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Implementation of Fuzzy Logic Method on Plantation Monitoring System in Website-Based Smart Farming

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ABSTRACT

The plantation sector is a crucial component of agriculture. However, plantation management faces several challenges, including limited technological integration within agriculture. The adoption of technology in plantations, particularly IoT (Internet of Things)-based monitoring systems, has become a significant trend in recent years. This system is designed to improve the efficiency of Smart Farming, allowing for more optimized management. This study implements the Fuzzy Logic method in a corn plantation monitoring system to address uncertainties and complexities in decision-making. The system integrates hardware and software, enabling real-time monitoring of environmental conditions through a web-based interface. Testing results indicate that the developed system achieves an accuracy level of 97.42%, providing valuable and responsive data to support farmers in decision-making. With this system, farmers can more effectively monitor and manage plantation conditions, potentially increasing productivity and agricultural yield quality.

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1. INTRODUCTION

Agriculture plays a vital role in ensuring the stability of food supplies. According to data from Statistics Indonesia (Badan Pusat Statistik) in 2021, approximately 37.02% of Indonesia's population is employed within the agricultural sector [1]. In Indonesia, much of the plantation sector still relies heavily on conventional methods, with monitoring, maintenance, and operations often carried out manually. This reliance on manual processes hinders improvements in operational efficiency, effectiveness, and productivity [2].

Plantations, as an integral part of agriculture, encounter significant challenges, particularly in management. Plantation management is often complex due to variations in environmental conditions and differing crop requirements. Key aspects such as soil quality, temperature, and water availability play critical roles in determining crop quality and productivity. To meet the water demands necessary for optimal agricultural operations, it is essential to supply water in the right quantity, at the right time, and with appropriate quality. If these conditions are not met, plant growth may be adversely affected, ultimately impacting agricultural yields [3].

Smart Farming is an innovative approach to agricultural management that utilizes modern technology, machinery, agricultural equipment, and digital solutions. This approach aims to increase productivity, add value, enhance competitiveness, and generate sustainable profits in agricultural ventures [4]. The application of AI-based Internet of Things (IoT) technology provides benefits to the agricultural sector by effectively regulating plant temperature. This is done through monitoring systems and fuzzy logic algorithm testing [5].

Intelligent agricultural systems supported by IoT have the potential to change the paradigm of the agricultural sector by providing real-time information about crops and environmental conditions [6]. This study employed the Fuzzy Logic method to address data uncertainty. Fuzzy Logic, a branch of artificial intelligence, enables computers to mimic human intelligence, with the aim that computers can replace human roles in tasks requiring a certain level of intelligence. Particularly in the electronics industry, the use of Fuzzy Logic-based control systems has proven beneficial, aiding both electronic industry owners and their workers [7]. According to research [8], the system can be integrated with fuzzy logic methods in smart drip irrigation systems with a success percentage of 99.98%.

In the context of logic, "fuzzy" denotes uncertainty or vagueness, where a value may equally represent truth or falsehood. Fuzzy logic operates within degrees of truth ranging from 0 to 1, allowing for a blend of true and false values. This type of logic accommodates ambiguity, with the extent of truth or falsehood determined by its membership weight [9]. Given its adaptability, Fuzzy Logic has been successfully applied in agricultural systems for handling complex environmental data. For instance, previous studies have demonstrated its efficacy in optimizing irrigation systems by monitoring soil moisture and weather data, leading to significant improvements in water management and crop health. Other research in Smart Farming has integrated Fuzzy Logic to address fluctuations in environmental conditions, such as temperature and humidity, to aid real-time decision-making for sustainable crop management.

This research builds on such advancements by designing and implementing an IoT-based Smart Farming system tailored to the needs of corn plantations in Desa Tanjung Lago, Kabupaten Banyuasin, South Sumatra. Distinguishing this study from previous research is its integration of Fuzzy Logic specifically for real-time monitoring of multiple environmental factors soil moisture, air humidity, temperature, and smoke density within a corn plantation setting. This system aims to assist farmers in more accurately monitoring plantation conditions, potentially increasing productivity and enhancing crop quality.

2. MATERIAL AND METHOD

The framework of this research consists of several stages presented in a comprehensive diagram. The following flowchart outlines the stages in the plantation monitoring and management system using the fuzzy logic method. Flowchart of Research Framework can view as figure 1.

