



Fuzzy Logic Based Automatic Chili Plant Watering and Pest Monitoring Using the Internet of Things (IoT)

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ABSTRACT

A challenge many chili farmers currently face is how to streamline watering from manual to automatic for more effective chili plants. This research aims to streamline water use by utilizing fuzzy logic and the Internet of Things (IoT). The method used begins with modeling in fuzzy logic and pest monitoring program code, connecting the system to an Android device. Test results show that the soil moisture sensor is capable of detecting soil moisture in various conditions, both dry and wet. The error tends to be slightly larger due to the increased sensor sensitivity with an average accuracy error below 5%. This sensor is very suitable as an automatic monitoring tool, especially for determining the need for automatic plant watering.

INTRODUCTION

Plants are one of the living things that need water to breed. Plants also need soil as a medium to grow. Fertile soil is one of the main factors for plants to grow well. Meanwhile, the water content and pH in the soil greatly affect its fertility. Lack of water in plants can lead to a decrease in cell turgor pressure, increased macromolecule concentration, damage to cell membranes, and decreased the potential for water chemical activity in plants (Mubiyanto, 1997). But currently, humans still find it difficult to water plants, because they have to be done manually and do not know how much water and fertilizer plants need. The effects of this lack of water can interfere with the overall metabolic process of plants, which ultimately negatively impacts the growth rate and development of plants (Harnowo, 1993). One of the horticultural plants that is often consumed by many Indonesian people and is found in many countries. Chili plants require certain environmental conditions, such as a temperature of 18°C–30°C, soil moisture of 60%–80%. In cultivation practices, watering chili peppers is generally done once a day, especially in the morning after sunrise but not too high (Situmorang, 2020). Then the research entitled "Intelligent Irrigation System Using Fuzzy Logic Method in IoT-Based Tomato Plants". This research aims to design an IoT-based intelligent irrigation system using Fuzzy Logic for watering regulation in tomato plants. The system also monitors soil moisture and temperature in real time and adjusts automatic watering according to plant needs to optimize water usage. The design also uses fuzzy sugeno that combines soil temperature and moisture parameters and integrates IoT through Blynk's application. (Pogasang J et al, 2024)

The purpose of this research focuses on the application of modern technology to be an effective solution in increasing the efficiency and productivity of chili plants. Innovative smart farming system based on automatic watering integrated with IoT and fuzzy logic algorithms, monitoring plant conditions and pests using ESP32-Cam cameras. Several previous studies have also been observed, one of which is entitled "Implementation of Iot-Based Chili Plant Watering Monitoring System" which discusses the implementation of temperature and humidity sensors and microcontrollers connected to android applications to water plants. The result of this implementation is that the productivity of chili plants can be increased, the quality of crops is guaranteed, and efficiency in agricultural land management is achieved. (Nugraha and RR Hajar Puji Sejati, 2024).

LITERATURE REVIEW

Chili Plants

Chili plants are one of the horticultural crops with a fairly high selling value, but they require special attention in the cultivation process. The growth of chili plants is greatly influenced by the availability of water, both lack and excess water can interfere with the fertilization process and increase susceptibility to pest attacks (Imtiyaz et al., 2017). To support optimal growth, chili needs a growing medium with an appropriate level of humidity. Improper watering, both in terms of quantity and time, can negatively impact plant productivity. Therefore, the timeliness of watering is an important factor that

needs to be considered. Even if done regularly, watering that ignores the elements of time, temperature, and humidity can reduce crop yields.



Figure 1. Chili Plants

The classification of cayenne pepper according to Anggraini (2020) is as follows:

<i>Kingdom</i>	: <i>Plantae</i>
<i>Divisi</i>	: <i>Spermatophyta</i>
<i>Sub Divis</i>	: <i>Angiospermae</i>
<i>Class</i>	: <i>Dicotyledonae</i>
<i>Ordo</i>	: <i>Solanes</i>
<i>Famili</i>	: <i>Solanaceae</i> Sub <i>Famili</i> : <i>Solanaceae</i> Genus : <i>Capsicum</i> <i>Capsicum frutescens</i> L.

