maintaining the vegetative growth processes of plants, while red light is effective in enhancing the generative processes of plants [4]. Greenhouse at Institut Teknologi Telkom Surabaya cultivates melon fruit using vertical farming techniques. To address the deficiency in light intensity, the greenhouse at Institut Teknologi Telkom Surabaya has installed purple LED growth lights that can be fully illuminated and controlled by a system.

Based on the discussed background, there is a need for an internet of things based monitoring and light intensity control system for melon plants in the greenhouse at Institut Teknologi Telkom Surabaya. Plant growth phases and light intensity significantly influence plant growth, and optimizing their photosynthesis process is essential [5]. Chlorophyll can absorb wavelengths ranging from red (600-700 nm) to blue (400-500 nm) [6].

The proposed system employs blue, red, and white LED lights that will illuminate according to the growth phases using fuzzy logic methodology. Fuzzy logic is utilized due to its simplicity in the control process and its ability to be logically interpreted using language that humans can easily understand [7]. The type of fuzzy logic used in this study is Fuzzy Mamdani. Fuzzy logic is applied to control and determine the percentage of LED colors in accordance with the fuzzy rule base for plant growth phases. All the data is transmitted via Wi-Fi and monitored using a website.

II. DESIGN AND CONTROL SYSTEM

A. Design System

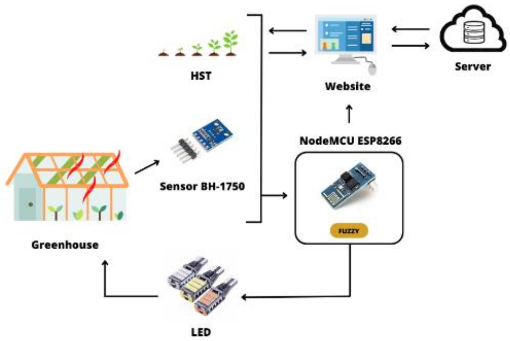

Fig. 1. Design System.

The methodology used in this research is Fuzzy Logic Mamdani. The Fuzzy Logic method functions to determine the rules for the lights based on the captured light intensity by the BH-1750 light sensor and the days after planting. Based on the system flowchart in Fig. 1, the processed data includes the greenhouse light intensity captured by the BH-1750 light sensor and the days after planting. The input data is sent to a microcontroller, where data transmission and decision-making take place. The microcontroller used in this study is the NodeMCU ESP8266.

Fuzzy logic is directly programmed into the ESP8266 to determine the plant growth phase output using the input of days after planting (DAP) and the LED light intensity output using the input of greenhouse light intensity. On the website, users manually input DAP and planting date according to the melon cultivation conditions. The microcontroller reads data from Firebase, processes it using Fuzzy Logic, and then sends back the Fuzzy analysis results to the Firebase real-time database using Wi-Fi. This data is then displayed on the website for monitoring. The website interface provides information about the planting date, DAP input, light intensity information, melon plant phase, and the percentage of light colors.

B. System Block Diagram

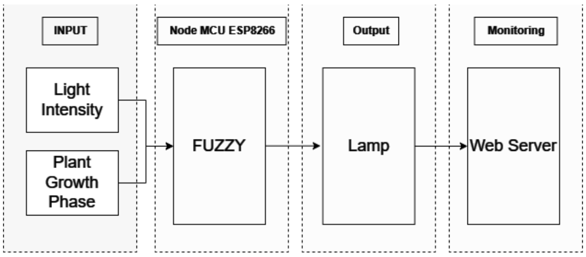

Fig. 2. System Block Diagram.

In the block diagram, as shown in Fig. 2, this research involves two inputs: the light intensity received by the BH-1750 light sensor and the age of the plant (DAP). Both input data will be processed using the chosen microcontroller, the NodeMCU ESP8266. Data processing occurs within the microcontroller using Fuzzy Mamdani logic to control the percentage of red, blue, and white LED light intensity. The output of this system is the light intensity with a specific color spectrum percentage based on the determined Rule Base. All inputs and outputs will be monitored using a website.