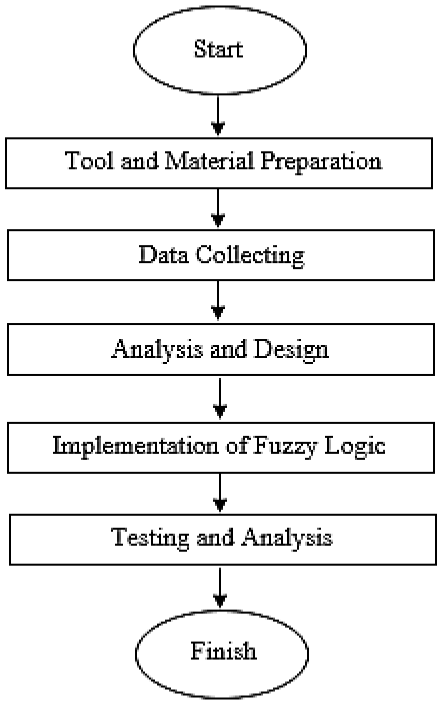

Figure 1. Flowchart of Research Framework

2.1 Tool and Material Preparation

2.1.1 Hardware Design

Hardware in the monitoring system refers to the physical components. The following hardware is used in this research.

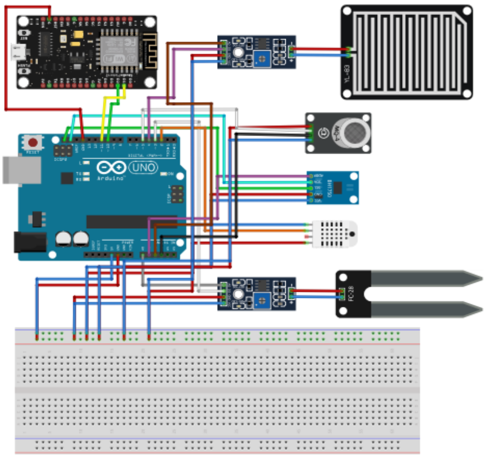

Figure 2. Hardware Design

The above figure 2 is a block diagram of the plantation monitoring and management system. The hardware design includes several main components such as microcontrollers, sensors, and other devices to collect data, process information, and display monitoring results. The Arduino Uno microcontroller is an open-source platform that facilitates the development of control systems and IoT technology, using an Atmel AVR processor and its own programming language [10]. NodeMCU simplifies the connection of devices to the internet via WiFi [11]. The DHT22 sensor measures temperature and humidity with high accuracy [12]. While the soil moisture sensor aids in agricultural management by measuring soil moisture levels [13]. The BH1750 sensor accurately measures solar radiation intensity [14], and the rain sensor detects raindrops and measures their depth in millimeters [15]. Lastly, the MQ-2 gas sensor detects flammable gases for air quality monitoring [16]. This hardware plays a crucial role in the input of the plantation monitoring and management system, enabling accurate and real-time environmental data collection for further analysis and informed decision-making.

2.1.2 Software Design

Software that functions as a user interface, which includes a database and monitoring display design that displays the results of sensor data in the form of a website.

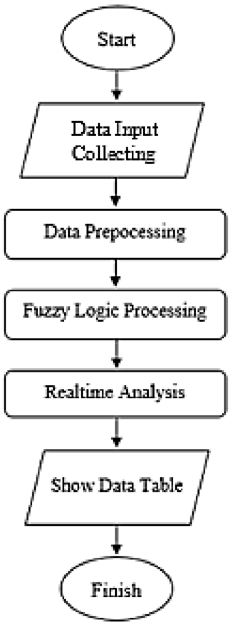

Figure 3. Software Design

The software design involves Sensor Data Acquisition, which collects data generated by sensors, and Data Preprocessing to prepare the data before further analysis. Next is the Fuzzy Logic Process, where data is processed by modeling and analyzing it to make decisions amid data uncertainty, resulting in more accurate outcomes. Real-time data analysis ensures effective system responsiveness to changes in plantation conditions, which is then presented in table form via a website.

2.2 Data Collecting

Data collection is a fundamental step in developing an efficient monitoring system for smart farming. This study employs various sensors to monitor environmental factors within a corn plantation. Key sensors include DHT22 for measuring air temperature and humidity, soil moisture sensors to assess soil water content, BH1750 lux sensors for light intensity, raindrop sensors for detecting rainfall, and MQ-2 gas sensors to monitor air quality. These sensors were strategically integrated to provide real-time data that are crucial for assessing the plantation's microclimate and environmental conditions.

