

IoT System Design for Dragon Fruit Plants Lighting and Watering Automation Using Fuzzy Method

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Abstract – Dragon fruit is a high-value commodity that has gained increasing popularity in the global market, yet requires intensive care, particularly in terms of precise watering and lighting management. In Indonesia, dragon fruit cultivation often faces challenges due to reliance on imprecise manual systems. Conventional systems currently available are frequently inefficient as they cannot dynamically adapt to fluctuating environmental conditions. Therefore, this research aims to develop an IoT-based automation system capable of optimizing dragon fruit growth through intelligent watering and lighting control using more adaptive fuzzy logic methods. The system is designed with an ESP32 microcontroller as the control center, integrated with a YL-69 soil moisture sensor and LDR light sensor. Both sensors were calibrated with high accuracy, showing errors of 2.85% for the moisture sensor and 2.80% for the light sensor respectively. Sensor data is then processed using fuzzy logic to generate proportional control through PWM modulation for water pump and LED light actuators. System implementation demonstrates robust performance, where lights turn on fully at light intensity ≤ 110 lux, dim at 110-640 lux, and turn off above 640 lux. Meanwhile, the pump operates at maximum capacity when soil moisture $\leq 45\%$, at half power between 45-70%, and stops above 70%. The Blynk platform is utilized for real-time environmental monitoring through a user-friendly mobile interface. Twenty-four hours test showed that the system is responsive and adaptive, and has the potential to increase water and energy efficiency compared to conventional systems.

Keyword: Dragon Fruit, ESP32, Fuzzy logic, Internet of Things

I. INTRODUCTION

Dragon fruit (*Hylocereus*) is one of the leading horticultural commodities with great potential for development in Indonesia, especially in tropical regions such as East Java. This plant is in high demand due to its high economic value and nutritional content, which is beneficial to health. However, despite increasing demand, domestic production is still not optimal. Data from the Central Statistics Agency of East Java shows an increase in dragon fruit production in Banyuwangi Regency from 1,234,567 quintals (2021) to 1,345,678 quintals (2022), and in Jember Regency from 890,123 quintals to 912,345 quintals during the same period [1]. This indicates significant opportunities for developing dragon fruit cultivation through the use of modern technology.

Dragon fruit is a cactus plant from the *Hylocereus* genus that blooms only at night (night-blooming cereus), making artificial lighting essential to stimulate flowering outside the harvest season. The application of artificial lighting between 5:00 PM and 6:00 AM has demonstrated a positive impact on plant productivity [2]. Alongside lighting, maintaining appropriate soil moisture remains essential for optimal plant growth. In addition to lighting, soil moisture is also a critical

parameter. Optimal soil moisture levels for dragon fruit cultivation typically range between 70% and 100%, where a lack of water can hinder growth and cause stress, while excess moisture may trigger root diseases [3].

Optimizing environmental factors such as lighting and moisture has been proven to significantly increase crop yields. Providing night lighting for six hours using 100W lamps at an intensity of 424.97 lux has been found to produce fruit with an average length of 9.66 cm and weight of 336.99 g, leading to yields of up to 19.85 tons per hectare [4]. Efforts to automate environmental control have gained attention in recent years. Hadi et al. developed a system that uses soil moisture sensors to trigger irrigation, ensuring that watering occurs only when necessary [5].

Previous studies have attempted to automate irrigation and lighting processes. Santosa and friends developed an automatic lighting system using LDR sensors and an Arduino Uno [6]. Meanwhile, Samsumar and Karim designed an IoT-based automatic irrigation system using Node MCU and humidity sensors, controlled via an online application [7]. These systems have demonstrated good efficiency in reducing manual intervention.

Based on this background, this study aims to design an IoT-based automation system for lighting and irrigation of

dragon fruit plants using fuzzy logic. This system utilizes a soil moisture sensor (YL-69), a light sensor (LDR), and an ESP32 as the main microcontroller connected to the Blynk platform for remote monitoring and control. With the fuzzy logic approach, the system is expected to provide adaptive decisions based on actual environmental conditions, thereby supporting efficient and sustainable dragon fruit cultivation.

II. METHODS

This study uses an experimental approach by designing and implementing an Internet of Things (IoT)-based automatic control system for dragon fruit cultivation, where the power source comes from a 12V adapter. The method used in this system is fuzzy logic, which is a decision-making method based on the membership degree of input values (soil moisture and light intensity), enabling smoother and more adaptive actuator control compared to rule-based systems.

