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Smart Drip Irrigation System Based on IoT Using Fuzzy Logic

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Abstract— The absence of a water drip rate control system in drip irrigation systems has impacted water use efficiency and normalization of soil moisture. Therefore, this research aims to develop an intelligent system using the fuzzy logic method to control the rate of water droplets in a drip irrigation system and maintain soil moisture in normal conditions. The DHT22 sensor is used to obtain temperature and humidity values, which are then used as input data and processed by the ESP32 microcontroller, which includes a fuzzy system. The Internet of Things (IoT) is also used to send data from the microcontroller to the Thingspek web server. The Blynk application is used to make it easier to monitor temperature, humidity, and water droplet rate values. The results of this research show that the temperature accuracy values produced using the MSE evaluation were 6.66667 and RMSE were 2.58199, while for temperature, the values for MSE were 0.128333 and RMSE were 0.358236. The average value of soil moisture produced in the planting medium is 44.46%; this value is within normal conditions for chili plants, where normal soil moisture conditions range between 40% - 60%.
Keywords— Smart Drip Irrigation System; Fuzzy Logic; IoT; Thingspek; Blynk

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I. INTRODUCTION

Ineffective irrigation management and scheduling can lead to plant stress and ultimately reduce the quality and yield of crops. Therefore, there is a significant demand for efficient irrigation, which requires timely, accurate information on irrigation needs[1]. Currently, agriculture utilizes almost 85% of the world's freshwater resources, with the majority still relying on traditional irrigation methods. Consequently, the water demand is projected to increase in the coming years[2]. The emergence of smart irrigation systems is one solution to enhance agricultural productivity and efficiency while reducing environmental impact. Modern agricultural technology utilizes many sensor devices to acquire data, yielding a more comprehensive understanding of the environment [3].

Managing agricultural irrigation is one of the critical parameters for better Researchers have developed numerous smart irrigation systems to support the advancement of agricultural technology. A study on irrigation management systems and plant health status was conducted, where the system involved the analysis of water levels, temperature, and a control mechanism to determine whether water should be supplied. Sensor data was displayed graphically on the Adafruit cloud platform, an Internet of Things (IoT) platform. The data was further used to analyze plant health and send notifications to users via email regarding the current conditions [4]. The use of IoT technology is prevalent in the advancement of irrigation systems, namely in the transmission of sensor-generated data to the designated storage location [5]. Several network devices commonly serve as boosters of IoT technologies for data communication. These devices include GSM [6], Zigbee [7][8], and LoRaWAN [9][10]. In addition to the mentioned above technology, there are several crucial aspects to consider when constructing a system. One such example is machine learning, which has been employed as a decision support system in irrigation management through a learning process [10]. Integrating machine learning into an irrigation system is akin to enabling plants to communicate their requirements during the growth process [11], such as their need for water, nutrients, and other factors. In addition to machine learning, there is another equally powerful technology called Artificial Intelligence. Research utilizing artificial intelligence has been conducted by Naseeb Sighn and colleagues [12]. in their study, an artificial intelligence system, specifically Convolutional Neural Networks (CNN), was embedded in a mobile-based application. This application recommends the appropriate irrigation timing based on the soil moisture in agricultural land using the sprinkler irrigation method. The sprinkling method is a technique of watering plants by spraying water into the air such that it falls like rain [13].

