Implementation of Fuzzy Logic on Watering Automation System for Palm Tree Planting Media Based on WSN

Muhammad Farras Rafi Muflih[1], Azam Muzzakhim[2], Mila Kusumawardani [3]

[1,2,3] Digital Telecommunication Network Study Program,
Electrical Engineering, State Polytechnic of Malang, Indonesia

[1]faras930@gmail.com, [2]azam@polinema.ac.id, [3]mila.kusumawardani@polinema.ac.id

***Abstract*— Currently, date palm farmers manually assess soil color and dryness without a definitive reference. Manual watering of date palms persists, although some gardens employ irrigation systems. The absence of communication infrastructure in plantations necessitates flexible network technology. The system comprises a DS18B20 soil temperature sensor and FC-28 soil moisture sensor. Temperature and humidity values identify soil dryness, determining water volume for date palm irrigation. Sensor data is stored on Arduino Uno, undergoes pre-programmed processing, and is then transmitted to the sink node via the LoRa Ra-02 communication module. The results of system testing can be concluded that the temperature and humidity sensors can detect the temperature and humidity of the growing media with a fairly small error rate. The use of fuzzy logic inference and watering automation goes according to plan. It is known that for a soil temperature of 25.31°C and soil moisture of 20%RH, the output volume of watering through the hardware is 15,31 liters. The communication module used as a data sender can also run well and stable at a range of up to 200 meters with RSSI = -105 and SNR = -7,1.**

***Keywords*— Automation System, Fuzzy Logic, Lora Ra-02, Palm Tree, Watering, Wireless Sensor Network.**

I. INTRODUCTION

The introduction explains the research background, a brief literature review, the aims and objectives of the research.

The KL-1 variety date palm [1] is one of the date palms that can grow and bear fruit in Indonesia. This date palm can start flowering at the age of 2 years and bear fruit at the age of 3 years from seeds [2]. As with most plants, an important factor for the growth of date palms is watering. On date palms, watering is done manually by date farmers. Some plantations already use irrigation systems [3]. For date palms that are 1-6 months old, watering is done every 1-2 days if conditions are not rainy [4]. Additionally, it is crucial to note that proper irrigation practices contribute significantly to the overall health and productivity of the KL-1 variety date palm. Adequate water supply supports optimal growth, ensuring a robust and fruitful harvest.

In determining the volume of water needed by date palms, it can be seen through the dryness level of the planting medium. The dryness level of the planting medium can be identified through the temperature and humidity values in the planting medium [5]. In determining the volume of water for watering date palms, farmers review it based on a rough estimate of the level of dryness in the planting medium. In addition, the irrigation canals used as a medium for watering date palms are often uneven because the volume of water cannot be controlled [6]. These modern systems can significantly improve water distribution, ensuring more efficient and uniform watering across date palm plantations.

Additionally, the absence of communication infrastructure on plantations poses a limitation in monitoring the condition of the date palm planting medium from the farmer's residence [7]. To overcome this hurdle, there is potential for the integration of smart technologies and remote monitoring systems, enabling farmers to receive real-time data on temperature, humidity, and soil moisture levels. This technological advancement could revolutionize date palm cultivation practices, enhancing precision in irrigation and optimizing overall crop management."

Therefore, a system that can determine the volume of water for watering date palms based on the dryness level of the planting media through indications of temperature and humidity [8] values are needed. This system should be equipped to automate the watering process [9] at specified intervals, taking into account the specific needs of date palms at different stages of growth. Moreover, to address the challenges of uneven irrigation and ensure precise control over the volume of water used, it is essential to integrate cutting-edge communication technology that is flexible and does not depend on existing infrastructure [10]. Implementing such a smart irrigation system would not only enhance the efficiency of water distribution but also empower date farmers with a user-friendly, remotely accessible interface, allowing them to monitor and adjust watering parameters based on real-time data, thereby promoting sustainable and optimized cultivation practices.