The data gathered through these sensors are processed using a NodeMCU ESP8266 microcontroller, which facilitates wireless data transmission. Each sensor's role is tailored to monitor conditions that directly impact crop health, such as temperature fluctuations, soil moisture levels, sunlight exposure, and potential air pollution, all of which are vital for precision agriculture. Data collection occurs continuously, with updates displayed on a web-based dashboard, allowing for immediate insights and intervention if needed.

2.3 Analysis and Design

The system's analysis and design are based on a Fuzzy Logic methodology (Sugeno model) to handle data uncertainties and variations in sensor readings. The use of Fuzzy Logic allows the system to interpret nuanced data from the environmental variables, such as varying levels of soil moisture, temperature, and humidity, by assigning membership values to each condition (e.g., "low," "medium," or "high" soil moisture). This categorization supports more flexible decision-making processes, as it mimics human reasoning in environmental assessment.

The system architecture integrates both hardware and software. The Arduino Uno microcontroller is responsible for sensor data acquisition and initial processing, while the NodeMCU module enables remote data access through IoT capabilities. The real-time data is processed and presented via a web interface, built with PHP and supported by a MySQL database. This interface displays real-time insights on environmental factors, enabling farmers to make informed decisions regarding irrigation, fertilization, and other essential agricultural practices.

In testing, the system achieved a high accuracy rate of 97.42%, demonstrating its reliability for real-time plantation monitoring. This design approach, combining IoT with Fuzzy Logic, allows for adaptive responses to environmental changes, helping to optimize crop management and potentially enhance agricultural productivity.

2.4 Fuzzy Logic

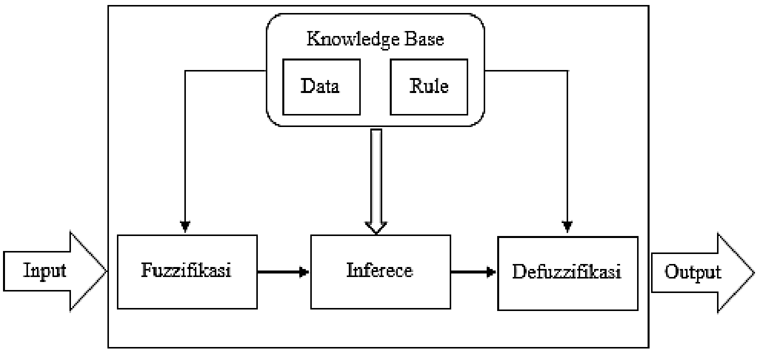

Figure 4. Fuzzy Logic Design

A control system known as a fuzzy logic controller is developed using fuzzy set theory. There are three main steps in a fuzzy logic controller: fuzzification, inference, and defuzzification. The first step, called "fuzzification," transforms crisp data into fuzzy data (linguistic variables), which are typically represented as fuzzy sets with associated membership functions. During the inference stage, the relationship between the crisp input values and the desired crisp output values is processed based on a set of rules. These rules determine the system's response to various set points and disturbances. Finally, the defuzzification procedure converts the output values from the fuzzy inference mechanism back into crisp form [17]. The following are the stages of calculating the Sugeno fuzzy method:

2.4.1 Fuzzification

Fuzzification is the first step in converting conventional variables into linguistic variables arranged in fuzzy sets. This process aims to determine the degree of membership of values to each predetermined fuzzy set [18].

2.4.2 Inference

Inference is a process that determines the output value of IF-THEN rules by finding the minimum value of each rule that has been set. In Sugeno model inference, the MIN implication function is used to calculate the α-predicate value of each rule, which is then used to produce a concrete (crisp) output value from each rules [19].

2.4.3 Defuzzification

Defuzzification is the process of mapping a fuzzy variable to a single output variable using the maximum membership method, typically involving the use of the Weighted Average (WA) formula [20]. Formula defuzification can show equation 1.

$$WA = \frac{a_1 z_1 + a_2 z_2 + \ a_3 z_3 + \cdots + \ a_n z_n}{a_1 + \ a_2 + \ a_3 + \cdots + \ a_n} \quad (1)$$

Description: α_n is rule predicate value-n; and z_n is index of output value-n

3. RESULTS AND ANALYSIS

The following details the results and analysis of the hardware and software design for a monitoring and management system in agriculture using fuzzy logic methods for the optimization of Smart Farming.