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The subject of this study is a drip irrigation system. *Drip irrigation* is a technique that involves the slow distribution of water to the soil through a system of narrow plastic pipes with a tiny diameter, typically ranging from 2 to 20 liters per hour [13]. Several studies have been conducted, including comparing the Drip irrigation and Crop evapotranspiration (ETc) systems. The research findings indicate that the Drip irrigation method can yield around 12.05% higher results and save 11% water compared to the ETc-based irrigation method. The IoT system developed is durable and waterproof, allowing it to be implemented in agricultural field [14]. The Drip Irrigation system has been developed by integrating the Ant Colony Optimization (ACO) algorithm to control the timing and process of opening and closing the solenoid valve while also tracking the location of the priority irrigation land. Based on the testing conducted over ten days, the model's error rate reached 26%, and the model's accuracy value was 74% A study was done to enhance water efficiency in Drip irrigation systems. The study developed a Prediction Control (MPC) Model, which effectively manages soil moisture, regulates irrigation schedules and controls water pumps. To facilitate control systems, the Internet of Things (IoT) technology is employed to simplify monitoring soil moisture, weather, and plants [15]. The research findings indicate that the fruit quality is significantly better in good condition, with an average sweetness level of 13.5 Brix and a higher water productivity index of 36.8 g/liter compared to the evapotranspiration (ETo) based automatic control system, which had 10.5 Brix and 25.6 g/liter respectively. However, the overall fruit mass harvested in ETo is higher than MPC's. The performance comparison shows that both methods have advantages and disadvantages [15]. A web and Android-based monitoring system for the Drip irrigation system is also being developed. In addition to providing real-time monitoring, the application is designed to take appropriate actions for users during the irrigation process. The sensors included in the system are the air humidity sensor, air temperature sensor, and soil moisture sensor, which then provide data to the microcontroller to estimate the water requirements accurately. This system may be remotely controlled and visualized anywhere and anytime The method used is fuzzy logic, which is based on partial truth. The stages of fuzzy logic begin with the input, which is in the form of crisp values, being converted into linguistic values during the fuzzification process. A Fuzzy Inference System (FIS) is executed, resulting in a fuzzy output. The next step is defuzzification, which involves transforming the fuzzy output into crisp values [16].

Implementing fuzzy logic has been widely applied in Drip Irrigation Systems. Hairu et al. [17] employed fuzzy logic to regulate the nutrient delivery process in urban chili plant cultivation using Drip Irrigation Systems. The research findings indicate that although the plant growth rate is comparable to traditional nutrient application methods, several advantages are provided. These include the remote monitoring system enabled by Internet of Things (IoT) technology, which

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allows users to monitor various parameters such as water and fertilizer requirements in real time. Additionally, this technology reduces the need for human labor in maintaining the plants. Ali conducted a study utilizing fuzzy logic in the Drip irrigation system. The system monitored various parameters such as temperature, controlled the process of watering plants, and provided appropriate nutrition based on fuzzy rules. The main objective of the research is to optimize the parametric estimation and control of an automatic Drip irrigation system based on fuzzy logic.

The research findings achieved a 20-30% improvement in the efficiency of electricity and water usage [18] In a research conducted by Wahyuni [19], a fuzzy-based intelligent Drip irrigation system was created for chili production. The input parameters consisted of temperature and humidity, while the output parameter was the duration of watering the plants. Based on this study, the soil moisture sensor remained consistent at ideal levels, ranging from 60% to 80%, after being watered for four consecutive days. This demonstrates that the irrigation system autonomously adjusts the watering process based on the specific requirements of the chili plants. However, they have yet to focus on the duration of water delivered to the drip device without discussing the rate of release of water droplets onto the plant. The flow rate of water droplets is still controlled manually, and it is crucial in the Drip Irrigation method. To maintain the soil moisture in a normal state, it is necessary to regulate and adjust the water droplets according to the needs of the plants. Therefore, this research focuses on developing a technology for controlling the flow rate of water droplets in a Drip irrigation system based on air temperature and humidity [20]. The approach will utilize fuzzy logic, IoT technology, and a mobile-based application to enable remote monitoring. The contribution of the research is the production of an intelligent system using fuzzy logic capable of controlling the water droplet speed in an irrigation system, therefore maintaining the soil moisture condition in a normal state. A prototype of an IoT-based Smart Drip Irrigation device, which can be monitored remotely at any time and anywhere, was developed.

II. RESEARCH METHOD

A. Hardware and software Requirements

This step involves determining the specific requirements for both the hardware and software components necessary for constructing the system. The required hardware is presented in the table 1.