Watering Chili

The ideal watering time for chili plants is in the morning at around 07.00 and in the afternoon at 17.00 WIB (Mootalu et al., 2022). Based on the age of the plant, water needs vary, namely at the age of one month around 0.111 liters per day, at the age of two months 1,148 liters per day, at the age of three months 1,223 liters per day, and at the age of four months it remains around 1,323 liters per day. In addition, chili peppers are also susceptible to pests such as caterpillars and aphids, which can cause serious damage to crops

Chili Pests

Chili plants require special attention in cultivation, this special attention is paid so that chili produces abundant and quality fruits, this plant is a plant that is often targeted by various pests that can damage growth and reduce crop yields

Internet of Things

The Internet of Things (IoT) is a technology that allows communication between machines through internet connections often referred to as M2M (Machine-to-Machine) with humans playing the role of users as well as managers. IoT consists of three main elements, namely physical devices equipped with IT modules, internet connectivity, and cloud-based data centers to store information. This technology continues to enable continuous connections between devices, machines, tools, and other physical objects through network sensors and actuators. In its operation, IoT devices connected

to the internet collect data stored as Big Data to be processed and analyzed as needed. With this capability, the device can monitor its own performance and independently take actions or decisions based on the information obtained. Collaboration between integrated machines creates an intelligent, efficient, and automated ecosystem, so that it can optimally improve various aspects of human life.

The initial idea of IoT was first introduced by Kevin Ashton in 1999 in one of his presentations. Since then, many major companies in the tech world, such as Intel, Microsoft, Oracle, and others, have begun to pay great attention to IoT development. Technologists predict that the influence of IoT will be the next big revolution in the world of information technology. This optimism arises because IoT holds various extraordinary potentials that can continue to be explored and utilized to create innovative solutions in various areas of life. There are several stages of how IoT works, namely sensors, data processing, connectivity, and actions, as seen in figure 2.10 (Sawitri, 2023).



Figure 2. How the Internet of Things Works

In the way IoT works, the four stages are interrelated and affect each other. Sensors are used to collect data, the data is then processed and sent through the IoT network, and finally the device can respond automatically without the need for human intervention (Sawitri, 2023).

Fuzzy Logic

In June 1965, the concept of fuzzy logic was first introduced by Professor Lotfi A. Zadeh of the University of California (Kaswidjanti, Aribowo, & Wicaksono, 2014). The basis of fuzzy logic is fuzzy set theory. According to Edy Victor Haryanto (2015), this theory states that the degree of membership of an element in a set is not only limited to the values of 0 and 1 (not members or members), but can be between these ranges. Thus, there is a logical "gray area" between the values of 0 and 1.

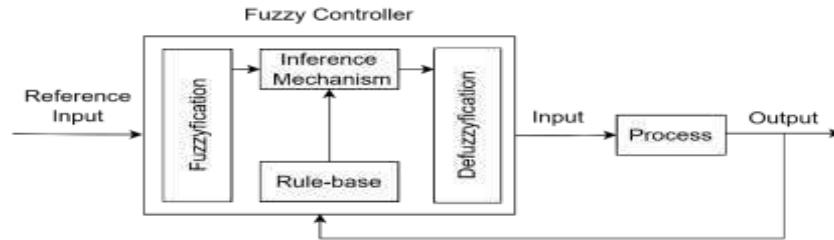


Figure 3. Fuzzy Logic Modeling

Fuzzy logic is one of the algorithms that is part of the study of artificial intelligence. This algorithm is applied in various fields, such as medicine to detect diseases, economics, and so on. In general, fuzzy logic is used to solve problems that contain uncertainty. Some of the reasoning methods commonly used in the development of fuzzy systems include the Tsukamoto, Mamdani, and Sugeno methods (Jayanti & Hartati, 2012).

ESP32-CAM

The ESP32-CAM is an ESP32-based microcontroller module equipped with an integrated camera, making it a very popular choice for applications that require the ability to shoot or video in Internet of Things (IoT) projects. Especially in this Final Project, ESP32-cam is used as a monitoring of the condition of chili plants and the surrounding environment.



