Design and Development of Monitoring and Controlling Claypot Compost from Household Waste Using Fuzzy Logic

Fery Aditya Prayoga[1], Farida Arinie Soelistianto[2*], Waluyo Waluyo[3], Dianthy Marya[4]

1,2,3,4 Digital Telecommunication Network Study Program, Department of Electrical Engineering, State Polytechnic of Malang, 65141, Indonesia.

[1]feryadit721@gmail.com , [2]farida.arinie@polinema.ac.id , [3]waluyo@polinema.ac.id , [4]dianty@polinema.ac.id

***Abstract*— Household waste production in Indonesia has seen a significant increase, rising from 64 million tons in 2016 to 70 million tons in 2020. Poorly managed waste can lead to various environmental issues, including pollution, pest outbreaks, and ecosystem damage. To address these challenges, effective waste management is crucial, with composting being chosen as one of the primary methods to reduce organic household waste. This study focuses on developing an IoT-based composting system that can monitor key parameters such as temperature, pH, and moisture, using the DS18B20 sensor for temperature, a Capacitive Soil Moisture Sensor for moisture, and a Soil pH Sensor for pH levels. The system utilizes a zero-order Sugeno-type fuzzy logic to make decisions regarding the addition of the EM4 bio activator liquid, which is necessary to maintain optimal conditions during the composting process. This method was chosen for its efficiency in handling uncertain data. Data obtained from the sensors are processed by the fuzzy logic system to determine the compost's condition, and if needed, the bio activator liquid is added via a DC water pump controlled by a water flow sensor. Additionally, information about the compost's condition can be accessed in real-time through a smartphone application, enabling remote monitoring. The results of this study show that the system successfully implemented zero-order Sugeno-type fuzzy logic as a decision-making tool, with an average error of 8.16%. The sensors used demonstrated high accuracy, with very low average errors: 1.31% for the pH sensor, 0.60% for the moisture sensor, and 0.53% for the temperature sensor, while the water flow sensor had an average error of 2.10%. In conclusion, the system proved effective in monitoring and controlling the addition of the bio activator liquid, thereby aiding the decomposition process by keeping the temperature, pH, and moisture parameters of the compost medium within the optimal range.**

Keywords*— *Claypot, Compost, EM4, Sugeno Fuzzy Logic, Waste.

I. INTRODUCTION

Household waste production in Indonesia has been steadily increasing year by year. In 2016, the production of household waste reached 64 million tons, and this figure rose to 70 million tons by 2020 [1] [2] [3]. This trend indicates a significant growth in the amount of waste generated by households. Improperly managed waste can lead to various environmental problems, such as air and water pollution, the proliferation of pests and diseases, and overall environmental degradation. Given the increasing amount of household waste being sent to landfills, it is crucial to implement strategies to reduce this waste. One approach is through circular economy principles, which involve designing materials for recycling and ensuring that value is added at every stage of the product lifecycle, ultimately aiming to minimize waste to near zero [4].

One effective method for reducing organic household waste at landfills is composting. Composting is a relatively simple and highly effective way to reduce organic household waste. However, to produce high-quality and optimal compost, it is necessary to maintain specific parameters throughout the composting process, which typically takes about 2 to 4 weeks. The optimal composting parameters include a temperature of around 22°C, a pH level between 6.8 and 7.4, and a maximum moisture content of 50% to 60% [5] [6] [7]. Comprehensive testing of the composting process has shown that meeting these standards results in compost with a moisture level of 50.35%, a temperature of 25°C, and a pH of 6.7, which are ideal conditions for producing high-quality compost [8]. Therefore, proper and regular monitoring is essential. Inadequate monitoring can lead to various negative consequences, including slower composting processes and poor compost quality. Moreover, anaerobic conditions can result in the production of methane, a potent greenhouse gas, along with foul odors and pest infestations.

The natural composting process can take a long time, ranging from 2 to 3 months, and in some cases, even 6 to 12 months [9] [10]. However, this process can be accelerated with the use of activators. EM4 activator is one such agent that can shorten the composting time to just 4 to 7 days, producing compost that is not hot, free from foul odors, and devoid of pests and diseases [11]. Additionally, EM4 helps maintain the compost's pH at neutral levels.