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Table 1. Hardware and Software Requirements

Hardware and Software	Functionality And Usability
NodeMCU ESP32	It is a microcontroller that is used as the brain of a system that is integrated with sensors and actuators.
Motor Servo	It is an actuator that is used to move and regulate the degree of rotation of the emitter.
DHT 22	It is a sensor that is used to take temperature and humidity values and then send them to the microcontroller.
Arduino IDE	It is an application using the C++ language, which is used by a program editor that is built and compiled on a microcontroller.
Thingspeak	It is an IoT platform used to store temperature, humidity, and emitter data.
Blynk	It is an IoT platform used to display temperature, humidity, and emitter data to mobile applications.

The ESP32 is a commonly used microcontroller in the development of IoT devices. It is a cost-effective, low-power device with dual-mode Bluetooth and internal Wi-Fi [21]. Additionally, it is supported by several programming languages such as C/C++, Rust, Tiny Go, and Micro Python [22]. The Motor Servo in this study functions to regulate the degree of opening of the aerator valve, which is responsible for controlling the rate of water droplet flow. The DHT22 is a sensor that measures air temperature and humidity. It provides a digital signal output calibrated using a sophisticated temperature and humidity sensor. This technology guarantees the microcontroller's high dependability and exceptional long-term consistency when coupled to an 8-bit high-performance system. This sensor comprises a resistive element and an NTC temperature measurement device. The device possesses exceptional quality, rapid responsiveness, strong anti-interference capability, and remarkable cost-effectiveness advantages. [23]. The Arduino IDE is a text editor designed for writing programs in the C++ programming language and can directly interface with Arduino hardware. However, as it has evolved, other devices such

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as NodeMCU ESP8266, ESP32, and similar ones can also utilize this text editor. Thingspeak.com functions as a data aggregator for node devices equipped with sensors that are connected to the internet. It also allows data retrieval from software applications for visualization, notifications, control, and historical data analysis purposes. Blynk is an Internet of Things (IoT) platform that can connect IoT hardware with an IoT platform. By using this platform, we can control and monitor hardware remotely. Apart from that, this platform can store sensor data and display the results of data measurements.

B. System Design Integrated

The Irrigation Drip System in this study consists of a sensor, namely the DHT22 sensor which functions to read Humidity and temperature values. There is also an actuator, namely the Servo, which regulates water flow rate in the emitter. There is also a water tank used as a storage medium for water. Figure 1 displays the design of the drip irrigation device that will be created.

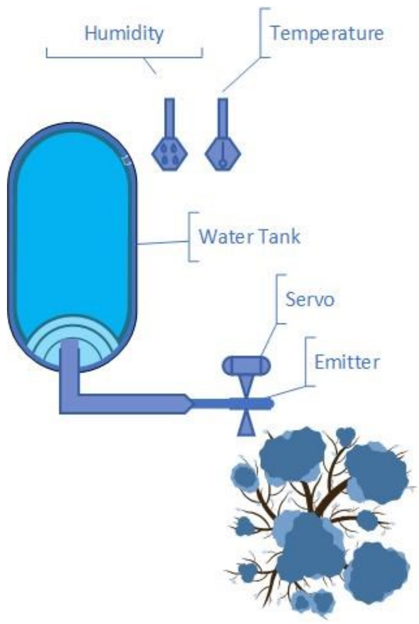

Fig 1. Drip Irrigation Design

Figure 2 shows that data communication involves multiple steps, beginning with the sensors reading the data. This data was inputted into the fuzzy system, which provides commands to regulate the rate or speed of water droplets from the drip irrigation tool to the planting medium. The subsequent step involves transmitting sensor data to Thingspeak and displaying it through Blynk.

