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Research Article

Design and Build an Automatic Spraying System for Shallot Plants using Soil Moisture and Air Temperature Sensors with the Fuzzy Method

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Abstract:

Agriculture utilizes biological resources to produce food, industrial raw materials, energy sources, and manage the environment. This sector plays a strategic role in national economic development. This research aims to design an automatic spraying system for shallot plants based on soil moisture using soil moisture sensors. This system utilizes soil moisture sensors to detect the water content in the soil as well as soil moisture sensors to measure the air humidity around the plants. Data from both sensors are processed by the microcontroller to regulate the timing and duration of the spraying. The prototype of this system was built using soil moisture sensors, soil moisture sensors, microcontrollers, water pumps, solenoid valves, and other supporting components. Testing was conducted in the field with red onion plants as the test subjects. The results show that the system is capable of functioning effectively in watering plants based on soil moisture levels. The sensor works accurately in measuring water content, while the microcontroller successfully controls the spraying optimally. The implementation of this system has proven to increase water usage efficiency and support better growth of shallot plants. Thus, this automatic spraying system offers an environmentally friendly and efficient solution for irrigation based on soil moisture and soil moisture sensors.

Keywords: Automatic Sprinkler, Soil Moisture Sensor, Solenoid Sensor, ADC Signal.

1. Introduction

Shallots are one of the main agricultural commodities in Indonesia, which have high economic value and are widely cultivated. However, inefficient and untimely irrigation practices often pose challenges in shallot cultivation. This can lead to stunted plant growth and reduced crop yields [1], [2], [3]. To address this issue, the use of modern agricultural technology, such as soil and air moisture sensors, becomes a potential solution. This technology enables a more accurate and efficient automatic irrigation system, while also supporting sustainable agricultural practices.

Although automatic irrigation system technology has proven to increase agricultural productivity, most shallot farmers in Indonesia still do not utilize this technology due to limited knowledge and resources. Moreover, the existing systems are often not yet adapted to the specific needs of shallot cultivation. This research aims to develop an effective and cost-efficient solution thru the integration of soil moisture sensors into an automatic irrigation system to improve water use efficiency and the productivity of shallot plants. This research aims to design and implement an automatic irrigation system based on soil moisture sensors, specifically designed for shallot cultivation [4], [5], [6], [7]. This system is expected to enhance water use efficiency and support optimal plant growth.

This research seeks to answer the question of how soil moisture sensors can be effectively utilized in an automatic irrigation system for shallot plants, as well as to evaluate the impact of the developed system on water use efficiency and plant productivity.

This research was conducted in Anggeraja, Enrekang Regency, with a focus on the development and testing of an automatic irrigation system prototype for shallots. This system uses the ESP32 microcontroller, soil moisture sensors, and solenoid valves. This research focuses on improving system accuracy, water use efficiency, and affordability, but does not include an analysis of long-term economic impacts or implementation on a larger scale.

This research contributes to the development of precision agriculture technology thru an automated irrigation system specifically designed for shallots. By utilizing fuzzy logic methods for real-time decision-making [8], [9], [10], [11], this system can improve irrigation accuracy, save water, and reduce energy consumption. The results of this study can also serve as a reference for the development of similar systems for other types of plants and support environmentally friendly agricultural practices.

2. Method:

Research Design

This research uses an experimental research design with a fuzzy logic-based approach to develop and test an automatic irrigation system for shallot plants [12], [13], [14], [15]. This approach allows for the processing of input data from soil moisture sensors and air humidity sensors (DHT11) to produce optimal watering decisions based on fuzzy rules. The research was conducted in Anggeraja District, Enrekang Regency, over a period of eight months. The research stages using the Prototyping model to be implemented can be seen in **Figure 1**.

