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Design and Construction of Cocoa Bean Drying Equipment For Regulating Water Content Using The Fuzzy Method

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Abstract

Indonesia is one of the largest cocoa-producing countries, exporting much of its cocoa to Japan, China, and Malaysia. The export standard for dried cocoa beans is a maximum moisture content of 7%. Traditional sun drying methods in Indonesia do not consistently achieve this standard. Therefore, a cocoa bean dryer using the Mamdani type fuzzy method was designed to control moisture content. This dryer features heaters regulated by dimmers and sensors that monitor temperature and humidity in the drying chamber. The ESP32 microcontroller processes the sensor data and connects to the Internet for control and monitoring via Blynk software, enabling more efficient and faster drying compared to traditional methods. Testing showed the dryer functions as intended. Temperature sensor tests indicated minor variations between sensor and thermogun readings, with an average sensor reading of 42.3°C, thermogun reading of 42.5°C, an average error of 0.4°C, and a 1% error percentage. Humidity sensor tests revealed similar consistency, with an average sensor reading of 46.5%, hygrometer reading of 46.2%, an average error of 0.3%, and a 0.53% error percentage. Load cell tests showed an average sensor reading of 0.32 kg compared to a digital scale reading of 0.33 kg, with an average error of 0.01 kg and a 5.34% error percentage. Each sensor was tested 30 times. Fuzzy control testing yielded satisfactory results, with an average error of 0.4% compared to Matlab results. Moisture content measurements met the export standard. This system is expected to improve the quality and market value of Indonesian cocoa beans.

Keywords: Cocoa Bean Dryer; Water content; Fuzzy Method.

1. Introduction

Cocoa is an export commodity that can contribute to increasing Indonesia's foreign exchange [1]. Reporting from an article from the Ministry of Industry of the Republic of Indonesia, the cocoa processing industry is capable of contributing foreign exchange of more than USD 1 billion in 2020 and 2021. Meanwhile, 85 percent or 319,431 tonnes of the total production volume of the cocoa processing industry has been exported to 96 countries, including America. United States, India, China, Estonia and Malaysia. Based on data from the International Cocoa Organization (ICCO) for 2021/2022, Indonesia is ranked third in the world as a country processing cocoa products, apart from that, Indonesia is in sixth place in the world as the largest producer of cocoa beans [2]. The cocoa plant is a type of plant that can bear fruit all year round. However, Indonesia's climate is tropical, where there are two seasons, namely dry and rainy seasons. During the dry season the drying process can still take place, however during the rainy season the cocoa drying process will be disrupted and if the weather does not clear up it can cause the presence of mold which can damage the aroma and taste as well [3].

Currently, the problems we can see among farmers in the cocoa processing process are the lack of knowledge, skills and creativity as well as the efficient use of farmers' time when processing cocoa beans. Processing that still uses traditional methods can result in the quality of cocoa beans decreasing. The traditional processing process includes a pure drying process using only sunlight during the day and farmers only have experience, whereas when the weather is cloudy or at night the drying process cannot be carried out, if the sun does not appear or the weather is cloudy then the drying process cannot be carried out. carried out and if it continues for a long time, the cocoa bean drying process will be disrupted, resulting in the quality of the cocoa beans decreasing drastically and farmers may suffer losses. In general, the traditional cocoa drying process takes approximately 14 days or 2 weeks and the length of time can be adjusted to the weather conditions of the local area, the land needed for the drying process must also be large to suit the amount of harvest, besides drying in the sun the percentage of humidity is not It can be estimated that normally to achieve good quality cocoa the moisture content is 6-8%. An inappropriate percentage of water content causes the drying process to fail or the quality of the seeds can also be poor [4].

SNI sets standards for the quality of cocoa beans based on physical aspects such as water content, contamination with insects, foreign objects and various aromas that can damage the distinctive aroma of cocoa. Water content is the amount of water contained in a material expressed in a certain percentage. The high water content in cocoa beans can affect the appearance, texture and taste. However, if the water content is too low <7% the seeds will easily break and split [5]. The low quality of cocoa beans is caused by inappropriate processing methods. To increase the yield, quality and quality of cocoa beans requires processes that must be considered, such as the use of technological advances. Technological advances can be utilized to make human work easier, so that they can innovate and create problems that arise [6]. Drying wet cocoa to dry can be replaced using drying technology with even temperature distribution and shorter time so that the drying process is better [2].