III. IMPLEMENTATION OF FUZZY LOGIC

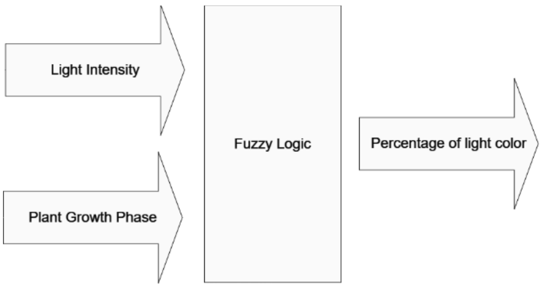

Fig. 3. Fuzzy Input and Output Parameters.

Based on the block diagram of the input and output Fuzzy parameters shown in Fig. 3, this system has two inputs: light intensity and the melon plant growth phase. The output of the system is the value indicating which color of light will be illuminated based on the calculations performed.

A. Membership Functions for Input Light Intensity

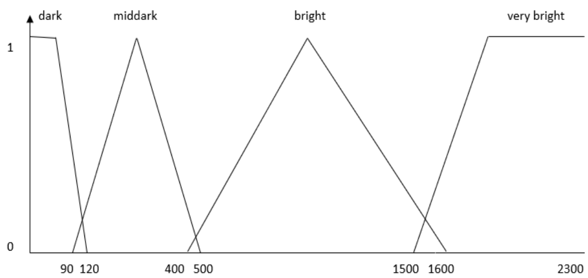

Fig. 4. Graph of Light Intensity Input Membership Function.

In Fig. 4, there is a graph illustrating the membership functions for the input variable "Light Intensity," which consists of four fuzzy sets. Meanwhile, the range of the input light intensity is provided in Table I. The following is the membership function equation for the light intensity input.

TABLE I. DOMAIN RANGE INPUT LIGHT INTENSITY

No	Fuzzy Membership	Domain
1	Dark	[0-120]
2	Middark	[90-500]
3	Bright	[400-1600]
4	Very Bright	[1500-2300]

Here are the membership function equations for the input variable light intensity.

a.) Dark Fuzzy Set

$$f_{dark} = \begin{cases} 1, \; if \; x \leq 80 \\ \frac{120-x}{120-80}, \; if \; 80 \leq x \leq 120 \\ 0, \; if \; x \geq 120 \end{cases} \quad (1)$$

b.) Middark Fuzzy Set

$$f_{Middark} = \begin{cases} \frac{x-90}{300-90}, \; if \; 90 \leq x \leq 300 \\ \frac{500-x}{500-300}, \; if \; 300 \leq x \leq 500 \\ 0, \; if \; x \leq 90 \; or \; x \geq 500 \end{cases} \quad (2)$$

c.) Brigth Fuzzy Set

$$f_{Bright} = \begin{cases} \frac{x-400}{1000-400}, \; if \; 400 \leq x \leq 1000 \\ \frac{1600-x}{1600-1000}, \; if \; 1000 \leq x \leq 1600 \\ 0, \; if \; x \leq 400 \; or \; x \geq 1600 \end{cases} \quad (3)$$

d.) Very Bright Fuzzy Set

$$f_{VeryBright} = \begin{cases} 1, \; if \; x \geq 2000 \\ \frac{x-1500}{2000-1500}, \; if \; 1500 \leq x \leq 2000 \\ 0, \; if \; x \leq 1500 \end{cases} \quad (4)$$

B. Membership Functions for Input Plant Growth Phase

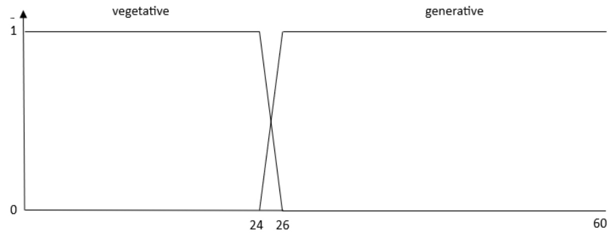

Fig. 5. Graph of Plant Growth Phase Input Membership Function.