To achieve high-quality compost more efficiently and enable compost makers to monitor the process remotely without the need for direct inspection, it is necessary to develop a system for monitoring and controlling the composting process. This study leverages the Internet of Things (IoT) to monitor compost parameters using a DS18B20 sensor for

*Corresponding author

temperature, a Capacitive Soil Moisture Sensor for moisture, and a Soil pH Sensor to measure the pH of the compost medium. The system also utilizes a zero-order Sugeno fuzzy logic method to make decisions regarding the addition of EM4 liquid to the compost to help maintain optimal compost parameters. The choice of zero-order Sugeno fuzzy logic is due to its use of constant outputs, making it simpler, faster, and less resource-intensive in terms of computational power [12] [13] [14]. In IoT applications, data is often uncertain or vague, such as sensor readings that may have some level of uncertainty. Sugeno fuzzy logic is well-suited for handling such uncertainty. Fuzzy logic-based systems are also easily adaptable to changes in conditions or environments [15].

In this study, the device functions by having the DS18B20 sensor monitor temperature, the Soil Moisture Sensor monitor moisture, and the Soil pH Sensor monitor pH levels. The readings from these sensors serve as inputs to the zero-order Sugeno fuzzy logic method used by the system. After processing the sensor data, the fuzzy logic system outputs the current status of the compost based on the sensor readings. If the system determines that additional liquid is needed, the process of adding the liquid is carried out. The addition of liquid is facilitated by a DC water pump that pumps the liquid, with a Waterflow sensor measuring the amount of liquid dispensed. All information, including sensor readings, compost status, and history logs, can be accessed via an application, allowing for monitoring from anywhere and at any time. The system also provides a manual mode for controlling the liquid addition process through the hardware interface possible by selecting the manual mode on the hardware.

II. METHOD

A. *Research Stages*

The design of the system that will be created will first go through several paths. This is intended so that the research is carried out in detail so that the results obtained can achieve maximum results. The research stages that will be carried out in creating this system are shown in Figure 1. The following is a description: 1) In the first stage, a literature study is conducted to gather various references related to the research, including journals, articles, digital books, and regular books. This stage also involves determining the objects and variables to be tested in the study and identifying the necessary tools and materials. 2) The second stage involves planning the design of the device. This requires creating design sketches to illustrate the final product. A list of required tools and materials for building the device is also prepared during this stage. 3) The third stage is the construction of the device according to the previously designed system plan and the specified tools and materials. 4) The fourth stage involves testing the constructed device to achieve the desired results. 5) Data Collection, if there are no issues during the device testing stage, data collection is conducted to gather the expected data. If the obtained data does not meet expectations, data collection is repeated. 6) The sixth stage is the analysis of the data collected during the testing stage. 7) The seventh stage involves drawing conclusions based on the data analysis. The conclusions should address the research questions and objectives formulated at the beginning.

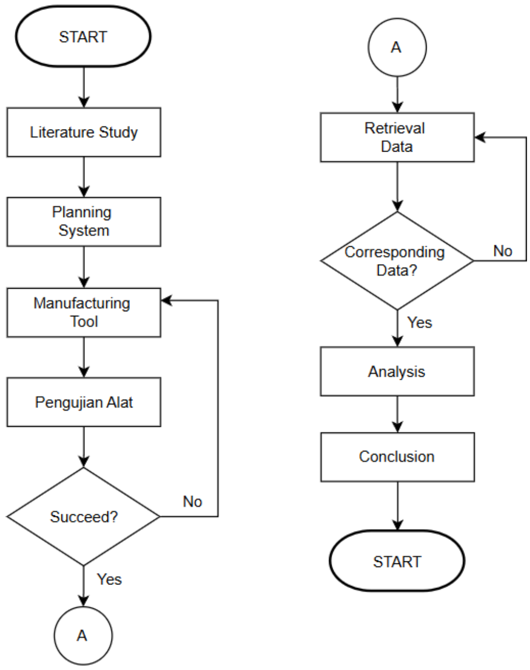

Figure 1. Research stages

B. *Block Diagram*

The system design to be created is divided into four parts, namely system block diagram, system flowchart, hardware design, and software planning.