The way this cocoa bean dryer works is by pressing the relay as a sign that the system is on and will operate, then the heater and fan automatically work to spread the heat and the thermocouple sensor will detect the temperature in the drying chamber, the load cell weight sensor measures the mass of the cocoa beans during the drying process, the DHT22 sensor detect humidity. Next, the ESP32 microcontroller processes the data produced by the working sensors and the heater controlled by the dimmer using the Fuzzy Mamdani method to produce the desired output and display it via the LCD. Then the resulting data is also displayed in the blynk software to monitor the progress of the drying process.

This research uses the Mamdani fuzzy method for control during the drying process, where the fuzzy method functions to regulate the maximum temperature produced by the heater during the drying process so as to produce the desired output in the form of a PWM dimmer. The Mamdani fuzzy method is one part of the fuzzy inferences system which is useful for drawing conclusions or the best decision in uncertain problems [7]. The Mamdani fuzzy method is also often known as the Max-Min Method, this method was first introduced by Ebrahim Mamdani in 1975. To get the output, 4 stages are required: (1) Formation of fuzzy sets, (2) Application of implication/rule functions, (3) Composition of rules, (4) Affirmation or defuzification. The Mamdani fuzzy method was chosen because it has a high level of accuracy because it uses the CoA (Centroid of Area) method in the Deffuzification process [8].

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2. Material and methods

This research involved several stages in its creation, starting from making the hardware, programming the microcontroller, to programming the Blynk application which can be accessed via smartphone. The tools and materials used in this research are generally designed according to the block diagram shown in Figure 1 below.

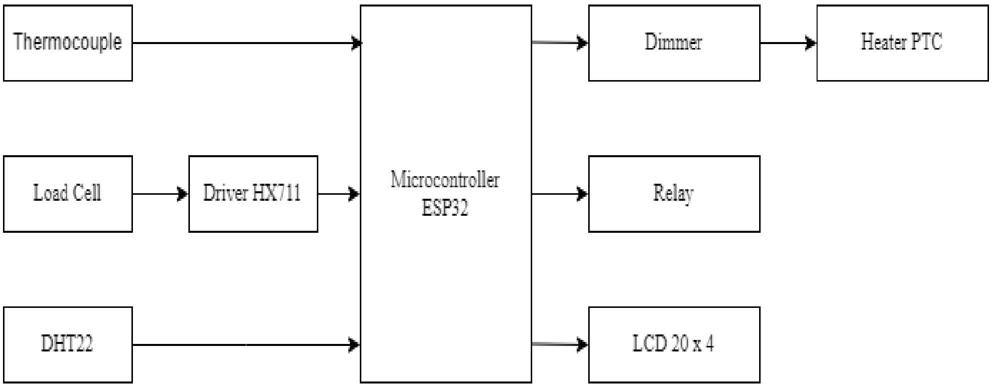

Figure 1. System Block Diagram

The system block diagram in Figure 1 shows the system structure which consists of various components, each of which has a different function. ESP32 functions as a microcontroller in this tool. This tool has three inputs: a thermocouple to measure the water content or humidity in the drying chamber, a load cell sensor to detect the mass of the cocoa beans, and a DHT22 to detect the drying temperature and the moisture content of the cocoa beans. The output of this system includes a heater controlled by a dimmer as a heating element in the drying room. Apart from that, this tool is also equipped with an LCD to display data in the form of cocoa bean mass, cocoa bean moisture content, and the temperature required by the dryer. The ESP32 also functions as a serial communication device that can carry out microcontroller functions and connect to the Blynk application for monitoring during the drying process. The relay is used as a heating On/Off switch which is controlled via Blynk.