Figure 4. ESP-32 CAM

DS18B20 Sensor

DS18B20 sensors are analog sensors designed to measure temperature with high accuracy and simple data output via the 1-Wire analog communication protocol. These sensors are widely used in various applications such as temperature control, refrigeration systems, environmental monitoring, and IoT projects.



Figure 5. DS18b20 Temperature Sensor Module

Soil Moisture Sensor

Soil Moisture *Sensor* is an electronic device used to detect soil moisture levels. This tool works by measuring the electrical conductivity of the soil, where the level of soil moisture affects the ability of the soil to conduct electricity. The

more water content in the soil, the lower the electrical resistance, so the output value of the sensor becomes higher. *Soil Moisture* consists of components with two metal rods that are embedded into the soil. These two metal rods are used for probes and electrodes to measure the electrical resistance of the ground. This soil moisture sensor has the following specifications:

1. The input voltage is 3.3V or 5V.
2. The output voltage is 0 – 4.2V.
3. The current is 35 mA.

The value range of ADC is 1024 bits ranging from 0 – 1023 bits.



Figure 6. Soil Moisture Sensor Module

Flow Meter yf-s401 Sensor

The YF-S401 flow meter sensor is a Hall Effect-based flow sensor module commonly used to measure the rate of liquids, specifically water, in closed pipes. The specifications of this sensor are as follows:

Operating Voltage : 3.3 V – 5 V

Working Current : ≤ 15 mA

Measurement range : 1 – 30 L/min

Accuracy : ± 10

Signal Output: PWM

Diameter Pipa : $\frac{1}{2}$ inch (G1/2)

Maximum pressure : < 1.75 MPa



Figure 7. YF-S401 Flow Meter Sensor Module

Codular

Codular is a drag-and-drop based Android app development platform that allows users, even without a programming background, to create Android apps easily and quickly. Using the visual interface, users can add elements such as buttons, images, and text inputs and structure the app's logic using visual code blocks, which resemble puzzle pieces that can be combined to form a program flow. Kodular provides a variety of components, ranging from user interfaces, sensors, to internet-based services, and supports integration with

third-party services such as Firebase, Google Maps, and advertising. The platform allows developers to test apps directly on Android devices through live testing features, as well as offering app monetization capabilities through ads and in-app purchases.



Figure 8. Apps Kodular

MQTT

MQTT (Message Queuing Telemetry Transport) is a lightweight communication protocol based on a publish-subscribe architecture designed specifically for machine-to-machine (M2M) communication and Internet of Things (IoT) applications. In its mechanism, MQTT sends data in the form of a message to a topic, which is a kind of category or virtual address used to group and convey data. The publisher sends a message to a specific topic, and the broker forwards that message to all subscribers who have subscribed to the same topic. In this way, communication between devices becomes more flexible, efficient, and not directly dependent on each other. For example, a temperature sensor can send data to a sensor/temperature topic, and the monitoring device only needs to subscribe to that topic to receive real-time temperature data (Pratama et al, 2023).



Figure 9. MQTT Communication Architecture

MQTT is designed to operate efficiently on low-bandwidth, high-latency networks, making it ideal for use in IoT devices with limited power and connectivity. This protocol also supports the reliability level of message delivery through the Quality of Service (QoS) feature, as well as provides a Last Will and Testament (LWT) mechanism to handle sudden connection disconnections.



Figure 10. MQTT

Error Calculation

The measurement calculation in this study was carried out using the relative error method. This method is used to find out how close to the actual value obtained from a standard measuring device. In other words, relative error indicates the level of accuracy of the sensor in reading a physical quantity when

compared to a reference measuring instrument. In the process of measuring a physical quantity, be it temperature, humidity, water discharge, or other parameters, it is important to evaluate how accurate the sensor or measurement instrument used is. One of the commonly used methods is the calculation of relative error.