In general, fuzzy systems are excellent for approximative reasoning, particularly for those that deal with issues that are challenging to express mathematically. Fuzzy logic has the benefit of being able to reason linguistically, negating the necessity for a mathematical equation to describe the controlled object in its design [11]. Fuzzy also makes use of a system that is simple to use, adaptable, and easy to learn. It also has tolerance for all types of data, the ability to build extremely complicated systems, and a human-friendly language [12].

Moreover, the versatility of fuzzy systems extends to their adaptability in dynamic and complex environments, making them particularly suitable for applications in agriculture, such as optimizing irrigation strategies for date palm cultivation. The inherent ability of fuzzy logic to handle uncertainties and imprecise information aligns seamlessly with the inherent variability in agricultural processes. This characteristic makes fuzzy systems a valuable tool for developing intelligent irrigation systems that can efficiently respond to the ever-changing conditions of the planting medium, further contributing to sustainable and resource-efficient farming practices.

In a previous study by Deska Mukhamad Alfian [13], in his thesis entitled "Implementation of Fuzzy Logic in the Design of Arduino-Based Irrigation Systems," the fuzzy method was used to determine how long the watering process should take to meet the water needs of the plants. This study still does not involve a flow sensor to regulate the volume of water needed for watering the plants.

To further enhance the precision and control of the irrigation process, future research could explore the integration of advanced technologies, such as incorporating a flow sensor into the fuzzy logic-based irrigation system. A flow sensor would enable real-time monitoring of water usage, allowing the system to dynamically adjust the watering duration based on the actual flow rate. This addition would not only refine the accuracy of the irrigation system but also contribute to resource efficiency by ensuring that the plants receive the optimal volume of water required for their growth and development. By combining fuzzy logic with cutting-edge sensors, researchers can continue to innovate and improve irrigation systems for sustainable agriculture practices.

Based on the above problems, this research entitled "Implementation of Fuzzy Logic on Watering Automation System [14] for Palm Tree Planting Media Based on WSN [15]," will develop a comprehensive system to address the challenges in date palm cultivation. This system aims to monitor the dryness level of date palm planting media using communication technology that does not depend on existing infrastructure. Additionally, it will incorporate an automated watering mechanism based on specified time intervals. The volume of water dispensed will be precisely determined by utilizing WSN-based fuzzy logic [16], which takes into account real-time data on soil dryness levels.

By integrating WSN technology with fuzzy logic, the proposed system strives to provide an intelligent and adaptable solution for date farmers. This approach not only ensures efficient water management but also minimizes human intervention in the irrigation process. The utilization of fuzzy logic enables the system to make linguistic decisions based on sensor data, creating a self-regulating irrigation system that responds dynamically to the unique requirements of date palms at different growth stages. This research endeavors to contribute to the advancement of precision agriculture, promoting sustainable and resource-efficient practices in date palm cultivation.

II. METHOD

The stages of research that will be taken in determining the next steps in the preparation of this research are as follows:

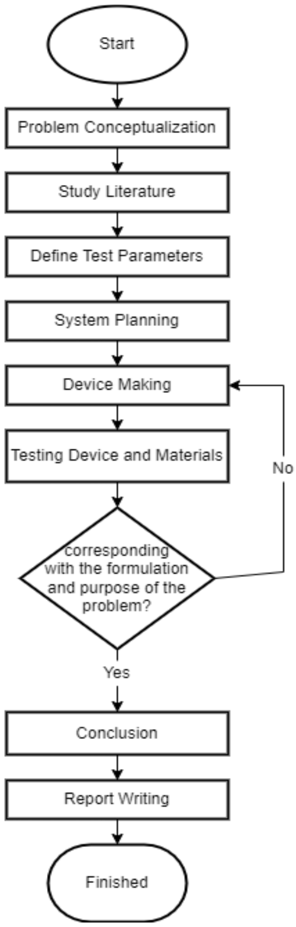

Figure 1. Research design flowchart

Fig. 2 is a grouping of the types of purposes and uses of each component. Sensors DS18B20 (temperature) and FC-28 (humidity) are planted on the roots of date palms to the identification of the level of soil dryness. Data from the input of the two sensors will be processed on Arduino Uno to output the volume of irrigation water using the fuzzy inference method. The watering automation system will run according to the time specified according to the RTC reading and will stop when the volume of water flow detected by the flow sensor has reached the volume of fuzzy interference output.

