Journal of Applied Science, Technology & Humanities
Volume 2, Issue 1, January, 2025, Pages 26-36

ISSN 3032-5765
DOI : https://doi.org/10.62535/89fr2w25

Automatic Watering System on Microcontroller-Based Tomato Plants With The Fuzzy Logic Approach

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Abstract

One of the main challenges in crop cultivation is addressing irrigation issues, which are often carried out conventionally. This research aims to tackle this problem by implementing fuzzy logic in the development of an automatic irrigation system for tomato plants based on a microcontroller. The system is designed to create an intelligent irrigation solution capable of adjusting water supply according to environmental conditions and the needs of tomato plants. The research methodology includes system design, environmental data collection, and implementation of fuzzy logic algorithms for decision-making. The research findings demonstrate the effectiveness of the fuzzy logic-based approach in optimizing irrigation schedules, resulting in improved plant health and water conservation. Thus, the conclusion emphasizes the potential of fuzzy logic in enhancing precision farming practices and underscores the importance of adaptive irrigation systems in supporting sustainable crop production.

Keywords: Automation, Fuzzy, Irrigation, Sustainable, Technology.

INTRODUCTION

Modern agriculture is experiencing rapid development along with technological advancements. Various innovations have been introduced to improve agricultural productivity and efficiency, such as automated systems for crop cultivation. Tomato plants (Solanum lycopersicum syn. Lycopersicum esculentum) are easy to grow in Indonesia's tropical climate, have high economic value, and are one of the raw materials needed in the food industry (Palupiningsih, Sujiwanto, and Prawirodirjo 2023).

Tomatoes are a vegetable that has been cultivated for hundreds of years. Looking back at its history, the tomato originated in the Andean region of America. Initially, tomato plants were only known as weeds in their homeland. But over time, tomatoes began to be planted both in fields and in home yards as food crops or consumption crops.

Based on data from the Central Bureau of Statistics, in 2022, the amount of tomato production in Indonesia reached 11.6 million quintals. This number increased by 4.5% from 2021, which amounted to 11.1 million quintals. One of the reasons why tomatoes remain the most important crop in Indonesia is because the country's climate is very suitable for growing tomato plants. Tomato plants prefer to grow in the lowlands or highlands of Indonesia. This is why environmental factors play an important role in achieving maximum growth and yield (Bui, Lelang, and Taolin 2016). Plant watering is an important aspect of plant growth as it affects crop growth and yield. Proper watering management increases water and nutrient use efficiency and reduces the risk of water scarcity or excess.

Sufficient water is given to the plants from the beginning of planting until harvest so as not to stress the plants. Watering is done in the morning and evening depending on soil moisture conditions. If it rains on the day, no irrigation will occur (Mardaus. Intan Sari. Elfi Yenny Yusuf 2020). However, watering tomato plants is often a major obstacle in agricultural practices, mainly due to the difficulty of farmers to accurately monitor water requirements. Manual monitoring is difficult to do consistently due to limited time, labor, and resources. The growing medium of tomato plants should not contain too much water or too little water. This condition can cause an imbalance in the water supply that can affect the growth and productivity of tomato plants. In addition, many parameters become a reference for the duration of watering tomato plants. In this context, an automated watering system is a promising solution to overcome these challenges.

Some parameters that can affect the duration of watering tomato plants are temperature and soil moisture. One method that can be applied to this problem is Fuzzy Logic. Fuzzy logic is a type of logic that involves the existence of fuzzy values between true and false (Shaum et al. 2023). Where this method will be combined and implemented to determine the logic of the duration of watering tomato plants from the input of influencing parameters.

METHODS

This study uses a qualitative approach to test the application of fuzzy logic in determining the duration of plant watering time. The research design includes the development of a fuzzy logic control system, the collection of soil temperature and humidity data, and the analysis of simulation results.

Research Location and Time

The research was conducted online using relevant platforms to search for the temperature and soil moisture data required for tomato plants, based on previous studies. The research was conducted from February 22nd to March 4th, 2024.