In Fig. 5, there is a graph illustrating the membership functions for the input variable "Plant Growth Phase," which consists of two fuzzy sets. Meanwhile, the range of the input plant growth phase is provided in Table II.

TABLE II. DOMAIN RANGE INPUT PLANT GROWTH PHASE

No	Fuzzy Membership	Domain
1	Vegetative	[0-26]
2	Generative	[24-60]

Here are the membership function equations for the input variable plant growth phase.

a.) Vegetative

$$f_{Vegetative} = \begin{cases} 1, & if\ x \le 24 \\ \frac{26-x}{26-24}, & if\ 24 \le x \le 26 \\ 0, & if\ x > 26 \end{cases} \quad (5)$$

b.) Generative

$$f_{Generative} = \begin{cases} 1, & if\ x \ge 26 \\ \frac{x-124}{26-24}, & if\ 24 \le x \le 26 \\ 0, & if\ x \le 24 \end{cases} \quad (6)$$

C. Membership Functions for Output LED Light

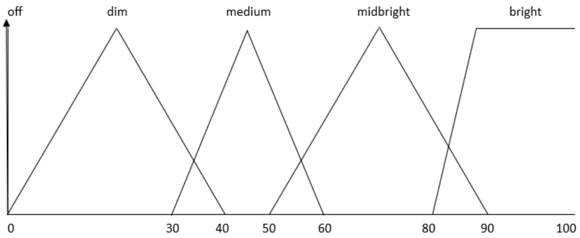

Fig. 6. Graph of LED Light Output Membership Function.

The membership functions for the output LED light, whether blue, red, or white, are the same, each consisting of five fuzzy sets. Therefore, the graphs illustrating the membership functions for the LED lights are presented in Fig. 6. Meanwhile, the range of input light intensity is provided in Table III, with a range of 0 to 100.

TABLE III. DOMAIN RANGE OUPUT LED LIGHT

No	Fuzzy Membership	Domain
1	Off	[0]
2	Dim	[0-40]
3	Medium	[30-60]
4	Midbright	[50-90]
5	Bright	[80-100]

Here are the membership function equations for the output variable LED light.

a.) Dim Fuzzy Set

$$f_{Dim} = \begin{cases} \frac{x-0}{20-20}, & if\ 0 \le x \le 20 \\ \frac{40-x}{40-20}, & if\ 20 \le x \le 40 \\ 0, & if\ x \ge 40 \end{cases} \quad (7)$$

b.) Medium Fuzzy Set

$$f_{Medium} = \begin{cases} \frac{x-30}{45-30}, & if\ 30 \le x \le 45 \\ \frac{60-x}{60-40}, & if\ 45 \le x \le 60 \\ 0, & if\ x \le 30\ or\ x \ge 45 \end{cases} \quad (8)$$

c.) MIdbright Fuzzy Set

$$f_{Midbright} = \begin{cases} \frac{x-50}{70-50}, & if\ 50 \le x \le 70 \\ \frac{90-x}{90-70}, & if\ 70 \le x \le 90 \\ 0, & if\ x \le 50\ or\ x \ge 90 \end{cases} \quad (9)$$

d.) Bright Fuzzy Set

$$f_{Bright} = \begin{cases} 1, & if\ x \ge 90 \\ \frac{x-80}{90-80}, & if\ 80 \le x \le 90 \\ 0, & if\ x \le 80 \end{cases} \quad (10)$$

D. Rulebase Fuzzy

The formation of fuzzy rules is used to express the relationships between input and output variables. There are two input variables: light intensity and plant growth phase, while there are three output variables: the percentage of blue, red, and white LED light intensity. A total of 8 fuzzy rules have been generated, as listed in Table IV.