This experimental method was conducted through the direct application of hardware and software to test the system's performance in real-time. Soil moisture sensors (YL-69) and light sensors (LDR) are used as inputs for the fuzzy system controlled by the ESP32 microcontroller. Sensor values are processed in fuzzy form to determine the intensity level of the pump and lighting power using PWM (Pulse Width Modulation). The system is designed to provide multi-level control, not just ON/OFF, according to environmental conditions.

For remote monitoring and control, the system uses the Blynk platform, which allows users to view sensor values and actuator status in real-time through an app on a mobile device. Data from the ESP32 is sent to Blynk via a Wi-Fi connection, which is then visualized in the form of an interactive dashboard interface. The system as a whole is designed to improve the efficiency of irrigation and lighting in dragon fruit cultivation.

Hardware Design

Hardware system design was carried out to ensure optimal integration between components in controlling the automatic watering and lighting processes for dragon fruit plants. This system consists of several main components, such as the ESP32 microcontroller, YL-69 soil moisture sensor, LDR light sensor, L298N motor driver, LCD 16x2, DC pump, and DC lamp. All components are integrated and designed in a compact and functional prototype. Figure 1 shows the hardware system design used in this study.

Figure 1 shows the hardware design of the IoT-based dragon fruit irrigation and lighting automation system. The system is controlled by an ESP32 microcontroller connected to two main sensors, namely the YL-69 soil moisture sensor and the LDR light sensor. These two sensors send analog data that is used to monitor the environmental conditions of the plants in real time. Next, the ESP32 processes this data

using fuzzy logic to determine the PWM value sent to the actuator based on light and moisture conditions.

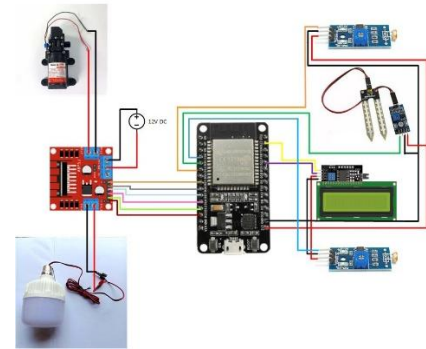


Figure 1. Hardware System Design

The PWM output from the ESP32 is sent to the L298N motor driver, which controls the two main actuators: the DC water pump and the DC LED light. Both actuators use an external 12V power supply as the main voltage source, supplied through a connection to the motor driver's input terminals. This 12V voltage ensures that the pump and light receive sufficient power to operate optimally, while the ESP32 remains powered by a 5V source. The entire circuit is compactly assembled in a control box equipped with WiFi connectivity, enabling the system to send data to the Blynk app for remote monitoring and control via a smartphone.

Fuzzy Logic System

Before the fuzzy logic system can be used as a controller for water pump actuators and LED lights in dragon fruit cultivation, a fuzzy logic design must first be carried out, which includes three main stages: fuzzification, inference, and defuzzification. This design aims to regulate the magnitude of the PWM value on the actuator based on soil moisture and light intensity from the surrounding environment. The method used is Mamdani fuzzy logic because it is suitable for decision-making involving linguistic logic [8].

The first stage in the fuzzy system is fuzzification, which is the process of converting numerical inputs from sensors into linguistic values. In this study, there are two fuzzy input variables, namely soil moisture (from the YL-69 sensor) and light intensity (from the LDR sensor). Moisture values are categorized into three linguistic sets: Dry, Moist, and Wet. Meanwhile, light intensity is categorized into Dark, Medium, and Bright. The determination of these linguistic values uses triangular and shoulder membership functions, as shown in Figures 2 and 3.

The right shoulder membership function is used for extreme values to reflect the stability of extreme conditions such as very bright conditions. The domain range for each category is determined based on field observation data and reference to the optimal growth conditions of dragon fruit plants.