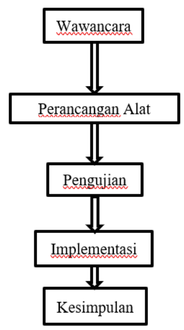

Figure 1. Research Design

1. Problem: The interview technique is used as a data collection method thru a series of questions posed to subjects relevant to the research object. In this context, interviews were conducted with members of the community who work as shallot farmers.
2. Tool Design: The design process begins with preparing all the hardware components that will be used in the irrigation tool. This design is divided into three main parts: the input section, the processing section, and the output section. Further details can be found in the block diagram included in this research.
3. Testing: The testing of the tool aims to understand the electronic working principles of the developed automatic spraying system. The performance of this tool is measured based on the effectiveness of the watering produced, which will be assessed thru its ability to water pots under various conditions.
4. Implementation: The implementation stage is a crucial step where the watering device is tested in real conditions on plant pots. In this phase, the effectiveness of the watering device can be precisely measured, and all the advantages and disadvantages present in the system can be identified. All hardware components that make up the automatic watering device are expected to function according to the stages that have been carried out previously.
5. Conclusion: At this stage, we formulate conclusions based on the results of the automatic spraying tool tests that have been conducted.

Research Implementation Stage

This research uses an experimental method with a fuzzy logic approach to control the plant spraying process [14], [16], [17]. The fuzzy method is implemented to address uncertainty by utilizing input from soil moisture sensors and the DHT11 sensor for air humidity. The collected data is then processed thru fuzzy rules to generate optimal spraying decisions. Experiments were conducted by comparing the output of the system that applies the fuzzy method with the output produced without variable control, in order to evaluate the system's effectiveness. Data collection techniques include measurements from sensors, testing on solenoid valves, and result analysis to ensure that the system functions optimally and efficiently in improving the spraying process of shallot plants. In this research, data collection techniques are divided into several parts, namely: 1. Interview technique is a data collection method by asking several questions to subjects related to the research object, in this case, conducted with the community who work as red onion farmers. 2. Observation technique is a data collection method by directly observing the research object, in this case, the routine of farmers in maintaining red onions and noting the problems. 3. Literature study technique is a data collection method by studying and gathering information from various written sources. Such as from books, journals, articles, magazines, and other sources on the internet.

Research Method

In conducting this research, the research method used is the experimental research method where if we do something under controlled conditions, will something controlled happen, to determine whether there is a change or not in something controlled, this is what is done in experimental research. As shown in the following **Figure 2**.

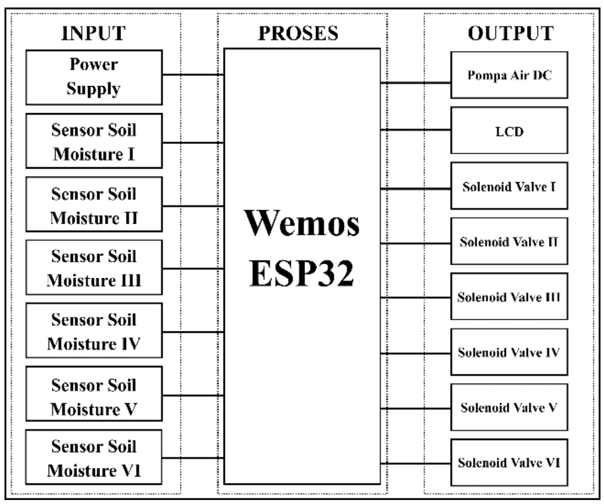

Figure 2. Diagram Block

The function of each block of the above hardware is as follows:

1. One Wemos Uno using the ESP32 microcontroller, functions as the control center for both sensor input and output data. The input data is obtained from Soil Moisture sensors I - VI. From the reading of the input that has entered the Wemos, the Wemos will control all outputs.
2. This Solenoid Valve is used to open and close the water flow directed toward the onion plants. 3. This DC Water Pump is used to extract water from the pesticide tank to be sprayed onto the shallots.
3. The LCD functions as a display of the system's operation in the form of character text, for example, displaying the time.
4. The power supply functions as the source of voltage and current for the entire system.
5. The relay functions to disconnect and connect high currents, the relay will receive instructions from Wemos to control the high-voltage water pump.

Hardware Design

The design of the electronic circuit was created using the Fritzing application, **Figure 3** shows the circuit used.