Figure 2 presents a detailed explanation of the system workflow through a flowchart as a visual representation. The flowchart above illustrates how the system works which starts by inserting the cocoa beans into the drying chamber. Furthermore, the load cell, thermocouple and DHT22 sensors are active and function according to their respective tasks. If the seed mass is more than 0.65 kg and the humidity is more than 30%, the heater will turn on. If the mass decreases or is less than 0.45 kg and the humidity is less than 25%, the heater will turn off. Data regarding mass, humidity and PWM dimmer will be displayed on the LCD, and sent and displayed in the Blynk application for monitoring, indicating that the drying process has been completed.

Figure 3 shows a circuit schematic that details the relationships between the components used in the system. This scheme is designed according to the explanation in the block diagram, which also illustrates the relationship between components.

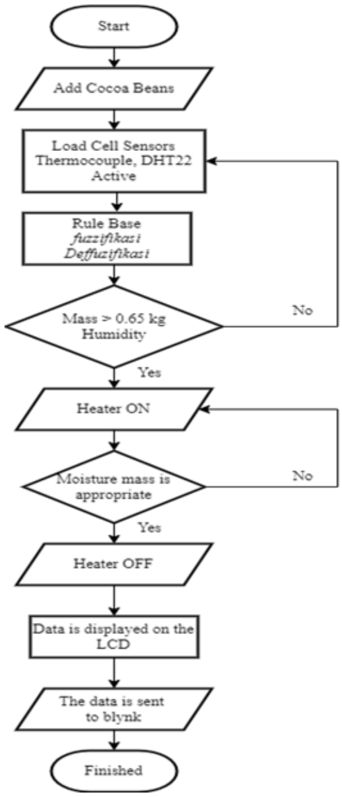

Figure 2. System Flowchart

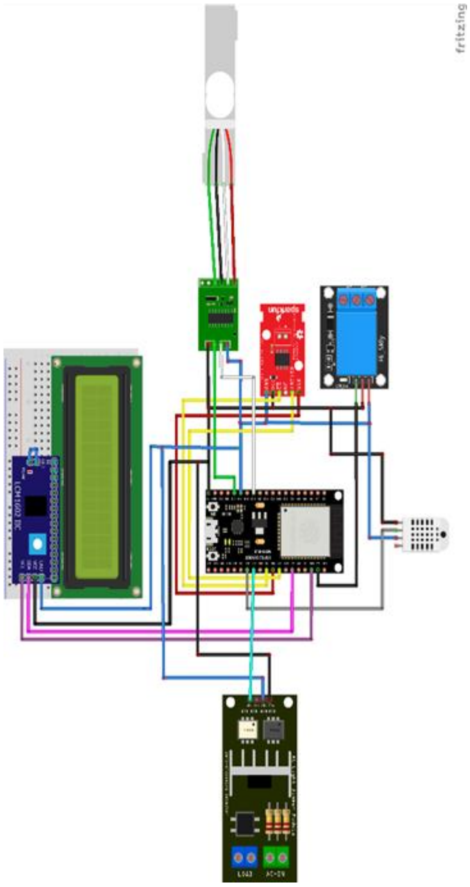

Figure 3. System Electrical Circuit

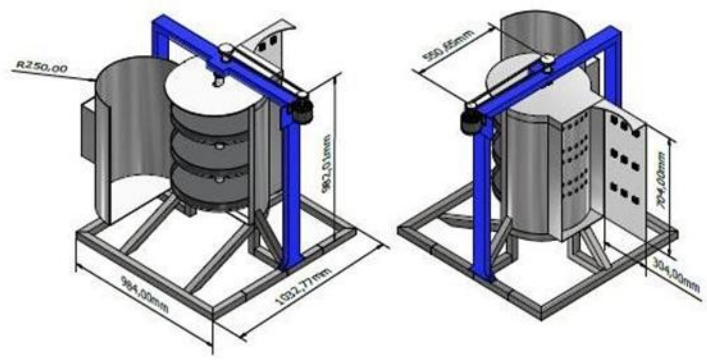

Figure 4. System Design

2.1 Fuzzy Control System

The fuzzification process involves two input fuzzy variables, namely cocoa bean mass which is measured by a load cell sensor and humidity which is measured by a DHT22 sensor. Fuzzification is the process of converting hard values, such as mass and humidity, into fuzzy sets. The mass and humidity values are then searched for membership values in the fuzzy or implied set. After the fuzzification process, the input value in the form of membership for each input is processed based on Mamdani's fuzzy inference rules. These two inputs are then implied to obtain output values based on predetermined rules, thus forming a rule base. The final stage is defuzzification, where several fuzzy set values obtained are defuzzified using the centroid method, producing one output in the form of a PWM dimmer.