3.1 System Design Result

In the process of designing the monitoring and management system for plantations conducted in this research, the hardware and software design results were obtained.

3.1.1 Hardware Design Result

The hardware design result in this research is a device that functions as an input to obtain data from corn plantations.

Figure 5. Hardware Design Result

Figure 5 shows the field setup of the smart farming hardware among corn crops. It includes sensors for temperature, humidity, soil moisture, light intensity, rainfall, and air quality, all connected to an Arduino Uno and NodeMCU ESP8266 for data collection and wireless transmission. This arrangement allows continuous, on-site monitoring of environmental conditions essential for crop health.

3.1.2 Software Design Result

The result of this software design is a website that can display monitoring data from various sensors used. This website is designed to provide real-time information about the conditions on the plantation.

Figure 6 presents the web-based dashboard displaying real-time data from the sensors. Metrics include soil moisture (66%), air humidity (78.80%), temperature (29.80°C), light intensity (12381.67 lux), rainfall (1 mm), and smoke level (774 ppm). The color-coded display allows farmers to easily monitor and respond to changing conditions for optimized crop management.

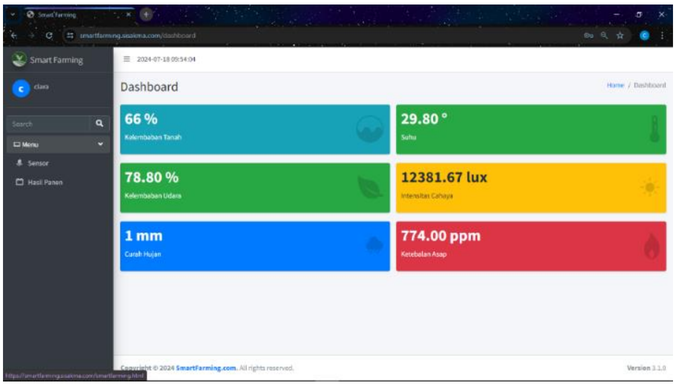

Figure 6. Software Design Result

3.2 Fuzzy Logic Implementation Result

The fuzzy logic process begins with determining the membership values, which are derived from various previous studies. Additionally, the authors conducted field tests and interviews with farmers in corn plantations in Tanjung Lago Village, Banyuasin Regency, South Sumatra.

3.2.1 Fuzzification Result

The membership value graph for soil moisture consists of three categories, “Dry” covering the range from 0% - 65%, “Optimal” covering the range from 60% - 80%, and “Wet” covering the range from 75% - 85%. The membership value graph for temperature consists of three categories, “Cold” covering the range from 0° - 24°, “Normal” covering the range from 21° - 34°, and “Hot” covering the range from 34° - 40°. The membership value graph for humidity consists of three categories, “Low” covering the range from 0% - 82%, “Normal” covering the range from 80% - 90%, and “High” covering the range from 88% - 100%. The membership value graph for light intensity consists of three categories, “Dim” covering the range from 0 lux - 12,000 lux, “Medium” covering the range from 10,000 lux - 16,000 lux, and “Bright” covering the range from 14,000 lux - 18,000 lux. The membership value graph for smoke thickness consists of three categories, “Low” covering the range from 0 ppm - 700 ppm, “Medium” covering the range from 500 ppm - 1200 ppm, and “High” covering the range from 1000 ppm - 1400 ppm. The complete membershif fuction can be seen in Figure 7 to Figure 11.