Data Collection Technique

Quantitative data collection techniques in the study of fuzzy logic implementation for automatic watering systems on microcontroller-based tomato plants can also involve study of literature and direct observation. 1) The study of literature in this research refers to a series of activities related to library data collection, reading and note-taking, as well as how to treat research data objectively, systematically, analytically, and critically (Putri, Bramasta, and Hawanti 2020). 2) Observation, is a data collection technique that involves direct observation of participants and the context involved in the research phenomenon. Qualitative observations can be carried out in real situations or in environments that have been specifically designed for research (Ardiansyah et al. 2023).

A. Study of Literature

In this study, a literature review was conducted to find temperature and soil moisture data required for tomato plants. The data referenced in this research are from a study conducted by Ginanjar, Candra, and Kembaren (2018). The qualitative data obtained from this literature review provide valuable insights for further evaluation of system performance and potential improvement needs.

B. Observation

In this study, field observations were made to collect data related to watering tomato plants. Observations were made directly at the farm or greenhouse where the tomato plants were grown. Researchers paid close attention to the watering process, including the frequency and duration of watering, as well as the soil condition after watering. The data collected from these observations provides an accurate picture of existing watering practices, as well as providing insight into water requirements and soil conditions that may affect the growth and health of tomato plants.

Data Analysis

The data analysis method used in this research is quantitative. This involves first preparing numerical data for analysis using statistical software, conducting analysis using statistics that provide descriptive and inferential results, presenting the results using tables, figures, and discussing each statistical test, and finally interpreting the results (Siregar 2021).

A. System Design

In the design of a fuzzy logic implementation system for an automatic watering system on tomato plants, aspects of fuzzy logic allow the system to model input variables such as air temperature and soil moisture in the form of fuzzy sets with membership functions that capture the nuances and uncertainties in sensor data. Using predefined fuzzy rules, the system can generate outputs in the form of watering duration and intensity based on a combination of inputs from the sensors, and a defuzzification process is used to convert the fuzzy outputs into concrete values that can be implemented. By utilizing fuzzy logic, the automatic watering system becomes more adaptive and responsive to variations in environmental conditions, improving water use efficiency and ensuring optimal growth for tomato plants.

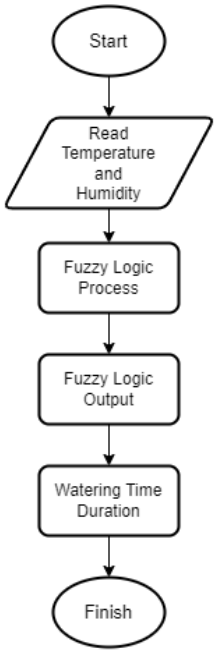

Figure 1. System Design Method

B. Fuzzification

Fuzzification is a stage in the fuzzy logic calculation process where strict or numerical values are converted into fuzzy values. In this stage, calculations are performed to determine the degree of membership of each fuzzy variable to an existing fuzzy set. This allows for a more flexible and adaptive interpretation of numerical data, thus allowing the system to make decisions based on environmental conditions more accurately and complexly.

C. Reasoning

Reasoning, as a process, involves the use of If-Then rules in fuzzy logic to convert fuzzy inputs into fuzzy outputs. Meanwhile, a rule base is a set of rules needed to achieve a predefined goal. In the context of an automatic watering system, fuzzy rules are applied to fuzzy input values to produce fuzzy output values that predict plant watering duration more accurately.