Table 1. Mass Input Variables

Variable	Set	Domain
Mass	Light	0 - 0.45 kg
	Normal	0.30 - 0.65 kg
	Heavy	0.50 – 1 kg

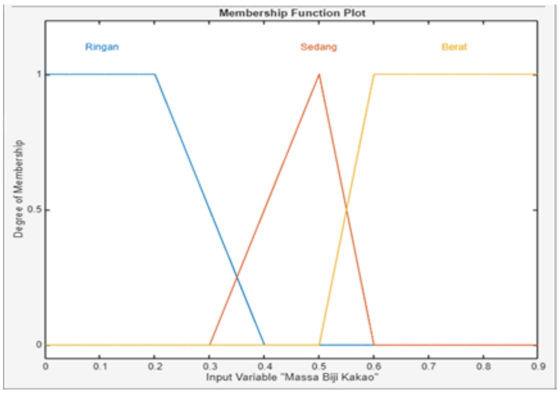

Figure 5. Mass Membership Degree Curve

Fuzzy set of light masses

$$\mu Light\ (x) = \begin{cases} 0;\ x \geq 0.45 \\ \dfrac{0.45 - x}{0.45 - 0.20} 0.20 \leq x \leq 0.45 \\ 1;\ x \leq 0.45 \end{cases} \quad (1)$$

Fuzzy set of normal masses

$$\mu Normal\ (x) = \begin{cases} 0;\ x \leq 0.30\ atau\ x \geq 0.65 \\ \dfrac{x - 0.30}{0.45 - 0.30};\ 0.30 \leq x \leq 0.45 \\ \dfrac{0.65 - x}{0.65 - 0.45};\ 0.45 \leq x \leq 0.65 \\ 1;\ x = 0.45 \end{cases} \quad (2)$$

Fuzzy set of heavy masses

$$\mu Heavy\ (x) = \begin{cases} 0;\ x \leq 0.45 \\ \dfrac{x - 0.45}{0.65 - 0.45} 0.45 \leq x \leq 0.65 \\ 1;\ x \geq 0.45 \end{cases} \quad (3)$$

Table 2. Humidity Input VariablesTabel

Variable	Set	Domain
Humidity	Dry	0-20%
	Normal	15-40%
	Moist	35-100%

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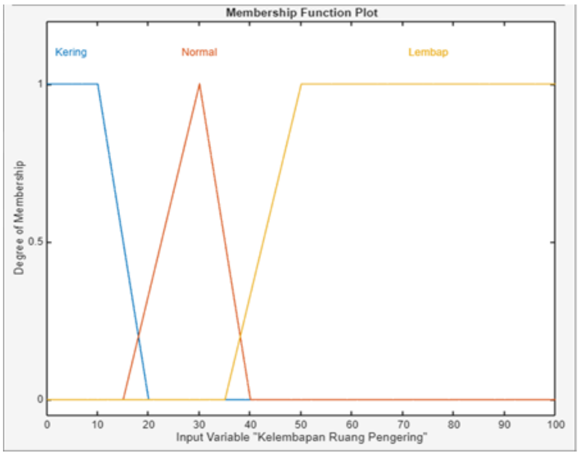

Figure 6. Humidity Membership Degree Curve

Dry moisture fuzzy set

$$\mu Dry\ (x) = \begin{cases} 0; x \geq 20 \\ \dfrac{20 - x}{20 - 15}\ 15 \leq x \leq 20 \\ 1; x \leq 15 \end{cases} \tag{4}$$