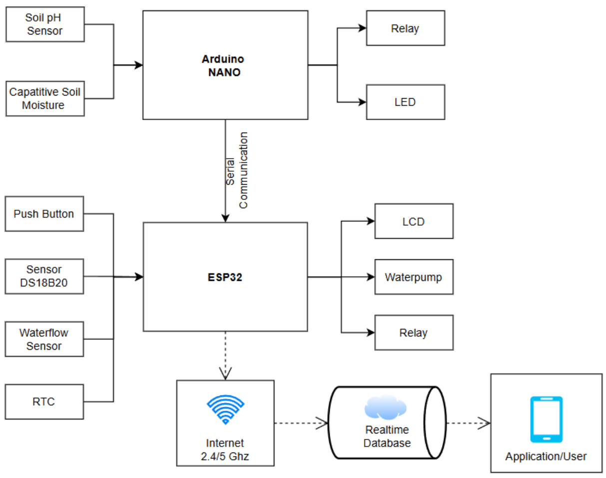

Figure 2. System block diagram

In Figure 2, is a block diagram of the system, where an Arduino NANO is used as the NodeMCU or microcontroller. It has four sensor inputs: a pH sensor for measuring the pH of the composting media, a soil moisture sensor for measuring the moisture of the composting media, and a DS18B20 sensor for measuring the temperature. The system has outputs including a solenoid valve used to dispense the bio activator onto the compost and a water flow sensor to measure the amount of bio activator added. Sensor data is sent from the Arduino NANO to the ESP32 via serial communication. The ESP32 then sends the received data to a real-time database, allowing for remote monitoring and control through a web application or smartphone app by the user.

C. System Flowchart

Figure 3 shows the flowchart of the processing system that occurs in the design of the system for adding bio activator liquid to the compost media.

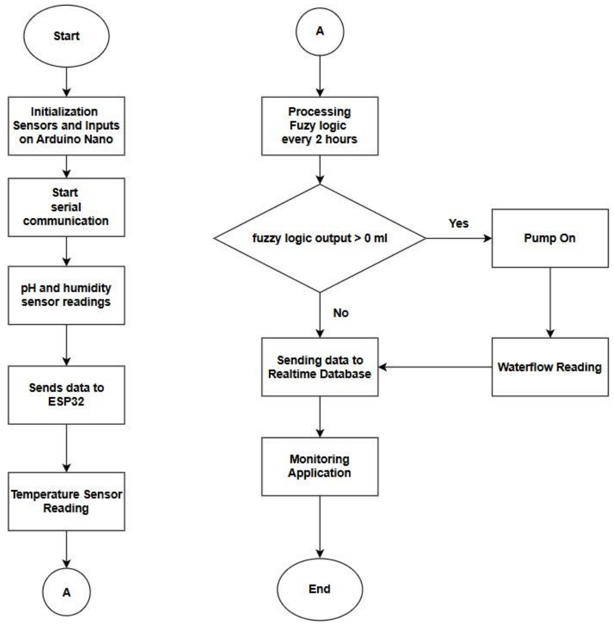

Figure 3. System flowchart

In Figure 3, the process begins with the initialization of input and output sensors connected to the Arduino Nano, followed by establishing serial communication between the Arduino Nano and ESP32. The system then reads the pH and moisture levels of the compost medium, sending this data from the Arduino Nano to the ESP32. Subsequently, the temperature of the compost medium is read, and data on temperature, moisture, and pH is processed as input for the fuzzy logic system every 2 hours. If the fuzzy logic output is greater than 0, the pump is activated, and the water flow sensor measures the amount of liquid dispensed. The information on temperature, moisture, pH, the amount of added bio activator, and the fuzzy logic output is then sent to Firebase. This data is displayed on a smartphone application, accessible by the user for monitoring.