Table 1. Rule Base

IF	Humidity	Temperature	Then	Duration
IF	Dry	Cold	Then	Fast
IF	Dry	Normal	Then	Medium
IF	Dry	Hot	Then	Long
IF	Moist	Cold	Then	Fast
IF	Moist	Normal	Then	Fast
IF	Moist	Hot	Then	Medium
IF	Wet	Cold	Then	Fast
IF	Wet	Normal	Then	Fast
IF	Wet	Hot	Then	Fast

D. Defuzzification

Defuzzification is a process in fuzzy logic in which a fuzzy set or fuzzy variable is converted back into a strict or definitive value. This process is necessary to convert the fuzzy outputs obtained from the fuzzy inference system into numerical values or specific actions that can be easily understood and implemented by the system or user. Defuzzification plays an important role in making final decisions or actions based on fuzzy logic inference results, thus enabling practical applications in various control systems and decision-making processes.

RESULTS AND DISCUSSION

As an illustration, in a greenhouse, there is a sample soil moisture of 65%, while the temperature reaches 25°C. From this data, we can determine the duration of watering required for tomato plants using fuzzy logic principles.

Based on the study of literature results obtained, there are 3 categories of soil moisture levels, namely Dry, Moist, and Wet with ranges as shown in the table below. The level of soil moisture suitable for tomato plants ranges from 60 - 80%.

Table 2. Variable Input Soil Moisture

Soil Moisture Level (%)	State
[30 - 65]	Dry
[60 - 80]	Moist
[75 - 100]	Wet

From Table 2, the following graph is obtained which shows the membership set of the input variable Humidity Level

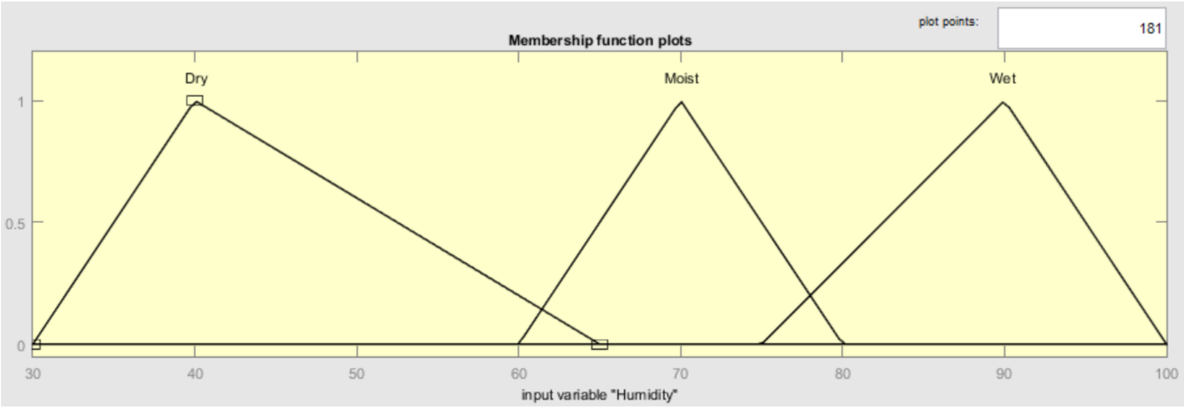

Figure 2. Membership Set of Soil Moisture

It can also be seen that the soil moisture membership set is as follows

$$
\text{Fx (Soil Moisture)}
\begin{cases}
Dry(x) \begin{cases} x < 30 & ;0 \\ 30 \le x \le 40 & ;\frac{x-30}{40-30} \\ 40 \le x \le 65 & ;\frac{65-x}{65-40} \\ x > 65 & ;0 \end{cases} \\
Moist(x) \begin{cases} x < 60 & ;0 \\ 60 \le x \le 70 & ;\frac{x-60}{70-60} \\ 70 \le x \le 80 & ;\frac{80-x}{80-70} \\ x > 80 & ;0 \end{cases} \\
Wet(x) \begin{cases} x < 75 & ;0 \\ 75 \le x \le 90 & ;\frac{x-75}{90-75} \\ 90 \le x \le 100 & ;\frac{100-x}{100-90} \\ x > 100 & ;0 \end{cases}
\end{cases}
$$