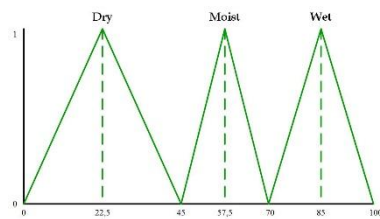


Figure 2. Soil Moisture Membership Function

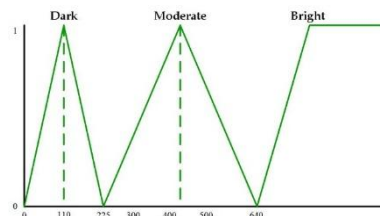


Figure 3. Light Intensity Membership Function

The next stage is the inference process, which is the decision-making mechanism based on predefined fuzzy rules (fuzzy rule base). Fuzzy rules are formulated in the form of IF-THEN by combining input conditions such as humidity and light intensity to produce responses on the pump and light actuators. Each input combination will produce a linguistic output indicating the actuator's operating level, whether for irrigation or lighting.

To facilitate the reading and analysis of the fuzzy logic used, these fuzzy rules are presented in two separate tables: Table 1 for Fuzzy Rule Base Pump and Table 2 for Fuzzy Rule Base Lamp. Both tables represent environmental condition combinations based on the fuzzification results and determine the fuzzy system output proportional to those conditions.

Table 1. Fuzzy Rule Base Pump

Moisture \ Light Intensity	Moisture		
	Dry	Moist	Wet
Dark	High	Medium	Off
Medium	High	Medium	Off
Bright	High	Medium	Off

Table 2. Fuzzy Rule Base Lamp

Moisture \ Light Intensity	Moisture		
	Dry	Moist	Wet
Dark	Bright	Bright	Bright
Medium	Moderate	Moderate	Moderate
Bright	Off	Off	Off

After obtaining the fuzzy output from the inference process, the system needs to convert the results into crisp (numerical) values that can be used by the microcontroller to regulate the magnitude of the PWM signal to the actuator. This process is known as defuzzification. The method used in this study is the centroid or center of area (COA) method, which calculates the midpoint of the area under the membership function curve to obtain a single numerical value as the final system output.

The membership function output used is triangular in shape, with three membership level categories. For the pump, the output categories consist of: Off, Medium, and High, while for the light, the linguistic categories are: Off, Moderate, and Bright, as shown in Figures 4 and Figure 5 below.

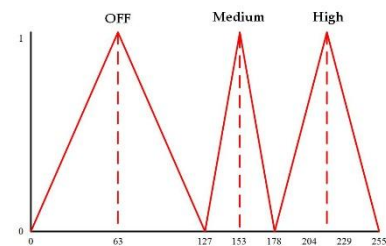


Figure 4. Membership Function Output Pump

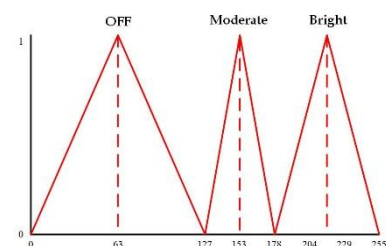


Figure 5. Membership Function Output Lamp

With this centroid method, the system is able to generate a gradual and proportional PWM signal in response to changes in environmental conditions. This enables the irrigation and lighting processes for plants to occur in a more adaptive and efficient manner, without relying solely on binary control (ON/OFF).

Software Design

The software design for this system aims to automatically control the working logic of sensors and actuators using an ESP32 microcontroller. The system was developed using the Arduino IDE programming language with a fuzzy logic approach, and is supported by the Blynk Internet of Things (IoT) platform for real-time remote monitoring and control via smartphone. The system logic design is illustrated in the form of a flowchart to facilitate understanding of the overall program workflow.

The flowchart in Figure 6 shows the process of starting the system with sensor initialization and communication to the Blynk server. Next, the microcontroller reads input from the soil moisture sensor and light sensor, then applies fuzzy logic to determine how much PWM signal to send to the water pump and LED lights. Each decision to activate the pump and lights is based on actual environmental conditions and sent to the Blynk app so users can monitor the system status in real-time.