D. System Design

The image on Figure 4. represents the mechanical device used in this research. The microcontroller box is positioned on top of a supporting board, with the bio activator liquid box, having a volume of 2.5 litres, placed beside it. A clay pot compost container is set on a base, and a water flow sensor is attached to the microcontroller box. The soil moisture sensor, soil pH sensor, and DS18B20 temperature sensor are all inserted into the compost medium. An LCD 12C 16x2 is used to display information, while a button is used to control the hardware system. The following is an illustration of the system design on the prototype.

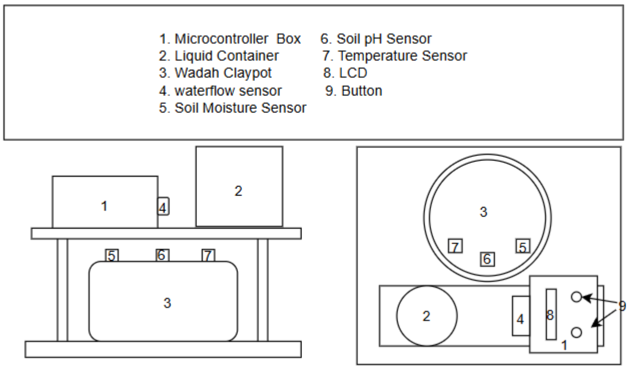

Figure 4. System Design

Figure 5 shows a schematic diagram connected to the components of the ESP32 microcontroller and the Arduino Nano microcontroller, where the two microcontrollers are connected using serial communication. A list of pins and components used can be seen in Table 1.

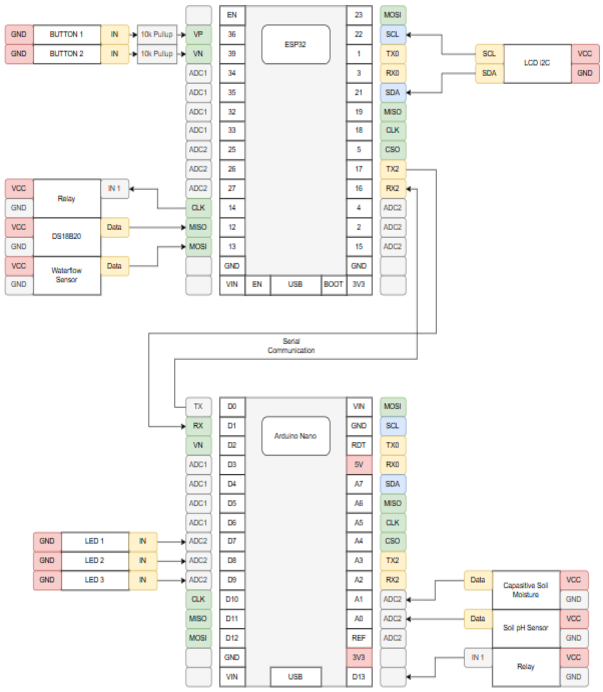

Figure 5. Schematic diagram of the entire system

TABLE I
ELECTRONIC CIRCUIT CONNECTIONS

No	Component	Pin Source	Pin Destination
1	DS18B20	Power - Data	5V(PSU) GND GPIO12(ESP32)
2	Capacitive Soil Moisture	Power - Data	5V(PSU) GND A1(Arduino Nano)
3	Soil pH	-	GND

No	Component	Pin Source	Pin Destination
		Data	A0(Arduino Nano)
4	Waterflow Sensor	Power - Data	5V(PSU) GND GPIO13(ESP32)
5	LCD I2C	Power - SDA SCL	5V(PSU) GND SDA(ESP32) SDA(ESP32)
6	Relay Module 2 Channel	VCC - In 1 In 2	5V(PSU) GND D13(Arduino Nano) GPIO14(ESP32)
7	Button 1	- IN	GND GPIO 36(ESP32)
8	Button 2	- IN	GND GPIO 39(ESP32)
9	LED 1	+ -	D7(Arduino Nano) GND
10	LED 2	+ -	D8(Arduino Nano) GND
11	LED 3	+ -	D9(Arduino Nano) GND
12	Arduino Nano	TX RX	RX(ESP32) TX(ESP32)
13	ESP32	TX RX	RX(Arduino Nano) TX(Arduino Nano)