To determine the degree of membership of soil moisture with a soil moisture value of 65 which is in the moist range. Then, the equation obtained is

$$\mu_{x\_Moist}[65] = \frac{x-a}{b-a} = \frac{65-60}{70-60} = \frac{5}{10} = \frac{1}{2} = 0{,}5$$

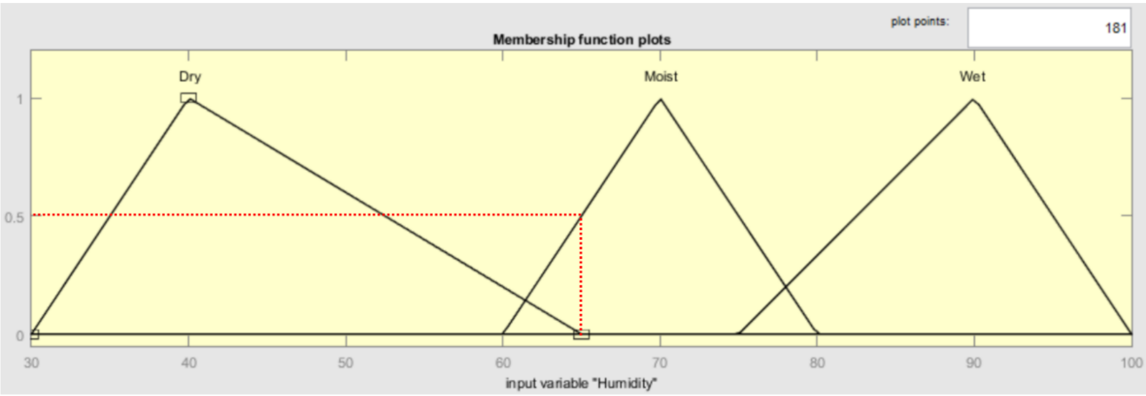

Figure 3. Membership Degree Graph of Soil Moisture

The ideal temperature for tomato plants is 20 - 27°C. There are 3 temperature categories namely, Cold, Normal, and Hot.

Table 3. Variable Input Temperature

Temperature Level (°C)	**State**
[10 - 23]	Cold
[20 - 27]	Normal
[26 - 35]	Hot

The graph of the membership set on the temperature level input variable is as follows