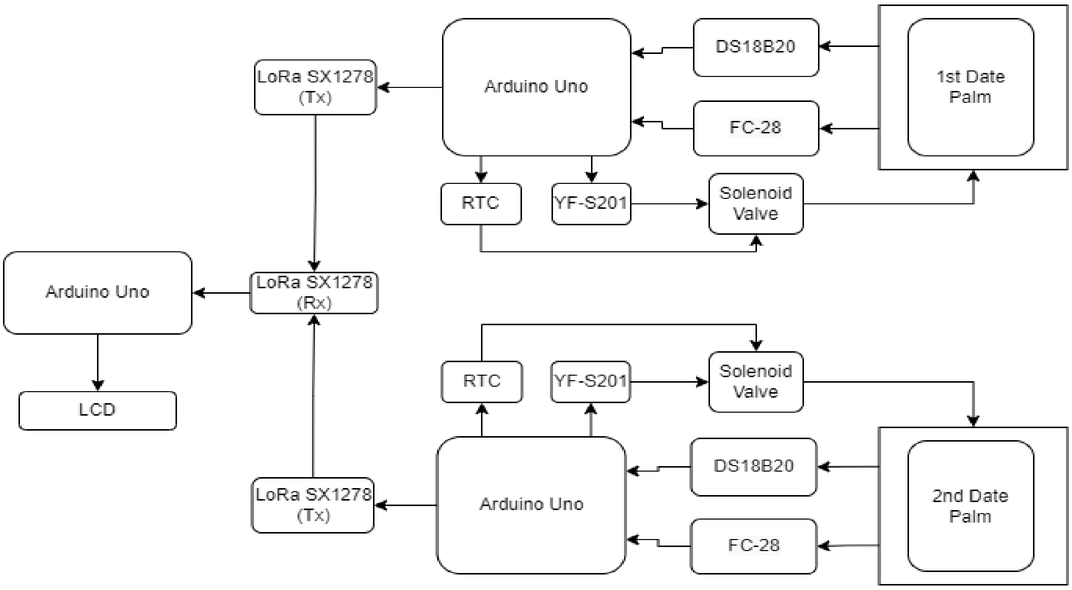

Figure 2. System design block diagram

To enhance the efficiency of the system, an additional feature will be incorporated to provide real-time feedback to the date farmers. The system will be designed to transmit status updates and relevant data to a user interface accessible through a web-based platform or a dedicated mobile application. This communication interface will allow farmers to remotely monitor the irrigation process, receive alerts, and make adjustments to the system settings as needed. This level of connectivity ensures that farmers have convenient access to crucial information, promoting effective decision-making and contributing to the overall success of date palm cultivation.

To further optimize the system's functionality, a predictive analytics feature can be integrated, leveraging historical data and real-time information to anticipate potential irrigation needs. This predictive capability enables the system to proactively adjust watering schedules based on weather forecasts, seasonal variations, and specific growth stages of date palms. By incorporating predictive analytics, the irrigation system becomes more adaptive and responsive, contributing to resource efficiency and maximizing the yield of date palm cultivation.

Additionally, considering the geographical dispersion of date palm plantations, the system could benefit from incorporating a remote diagnostic feature. This feature allows the system to conduct self-checks and diagnostics, identifying potential issues or malfunctions. In the event of any anomalies, the system can automatically alert farmers, providing detailed diagnostics and suggestions for resolution. This proactive approach minimizes downtime, enhances system reliability, and empowers farmers with timely information, reinforcing the sustainability and success of date palm cultivation practices.