Normal humidity fuzzy set

$$\mu Normal\ (x) = \begin{cases} 0; x \leq 15\ \ atau\ x \geq 40 \\ \dfrac{x - 15}{30 - 15}; 15 \leq x \leq 30 \\ \dfrac{40 - x}{40 - 30}; 30 \leq x \leq 40 \\ \ 1 = 30 \end{cases} \tag{5}$$

Humidity fuzzy set

$$\mu Moist\ (x) = \begin{cases} 0; x \leq 35 \\ \dfrac{x - 35}{50 - 35}\ 35 \leq x \leq 50 \\ 1; x \geq 50 \end{cases} \tag{6}$$

Table 3. Dimmer output variables

Variable	Set	Domain
PWM Dimmer	PWM Low	0-160
	PWM Medium	150-200
	PWM High	190-255

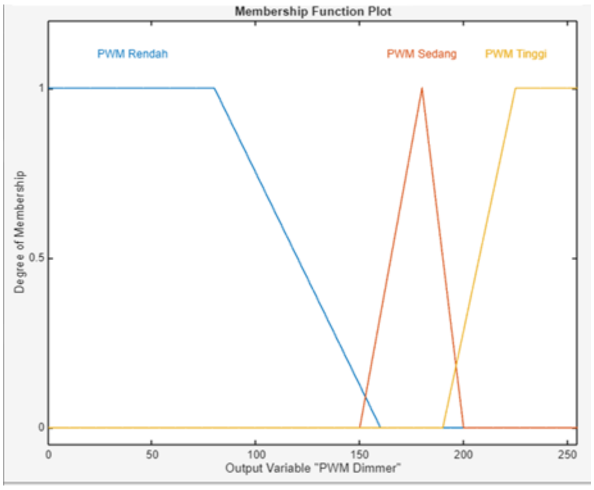

Figure 7. Dimmer Membership Degree Curve

Low dimmer PWM fuzzy set

$$\mu PWM\ Low\ (z) = \begin{cases} 0; z \geq 160 \\ \dfrac{100 - z}{160 - 100}; 100 \leq 160 \\ 1; z \leq 100 \end{cases} \quad (7)$$

Medium dimmer PWM fuzzy set

$$\mu PWM\ Medium\ (z) = \begin{cases} 0; z \leq 150\ atau\ z \geq 200 \\ \dfrac{z - 150}{180 - 150}; 150 \leq z \leq 180 \\ \dfrac{200 - z}{200 - 180}; 180 \leq z \leq 200 \\ 1; z = 180 \end{cases} \quad (8)$$

High Fuzzy PWM Dimmer Set

$$\mu PWM\ High\ (z) = \begin{cases} 0; z \leq 190 \\ \dfrac{z - 190}{225 - 190}; 190 \leq z \leq 225 \\ 1; z\ \geq 225 \end{cases} \quad (9)$$

Next are the Fuzzy rules used in this research:
R1 = If the mass is Light and the Humidity is Dry then the PWM is Low
R2 = If the mass is Light and the Humidity is Normal then the PWM is Medium
R3 = If the mass is Light and the Humidity is Humid then the PWM is High
R4 = If the mass is Normal and the Humidity is Dry then the PWM is Low
R5 = If the mass is Normal and the Humidity is Normal then the PWM is Medium
R6 = If the mass is Normal and the Humidity is Humid then the PWM is High
R7 = If the mass is Heavy and the Humidity is Dry then the PWM is Low
R8 = If the mass is Heavy and the Humidity is Normal then the PWM is Medium
R9 = If the mass is Heavy and the Humidity is Humid then the PWM is High

There are several methods used for the Defuzzification process, one of which is the Centroid Method. Centroid is also called the Center of Grafity method or center of area method (Center of Area, CoA). The defuzzification process in the Centroid method is to take the center point (x) value of the area in the membership function.

$$z = \frac{\int \mu(z).z\,dz}{\int \mu(z)\,dz} \tag{10}$$

3. Results and discussion

The test was carried out by starting with testing the Termocouple temperature sensor by comparing the results of the temperature sensor readings with the Termogun measuring instrument as in the table below:

Table 4: Comparison of thermocouple and thermogun sensor readings

No	Thermocouple Sensor	Termogun	Error	% Error
1	31,0	31,1	0,1	0,32%
2	31,4	31,6	0,2	0,64%
3	31,7	31,9	0,2	0,63%
4	32,3	32,4	0,1	0,31%
5	32,9	33	0,1	0,30%
6	35,8	35,9	0,1	0,28%
7	38,8	39	0,2	0.52%
8	34,0	34,4	0,4	1,18%

The test results show that there are variations between the temperature detected by the sensor and the temperature reading using the thermogun, with small to moderate differences in the measured values. This test was carried out 30 times, the majority of experiments showed an error percentage below 1%, indicating good accuracy of the sensor in measuring temperature.

Next, testing is carried out on the humidity sensor by comparing the readings from the humidity sensor with the hygrometer measuring instrument, as shown in the table below.

Table 6. Comparison of load cell sensor readings and digital scales

No	Load Cell Sensors	Digital scales	Error	% Error
1	0,45	0,48	0,03	6,67%
2	0,44	0,45	0,01	2,27%
3	0,43	0,47	0,04	9,30%
4	0,42	0,43	0,01	2,38%
5	0,41	0,42	0,01	2,44%
6	0,40	0,44	0,04	10.00%
7	0,39	0,40	0,01	2,56%
8	0,38	0,39	0,01	2,63%

Test results show that there are variations between seed mass readings by sensors and digital scales, with small to moderate differences in the measured values. In most experiments, the error percentage was below 5%, indicating good accuracy in mass measurement by the sensor. This experiment was carried out 30 times. However, some measurements show a higher percentage error, which is likely caused by calibration error factors.

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Table 7. Fuzzy Mamdani Test

No	Mass (kg)	Initial Humidity	PWM Dimmer	Matlab	Error Difference
1	0.90 kg	61,8%	230	231	1
2	0.80 kg	59.1%	229	230	1
3	0.70 kg	40%	225	226	1
4	0.22 kg	61%	230	230	0
5	0.21 kg	29.20%	176	176	0
6	0.29 kg	22.40%	104	104	0
7	0.38 kg	57.40%	229	229	0
8	0.30 kg	31.10%	175	176	1
9	0.33 kg	47%	226	226	0
10	0.48 kg	33.30%	176	176	0
11	0.61 kg	36.50%	191	191	1
12	0.81 kg	37.70%	201	201	0
13	0.90 kg	34.10%	176	176	0
14	0.90 kg	27.60%	105	105	0
15	0.77 kg	28.20%	116	116	0
16	0.84 kg	28.50%	123	123	0
17	0.51 kg	39.70%	176	176	0
18	0.47 kg	40.20%	176	177	0
19	0.36 kg	40.70%	176	176	0
20	0.44 kg	57.90%	229	229	0
21	0.51 kg	58.1%	226	230	4
22	0.61 kg	58.20%	225	225	0
23	0.28 kg	56.60%	226	228	2
24	0.31 kg	55.60%	227	227	0
25	0.18 kg	55.40%	230	230	0
26	0.20 kg	36.40%	176	176	0
27	0.32 kg	35.20%	176	176	0
28	0.42 kg	32.40%	176	176	0
29	0.26 kg	27.3%	101	101	0
30	0.22 kg	29.10%	138	139	1

The tests in table 7 were carried out to find out whether the Mamdani fuzzy method was suitable to be applied to a cocoa bean drying system or equipment. From the test results above, there is a difference in the error output from the dryer and the Matlab simulation with an overall average error of 0.4%, where this result is considered very small for fuzzy testing, therefore the Mamdani fuzzy method can be applied well to the cocoa bean dryer that has been made.