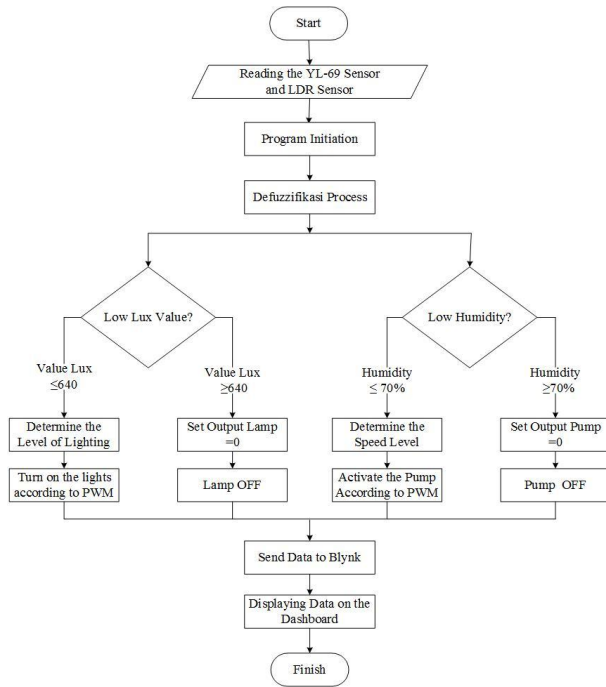


Figure 6. Programming Flowchart

Testing

After the design and implementation of the system were completed, several tests were carried out to ensure that each component functioned as intended. The primary objective of this testing phase was to verify that the system could automatically respond to changes in environmental parameters—namely soil moisture and light intensity—and provide proportional control to the pump and lamp actuators based on the fuzzy logic algorithm.

a. Sensor Testing

The soil moisture sensor (YL-69) and light sensor (LDR) were tested separately to evaluate their accuracy. The YL-69 sensor readings were compared to those obtained from an analog soil moisture meter, while the LDR was tested using a digital lux meter. Measurements were taken under various humidity and lighting conditions, and repeated to confirm data consistency.

To assess the level of accuracy, two performance metrics were used: absolute error and Mean Absolute Percentage Error (MAPE). The absolute error measures the difference between the sensor reading and the reference value, while the MAPE quantifies the average percentage error across all measurements. According to Miftahuddin et al. [9], the MAPE can be calculated using the formula:

$$Error = \frac{|x - x_{Ref}|}{x_{Ref}} \times 100\% \quad (1)$$

This formula calculates the percentage error by comparing the measured value X to the reference value X_{Ref} . The absolute difference is divided by the reference value and multiplied by 100% to express the deviation as a percentage.

$$MAPE = \frac{1}{n} \sum_{i=1}^n \left(\frac{|X_i - Y_i|}{Y_i} \right) \quad (2)$$

MAPE (Mean Absolute Percentage Error) calculates the average percentage difference between observed values X_i and reference values Y_i where n is the total number of observations.

b. Actuator Testing

The pump and lamp were tested using PWM signals of 0%, 50%, and 100%. This was intended to evaluate whether the actuators could operate at different intensity levels based on fuzzy logic outputs. At 0%, the system was expected to remain OFF, at 50% to operate at medium intensity, and at 100% to operate at full capacity. This test validated the ability of the actuators to respond proportionally to environmental changes and ensured system stability over extended operation.

c. Full System Testing

Comprehensive system testing was conducted during four different time intervals: morning (04:00–06:00), noon (11:00–13:00), evening (16:00–18:00), and night (23:00–02:00). These intervals were selected to represent variations in natural lighting and soil moisture throughout the day. Data such as sensor readings and actuator status were collected every 15 minutes and whenever state changes occurred. The Blynk platform was used for real-time data visualization, and a 16x2 LCD display showed key system information. This stage aimed to evaluate the system's overall responsiveness, adaptability, and consistency in real-world operating conditions.

Data Analysis

After the system has been successfully implemented and tested, the next step is to conduct an analysis to evaluate the overall performance of the system. The main focus of the analysis includes sensor accuracy, fuzzy logic control effectiveness, and actuator response to environmental conditions.

a. Sensor Accuracy Analysis

Sensor testing is done by comparing the readings from the humidity sensor (YL-69) and light sensor (LDR) with reference measurement tools, namely a soil moisture meter and lux meter. The difference between the sensor data and the reference is calculated to determine the level of deviation. Sensor accuracy was measured using the Error and Mean Absolute Percentage Error (MAPE) formulas described in Equations (1) and (2). These results were used to assess whether the sensors could be used as reliable inputs in the fuzzy system.

b. Evaluation of System Response to Fuzzy Rules

The output values in the form of PWM signals were analyzed based on their compatibility with the designed fuzzy rule base. The evaluation is conducted to assess the

consistency of the system output in response to changes in humidity and light, and to ensure that control of the pump and lights occurs proportionally and in a timely manner.

c. Interpretation of Test Results Data

Test results data consisting of sensor values, PWM, and actuator status are collected based on time periods (morning, afternoon, evening, night). The data is analyzed to identify the system's response patterns to real-world environmental variations and to what extent the system can adaptively adjust its control based on fuzzy inference results.