E. Software Planning MATLAB

1. Temperature

The fuzzy temperature sets are divided into three categories: Low Temperature, Medium Temperature, and High Temperature. Their membership values are defined as follows:

- Low Temperature: ≤ 20°C
- Medium Temperature: 17-30°C
- High Temperature: ≥ 37°C

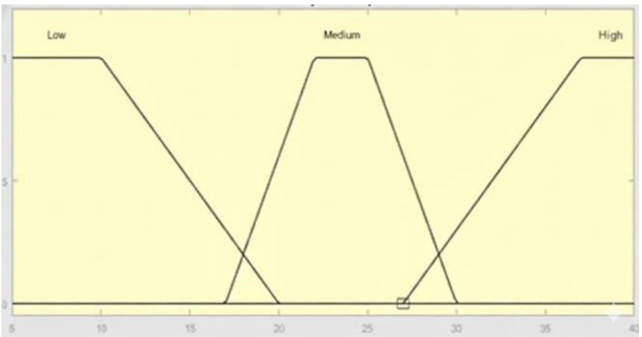

Figure 6. Temperature Membership Curve

In Figure 6, the curves representing the input temperature are shown, depicting the fuzzy sets for Low Temperature, Medium Temperature, and High Temperature.

2. pH

The fuzzy pH sets are divided into three categories: Acidic pH, Neutral pH, and Basic pH. Their membership values are defined as follows:

- Acidic pH: ≤ 6.8
- Neutral pH: 6.5-7.7
- Basic pH: ≥ 7.4

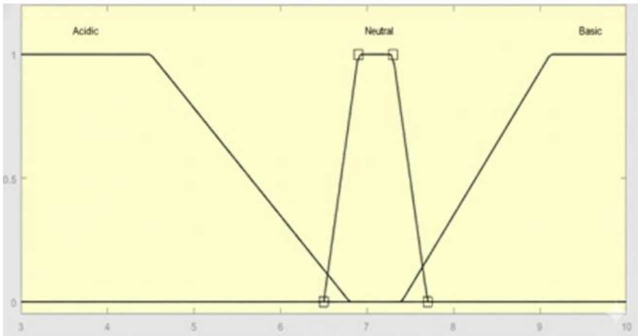

Figure 7. pH Membership Curve

In Figure 7, the curves representing the input pH are shown, illustrating the fuzzy sets for Acidic pH, Neutral pH, and Basic pH.

3. Moisture

The fuzzy moisture sets are divided into three categories: Dry, Normal, and Damp. Their membership values are defined as follows:

- Dry: 0-45%
- Normal: 35-65%
- Damp: 55-100%

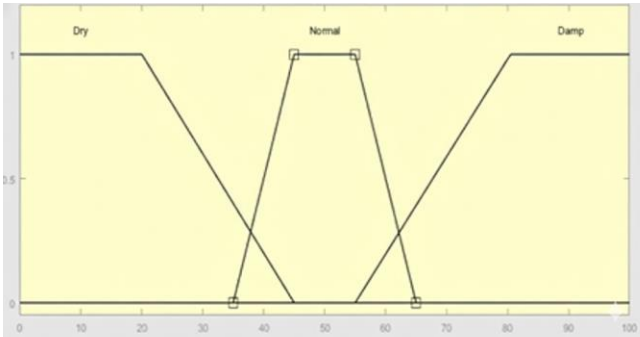

Figure 8. Moisture Membership Curve

In Figure 8, the curves representing the input moisture are shown, illustrating the fuzzy sets for Dry, Normal, and Damp.

4. Output Sets

The output fuzzy sets, which represent the results of the fuzzy logic system, are determined based on the input read by the sensors and sent to the system. The fuzzy output is divided into five categories, measured in mL, with the following membership values:

- VLow: 0 mL of fluid
- Low: 50 mL of fluid
- Medium: 100 mL of fluid
- High: 150 mL of fluid

- VHigh: 200 mL of fluid

5. Formation of Fuzzy Rules
   Fuzzy rules are created based on expert knowledge or empirical data. Each rule consists of a condition (IF) and an action (THEN). Table 2 shows the rules that were applied, with 3 inputs temperature, moisture, and pH each having 3 fuzzy sets, a total of 27 rules are generated.