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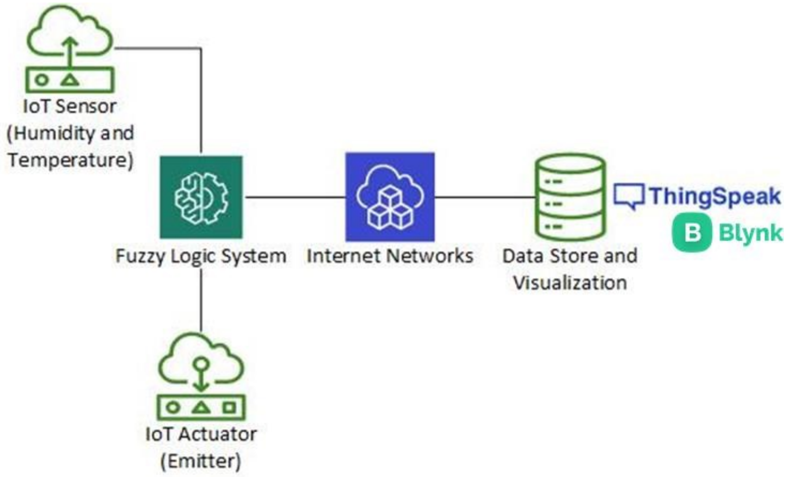

Fig 2. Data Communications System

The fuzzy inference system used in this research is Mamdani [24], There are several steps in the fuzzy logic system, starting with the input data process, which consists of two variables: temperature and humidity. Next, the fuzzification process was performed, which involved transforming the input variables from crisp sets into fuzzy sets. Next, the fuzzy inference system (FIS), which is the process of decision-making based on the previously created fuzzy rule base, was performed. After the decision-making process is completed, the final step is defuzzification, which transforms fuzzy sets into crisp sets. Figure 3 illustrates the stages of the fuzzy logic system.

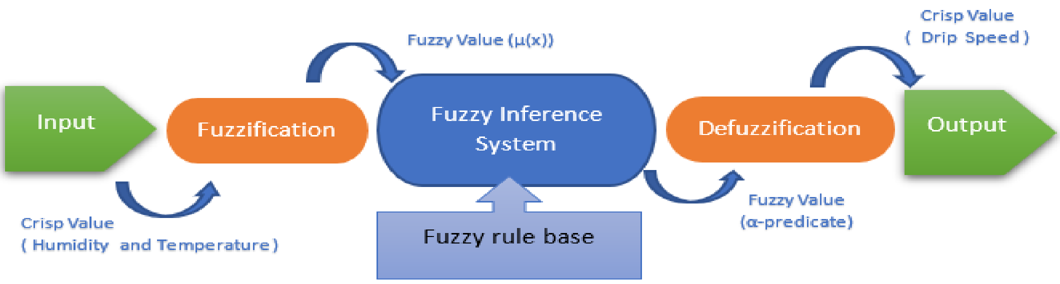

Fig 3. Fuzzy Logic System

Both the process of converting crisp inputs into fuzzy inputs (fuzzification) and the process of converting fuzzy outputs into crisp outputs (defuzzification) necessitate the use of a method for transforming crisp values into fuzzy values (fuzzifier method). This study utilizes linear ascending, linear descending, and triangular fuzzifier methods in the fuzzification process, whereas the Centroid approach is used for defuzzification. Figure 4 illustrates the visual representation of a fuzzifier.

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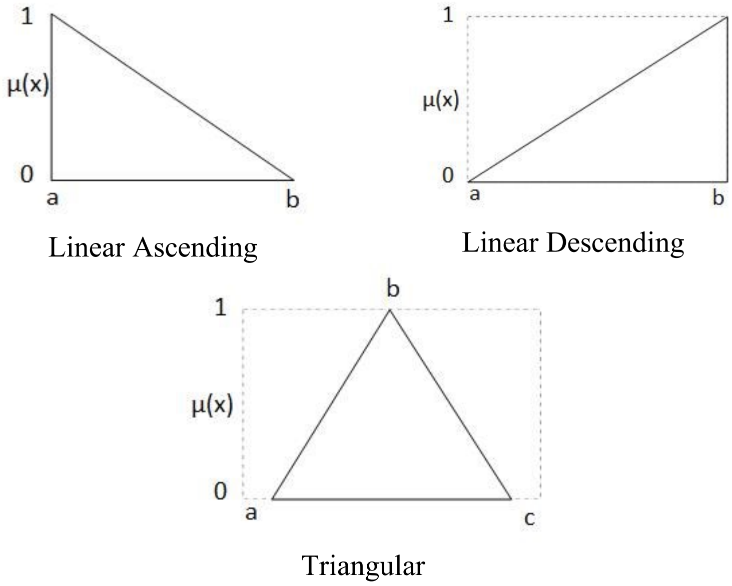