With this approach, the system's performance is evaluated to provide a comprehensive overview of the effectiveness of the developed system.

III. RESULT AND DISCUSSION

The designed system was successfully implemented to automate irrigation and lighting for dragon fruit cultivation. Before discussing specific test results and performance evaluations, the overall structure and arrangement of the developed prototype are shown in Figure 7.

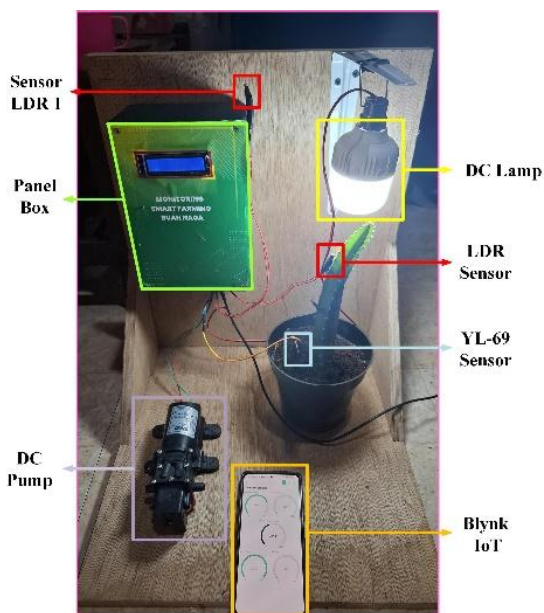


Figure 7. Programming Flowchart

Sensor Testing

To ensure accuracy, each sensor was calibrated using reference instruments. The readings of the YL-69 soil moisture sensor were compared with values obtained from a commercial soil moisture meter, while the LDR readings were verified using a digital lux meter. Measurements were taken under varying environmental conditions to evaluate consistency and reliability. The degree of error was measured using percentage error and Mean Absolute Percentage Error (MAPE), as formulated in Equations (1) and (2). The calibration results for both sensors are presented in Table 3 and Table 4.

Table 3. LDR Sensor Calibration Results

LDR 1 Sensor Value (lux)	LDR 2 Sensor Value (lux)	Lux Meter Value (lux)	LDR 1 Sensor Error (%)	LDR 2 Sensor Error (%)
25	27	26	3,84	3,84
63	62	65	3,07	4,61
226	229	235	3,82	2,55
725	755	734	1,22	2,78
975	1005	1025	4,87	1,95
2157	2162	2132	1,15	1,15
4246	4311	4366	2,76	1,25

Table 4. YL-69 Sensor Calibration Results

NO	Moisture Meter Value (%)	Sensor YL-69 Value (%)	Selisih (%)	Nilai Error (%)
1	10	10	0	0
2	20	19	1	5
3	30	32	2	6.67
4	40	42	2	5
5	50	51	1	2
6	60	61	1	1.67
7	70	69	1	1.43
8	80	78	2	2.50
9	90	88	2	2.22
10	100	100	0	0

The results show that both sensors provide consistent readings, with the YL-69 moisture sensor achieving a MAPE of 2.85% and the LDR sensor achieving a MAPE of 2.80%. These values confirm that the sensors are sufficiently accurate and suitable for use as fuzzy logic inputs in a control system.

Aktuator Testing

Testing was conducted on water pumps and LED lights to evaluate their responsiveness to PWM signals generated by fuzzy logic controllers. The purpose of this testing was to determine whether the actuators operated proportionally to changes in the duty cycle.

The relationship between PWM values, output voltage, current, and power consumption was recorded and displayed in Tables 5 and 6. The results show that both actuators respond proportionally, confirming the effectiveness of the fuzzy logic control system.

Table 5. Pump Test Results

PWM	Duty Cycle (%)	Voltage Output (V)	Current (A)	Power (Watt)	Pump Status	Description
0	0	0	0	0	OFF	Not flowing
102	40%	3,80	0,00	0,00	OFF	Not flowing
127	50%	5,26	0,65	3,42	OFF	Flowing moderately
255	100%	9,08	1,20	10,90	ON	flowing Strongly