Relative error provides information about the extent to which the sensor reading results are close to the actual value obtained from a reference or standard measuring instrument. Thus, this method not only shows the difference in values, but also emphasizes the proportion of errors to the reference values. This is important because the same error can be considered small at large measurement values, but significant at small measurement values. (Bakshi & Bakshi, 2009).

$$Error = \frac{Sensor\ Value - Measuring\ Instrument\ Value}{Measuring\ Instrument\ Value} \times 100\% \quad (1)$$

Then to find the average value of the error from the entire data to be tested is as follows:

$$Average\ error = \frac{Total\ number\ of\ error\ data}{lots\ of\ error\ data} \quad (2)$$

METHODOLOGY

In this study, the algorithm used in the design of this final project is the fuzzy mamdani method. This system consists of 2 inputs that act as linguistic variables, namely soil temperature and soil moisture, and 1 output, namely the amount of watering discharge. Here is a more detailed explanation of the system:

Membership Function Planning

In the fuzzification system focused on finding the membership function, it has two inputs, namely temperature and humidity. Each of these inputs comes from the input of each sensor, such as the DS18B20 sensor to measure soil temperature and the soil moisture sensor to measure soil moisture. On the temperature variable, marks (D) are given for cold, (N) for normal, (P) for heat and (SP) for very hot. The temperature input variables are shown in the table as follows:

Table 1. Temperature Input			
No	Temperature Input Variables	The Universe of Talk	Domain
1.	Cold (D)	[0, 22]	[0 15 18 22]
2.	Normal (N)	[20, 29]	[20 25 25 29]
3.	Heat (P)	[27, 35]	[27 32 32 35]
4.	Very Hot (SP)	[33, 50]	[33 45 50 50]

The following is an equation from the manual function looking for the parameters of *fuzzyfication*:

$$\begin{aligned}\mu_{\text{Normal}}[x] &= \begin{cases} 1 & \text{for } x \leq 15 \\ \frac{18-x}{18-15} & \text{for } 15 < x < 18 \\ 0 & \text{for } x \geq 22 \end{cases} \\ \mu_{\text{Normal}}[x] &= \begin{cases} 0 & \text{for } x \leq 20 \text{ or } x \geq 25 \\ \frac{29-x}{29-25}; & \text{for } 25 < x < 29 \end{cases} \\ \mu_{\text{Heat}}[x] &= \begin{cases} 0; & \text{for } x \leq 27 \text{ or } x \geq 32 \\ \frac{35-x}{35-32}; & \text{for } 32 < x < 35 \end{cases} \\ \mu_{\text{Very Hot}}[x] &= \begin{cases} 0; & \text{for } x \leq 33 \\ \frac{x-45}{50-45}; & \text{for } 45 < x < 50 \\ 1; & \text{for } x > 50 \end{cases} \end{aligned} \quad (3)$$

From the table above, it can be concluded that for cold temperatures it is in the value range of 15-22 °C, for normal temperatures it is at 22-28 °C, for hot temperatures it is in the value range of 28-35 °C and for very hot values it is above ≥35 °C.

The soil moisture variables were taken based on the soil moisture sensor parameters by initiating the variables very dry (SK), dry (K), Normal (N), Wet (B). The following is a table of soil moisture *input* variables:

Table 2. Moisture Input			
No	Variable Input Humidity	The Universe of Talk	Domamin
1.	Very Dry (SK)	[0, 30]	[0 10 15 30]
2.	Dry (K)	[25, 60]	[25 45 45 60]
3.	Normal (N)	[50, 80]	[50 70 70 80]
4.	Wet (P)	[70, 100]	[70 80 100 100]