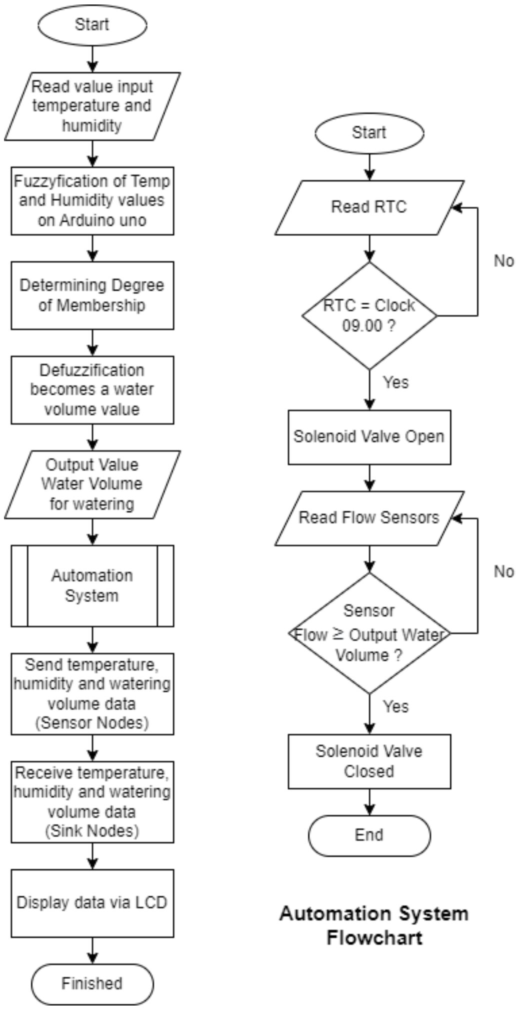

Figure 3. System flowchart

The sensors were planted in the planting medium of date palm trees. The sensor will read the temperature and humidity values as input. Input values from sensors that still have firm (crisp) values will be mapped into the fuzzy set, then adjusted according to the degree of membership, then mapped back into the output volume of irrigation water. The water volume output value will be used to support the watering automation system as a limiter for the amount of water used for watering. Sensor input value data and volume output results will be sent by the sink node via a microcontroller supported by the LoRa communication module. In the sink node section, the microcontroller with the support of the LoRa communication module will receive data that has been sent by the sensor nodes. The received data contains information about the temperature, soil moisture of the date palm trees, and the volume of water that will be displayed on the LCD. This system also has a watering automation system as a support that is installed on the sensor nodes. First of all, Arduino uno will read the time on the RTC (Real Time Clock). When the time reading shows 09.00, Arduino Uno will activate the relay and open the solenoid valve so that water can flow. A flow sensor is used to calculate the total volume of flowing water. The flow sensor will continue to measure until the volume of flowing water is more than equal to the fuzzy output. If the volume of water flowing through the pipe reaches the output value of the fuzzy calculation, Arduino Uno will turn off the relay and close the solenoid valve.

III. RESULTS AND DISCUSSION

A. *DS18B20 Sensor (Soil Temperature)*

The following is a test to see how well the system's scales work. This experiment aims to evaluate the precision of readings made from date planting media in Fig. 4.

Figure 4. DS18B20 sensor test

TABLE I
COMPARISON OF TEMPERATURE ON SENSORS AND MEASURING INSTRUMENTS

Attempt	Test result (°C)		
	Measuring instrument	**Sensor DS18B20**	**Error (%)**
1	32,9	32,75	0,001%
2	33,1	32,94	0,001%
3	33,4	33,23	0,01%
4	34,6	34,42	0,01%
5	35,4	35,19	0,01%
6	35,6	35,31	0,01%
7	41,3	39,63	0,04%
8	41,9	40	0,05%
9	42	40,88	0,03%
10	42,7	41	0,04%
	Average		0.02%

The test between the temperature on sensors and measuring instruments has almost the same value, it shows that the accuracy of the load cell sensor is good. The average error value that results is 0.02%.

B. *FC-28 Sensor Testing (Soil Moisture)*

The following is a test to see how well the system's scales work. This experiment aims to evaluate the precision of readings made from date planting media in Fig. 5.