TABLE II
FUZZY RULES

No	Temp	pH	Moist	Output
1	Low	Acidic	Normal	Medium
2	Low	Acidic	Damp	Low
3	Low	Acidic	Dry	High
4	Low	Neutral	Normal	Low
5	Low	Neutral	Damp	Low
6	Low	Neutral	Dry	High
7	Low	Basic	Normal	Medium
8	Low	Basic	Damp	Low
9	Low	Basic	Dry	High
10	Medium	Acidic	Normal	Low
11	Medium	Acidic	Damp	Low
12	Medium	Acidic	Dry	High
13	Medium	Neutral	Normal	Low
14	Medium	Neutral	Damp	Low
15	Medium	Neutral	Dry	Medium
16	Medium	Basic	Normal	Low
17	Medium	Basic	Damp	Low
18	Medium	Basic	Dry	High
19	High	Acidic	Normal	Low
20	High	Acidic	Damp	Low
21	High	Acidic	Dry	High
22	High	Neutral	Normal	Low
23	High	Neutral	Damp	Low
24	High	Neutral	Dry	High
25	High	Basic	Normal	Medium
26	High	Basic	Damp	Low
27	High	Basic	Dry	High

F. Application Planning

Figure 9 illustrates the initial login interface of the Monitoring and Controlling application. To enter the system, users are required to input the registered username along with the corresponding password, and then select the "Login" option to proceed. This login process ensures controlled access to the application's features. Figure 10 shows the Compost Monitoring interface, where users can observe real-time monitoring information, including pH value, moisture level, temperature, and overall compost condition. Navigation to the historical data view can be performed easily by selecting the blue "History" button provided on the interface. Figure 11 presents the historical monitoring display, which allows users to review previously recorded data. This section provides access to automatically stored readings of pH, humidity, temperature, and compost conditions, enabling users to analyze changes and trends over time.

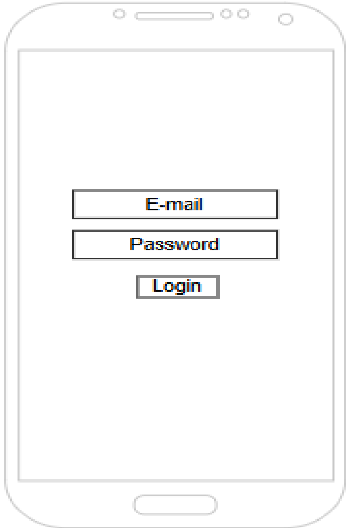

Figure 10. Application Login screen

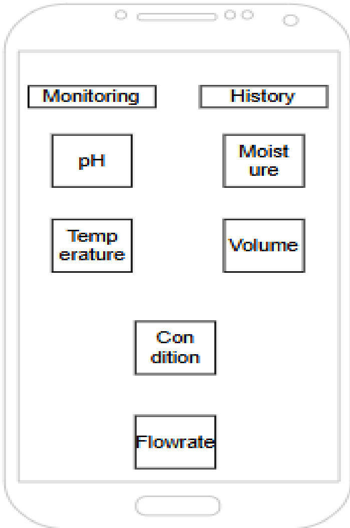

Figure 11. Application Monitoring screen

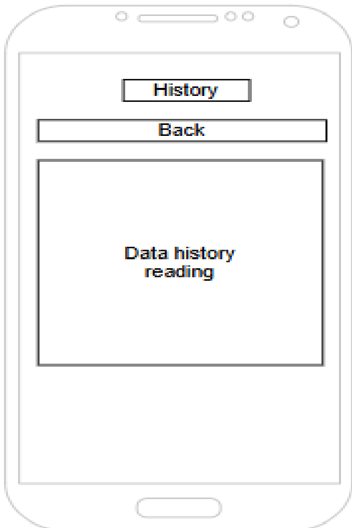

Figure 12. Application History screen

III. RESULTS AND DISCUSSION

A. Waterflow Sensor Testing Results

The water flow sensor YF-S401 was tested using a measuring cup as a reference with millilitre measurements. The table below presents the results of the water flow sensor testing. From 10 trials with the water flow sensor, as shown in Table 3, the smallest error was recorded in the 6th trial at 0.19%, while the largest error occurred in the 1st trial with a value of 8.88%. The average error across all trials was 2.10%.