Fig 4. Fuzzifier Visual Representation

The equation for the Fuzzification process as follows:

Linear Ascending
$$\mu(x)\begin{cases} 1\,;x \le a \\ \frac{b-x}{b-a}\,;a\ < x\ < b \\ 0\,;x\ \ge b \end{cases} \quad (1)$$

Linear Descending
$$\mu(x)\begin{cases} 1\,;x\ \ge b \\ \frac{x-a}{b-a}\,;a\ < x\ < b \\ 0\,;x \le a \end{cases} \quad (2)$$

Triangular
$$\mu(x)\begin{cases} 1\,;x =\ b \\ \frac{x-a}{b-a}\,;a\ < x\ < b \\ \frac{c-x}{c-b}\,;b\ < x\ < c \\ 0\,;c \le x \le a \end{cases} \quad (3)$$

The defuzzification equation use the centroid method as follows:

$$z^* = \frac{\int_z \mu(z)z\,dz}{\int_z \mu(z)\,dz} \quad (4)$$

Where z^* represent the value of the defuzzification center point of the fuzzy region, μ(z) represent the membership value, and $\int_z \mu(z)z\,dz$ represent the moment for all regions of the rule composition result.

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III. RESULT AND DISCUSSION

Based on the research conducted by Sikandar Ali [20] and Wahyuni [21], the input parameters for humidity and temperature values for plant monitoring are presented in table 2 and table 3. In contrast, the parameters for drip speed in the emitter are presented in Table 4.

Table 2. Range of Humidity and Temperature Parameters

Parameter	Low	Medium	High
Humidity	0 % - 60 %	40 % – 80 %	60 % - 100 %
Temperature	0 ^oC – 30 ^oC	25 ^oC - 70 ^oC	70 ^oC – 100 ^oC

Table 3. Range of Emitter Parameter

Parameter	Slow	Normal	Fast
Emitter	0 ^{o} - 80 ^{o}	0 ^{o} - 180 ^{o}	80 ^{o} - 180 ^{o}

Table 4. Fuzzy Rule Base

IF Humidity	AND Temperature	THEN Emitter
Dry	Low	Normal
Dry	Medium	Normal
Dry	High	Fast
Moist	Low	Slow
Moist	Medium	Normal
Moist	High	Fast
Wet	Low	Slow
Wet	Medium	Slow
Wet	High	Normal

Figure 5 shows a Fuzzy logic system that consists of two input variables, specifically humidity, and temperature, each possessing three membership functions. This design uses The Mamdani method as the fuzzy inference system. As a result, the output variable refers to the velocity of water droplets controlled by the emitter. Figure 6 (a) represents an input variable (air humidity) exhibiting three membership functions: Dry, Moist, and Wet. The Dry membership function is defined by a decreasing linear function with a range of (30, 60). The Moist membership function is defined by a trigonometric function with a range of (40, 60, 80). Lastly, the Wet membership function is defined by an increasing linear function with a range of (60, 100). Figure 6 (b) represents the input variable (air temperature) which consists of three membership functions,

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namely Low utilizing a decreasing linear function (0, 30), Medium utilizing a trigonometric function (25, 30, 35), and High utilizing an increasing linear function (30, 50). Figure 6 (c) represents the output variable (water droplet velocity) which exhibits three membership functions, namely slow with a decreasing linear function (0, 80), normal with a trigonometric function (0, 80, 180), and rapid with an increasing linear function (80, 180). There are nine fuzzy rules for controlling drip speed from the emitter, as shown in Table 3 below:

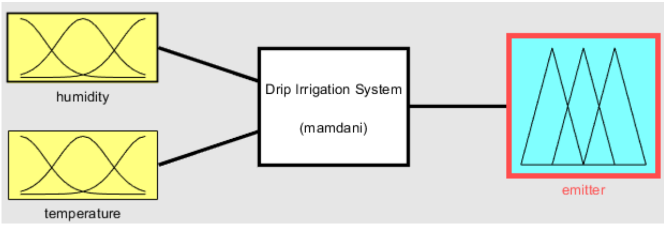
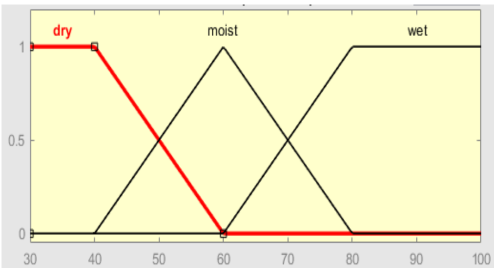
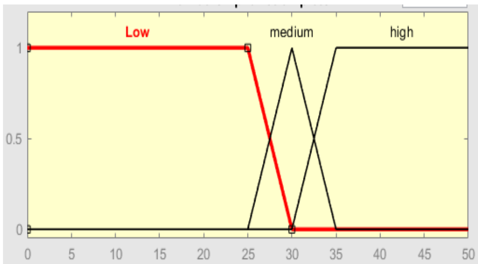