Figure 5. FC-28 sensor test

TABLE II
COMPARISON OF HUMIDITY ON SENSORS AND MEASURING INSTRUMENTS

Attempt	Test result (%RH)		
	Measuring instrument	**Sensor FC-28**	**Error (%)**
1	54,1	54,1	0,05%
2	54,8	54,8	0,07%
3	57,6	57,6	0,05%
4	58,2	58,2	0,07%
5	58,7	58,7	0,06%
6	59	59	0,03%
7	59,4	59,4	0,02%
8	60	60	0,03%
9	60,4	60,4	0,04%
10	60,8	60,8	0,01%
	Average		0.04%

The test between the humidity on sensors and measuring instruments has almost the same value, it shows that the accuracy of the load cell sensor is good. The average error value that results is 0.04%.

C. Soil pH Sensor (Soil Acidity Sensor)

The following is a test to see how well the system's scales work. Test were carried out with 2 samples of planting media in the form of ordinary soil and sandy humus to produce a comparison of temperature values in different soil conditions in Fig. 6.

Figure 6. pH sensor test

TABLE III
COMPARISON OF PH SENSORS IN YARD SOIL AND SANDY HUMUS

Attempt	Yard Soil	Sandy Humus
1	54,1	54,1
2	54,8	54,8
3	57,6	57,6
4	58,2	58,2
5	58,7	58,7
6	59	59
7	59,4	59,4
8	60	60
9	60,4	60,4
10	60,8	60,8

Over all the condition of the yard soil has a lower pH value (acid) than the soil condition after using sandy humus which has a higher pH value (alkaline).

D. YF-S201 sensor testing (Water Flow Sensor)

Testing the YF-S201 sensor on the system is used to calculate the volume of water flowing in the pipe.

Figure 7. Flow sensor testing process

TABLE IV
YF-S201 SENSOR TESTING ACCURACY MEASUREMENT

Attempt	Water Volume (L)		Error (%)
	Sensor Set	Measuring instrument	
1	0,5	0,46	0,080%
2	1	1,05	0,047%
3	1,5	1,54	0,027%
4	2	2,05	0,025%
Average			0,044%

Based on the sensor test that has been carried out 4 times, it shows that the value of the sensor test on the measuring instrument has a small difference, between the volume that has been set and the reading of the measuring instrument. With an average error rate of 0.044%.

E. Testing the LoRa Ra-02 (communication module)

Experimenting on the ability of the SX1278 LoRa Ra-02 module to transmit sensor data and calculation results from the sensor node hardware to the sink node hardware.

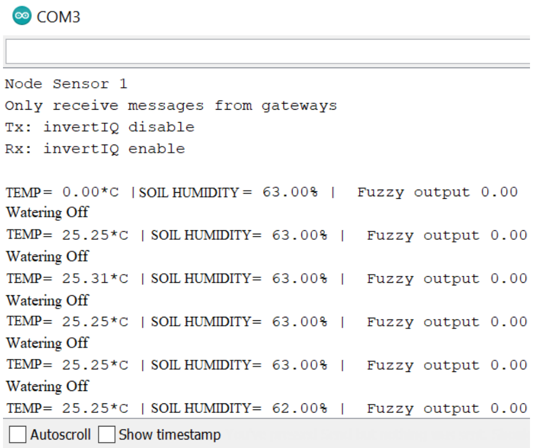

Figure 8. Testing data delivery on sensor nodes

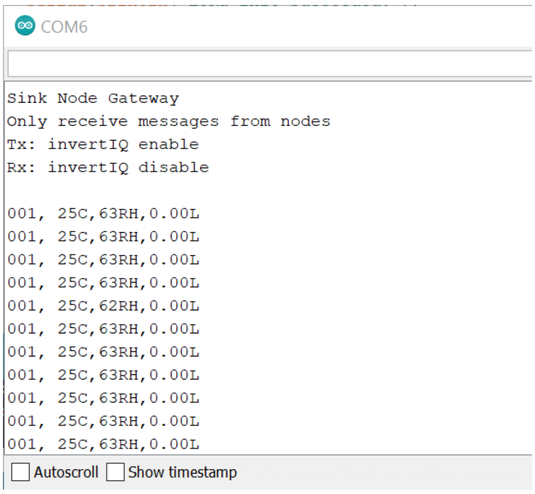

Figure 9. Data acceptance testing at sink node

Next is the distance test to determine the range of the SX1278 LoRa communication module in sending data from the sensor node to the sink node. The test was carried out with a scenario of sending 30 packets from the sensor node to the sink node with varying distances in rural areas with obstacles in the form of buildings, slopes and trees.