The following is an equation from the manual function looking for the parameters of *fuzzyfication* :

$$\begin{aligned}\mu_{\text{Very Dry}}[x] &= \begin{cases} 1 & \text{for } x \leq 0 \\ \frac{15-x}{15-10} & \text{for } 10 < x < 15 \\ 0 & \text{for } x \geq 30 \end{cases} \\ \mu_{\text{Kering}}[x] &= \begin{cases} 0 & \text{for } x \leq 25 \text{ or } x \geq 45 \\ \frac{60-x}{60-45}; & \text{for } 45 < x < 60 \end{cases} \end{aligned} \quad (4)$$

$$\mu_{\text{Normal}}[x] = \begin{cases} 0; & \text{for } x \leq 50 \text{ or } x \geq 70 \\ \frac{80-x}{80-70}; & \text{for } 70 < x < 80 \end{cases}$$

$$\mu_{\text{Wet}}[x] = \begin{cases} 0; & x \leq 70 \text{ or } x \leq 80 \\ \frac{x-80}{100-80}; & \text{for } 80 < x < 100 \\ 1; & \text{for } x \geq 100 \end{cases}$$

Fuzzy Output Planning

This system has an output of the amount of watering discharge(s) on the soil according to the desired humidity and temperature. Variable output was obtained from literature studies related to watering chili plants, the watering variables were obtained namely No Watering (T), Little Watering (SS), Half Watering (SS2) and Lots of Watering (BS).

Table 3. Watering Output

Yes	Variable Output Debit	The Universe of Talk	Domain
1.	No Flush (TS)	[0, 200]	[0 0 100 200]
2.	A Little Flush (SdS)	[150, 450]	[150 250 350 450]
3.	Half Flush (SS)	[400, 800]	[400 500 650 800]
4.	Lots of Flush (BS)	[750, 1200]	[750 900 1100 1200]

System Interface Design

The data that has been stored in the broker's MQTT is then connected to Kodular to be displayed in the form of real numbers. The creation of the application interface is carried out using the drag-and-drop method on the Koular platform, so that the development process becomes more efficient and easy to manage. Through this application display, users can monitor various important information in real-time, including:

1. Sensor log data – a historical record of sensor readings.
2. Up-to-date sensor reading data – direct sensor value information.
3. Data from fuzzy logic calculations – output from fuzzy-based data processing systems.

In addition to the monitoring feature, the application is also equipped with additional menus such as live camera streaming for visual observation, as well as a plant information database that includes plant life, plant type, and planting season. With this integration, users can monitor the condition and development of crops thoroughly in one platform.



Figure 11. Designing Displays on Mobile Applications

System Hardware Planning

In the hardware section, the system consists of ESP-32 and ESP-32 CAM microcontrollers, DS18B20 temperature sensors, soil moisture sensors, yf s401 sensors, 5V relay modules, DS3132 RTC modules, buck converter modules, and Solar Power Plant (PLTS) system as independent power sources. Here is a block diagram and schematic of the hardware part set.