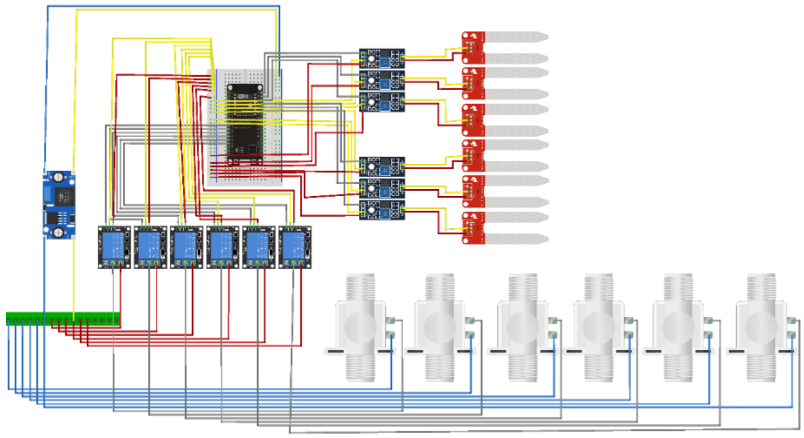

Figure 3. Electronic Design

Several components in the electronic design can be described as follows:

1. The solenoid valves, totaling 6 devices, are water channels connected to the field, functioning to hold and flow water to the planting area.
2. The relays, totaling 6 devices, are components that influence the valves on the solenoid valves, causing the valves to open or close.
3. The soil moisture sensors, totaling 6 devices, measure the level of moisture or dryness in the field, which will later be inserted into the land.
4. The LCD is a device that will display information to the user when the spraying device operates. In this circuit, the LCD is connected to the LCM1602 module.
5. The NodeMCU ESP32 is the brain of this spraying device, receiving information from the soil moisture sensors and giving commands to other devices.

The power supply is a device that functions as the power source or electrical supply for all the components of the automatic watering system.

3. Results and Discussion

Overall System Design Results

Characterization has been conducted on the soil moisture sensor and solenoid valve to determine whether the components used in the designed device can function properly. The results obtained from each device test were compared with the theoretical basis related to the devices used. The overall image of the automatic sprayer can be seen in **Figure 4**.

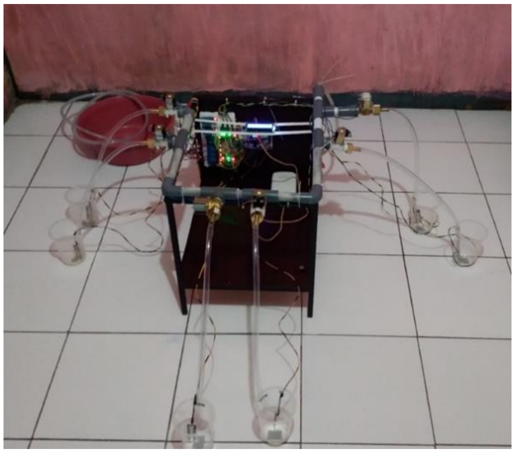

Figure 4. Final Testing of the Overall Circuit

Soil Moisture Sensor Testing Results

The purpose of testing the moisture sensor is to determine whether the sensor is ready to be used for measuring soil moisture in ornamental plants. In the following **Table 1**, a comparison of the measured data from the moisture sensor with the 6 ways soil moisture measuring device can be seen in **Table 2**.

Table 2. Results of the ultrasonic sensor testing

experiment number-	Sensor Soil Moisture	6 Ways Soil Moisture	Error
1	30,02 %	30 %	0,02 %
2	50,07 %	50 %	0,07 %
3	65,06 %	65 %	0,06 %
4	75,03 %	75 %	0,03 %
5	80,12 %	80 %	0,12 %
6	90,09 %	90 %	0,09 %

From **Table 2**, the results of the humidity test were obtained, with an average sensor error in comparison to the measuring instrument being 0.065%. This indicates that the sensor is functioning well.

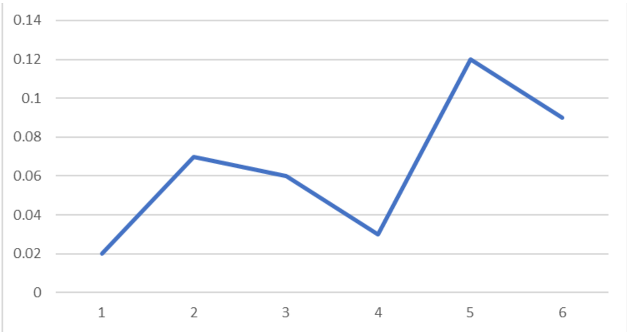

Figure 5. Graph of Soil Moisture Sensor Test Results

Overall System Testing

The overall system testing begins with testing the electrical components by measuring the voltage of each component used in this device, to determine whether the components in the system are functioning properly. The electrical testing of the device can be seen in **Table 3** below.