Figure 8. Fuzzy Input and Output

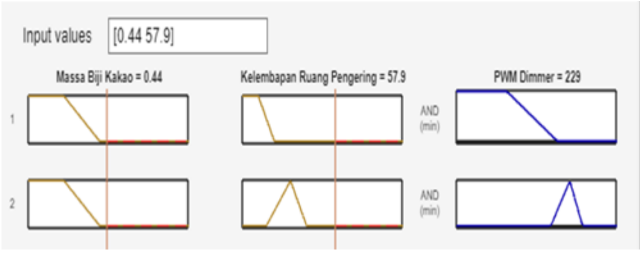

Figure 9. Matlab output

Figure 8 and Figure 9 show the fuzzy rules conditions in the dryer and Matlab. The experiment was carried out with an input mass value of 0.44 kg, which is included in the normal mass set and humidity of 57.90%, which is included in the damp humidity set. Then the output value for PWM Dimmer membership is 229, which means the High PWM Dimmer set.

Figure 10. Wet Cocoa Beans

Figure 11. Dried Cocoa Beans

Figure 12. Final Result of Water Content of Dried Cocoa Beans

Figure 12 shows the results of measuring the water content of dry cocoa beans using a soil moisture sensor measuring instrument with a water content result of 7%.

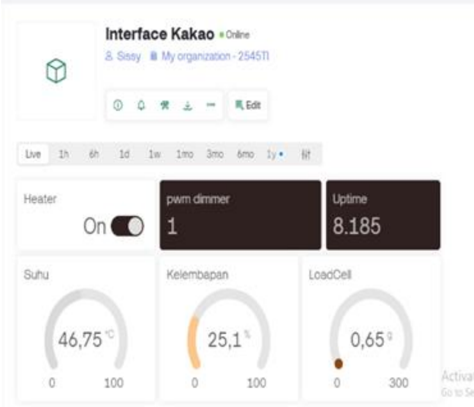

Figure 13. Blynk Application Appearance

The appearance of the Blynk application used can be seen in figure 13 above. From the test results, the Blynk application is proven to be able to be operated remotely provided there is an internet connection. This application is able to display information such as temperature, humidity, mass, time, and dimmer PWM. In addition, Blynk provides a button to turn the heater on and off, which works via a relay as a kill switch controlled by a microcontroller.

This study designs and implements a cocoa bean dryer that is able to automatically regulate water content using the fuzzy logic method, with Internet of Things (IoT)-based monitoring via the BLYNK application.

The drying process begins by reading temperature and humidity data from the DHT22 sensor. This data, along with the load cell weight readings, is used as input in the fuzzy control system to regulate the heating element and fan. The output from the fuzzy control system is then sent to the actuators to adjust the temperature and humidity in the drying chamber. During this process, temperature, humidity and cocoa bean weight data are displayed in real time on the blynk application, allowing remote monitoring and direct parameter adjustment.

This system also reduces dependence on external weather conditions, allowing drying to be carried out at any time, including at night or during the rainy season.

Previous research by Putri and Taali (2022) in JTEIN entitled "Design and construction of a cocoa bean dryer with humidity and temperature control based on Arduino Mega 2560" has a similar focus, but there are several significant differences, the main difference lies in the use of load cells to detect changes in cocoa bean weight, which provides a direct indication of the moisture content of the cocoa beans. In addition, the use of the blynk application allows remote monitoring and control, flexibility and convenience in operating the tool.

4. Conclusion

Based on the data and test results that have been carried out, it can be concluded that this tool functions well according to the desired design. Temperature sensor testing showed small to moderate variations between the sensor and thermogun measurement results, with an average temperature sensor measurement result of 42.3, an average measurement with a thermogun of 42.5, with an average error difference of 0.4 and an average percentage error of only 1%. Testing the humidity sensor showed similar results between the sensor and the hygrometer, with an average humidity sensor measurement of 46.5, a thermogun 42.5, an average error difference of 0.3 and an average error percentage of 0.53%. Load cell sensor testing showed an average load cell measurement result of 0.32, compared to a digital scale of 0.42, with an average error difference of 0.01 and an average error percentage of 5.34%. Each sensor test was carried out 30 times. Fuzzy testing on the cocoa bean dryer showed satisfactory results, because the output produced was in accordance with the input entered. Although there is some difference in error when compared with the results from Matlab, the average error calculated is only 0.4%. Apart from that, the results of measuring the water content of cocoa beans using a soil moisture tool show results that are in accordance with the maximum water content requirements set.

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