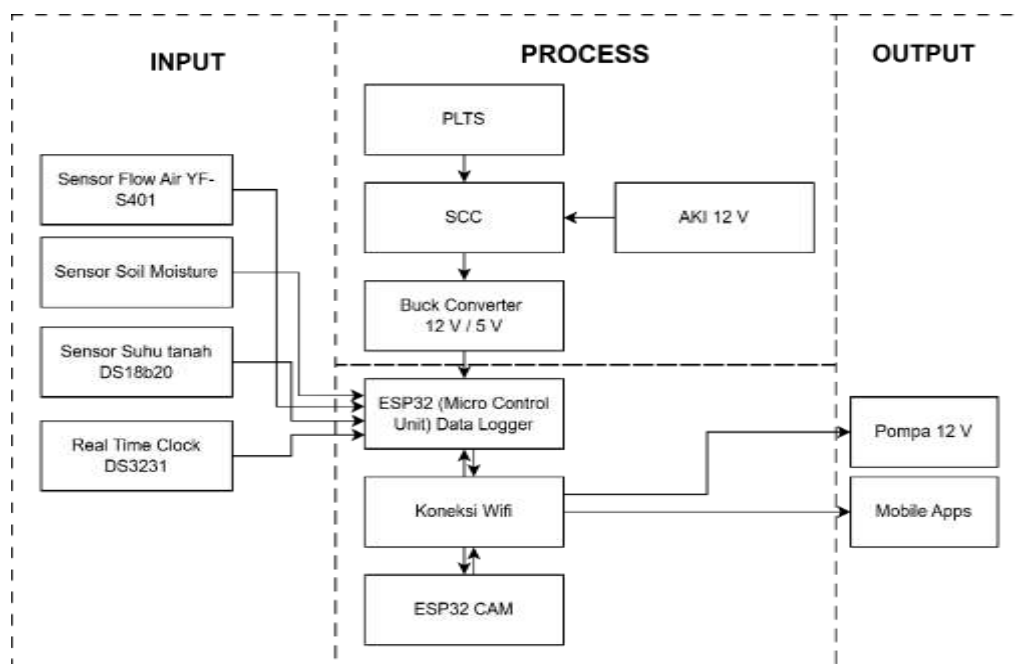


Figure 12. System Block Diagram

The ESP32 microcontroller functions to process data from these sensors. The data received from the sensor will be processed using Mamdani's fuzzy

algorithm to make decisions based on the DS3231 RTC in calculating the automatic watering time on chili plants. This processing process uses two main parameters, namely soil temperature and soil moisture. Based on the processing results of the fuzzy algorithm, the ESP32 can determine the optimal watering needs and transmit a signal to activate the watering system according to the temperature and humidity conditions of the soil. In addition, ESP32-CAM is used in this system to visually display chili plants and the surrounding environment. The camera on the ESP32-CAM functions to monitor the presence of pests on chili plants by capturing visuals with a camera. Once the shooting process is complete, the ESP32-CAM sends the resulting data to the ESP32 to be forwarded to cloud storage using the Wi-Fi connection owned by the ESP32. All information, both data from sensors and visual results from ESP32-CAM, is then stored and sent to the Firebase Realtime Database platform and can be accessed through the Koular application.

RESEARCH RESULTS

Fuzzy Logic and Internet of Things (Iot)-Based Testing

This table presents data on the test results of Fuzzy **Logic-based automatic** plant watering systems and **the Internet of Things (IoT)**. Each row shows measurements based on **the date and time** of data collection, as well as input values from the sensor, the output of the watering results, and the difference or error between the simulation results in Matlab and the microcontroller.

Table 4. Fuzzy Logic Testing Data

Time	Input			Debit (mL)		Error (%)
	Mouth (°C)	Moisture (%)	Duration(s)	Matlab	Microcontroller	
Morning, 7.10	25	78	6,48	78.7	85	7.86
Sore, 17.25	30	58	19,09	398	250	37.19
Morning, 7.10	26	73	6,48	80.8	85	5.20
Sore, 17.25	28	69	14,04	205	184	10.24
Morning, 7.10	24	86	6,87	80.8	90	11.36
Sore, 17.25	28	86	7,09	90.3	93	2.99
Morning, 7.10	23	77	6,87	82.9	90	3.74

Time	Input			Debit (mL)		Error (%)
	Mout h (°C)	Moisture (%)	Durati on(s)	Matlab	Microcontroller	
Sore, 17.25	29	78	12,29	179	161	10.06
Morni ng, 7.10	26	69	6,25	79.7	82	2.89
Sore, 17.25	28	77	14,04	205	184	10.24
Morni ng, 7.10	26	71	6,25	79.7	82	2.89
Sore17.25	28	66	14,04	205	184	10.24

$$\begin{aligned}
 Error &= \frac{\text{Nilai Mikrokontroler} - \text{Nilai Matlab}}{\text{Matlab Value}} \times 100\% \\
 &= \times 100\% \frac{85 - 78.7}{78.7} \\
 &= \times 100\% \frac{6.3}{78.7} \\
 &= 7.8\%
 \end{aligned}
 \tag{5}$$

The following is an average calculation of errors from the temperature data above.

$$\begin{aligned}
 \text{Avarage error} &= \frac{\Sigma \text{Error}}{\Sigma \text{ Trial Value}} \times 100\% \\
 \times 100\% &= \frac{114.9}{12} \\
 &= 9.57\%
 \end{aligned}
 \tag{6}$$

For the example of rules with a temperature of 25 and a humidity of 78%, the results of the fuzzy mamdani calculation of 78.7 mL were obtained as the output of the amount of watering. To see the dimensions on the matlab see the image below.