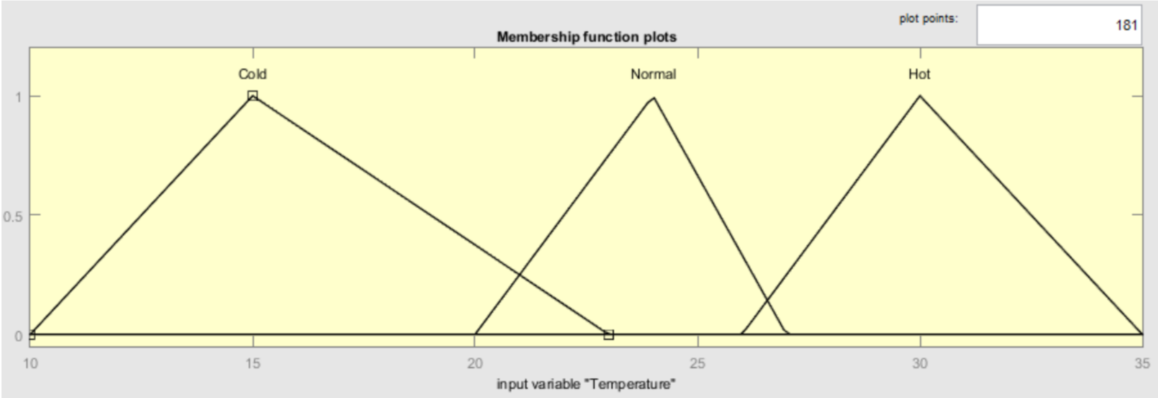

Figure 4. Temperature Membership Set

It can also be known that the temperature level membership set is as follows

$$
\text{Fx (Temperature)}\begin{cases}
Cold(x) & \begin{cases} x < 10 & ;0 \\ 10 \leq x \leq 15 & ;\frac{x-10}{15-10} \\ 15 \leq x \leq 23 & ;\frac{23-x}{23-15} \\ x > 23 & ;0 \end{cases} \\
Normal(x) & \begin{cases} x < 20 & ;0 \\ 20 \leq x \leq 24 & ;\frac{x-20}{24-20} \\ 24 \leq x \leq 27 & ;\frac{27-x}{27-24} \\ x > 27 & ;0 \end{cases} \\
Hot(x) & \begin{cases} x < 26 & ;0 \\ 26 \leq x \leq 30 & ;\frac{x-26}{30-26} \\ 30 \leq x \leq 35 & ;\frac{35-x}{35-30} \\ x > 35 & ;0 \end{cases}
\end{cases}
$$

To determine the degree of membership of the temperature level with a value of 25℃ which is in the normal range. Then, the equation obtained is

$$\mu_{y\_normal}[25] = \frac{c-x}{c-b} = \frac{27-25}{27-24} = \frac{2}{3} = 0{,}67$$

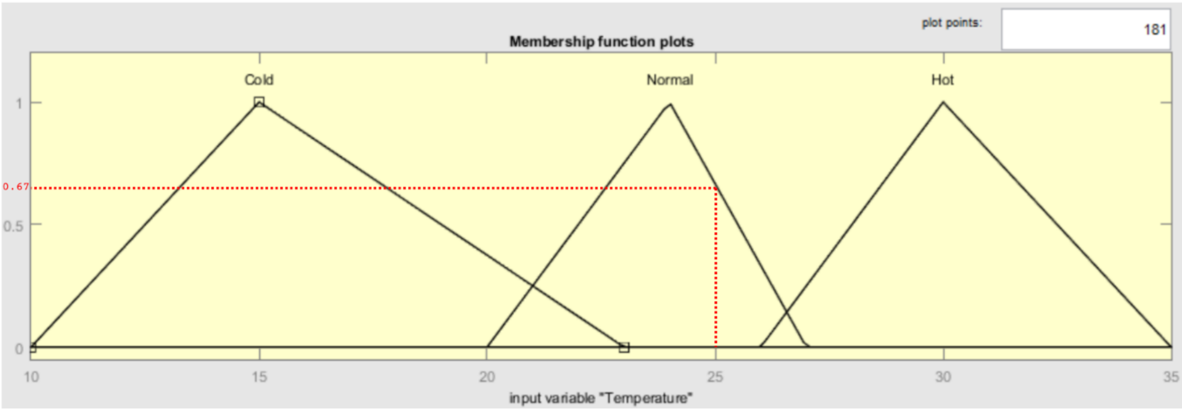

Figure 5. Temperature Level Membership Degree Graph

The output of this fuzzy logic is to determine the duration of watering tomato plants. Where the duration of watering is divided into 3 levels: Fast, Medium, and Long. And has a range as in the table below.

Table 4. Variable Input Watering Duration

Watering Duration (second)	State
[4 - 8]	Fast
[7 - 12]	Medium
[10 - 20]	Long

For the Membership Set Graph on the output variable Watering Duration is as follows