TABLE V
THE RESULTS OF TESTING THE SX1278 LORA COMMUNICATION MODULE TOWARDS DISTANCE

Test	Range (m)	Averange		Desc
		RSSI (dBm)	SNR (dB)	
1st	5	-74	8,8	Stable
2nd	50	-89	8,7	Stable
3rd	100	-103	-2,2	Stable
4th	200	-105	-7,1	Stable
5th	300	-	-10,5	Unstable
6th	400	-	-	Fail

TABLE VI
THE RESULTS OF TESTING THE SX1278 LORA COMMUNICATION MODULE TOWARDS DISTANCE

Test	Range (m)	Packet Data		Desc
		Sent	Received	
1st	5	30	30	Stable
2nd	50	30	30	Stable
3rd	100	30	30	Stable
4th	200	30	30	Stable
5th	300	30	4	Unstable
6th	400	30	0	Fail

Based on experiments that have been carried out 6 times on sending 30 packets at various distances, different levels of RSSI and SNR values were obtained. The test results show that the LoRa Ra-02 communication module can reach up to 200 meters and works well.

F. *Fuzzy Logic calculations*

The following is the result of defuzzification of measurement data processed using a fuzzy system to make a decision in the form of a watering volume category.

TABLE VII
SENSOR MEASUREMENT RESULTS ON HARDWARE AND MATLAB

Test	Hardware Defuzzification		Matlab Defuzzification	
	Node 1	Node 2	Node 1	Node 2
1st	16.67	15.30	15	13.8
2nd	14.27	15.5	14.5	13.8
3rd	15	15.31	15	13.3
4th	8	4.83	7.25	6.35

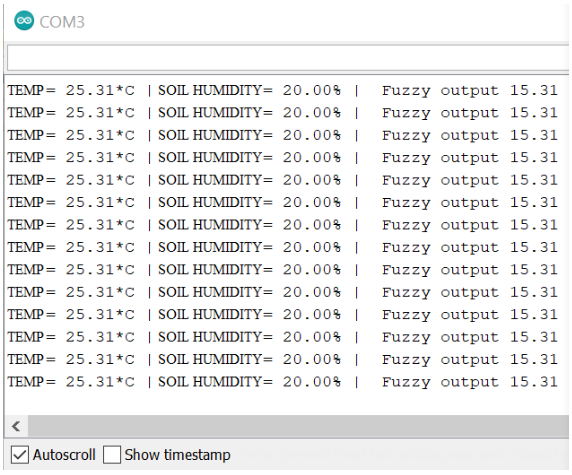

Figure 10. Fuzzy testing on hardware

In testing based on hardware simulations, a defuzzification value of 15.31 was obtained with the *Banyak* category.

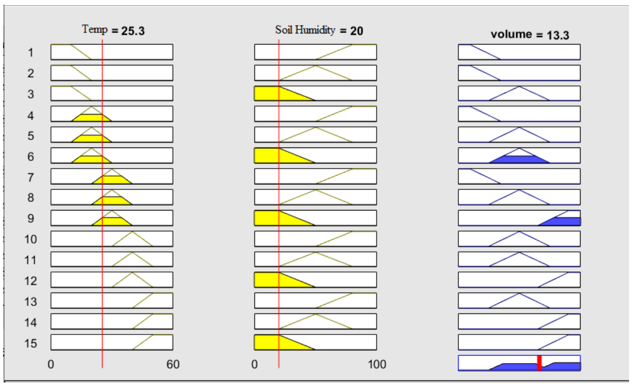

Figure 11. Fuzzy testing based on simulation on Matlab

In testing based on simulations on Matlab, a defuzzification value of 13.3 was obtained with the *Banyak* category.