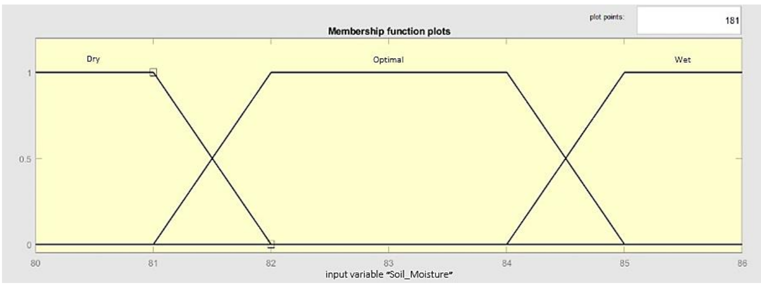

Figure 7. Soil Moisture Membership Value Graph

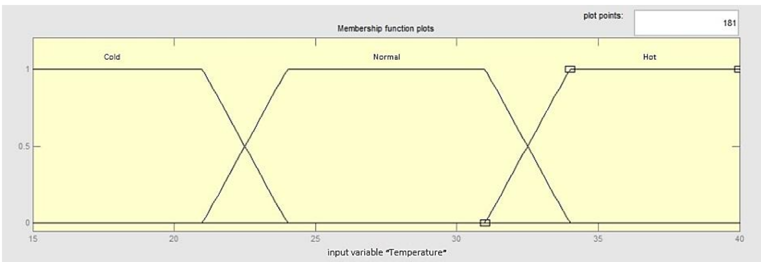

Figure 8. Temperature Membership Value Graph

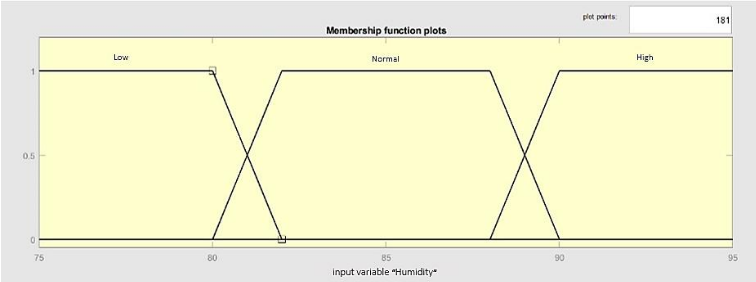

Figure 9. Humidity Membership Value Graph

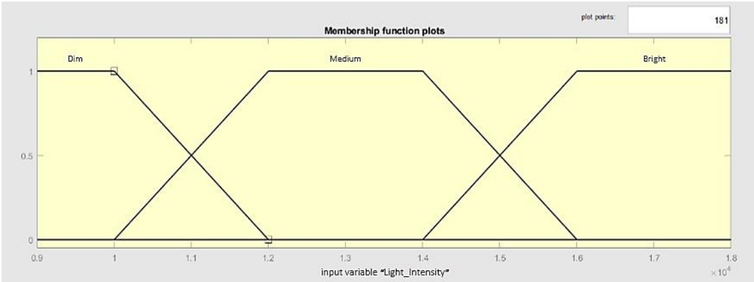

Figure 10. Light Intensity Membership Value Graph

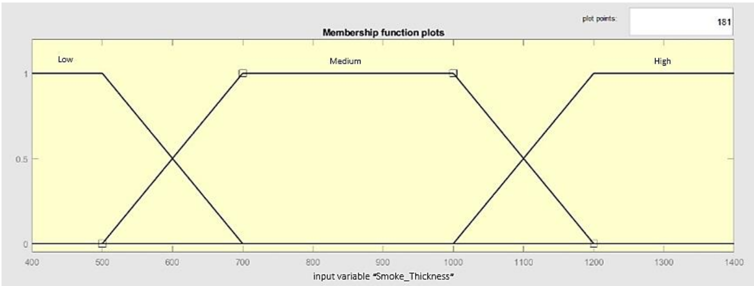

Figure 11. Smoke Thickness Membership Value Graph

3.2.2 Inference Result

In the fuzzy inference process, the designed fuzzy rules are employed to determine actions based on membership values. Considering 5 variable, each having three possible states, a total of 243 fuzzy rules are generated. These rules allow the system to handle various combinations of inputs and deliver appropriate responses according to the detected conditions. Fuzzy Rules Viewer view figure 12.

Figure 12. Fuzzy Rules Viewer

3.2.3 Defuzzification Result

1. Output “GOOD”

Table 1. Fuzzy Output Result “GOOD”

Soil Moisture	Temperature	Humidity	Light Intensity	Smoke Thickness	Result
74	30.50	64.00	20.00	766.00	GOOD

a. Soil Moisture: $u_{dry} = 0$, $u_{optimal} = 1$, $u_{wet} = 0$
b. Temperature: $u_{cold} = 0$, $u_{normal} = 1$, $u_{hot} = 0$
c. Humidity: $u_{low} = 1$, $u_{normal} = 0$, $u_{high} = 0$
d. Light Intensity: $u_{dim} = 1$, $u_{medium} = 0$, $u_{bright} = 0$
e. Smoke Thickness: $u_{low} = 0$, $u_{medium} = 1$, $u_{high} = 0$