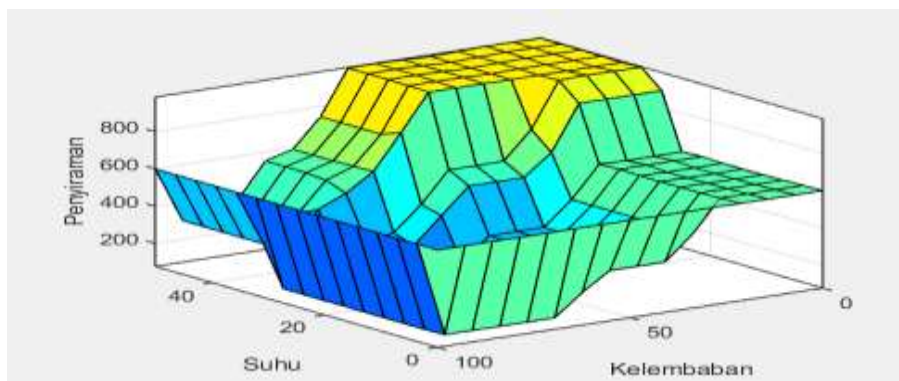


Figure 13. Matlab App Surface View

Figure 13 above is the calculation dimension used using variable input temperature and humidity which affects the size of the watering discharge. Blue represents the area with the lowest temperature and humidity while yellow represents the area with the most watering discharge.

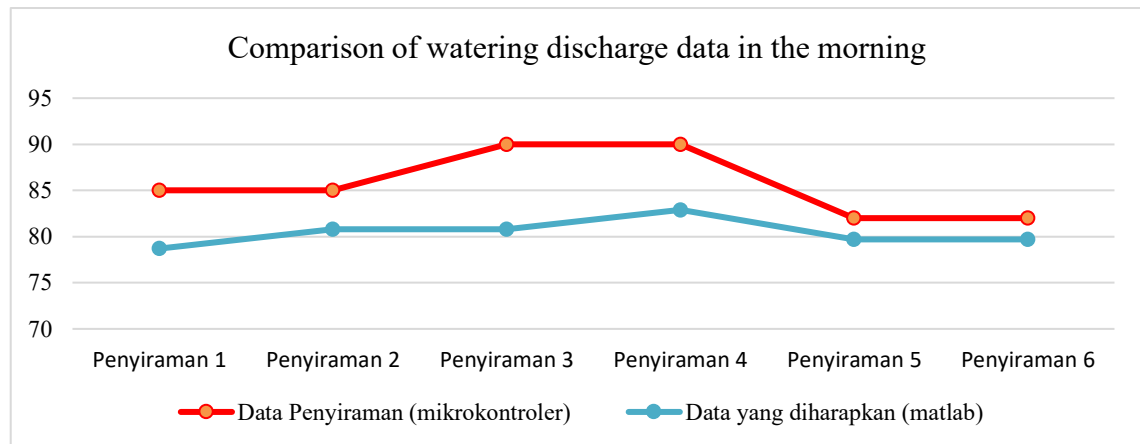


Figure 14. Comparison Chart of Watering Discharge Data in the Morning

Figure 14. Displaying a comparison of watering discharge data in the morning, two lines of data are visible: the blue line represents the actual data from the microcontroller, while the orange line represents the expected data or the simulation results from MATLAB. In general, the microcontroller data shows a higher discharge value compared to the expected value of MATLAB. The microcontroller graphic pattern shows an increase in discharge in the middle of the observation period, which then decreases again. Meanwhile, MATLAB data appears more consistent and tends to be flat, with small fluctuations over time. The difference between these two data shows that the actual watering system of the microcontroller tends to provide more water than the ideal calculation. This can happen because the fuzzy logic of microcontrollers is designed to be conservative, meaning that they prefer to water more to avoid the risk of underwatering plants. In addition, this difference can also be caused by technical factors such as inaccurate calibration of the flow sensor, or a delay in turning off the water pump, so that the discharge output is higher.