TABLE IV. RULEBASE FUZZY

No	INPUT		OUTPUT		
	Light Intensity	**Plant Growth Phase**	**Blue**	**Red**	**White**
1	Very High	Vegetative	Off	Off	Off
2	High	Vegetative	Dim	Dim	Dim
3	Middark	Vegetative	Midbright	Medium	Medium
4	Dark	Vegetative	Bright	Midbright	Midbright
5	Very High	Generative	Off	Off	Off
6	High	Generative	Dim	Dim	Dim
7	Middark	Generative	Medium	Midbright	Medium
8	Dark	Generative	Midbright	Bright	Midbright

IV. RESULT AND DISCUSSIONS

A. System Implementation

The next stage is the implementation of the system in the greenhouse. The BH-1750 sensor is placed above the melon plants in the greenhouse to capture light intensity, while the LED lights are installed above the melon plants as shown in Fig.7, placing the sensor above the LED lights aims to measure sunlight's intensity, which will serve as a fuzzy input in the system.

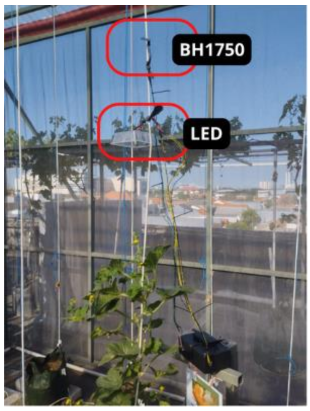

Fig. 7. System Implementation in the Greenhouse.

B. Light Intensity Measurement in the Greenhouse

The first BH-1750 sensor testing involves detecting the light intensity inside the ITTelkom Surabaya greenhouse. In this case, the sensor implementation and data collection are divided into three sessions: the morning session (05:00 – 08:00), the midday/afternoon session (12:00 – 15:00), and the afternoon/evening session (16:00 – 18:00). In Figure 8, the graph depicts the results of the Morning Session Data Collection.

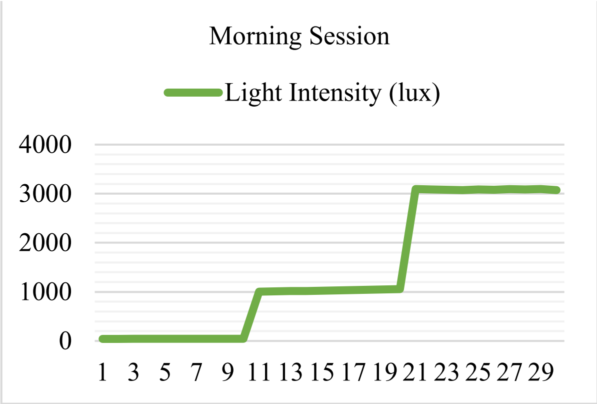

Fig. 8. Graph of Morning Session Data Collection Results.

In Figure 9, the graph depicts the results of the afternoon session data collection.

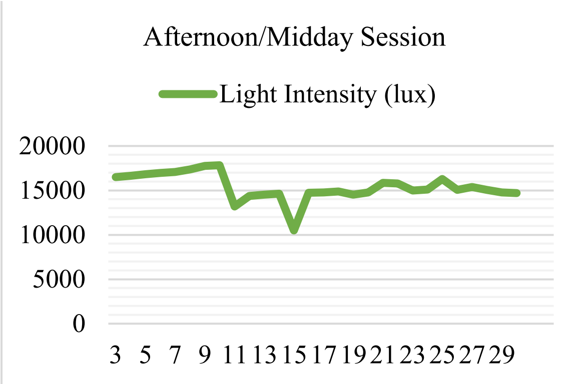

Fig. 9. Graph of Afternoon/Midday Session Data Collection Results.

In Figure 10, the graph depicts the results of the afternoon session data collection.