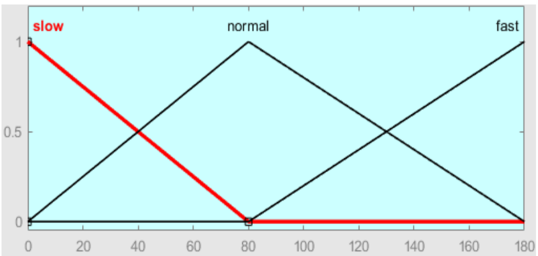
Fig 5. Fuzzy Logic Design



(a) Membership Function of Humidity



(b) Membership Function of Temperature



(c) Membership Function of emitter

Fig 6. membership Function of Each variable

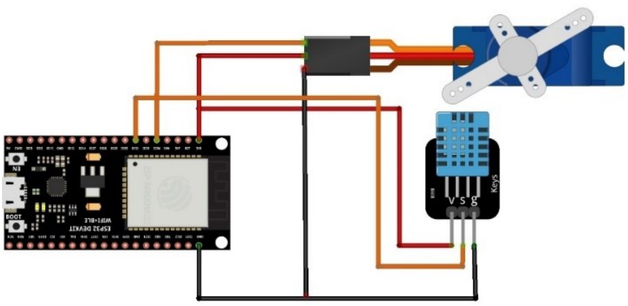


Fig 7. The Integration of Sensors, Actuators, and Microcontrollers

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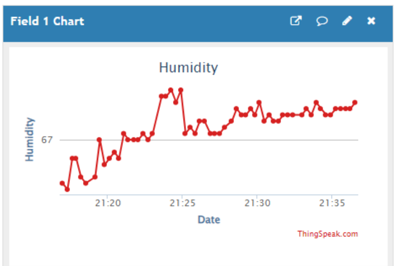
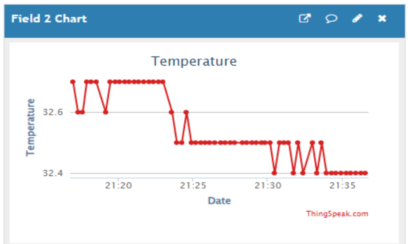
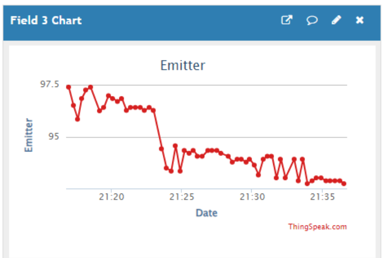
The diagram in Figure 7 illustrates a series of components consisting of a DHT 22 sensor, which collects temperature and humidity data, and a Servo actuator, which rotates the emitter to regulate the speed of water droplets. The NodeMCU ESP32S is a microcontroller designed to control sensors and actuators. The DHT 22 sensor has three pins: the Vcc pin, which is connected to a positive voltage of 3.3 volts; the GND pin, which is connected to a negative voltage; and the signal pin, which is connected to GPIO 34. The servo also has three pins, namely the Vcc and Gnd pins, which are connected to the same pins as the DHT 22, while the signal pin is connected to GPIO 32. The servo is responsible for spinning the emitter within a range of 0° to 180° and increasing the degree value results in quicker water droplets being emitted from the emitter. In Figure 8, the results of data recording in the Thingspeak application are shown. It can be seen that the higher the humidity value and the lower the temperature, the less the degree of rotation of the emitter, and vice versa. Figure 9 displays the results of data visualization in the blynk application.



(a) Humidity



(b) Temperature



(c) Emitter

Fig 8. The Presentation of Data Recording using Thingspek.

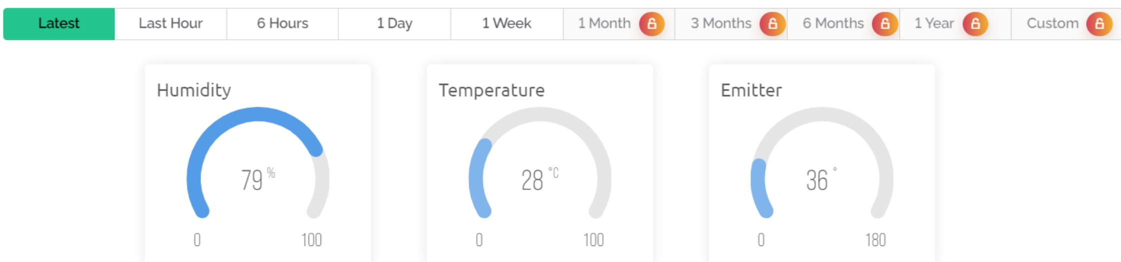


Fig 9. Blynk Application

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Fig 10. Prototype of Drip Irrigation System

In order to evaluate the precision of the DHT22 sensor in measuring temperature and humidity, a direct comparison was conducted between the readings acquired from the DHT22 sensor and the temperature and humidity measurement apparatus manufactured by HTC 2. Mean Square Error (MSE) and Root Mean Square Error (RMSE) serve as measures for quantifying the precision of data; The sensors are displayed in Table 5.

Table 5. Comparison of DHT 22 sensor with HTC - 2

Humi (DHT 22)	Humi (HTC-2)	SE	Temp (DHT22)	Temp (HTC-2)	SE
74 %	76 %	4	29.9 °C	29.9 °C	0
56 %	53%	9	27.2 °C	27.7 °C	0.25
54 %	54 %	0	28.7 °C	28.6 °C	0.01
70 %	73 %	9	30.9 °C	30.8 °C	0.01
82 %	86 %	9	27.4 °C	27.9 °C	0.25
89 %	93 %	9	25.2 °C	24.7 °C	0.25
MSE		6.66667			0.128333
RMSE		2.58199			0.358236

During the evaluation of the correctness of the fuzzy logic system implemented in the microcontroller, a comparative analysis is conducted with the fuzzy system constructed using the Matlab toolbox. The Mamdani approach, adapted to the method available in the Matlab toolbox, is employed as the fuzzy method in this research. *Mean Square Error* (MSE) and *Root Means Square Error* (RMSE) were also used to estimate the accuracy presented in Table 6. It is

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noticeable that the output values of the fuzzy system created on the microcontroller are not significantly different from the fuzzy system using the MATLAB toolbox. The only noticeable difference is a few values, where the discrepancy is limited to decimal places. Therefore, it may be said that the constructed system has operated effectively.