Table 3. Overall System Testing Results

Component	Working Voltage	Voltage on the Device
Wemos Esp32	5 VDC	4,89 VDC
Sensor Soil Moisture I	3,3 VDC	3,3 VDC
Sensor Soil Moisture II	3,3 VDC-5 VDC	4,87 VDC
Sensor Soil Moisture III	3,3 VDC-5 VDC	4,86 VDC
Sensor Soil Moisture IV	3,3 VDC-5 VDC	4,87 VDC
Sensor Soil Moisture V	3,3 VDC-5 VDC	4,87 VDC
Sensor Soil Moisture VI	3,3 VDC-5 VDC	4,87 VDC
Selonoid Valve I	12 VDC	11,98 VDC
Selonoid Valve II	12 VDC	11,98 VDC
Selonoid Valve III	12 VDC	11,98 VDC
Selonoid Valve IV	12 VDC	11,98 VDC
Selonoid Valve V	12 VDC	11,98 VDC
Selonoid Valve VI	12 VDC	11,98 VDC

Next, sensor testing was conducted on the soil moisture of each ornamental plant, which is expected to reach the predetermined set point. The testing was conducted on three types of ornamental plants with different moisture levels by comparing the soil moisture sensor data using a 3-way soil moisture meter. The sensor experiments were conducted with the soil moisture condition before watering or initial moisture, which are experiments 1 and 2. Meanwhile, the sensor experiments conducted with the soil moisture after watering are experiments 3 and 4. The expected soil moisture percentage for plant 1 is 50%. The following **Table 4** contains the measured data for plant 1.

Table 4. Sensor Testing on Plant 1

Experiment No-	Soil Moisture Sensor	Error
1	35%	3 %
2	35%	2 %
3	60 %	1 %
4	55 %	1 %

The expected soil moisture percentage for plant 2 is 60%. The following **Table 5** contains the measured data for plant 2.

Table 5. Sensor Testing on Plant 2

Experiment No-	Soil Moisture Sensor	Error
1	55%	1 %
2	55%	3 %
3	60 %	2 %
4	65 %	2 %

The expected soil moisture percentage for plant 2 is 70%. The following **Table 6** contains the measured data for plant 3.

Table 6. Sensor Testing on Plant 3

Experiment No-	Soil Moisture Sensor	Error
1	65 %	3 %
2	65 %	1 %
3	75 %	2 %
4	70 %	2 %

The expected soil moisture percentage for plant 2 is 75%. The following **Table 7** contains the measured data for plant 4.

Table 7. Sensor Testing on Plant 4

Experiment No-	Soil Moisture Sensor	Error
1	50%	3 %
2	45%	2 %
3	60 %	2 %
4	65 %	1 %

The expected soil moisture percentage for plant 2 is 70%. The following **Table 8** contains the measured data for plant 5.

Table 8. Sensor Testing on Plant 5

Experiment No-	Soil Moisture Sensor	Error
1	45%	3 %
2	50%	1 %
3	65 %	2 %
4	70 %	2 %

The expected soil moisture percentage for plant 2 is 65%. **Table 9** below shows the measured data for plant 6.

Table 9. Sensor Testing on Plant 6

Experiment No-	Soil Moisture Sensor	Error
1	55%	3 %
2	50%	2 %
3	70 %	2 %
4	65 %	1 %

The average sensor error values for plant 1 are 1.75%, for plant 2 are 2%, for plant 3 are 2%, for plant 4 are 1.75%, for plant 5 are 1.50%, and for plant 6 are 2%. Therefore, it can be concluded that the sensors are in good condition.

Next, a water flow test was conducted to determine the different water flow rates required by various ornamental plants. This test was carried out by measuring the water flow rate per minute at each solenoid valve. The moisture test was conducted three times using the same plants and solenoids. In **Table 10** below, the data obtained from watering Plant 1 is presented.