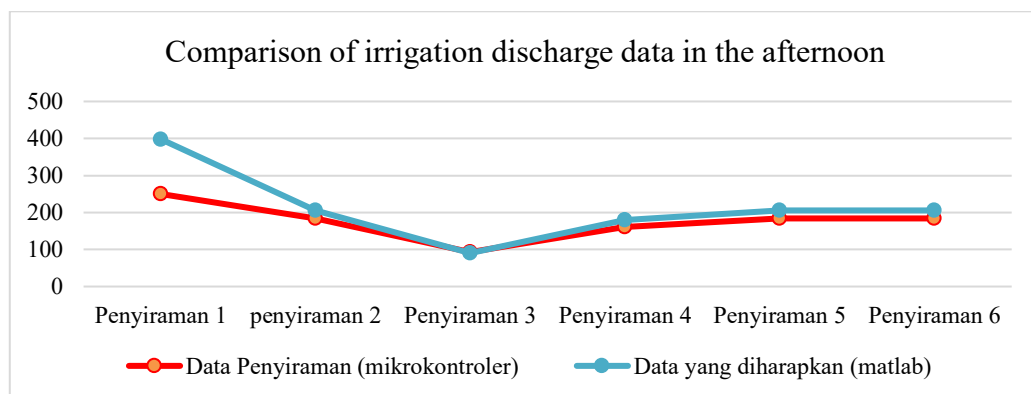


Figure 15. Comparison Chart of Watering Discharge Data in the Afternoon

Figure 15 shows a comparison of watering in the afternoon, showing a more significant difference than the morning graph. At the initial point, the data from MATLAB showed a very high watering discharge (about 400 ml), while the data from the microcontroller was much lower (about 200 ml). This indicates that in the early afternoon, the microcontroller system did not water as expected, or underwatering occurred. However, after that point, the graphs from the microcontroller and MATLAB began to show a similar pattern, although the discharge from the microcontroller was still slightly lower than the ideal value. This indicates that after a while, the system begins to adapt or read the environmental conditions better.

CONCLUSIONS AND RECOMMENDATIONS

An automatic plant watering system based on fuzzy logic designed for chili plants was successfully made according to the research objectives. This system is able to assist farmers in optimizing the plant care process by watering automatically at a predetermined time, without the need for continuous manual involvement. In addition, this system is able to save water use by adjusting the watering volume based on soil moisture values and temperature that has been processed using fuzzy logic algorithms. The implementation of the fuzzy logic algorithm on the microcontroller showed fairly accurate performance. The comparison of the calculation results between the Matlab and the microcontroller has only a small difference, which indicates that the system can run optimally and according to the calculation design. The results of this test show that soil moisture sensors can be relied upon to detect soil moisture in a wide range of conditions, whether it is very dry, dry, humid, or wet. The sensor is most optimally used in dry conditions, while in humid to wet conditions, although the accuracy is still good, the error tends to be slightly greater due to the increased sensitivity of the sensor. With an average error accuracy of below 5%, this sensor is very suitable as an automatic monitoring tool in IoT-based agricultural systems and fuzzy logic, especially to determine plant watering needs in real time. This system is able to provide additional support for farmers to monitor crop conditions and detect potential pest disturbances. In the next development, it is hoped that it can use cameras that are of better quality and can automatically detect small pests. To improve performance, it is necessary to consider the use of cameras with better optical quality, high-resolution image sensors, and faster image processing support, for example by integrating camera AI modules such as OpenMV or Raspberry Pi Camera which have more capable processors for testing with field conditions with a larger number of plants.

ADVANCED RESEARCH

Research can also be done in further development can increase the capacity of plants and the quantity of watering from this tool, in further development it can also be realized in terms of solutive products and not just prototype and in further development it is hoped that it can use a camera that is of better quality and can detect small pests.

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