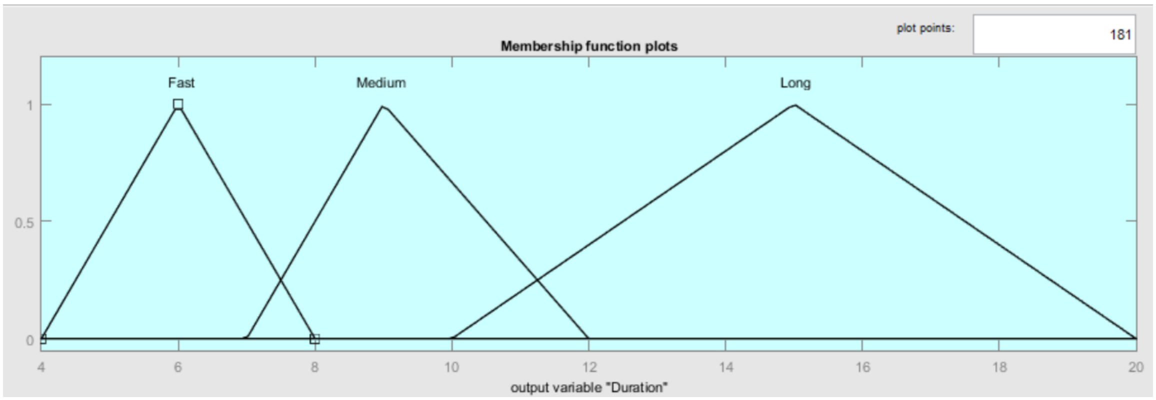

Figure 6. Membership Set of Watering Duration

The fuzzy rules used for this case amounted to 9. The rules that we have determined based on the results of the study of literature are as follows:

1. If (Humidity is Dry) and (Temperature is Cold) then (Duration is Fast) (1)
2. If (Humidity is Dry) and (Temperature is Normal) then (Duration is Medium) (1)
3. If (Humidity is Dry) and (Temperature is Hot) then (Duration is Long) (1)
4. If (Humidity is Moist) and (Temperature is Cold) then (Duration is Fast) (1)
5. If (Humidity is Moist) and (Temperature is Normal) then (Duration is Fast) (1)
6. If (Humidity is Moist) and (Temperature is Hot) then (Duration is Medium) (1)
7. If (Humidity is Wet) and (Temperature is Cold) then (Duration is Fast) (1)
8. If (Humidity is Wet) and (Temperature is Normal) then (Duration is Fast) (1)
9. If (Humidity is Wet) and (Temperature is Hot) then (Duration is Fast) (1)

Figure 7. Fuzzy Logic Rule Base

After determining the fuzzy rules, this case is subjected to rule number 5. Because the rule used is AND, the fuzzy operator used is the minimum value of the parameter input.

$$\alpha_1 = Min(\mu_{x\_moist[65]} \cap \mu_{y\_normal[25]}) = Min(0{,}5\ ;\ 0{,}67)$$
$$\alpha_1 = 0{,}5$$

From the fuzzy operator obtained, the equation below can be used to determine the implication function.
Left-side Implication Function:

$$\alpha_1 = \frac{z_1 - 4}{6 - 4}$$
$$0{,}5 = \frac{z_1 - 4}{2}$$
$$1 = z_1 - 4$$
$$z_1 = 5$$

Right-side Implication Function:

$$\alpha_1 = \frac{8 - z_2}{8 - 6}$$

$$0,5 = \frac{8 - z_2}{2}$$

$$1 = 8 - z_1$$

$$z_2 = 7$$

The implication function will divide the fast output part into 3 parts as shown in the graph below.