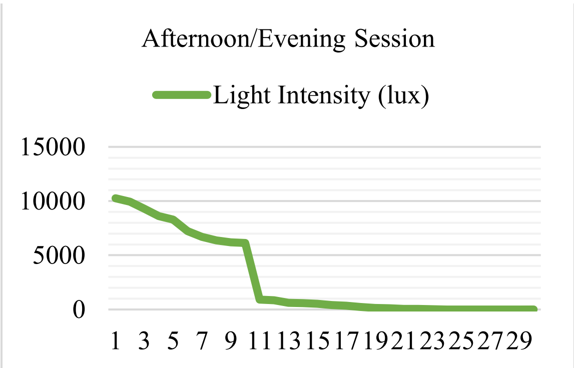

Fig. 10. Graph of Afternoon/Evening Session Data Collection Results.

C. *Measurement of LED Light Intensity*

The purpose of testing LED light intensity is to determine the amount of light received by the plants during the night. The distance is chosen based on the light exposure to the melon plants to ensure it's not too close, ensuring even light distribution. There are 2 testing schemes: the first measures light intensity with all three lights on, and the second measures the intensity of each color separately. For the light intensity testing condition, all three LEDs are turned on, with blue at 92%, red at 70%, and white at 70%.

TABLE V. MEASUREMENT OF LED LIGHT INTENSITY

Trial Attempt	Distance (cm)	Light Intensity (lux)
1	100	42.5
2		40.83
3		42.5
4		42.5
5		42.5
6	90	41.67
7		40.83
8		41.67
9		42.5
10		41.67
11	80	57.5
12		56.67
13		55.83
14		55.83
15		54.17
16	70	78.33
17		77.5
18		79.17
19		75.83
20		75
21	60	81.67
22		81.67
23		81.67
24		84.17
25		86.67
26	50	117.5
27		114.17
28		115
29		114.17
30		114.17

According to Table V, the average measured light intensities for all three LED lights at a distance of 100 cm is 40.75 lux, at 90 cm is 41.8 lux, at 80 cm is 56.08 lux, at 70 cm is 73.8 lux, at 60 cm is 84.8 lux, and at 50 cm is 116.5 lux. Hence, it can be concluded that the highest light intensity is observed at a distance of 50 cm, which aligns with the plant's height. The next testing scheme for LED light intensity involves measuring each LED light color at specific distances.

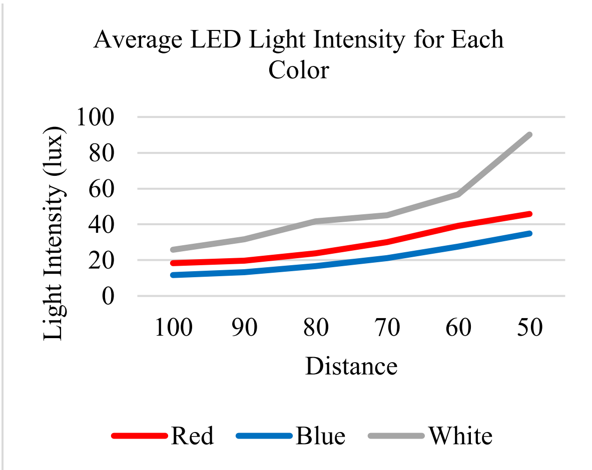

Fig. 11. Graph of Average LED Light Intensity for Each Color.

Based on the graph in Fig. 11, the average red LED light intensity at a distance of 100 cm is 19.17 lux and is highest at a distance of 50 cm with 45.83 lux. The average blue LED light intensity at a distance of 100 cm is 11.67 lux and is highest at a distance of 50 cm with 35 lux. Meanwhile, the average white LED light intensity is 25.83 lux at a distance of 100 cm and 90 lux at a distance of 50 cm.

D. System Testing using MATLAB

Before conducting system testing, the author designed MATLAB simulations for comparison. In MATLAB, a Fuzzy Logic Toolbox was used to facilitate the modeling of the fuzzy logic system. Membership functions for input and output were defined in MATLAB according to the planning and rule base. In Fig. 12, the results of creating the rule base in MATLAB are shown.