Table 6. Fuzzy Logic Comparison Between Microcontroller and Matlab Toolbox

Humi	Temp	Emitter Values (Micro)	Emitter Values (Matlab)	SE
9 %	87 °C	147.7 °	147 °	0 .49
6 %	10 °C	86.7 °	86.7 °	0
31 %	31 °C	86.7 °	89 °	5.29
23 %	85 °C	147.3 °	147 °	0.09
98 %	18 °C	26.1 °	26.1 °	0
32 %	70 °C	147.3 °	147 °	0.09
64 %	99 °C	121.6 °	122 °	0.16
86 %	65 °C	86.7 °	86.7 °	0
36 %	33 °C	105.8 °	106 °	0.04
95 %	6 °C	26.1 °	26.1 °	0
67 %	59 °C	109.2 °	109 °	0.4
70 %	47 °C	100 °	100 °	0
54 %	64 °C	144.9 °	145 °	0.01
88 %	18 °C	26.1 °	26.1 °	0
77 %	52 °C	88 °	88.1 °	0.01
MSE				0.414667
RMSE				0.643946

The evaluation of prototype accuracy will be shown in Table 7. The evaluation of the prototype is conducted by analyzing the soil moisture levels generated during the implementation of the drip irrigation process. This assessment is performed since the study focuses on the drip irrigation system. According to previous research [25], the optimal range for soil moisture in chili plants is typically between 40% and 60%.

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Table 7. The Evaluation of the Prototype

Time	Humidity	Temperature	Emitter	Soil Moisture
09.03	77%	30 °C	50 °	28.23%
12.05	75%	30 °C	62 °	38.10%
14.33	74%	30 °C	68 °	46.45%
18.13	78%	29 °C	38 °	48.35%
19.06	80%	29 °C	26 °	52.12%
20.42	83%	27 °C	30 °	53.54%
Average				44.46%

From the table 7, it can be seen that the average value of soil moisture is still normal = 44.46%, the experiment was carried out on potting media, the type of soil used was latosol soil, the condition of the pot was in the open but not directly exposed to sunlight, the data recording process was carried out on cloudy weather conditions.

IV. CONCLUSION

A study was conducted to regulate the water flow rate in drip irrigation by utilising air temperature and humidity. The DHT22 sensor was employed to measure temperature and humidity values. In order to assess the precision of the DHT22 sensor, a comparison was made with a manufacturer's measuring instrument, specifically the HTC-2. The accuracy comparison yields the following statistics: MSE = 6.66667 and RMSE = 2.58199 for humidity. As for temperature, the resulting values are MSE = 0.128333 and RMSE = 0.358236. Based on this comparison, it is evident that the DHT22 sensor is not suitable for accurately measuring humidity due to its relatively large error value. However, it does well in measuring temperature with a low error value. In order to assess the precision of the fuzzy logic algorithm implemented on the microcontroller, a comparison was conducted with the fuzzy logic generated using the Matlab toolbox. This comparison yielded the following values: MSE = 0.414667 and RMSE = 0.643946. The average soil moisture measurement in the drip irrigation system is 44.46%. This indicates that the system effectively maintains the humidity within the desired range of 40% - 60%.

In further research, several developments and improvements can be made, including adding sensors to determine the amount of water discharge in water storage and adding temperature and soil pH sensors, which also have an important role in the plant growth process. In this research, only one type of soil was used, namely latosol soil, so it is necessary to develop research using several types of soil because different types of soil have different characteristics, such as nutrients,

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water absorption processes and so on. In this research, the plants planted were not directly exposed to sunlight. Further research needs to be done where the plants can be exposed to direct sunlight, which will affect the evaporation process. This research also has a weakness in the section on setting the degree of rotation of the servo that regulates the emitter, where if the type or product of the emitter used is different, it has the potential to change the degree of rotation so that if a different emitter is used, it is necessary to reset the membership function in the fuzzy system.

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