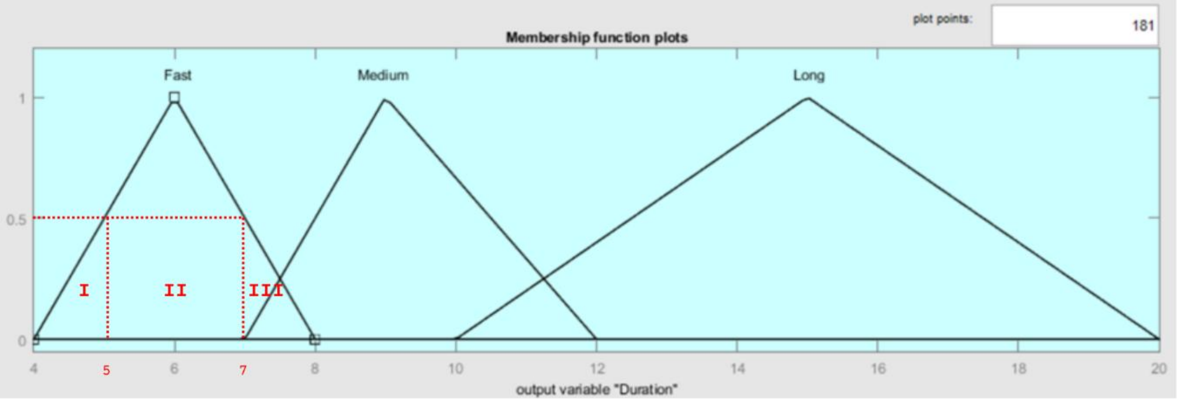

Figure 8. Implication Function

Next is to calculate the area of each region. For regions 1 and 3, we use the triangle area formula. For region 2, we use the rectangle formula.

$$LD_1 = \frac{(5 - 4) \times 0,5}{2} = 0,25$$

$$LD_2 = (7 - 5) \times 0,5 = 0,25$$

$$LD_3 = \frac{(8 - 7) \times 0,5}{2} = 0,25$$

Compose all the outputs into a set as follows.

$$F(x,a,b,c,d) = \begin{cases} x < 4, & 0 \\ 4 \le x \le 5, & \frac{x-4}{6-4} => 0,5x - 2 \\ 5 \le x \le 7, & 0,5 => 0,5 \\ 7 \le x \le 8, & \frac{8-x}{8-6} => 4 - 0,5x \\ x > 8, & 0 \end{cases} \quad \text{Moment} = \int_a^b F(x)\, x \,.\, dx$$

The composition of the output obtained will produce 3 set moments. So that the equation for the value of the moment set is obtained as follows

Moment Set 1

$$\int_4^5 (0,5x - 2)\, x\, dx \to \int_4^5 0,5x^2 - 2x\, dx \to \int_4^5 \frac{0,5x^3}{3} - x^2\, dx$$

$$\to \left(\frac{0,5(5)^3}{3} - (5)^2\right) - \left(\frac{0,5(4)^3}{3} - (4)^2\right) = -4,17 - (-5,33) = 1,16$$

Moment Set 2

$$\int_5^7 (0,5)\, x\, dx \to \int_5^7 0,5x\, dx \to \int_5^7 0,25\, x^2 \to (0,25(7)^2) - (0,25(5)^2) = 12,25 - 6,25$$

$$= 6$$

Moment Set 3

$$\int_7^8 (4 - 0,5x)\, x\, dx \rightarrow \int_7^8 4x - 0,5x^2\, dx \rightarrow \int_7^8 2\,x^2 - \frac{0,5x^3}{3} dx$$
$$\rightarrow \left(2(8)^2 - \frac{0,5(8)^3}{3}\right) - \left(2(7)^2 - \frac{0,5(7)^3}{3}\right) = 42,67 - 40,83 = 1,84$$

Finally, to determine the duration of watering, do defuzzification using the Center of Area (COA) method, with the following equation:

$$COA = \frac{\int_a^b F(x)x\,.dx}{\int_a^b F(x)dx}$$

$$COA = \frac{\sum Moment}{\sum Area}$$

$$COA = \frac{1,16 + 6 + 1,84}{0,25 + 1 + 0,25}$$

$$COA = \frac{9}{1,5} = 6$$

So with soil moisture conditions of 65% and temperature conditions of 25°C, the watering duration required by tomato plants is 6 seconds which is included in the fast watering category.

CONCLUSION

From this research, it can be concluded that the implementation of Fuzzy Logic in the context of agriculture, especially in determining the duration of automatic watering of tomato plants, provides an efficient and adaptive solution. By involving environmental factors such as temperature conditions and soil moisture in tomato plants, Fuzzy Logic allows automatic adjustment of watering duration according to the needs of tomato plants, increasing water use efficiency, and also reducing the risk of plant stress. Using Fuzzy Logic in this research can provide significant benefits in optimizing the growth and productivity of tomato plants and strengthening the role of technological innovation in encouraging sustainable modern agriculture in Indonesia.

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