Table 10. Water Flow Test on Solenoid I

Experiment No -	Debit(Liter/Minute)
1	0,75
2	0,75
3	0,62

From **Table 10**, the results of the water flow rate test were obtained, with an average water flow rate of 0.71 liters/minute for Plant 1 thru Solenoid 1 over 1 minute. In **Table 11** below are the data obtained for the watering of Plant 2.

Table 11. Water Flow Test on Solenoid II

Experiment No -	Debit(Liter/Minute)
1	0,65
2	0,69
3	0,65

From **Table 11**, the results of the water flow rate test were obtained, with an average water flow rate of 0.66 liters/minute for Plant 2 thru Solenoid 1. In **Table 12** below, the data obtained from watering Plant 2 is presented.

Table 12. Water Flow Test on Solenoid III

Experiment No -	Debit(Liter/Minute)
1	0,65
2	0,63
3	0,62

From **Table 12**, the results of the water flow rate test were obtained, with an average water flow rate of 0.63 liters/minute for Plant 3 thru Solenoid 1. In **Table 13** below, the data obtained for the watering of Plant 2 is presented.

Table 13. Water Flow Test on Solenoid IV

Experiment No -	Debit(Liter/Minute)
1	0,66
2	0,63
3	0,62

From **Table 13**, the results of the water flow test were obtained, with an average water flow rate of 0.64 liters/minute for Plant 4 thru Solenoid 1 over a duration of 1 minute. In **Table 14** below, the data obtained for the watering of Plant 2 is presented.

Table 14. Water Flow Test on Solenoid V

Experiment No -	Debit(Liter/Minute)
1	0,70
2	0,69
3	0,62

From **Table 14**, the results of the water flow rate test were obtained, with an average water flow rate of 0.65 liters/minute for plant 5 thru solenoid 1 over a duration of 1 minute. In **Table 15** below, the data obtained for the watering of plant 2 is presented.

Table 15. Water Flow Test on Solenoid VI

Experiment No -	Debit(Liter/Minute)
1	0,75
2	0,70
3	0,69

From **Table 15**, the results of the water flow rate test were obtained, with an average water flow rate of 0.72 liters/minute for plant 6 thru solenoid 3 over 1 minute.

Next, soil moisture monitoring was conducted using an automatic irrigation system. The results of this monitoring are supported by data from soil sensor 1 and soil sensor 2, which measure soil moisture over various time intervals, namely in real-time (LIVE), 1 hour (1H), 1 day (1D), 7 days (7D), and 15 days (15D). **Figure 6** shows the fluctuations in soil moisture monitored during that period.

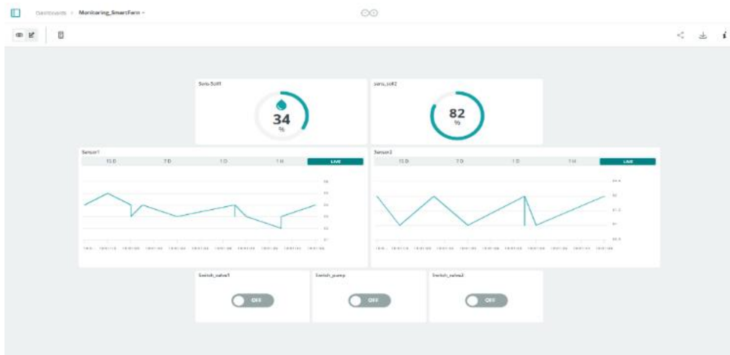

Figure 6. Results of Soil Moisture Sensor Testing

The results of soil moisture monitoring from sensor soil 1 are visualized thru the following graph, which illustrates the pattern of soil moisture changes over a certain period. In the first experiment using sensor soil 1 for one hour, it was observed that the soil moisture remained stable for 30 minutes. However, after that, there was a drastic decrease due to the lack of watering to observe the accuracy of moisture change readings. After the irrigation was reactivated, the soil moisture was successfully restored quickly and efficiently. The graph image can be seen in **Figure 7**.