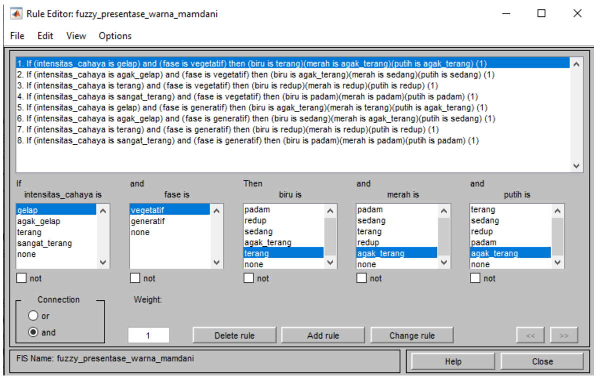

Fig. 12. Rule Base in MATLAB's Fuzzy Logic Toolbox.

Next, the testing was performed to assess the system's output conformity with the fuzzy rules or conditions that were established. Fuzzy logic testing involved comparing the system's output values with those generated by MATLAB's Fuzzy Logic Toolbox, and subsequently calculating the accuracy of the results.

TABLE VI. SYSTEM TESTING USING MATLAB

System Output (%)			MATLAB (%)			Accuracy (%)		
B	R	W	B	R	W	B	R	W
88.8	68.5	68.5	89.3	68.8	68.8	99.4	99.5	99.5
92.2	70	70	92.5	70	70	99.7	100	100
41.6	28.5	28.5	41.7	28.4	28.4	99.8	99.5	99.5
82.8	65.7	65.7	83.2	65.8	65.8	99.5	99.8	99.8
20	20	20	20	20	20	100	100	100
20	20	20	20	20	20	100	100	100
70	45	45	70	45	45	100	100	100
Rata-rata						99.9	99.7	99.9

From the testing results conducted with 15 tests for each growth phase, based on Table VI, the average accuracy for blue LED lights is 99.92%, for red LED lights is 99.74%, and for white LED lights is 99.95%. These high accuracy levels indicate that the system is in good agreement with the MATLAB simulation and performs effectively. The comparison graph of blue LED output between the system and MATLAB can be seen in Fig. 13.

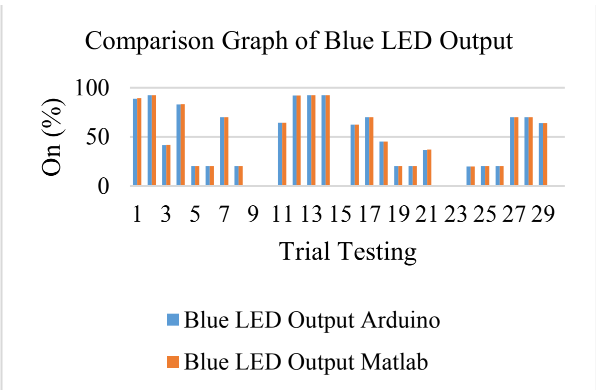

Fig. 13. Comparison Graph of Blue LED Output.

Based on the comparison graph of blue LED output between the system and MATLAB, the difference is not very significant, with only an error margin of 0.8%. Meanwhile, the comparison graph of red LED output between the system and MATLAB can be seen in Fig. 14.

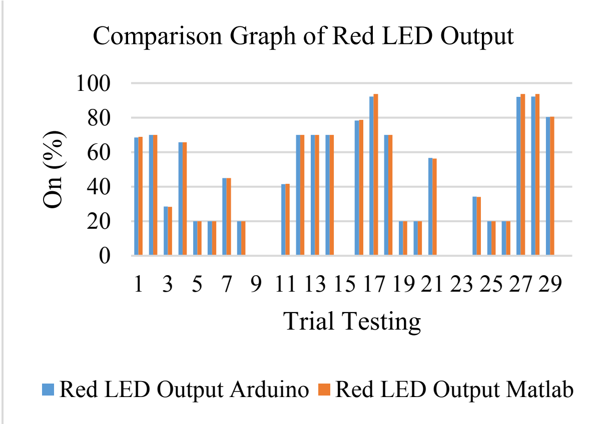

Fig. 14. Comparison Graph of Red LED Output.