Table 6. Lamp Test Results

PWM	Duty Cycle (%)	Voltage Output (V)	Current (A)	Power (Watt)	Light Status	Description
0	0	0	0	0	OFF	Not lit
127	50%	4,75	0,38	1,80	OFF	Dim light
153	60%	5,80	0,50	2,90	ON	Dim light
178	70%	6,90	0,68	4,70	ON	Dim light
204	80%	8,10	0,85	6,89	ON	Bright light
229	90%	9,10	1,00	9,10	ON	Bright light
255	100%	9,68	1,20	11,62	ON	Bright light

As shown in Tables 3 and 4, the actuator testing was conducted to assess the response of the water pump and LED light to PWM signals generated by the fuzzy logic controller. At 0% and 40% PWM, the pump remained off; at 50% it ran moderately, and at 100% it reached full output. The lamp gradually brightened with increasing PWM, achieving full brightness at 80% and above. As shown in Tables 3 and 4, both actuators responded proportionally, validating the fuzzy logic control system's effectiveness.

System Testing Based on Environmental Conditions

In this system, light intensity is measured using an LDR (Light Dependent Resistor) sensor to represent the lighting conditions of the environment surrounding the dragon fruit plants. The sensor readings serve as one of the main inputs to the fuzzy logic controller, along with soil moisture, to determine whether artificial lighting and irrigation are necessary.

Table 7 shows a summary of the system's behavior during different time periods—daytime, evening, nighttime, and morning. This table highlights the moments when changes in pump or light status occur, reflecting how the fuzzy system dynamically responds to environmental variations.

Table 7. System Response Based on Fuzzy Rules

Soil Moist (%)	Light Intensity (Lux)	Membership Function (Moisture / Light)	PWM Output (Pump / Lamp)	Membership Function (Pump / Lamp)	Remarks
28	5000	Dry / Bright	100% / 0%	High / OFF	Matches rule
30	543	Dry / Medium	100% / 50%	High / Moderate	Matches rule
23	2	Dry / Dark	100% / 100%	High / Bright	Matches rule
68	5000	Moist / Bright	50% / 0%	Medium / OFF	Matches rule
68	493	Moist / Medium	50% / 50%	Medium / Moderate	Matches rule
69	11	Moist / Dark	50% / 100%	Medium / Bright	Matches rule
94	5000	Wet / Bright	0% / 0%	OFF / OFF	Matches rule
86	612	Wet / Medium	0% / 50%	OFF / Moderate	Matches rule
82	2	Wet / Dark	0% / 100%	OFF / Bright	Matches rule

Based on the data summarized in Table 7, the system demonstrated consistent and responsive behavior in adjusting the PWM output for both the pump and the lamp according to real-time sensor inputs. For instance, under bright and dry conditions, the system delivered maximum PWM to the pump while keeping the lamp off. As soil moisture increased, the pump operation decreased or stopped. Conversely, the lamp was activated only under low-light conditions, with moderate to high PWM levels depending on the light intensity classification.

These results confirm that the fuzzy logic controller enabled proportional actuator control, enhancing energy efficiency and ensuring accurate environmental adaptation. The system successfully implemented all fuzzy rules as intended, with actuator responses matching the expected outcomes based on the defined membership functions.

To support monitoring and remote observation, the system was integrated with an IoT platform via the Blynk application. Real-time visual feedback such as sensor values, actuator status, and PWM levels is displayed through the mobile dashboard interface, as illustrated in Figure 8.



Figure 8. Real-Time Monitoring Interface via Blynk Platform

Figure 8 shows the real-time monitoring dashboard created using the Blynk platform. It displays key information such as soil moisture percentage, light intensity, PWM values, and the ON/OFF status of both the pump and lamp actuators.

IV. CONCLUSION

This research successfully developed an IoT-based automation system for the irrigation and lighting of dragon fruit plants using the Mamdani fuzzy logic method. The system was built using the ESP32 microcontroller, a YL-69 soil moisture sensor, an LDR for light intensity detection, and the Blynk platform for remote monitoring. PWM signals were used to regulate the pump and LED lighting in a graded manner based on fuzzy rules, providing more flexible control compared to traditional ON/OFF systems.

System testing confirmed that the sensors performed reliably with MAPE values of 2.85% for soil moisture and below 2.80% for both LDRs, indicating good measurement accuracy. The fuzzy logic controller effectively responded to environmental changes: the pump operated at 100%, 50%, or 0% based on soil moisture levels, and the lamp adjusted its brightness at 100%, 50%, or 0% depending on light intensity. These results demonstrate that the system enhances both energy and water efficiency while maintaining responsive and precise control.

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