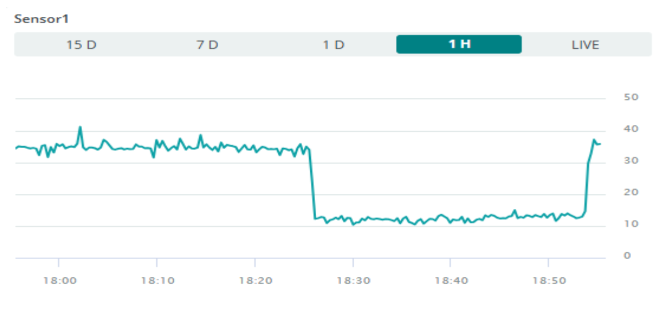

Figure 7. Graph of Sensor1 Test Results over 1 hour

In the 1-day test, a gradual decrease in soil moisture was observed over one hour without watering, followed by a significant spike after the automatic irrigation system was reactivated. This demonstrates the system's ability to effectively restore soil moisture. The graph is shown in **Figure 8**.

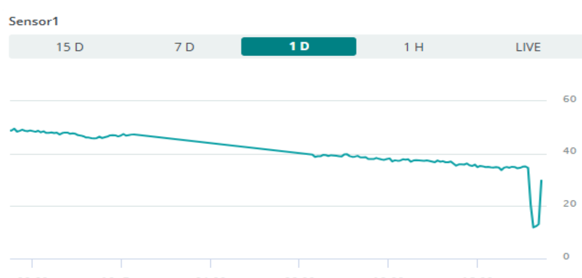

Figure 8. Graph of Sensor1 Test Results over 1 Day

Next, it includes a 7-day trial period, where a consistent decrease in soil moisture was observed. This decrease was intentionally carried out by stopping the automatic watering, aiming to test the system's performance when the soil is allowed to dry. At the end of the observation period, the graph showed an increase in moisture after the irrigation system was reactivated. These findings prove that the irrigation system has an effective ability to quickly improve soil conditions, allowing moisture to return to optimal levels after experiencing a deliberate "drought" period. The graph is shown in **Figure 9**.

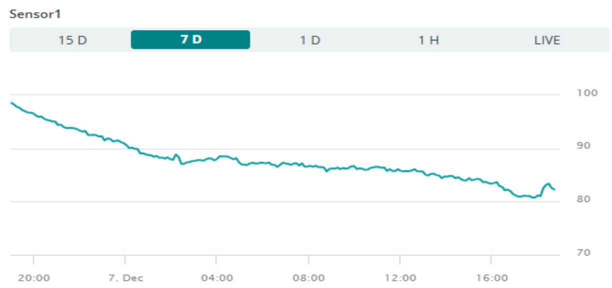

Figure 9. Graph of Sensor1 Test Results over 7 Days

As for the trial on sensor 1 over a 15-day period, a significant increase in humidity was initially observed, followed by a gradual decrease over 2 days. This decrease occurred due to the intentional cessation of watering, aimed at observing changes in soil conditions over time without any intervention from the system. Nevertheless, the obtained graph shows that within a span of the same day, soil moisture can return to stability when the automatic watering is reactivated. In **Figure 10**, these findings demonstrate that the system is capable of efficiently restoring soil moisture, even during drought conditions.

Figure 10. Graph of Sensor1 Test Results over 15 Days

Next, the results of soil moisture monitoring from soil sensor 2 are also visualized in several graphs, which show similar patterns in the same testing scenario.

In the first one-hour trial, the soil moisture pattern showed stability at the beginning of the period, before experiencing a sharp spike around 18:20. This spike indicates that the automatic irrigation system began operating after the testing period without any irrigation. This quick response reflects the effectiveness of the system in increasing soil moisture and maintaining stable conditions after the intervention was carried out. The image is shown in **Figure 11**.