Conditions: Optimal Soil Moisture, Normal Temperature, Low Air Humidity, Medium Light Intensity, Medium Smoke Thickness = 1.

$$WA = \frac{1.1 + 1.1 + 1.1 + 1.1 + 1.1}{1 + 1 + 1 + 1 + 1} = \frac{6}{6} = 1$$

2. Output “BAD”

Table 2. Fuzzy Output Result “BAD”

Soil Moisture	Temperature	Humidity	Light Intensity	Smoke Thickness	Result
19	29.90	82.70	2.50	773.00	BAD

a. Soil Moisture: $u_{dry} = 1$, $u_{optimal} = 0$, $u_{wet} = 0$
b. Temperature: $u_{cold} = 0$, $u_{normal} = 1$, $u_{hot} = 0$
c. Humidity: $u_{low} = 0$, $u_{normal} = 1$, $u_{high} = 0$
d. Light Intensity: $u_{dim} = 1$, $u_{medium} = 0$, $u_{bright} = 0$
e. Smoke Thickness: $u_{low} = 0$, $u_{medium} = 1$, $u_{high} = 0$

Conditions: Dry Soil Moisture, Normal Temperature, Low Air Humidity, Medium Light Intensity, Medium Smoke Thickness = 0

$$WA = \frac{1.0 + 1.0 + 1.0 + 1.0 + 1.0}{1 + 1 + 1 + 1 + 1} = \frac{0}{6} = 0$$

3.3 System Testing Results

This test is conducted to evaluate the system's performance and to assess the conditions of corn plantations located in Tanjung Lago Village, Banyuasin Regency, South Sumatra.

Table 3. System Testing Results

Time	Soil Moisture	Temperature	Humidity	Light Intensity	Rainfall	Smoke Thickness	Result
07.30	27.20	77	87.70	12700.83	1	773.00	GOOD
07.40	27.20	77	87.80	12700.83	1	773.00	GOOD
07.50	27.20	77	88.20	12320.50	1	774.00	GOOD
08.00	27.20	77	88.20	13740.17	1	774.00	GOOD
08.10	27.20	74	88.20	13730.33	0	773.00	GOOD
08.20	28.10	74	88.10	13750.00	0	773.00	GOOD
08.30	28.10	77	88.60	13770.50	1	773.00	GOOD
08.40	28.10	77	89.00	13780.33	1	773.00	GOOD
08.50	28.10	78	89.00	14490.17	1	778.00	GOOD
09.00	28.10	77	88.60	14450.83	1	773.00	GOOD
12.00	32.00	19	70.90	17200.33	1	779.00	BAD
12.10	31.90	19	70.20	17200.33	1	780.00	BAD
12.20	32.00	20	67.00	17380.90	0	780.00	BAD
12.30	32.90	20	66.50	17450.83	0	780.00	BAD
12.40	32.90	20	66.30	17780.90	0	780.00	BAD
12.50	33.10	20	66.00	17780.90	0	786.00	BAD
13.00	34.00	19	63.00	18270.31	0	786.00	BAD
13.10	34.10	20	64.00	18340.33	0	786.00	BAD
13.20	34.30	20	63.30	18340.33	0	786.00	BAD
13.30	34.00	19	63.10	18980.90	0	786.00	BAD
17:00	29.00	72	75.30	12500.00	1	780.00	GOOD
17:10	28.90	70	80.50	12200.00	0	779.00	GOOD

Time	Soil Moisture	Temperature	Humidity	Light Intensity	Rainfall	Smoke Thickness	Result
17:20	28.70	74	80.55	12000.00	1	780.00	GOOD
17:30	28.50	76	81.00	11500.00	0	780.00	GOOD
17:40	28.30	77	81.50	11000.00	1	779.00	GOOD
17:50	28.10	75	81.80	9500.00	1	780.00	GOOD
18:00	28.00	73	82.20	8000.00	0	779.00	GOOD
18:10	27.90	71	82.90	6200.00	0	778.00	GOOD
18:20	27.80	70	83.50	1130.00	1	779.00	GOOD
18:30	27.70	69	84.00	550.00	0	778.00	GOOD

Table 3 shows the results of time-based testing involving several critical variables, including temperature, soil moisture, air humidity, light intensity, and smoke density, with outcomes categorized as either 'GOOD' or 'BAD'. By closely monitoring changes in temperature and humidity levels, both in the air and soil, we can gain valuable insights into the patterns that influence plant growth, environmental comfort, and the overall health and conditions of the plantation. This analysis enables us to better understand how these environmental factors interact, allowing for more informed decision-making to optimize the growth environment and promote sustainable agricultural practices.