Based on the comparison graph of red LED output between the system and MATLAB, the difference is not very significant, with only an error margin of 0.26%. Meanwhile, the comparison graph of white LED output between the system and MATLAB can be seen in Fig. 15.

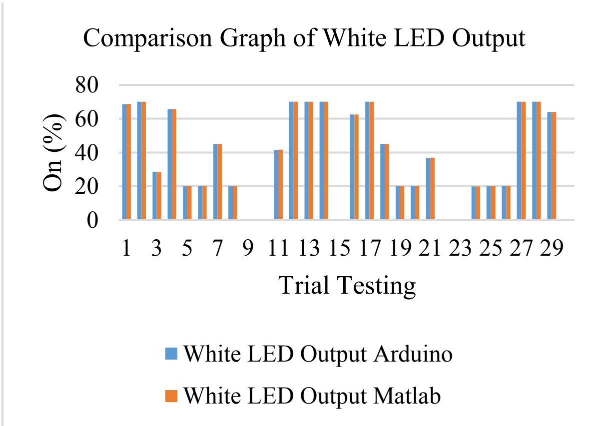

Fig. 15. Comparison Graph of White LED Output.

Based on the comparison graph of white LED output between the system and MATLAB, the difference is not very significant, with only an error margin of 0.05%. The overall output of the LED lamps in the system and MATLAB shows a small error. Therefore, it can be concluded that the system has successfully controlled the lamps according to the fuzzy rule base and has achieved a high level of accuracy.

E. Website Implementation

After the entire system is operational, the data will be sent to Firebase for storage and display through a hosted website. The data stored in Firebase includes the BH-1750 light intensity sensor data, days after planting (DAP), planting date, fuzzy processing results of lamp percentage output, and phase description. The Firebase database interface can be viewed in Fig. 16.

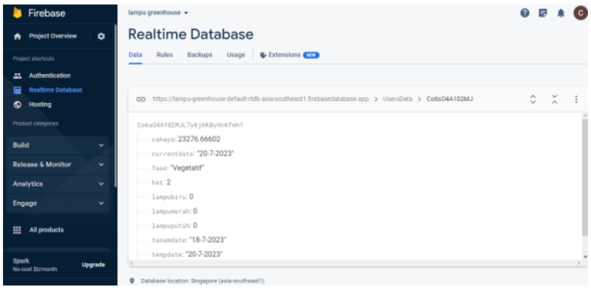

Fig. 16. Comparison Graph of White LED Output.

Website will display data as shown in Fig. 17. The displayed data includes light intensity, days after planting (DAP), plant growth phase, and the status of blue, red, and white LED percentages. The monitoring website can be accessed online.

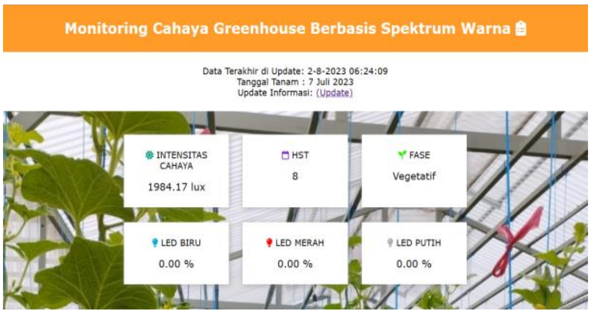

Fig. 17. Website Monitoring Interface.

V. Conclussions

The monitoring and control system for light intensity based on the developmental phases of melon plants using the fuzzy method has been successfully created and implemented in the ITTelkom Surabaya greenhouse. Based on the testing and discussion results, the system effectively processes data using fuzzy Mamdani and achieves a high level of accuracy. The accuracy levels obtained are as follows: blue LED lamp output with 99.92% accuracy and 0.08% error, red LED lamp output with 99.74% accuracy and 0.26% error, and white LED lamp output with 99.95% accuracy and 0.05% error. These high accuracy results demonstrate that the system has successfully engineered artificial lighting in the greenhouse based on harvest age and can meet the light requirements of melon plants.

Acknowledgment

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