TABLE III
WATERFLOW SENSOR TESTING RESULT

Trial-	Sensor (mL)	Measurement (mL)	Error (%)
1	54.87	50	8.88
2	105.74	100	5.43
3	151.23	150	0.81
4	201.98	200	0.98
5	253.52	250	1.39
6	299.43	300	0.19
7	351.12	350	0.32
8	403.35	400	0.83
9	458.16	450	1.78
10	501.82	500	0.36
Average Error (%)			2.10

B. Temperature Sensor (DS18B20) Testing

The DS18B20 temperature sensor was tested by comparing its measurements with those of a 4-in-1 Soil Tester. The following table presents the results of the temperature sensor testing. Based on 10 trials of the DS18B20 temperature sensor, as shown in Table 4, the smallest error occurred in the 9th trial at 0.36%, while the largest error was observed in the 2nd trial at 0.96%. The average error across all trials was 0.53%.

TABLE IV
TEMPERATURE SENSOR TESTING RESULT

Trial-	Sensor (^0C)	Measurement (^0C)	Error (%)
1	20.1	20	0.50
2	20.8	21	0.96
3	22.1	22	0.45
4	22.9	23	0.44
5	24.1	24	0.41
6	24.9	25	0.40
7	26.2	26	0.76
8	26.9	27	0.37
9	28.10	28	0.36
10	29.2	29	0.68
Average Error (%)			0.53

C. Capacitive Moisture Sensor Testing

The testing of the Capacitive Soil Moisture v1.2 sensor was calibrated by comparing its measurements with a soil moisture measuring device, specifically the Three-Way Meter pH + Moisture Meter. The following table presents the comparison between the measuring device and the soil moisture sensor. From 10 trials conducted with the capacitive moisture sensor, as shown in Table 5, the smallest error was observed in the 10th trial at 0.06%, while the largest error was recorded in the 8th trial at 1.42%. The average error across all trials was 0.6%.

TABLE V
SOIL MOISTURE SENSOR TESTING RESULT

Trial-	Sensor (%)	Measurement (%)	Error(%)
1	34.15	34	0.44
2	40.08	40	0.20
3	47.8	48	0.42
4	65.2	65	0.31
5	67.9	67	1.34
6	71.2	71	0.28
7	72.9	72	1.25
8	73.02	72	1.42
9	80.24	80	0.30
10	85.05	85	0.06
Average Error (%)			0.60

D. Soil pH Sensor Testing

The soil pH sensor was tested by calibrating it against a Three-Way Meter pH + Moisture Meter to compare the pH measurements. Below is a table showing the comparison results between the measuring instrument and the sensor. From 10 trials on the soil pH sensor, as shown in Table 6 the smallest error was observed in trial 3rd with a value of 1.86%, while the largest error was found in trial 6th with a value of 0.66%. The average error across all trials was calculated to be 1.31%.

TABLE VI
SOIL PH SENSOR TESTING RESULT

Trial-	Sensor	Measurement	Error (%)
1	5.32	5.4	1.48
2	5.64	5.7	1.05
3	6.01	5.9	1.86
4	6.11	6.0	1.83
5	6.04	6.1	0.98
6	6.12	6.1	0.33
7	6.27	6.2	1.13
8	6.67	6.6	1.06
9	6.8	6.7	1.49
10	7.13	7.0	1.86
Average *Error* (%)			1.31

E. Fuzzy Logic Testing Results

Here is the data from testing the rules or fuzzy logic rules for decision-making in fluid addition, based on the predefined rules in the MATLAB application that was previously developed. In the fuzzy logic testing conducted as shown in Table as shown in Table 7, the comparison between manual calculations and MATLAB results revealed that out of 27 trials, the largest calculation discrepancy was observed in trial 20th, with a difference of 5 mL. The smallest discrepancy was 0 mL, resulting in an average error of 8.16%.