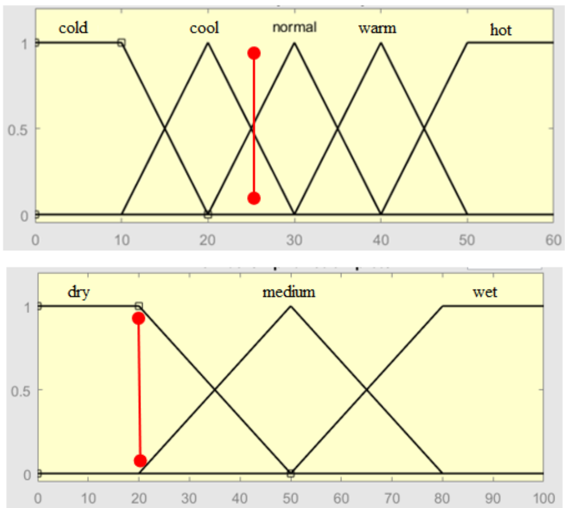

Figure 12. Membership input of soil temperature and soil moisture

The following calculation aims to see a comparison of fuzzy output according to hardware and matlab, therefore to get the output value using fuzzy calculations. The implication result value is used to form a fuzzy regional structure in the reasoning system contained in the aggregation.

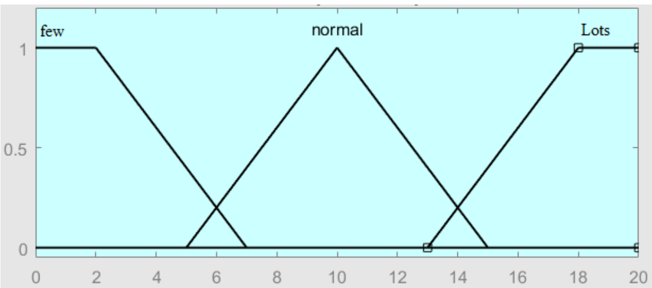

Figure 13. Membership output of water volume

In testing based on simulations on Matlab, a defuzzification value of 13.3 was obtained with the *Banyak* category. Based on the results of the Fuzzy test on Matlab, it has a relatively small difference in Defuzzification. The results of testing the volume of water in matlab compared to the calculations have an error rate of 0.081%. The results of testing the water volume on hardware compared to manual calculations are relatively in accordance with an error rate of 0.060%. So that the planning with the test results goes well.

IV. CONCLUSION

Based on the test results, the DS18B20 and FC-28 sensors are effective in detecting temperature and humidity, serving as reliable indicators for assessing the dryness level of the date palm planting media. Experimental findings reveal that yard soil exhibits a lower pH value, while sandy humus soils display a higher pH value.

The fuzzy logic-based water volume decision-making system, derived from conducted tests, indicates that higher temperatures coupled with lower humidity levels in the planting medium correlate with an increased need for water volume. The largest defuzzification value observed is 16.67 liters in the "many" category, whereas lower temperature values combined with high humidity result in the smallest defuzzification value of 4.83 liters in the "little" category, showcasing a remarkably small error difference of 0.060%.

The LoRa communication module serves as the key component for transmitting monitoring data to the microcontroller at the sink node. Distance experiments with the LoRa Ra-02 communication module and spring antenna demonstrate stable performance, reaching distances of up to 200 meters with RSSI = -105 and SNR = -7.1. The Watering Automation System functions effectively, opening the solenoid at specified hours to initiate drainage. The utilization of the YF-S201 sensor to measure water volume passing through the pipe aligns with the planned design, yielding an average error rate of 0.04465%.

ACKNOWLEDGEMENTS

In further development, incorporating a soil salinity sensor is advisable to determine the volume of water required by the soil based on its salinity level during testing. Additionally, it is recommended to enhance the sensor node's durability by utilizing a waterproof block box, especially designed to withstand outdoor conditions, preventing water infiltration into the components during rainfall.

For improved functionality, the communication system at the sink node can be enhanced by integrating a feature that enables data transmission to a cloud database. This enhancement allows convenient access to the data through a smartphone application, providing users with a user-friendly interface for monitoring and managing the system.

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