In analyzing the test results, the data were examined using the monitoring system designed by the researcher in conjunction with the conventional measurement tools or methods typically used by farmers at the data collection site, which is located in the corn plantations of Desa Tanjung Lago, Kabupaten Banyuasin, South Sumatra. Smart Farming with Fuzzy Logic Method Testing and Conventional Measurement Tools Testing view table 4 and table 5.

Table 4. Smart Farming with Fuzzy Logic Method Testing

Testing	Soil Moisture	Temperature	Humidity	Light Intensity	Smoke Thickness
1	74%	29°	66%	15000 lux	766 ppm
2	72%	28°	67%	15000 lux	780 ppm
3	75%	30°	65%	16000 lux	755 ppm
4	75%	27°	66%	17000 lux	770 ppm
5	74%	29°	67%	15000 lux	766 ppm
6	72%	28°	65%	14000 lux	780 ppm
7	75%	30°	66%	15500 lux	780 ppm
8	73%	27°	67%	17000 lux	776 ppm
9	74%	29°	65%	17000 lux	766 ppm
10	74%	28°	66%	16500 lux	770 ppm

Table 5. Conventional Measurement Tools Testing

Testing	Soil Moisture	Temperature	Humidity	Light Intensity	Smoke Thickness
1	75%	30°	65%	15500 lux	750 ppm
2	73%	29°	66%	16000 lux	765 ppm
3	77%	31°	64%	17000 lux	740 ppm
4	76%	28°	65%	17500 lux	755 ppm
5	75%	30°	66%	16000 lux	750 ppm
6	73%	29°	64%	15000 lux	770 ppm
7	76%	31°	65%	16000 lux	765 ppm
8	74%	28°	66%	17500 lux	770 ppm
9	75%	30°	64%	18000 lux	750 ppm
10	76%	29°	65%	17000 lux	755 ppm

After performing the calculations, the accuracy levels of the smart farming test data using the fuzzy logic method and the conventional tool test data from each experiment were obtained. The results are presented in the following graph. Accuracy Testing Result can view figure 13.

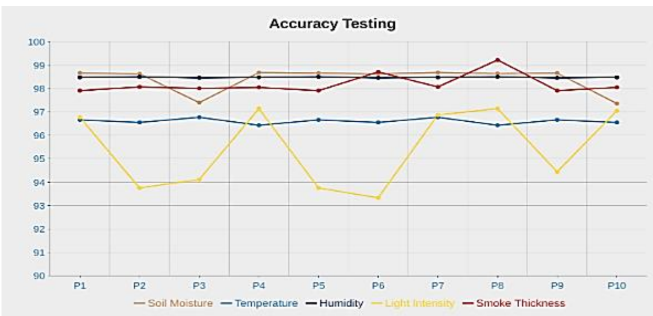

Figure 13. Accuracy Testing Result

Noted: *x-axis* (Horizontal) is Testing Quantity; and *y-axis* (Vertical) is Accuracy Rate.

This graph illustrates the accuracy testing results for the five parameters. Based on the conducted tests, all parameters demonstrate high accuracy levels, with an average above 90%. Soil moisture has an average accuracy of 98.40%, temperature has an average accuracy of 96.60%, air humidity has an average accuracy of 98.48%, light intensity has an accuracy of 95.45%, and smoke detection has an average accuracy of 98.19%. Overall, despite some fluctuations, all parameters exhibit good performance with high accuracy levels

4. CONCLUSION

Based on the conducted research, it can be concluded that the use of Fuzzy Logic in the plantation monitoring and management system is highly effective and accurate, achieving an accuracy rate of 97.42% in system testing. Integrating Fuzzy Logic enhances the precision of environmental monitoring and supports sustainable agricultural practices by enabling better resource management. This technology is expected to significantly boost agricultural productivity by ensuring optimal environmental conditions for plant growth and assisting farmers in monitoring and managing their plantations more responsively and effectively. The system provides real-time insights and data-driven decision-making tools, thereby empowering farmers with actionable information for improved crop management.

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