TABLE VII
FUZZY LOGIC TESTING RESULT

Trial	Temp (°C)	pH	Moist (%)	Rules	Manual Calculation (mL)	MATLAB Calculation (mL)	Error (%)
1	22.4	4.5	49	10	50	50	0
2	37	7.1	50	Rules 22	50	50	0
3	15.9	5.9	99	Rules 2	50	50	0
4	33.5	6.8	95	Rules 19, 23	0	03.01	100
5	21	7.8	45	Rules 16	50	50	0
6	10	7.5	22	Rules 9	150	150	0
7	10.6	7.4	19	Rules 6	150	150	0
8	15.1	7.5	50	Rules 4, 7	55.6	55.1	1.8
9	22.4	4.5	96	Rules 11	50	50	0
10	35.9	5.2	0	Rules 21	200	200	0
11	10	6.2	29	Rules 3	200	200	0
12	10	7.8	98	Rules 8	50	50	0
13	23	7.5	94	Rules 14, 17	5	5	0
14	31.8	4.5	54	Rules 19	50	50	0
15	37	7.5	91	Rules 26, 23	4.5	5	10
16	21.2	6.8	72	Rule 11, 14	0	2.89	100
17	14.1	6.9	91	Rules 5	50	50	0
18	22.2	5.3	3	Rules 12	150	150	0
19	30.2	4.5	97	Rules 20	50	50	0
20	25.4	7.5	25	Rules 15, 18	100	105	4.7
21	10	6.2	52	Rules 1	100	100	0
22	29.5	7.8	18	Rules 27	150	150	0
23	37	6.9	9	Rules 24	150	150	0
24	23.3	6.7	31	Rules 15, 12	109	107	1.8
25	21.3	7.2	47	Rules 13	50	50	0
26	29	7.6	59	Rules 25	41.5	41	1.2
27	14.1	6.9	43	Rules 4, 6	63.8	64.5	1
Average Error (%)							8.16

F. Analysis Data

The analysis of sensor data and fuzzy logic testing revealed the following results: During the waterflow sensor testing, the largest error was observed in the first experiment (54.87 ml) with an error of 8.88%, while the smallest error occurred in the sixth experiment (299.43 ml) with an error of 0.19%, resulting in an average error of 2.10%. The temperature sensor (DS18B20) testing showed the largest error in the second measurement (20.8°C) with an error of 0.96%, and the smallest error in the ninth experiment (28.1°C) with an error of 0.36%, yielding an average error of 0.53%. For the soil moisture sensor (Capacitive Moisture), the largest error was recorded in the eighth experiment (73.02°C) with an error of 1.42%, with an average error of 0.60% across all readings. The soil pH sensor testing showed the largest errors in the third and tenth experiments, each with an error of 1.86%, while the smallest error was in the sixth experiment at 0.33%, leading to an average error of 1.31%. Overall, all tested sensors exhibited good accuracy, with average errors below 2.10%, indicating their suitability for use as input data in this study. Additionally, in the fuzzy logic system testing, the largest calculation discrepancy was found in trial 20, with a difference of 5 ml, while the smallest discrepancies of 0 ml were found in trials 1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14, 17, 18, 19, 21, 22, 23, and 25. The average error across all trials was 8.16%.

IV. CONCLUSION

This study successfully implemented Sugeno order-0 fuzzy logic as a decision-making system for the addition of bio activator fluids in the claypot composting process. The results show that the applied fuzzy logic had an average error of 8.16%, which is relatively low. This indicates that Sugeno order-0 fuzzy logic is effective in regulating the addition of bio activator based on the actual conditions of the compost media. The sensors used in this study—soil pH sensor, soil moisture sensor, and temperature sensor—demonstrated good accuracy. The average error for the soil pH sensor was 1.31%, for the soil moisture sensor 0.60%, and for the temperature sensor 0.53%. The Waterflow sensor also showed satisfactory accuracy with an average error of 2.10%. These results suggest that the sensors are suitable for use as inputs in a fuzzy logic- based decision-making system.

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