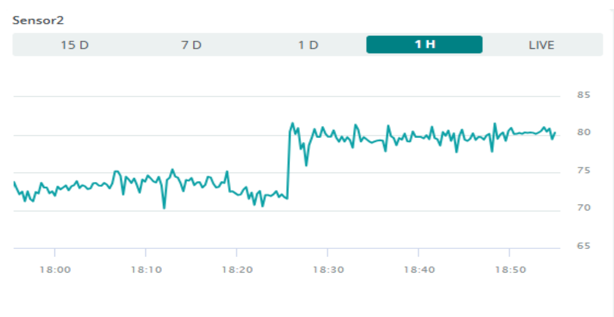

Figure 11. Graph of Sensor1 Test Results over 1 Hour

In the next experiment, monitoring was conducted for one day. The results showed a periodic decrease in soil moisture for more than 10 hours, caused by a lack of watering. However, when watering was resumed, there was a periodic increase in soil moisture stability. This indicates that timely watering is effective in restoring soil moisture stability, as shown in the graph in **Figure 12**.

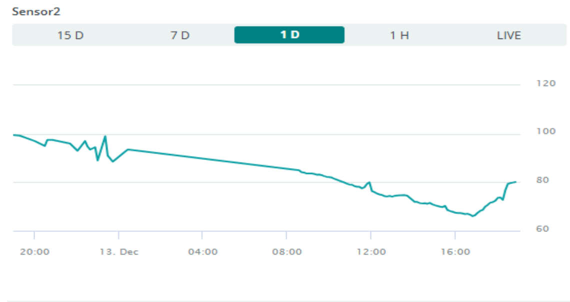

Figure 12. Graph of Sensor2 Test Results over 1 Day

Next, the 7-day trial showed stability in soil moisture at the beginning of the period, before then experiencing a sharp decline. This decrease was intentionally carried out by turning off the irrigation system as part of the performance test. At the end of the period, a spike in moisture appeared, indicating the system's success in restoring the soil condition to an optimal moisture level after the irrigation was reactivated. These findings demonstrate the system's reliability in responding to changes in soil conditions. The test graph is shown in **Figure 13**.

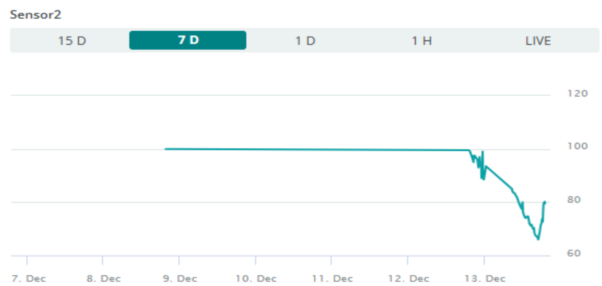

Figure 13. Graph of Sensor2 Test Results over 7 Days

Next, in the 15-day trial period, a significant increase in moisture was also observed initially, followed by a gradual decrease. This decrease also occurred due to the intentional cessation of watering, aimed at observing changes in soil conditions over time without any intervention from the system. Nevertheless, the obtained graph shows that soil moisture can stabilize again when the automatic irrigation is reactivated. These findings prove that the system is capable of functioning efficiently in restoring soil moisture, even after it has been allowed to dry out, as seen in **Figure 14**.

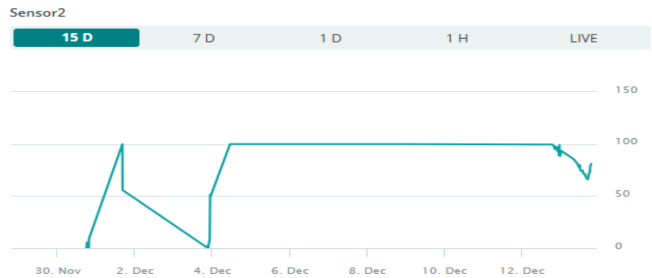

Figure 14. Graph of Sensor2 Test Results over 15 Days

4. Conclusion

The conclusion of this study shows that the automatic irrigation system based on soil moisture sensors can adaptively respond to dynamic soil conditions, as evidenced by variations in Soil Moisture values, the number of open solenoid valves, and the diverse irrigation durations. Additional testing demonstrates the system's ability to restore soil moisture to optimal levels after a period of artificial drought, affirming its reliability in maintaining soil moisture stability. This system makes a significant contribution to water use efficiency and the increase in shallot crop productivity, while also offering precision solutions for modern agricultural land management. As a recommendation, further research is suggested to integrate pesticide spraying and automatic nutrient delivery functions into this system to support more complex and sustainable agricultural needs.

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