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DESIGN OF VERTICULTURE PLANT MONITORING AND IRRIGATION SYSTEM USING FUZZY LOGIC AND WIRELESS SENSOR NETWORK

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Abstract

Vertical gardening (vermiculture) is one of the farming methods that can address land limitations by utilizing a vertically multi-tiered cultivation system. However, viticulture farming presents several challenges, including water provision based on plant needs. Watering in viticulture is typically done daily, either in the morning or afternoon, which can be time-consuming and labour-intensive for farmers. Therefore, this research aims to design a monitoring and irrigation system for viticulture plants based on soil moisture sensor data, processed using a fuzzy logic algorithm and Wireless Sensor Network (WSN) technology. This research results in a home-based viticulture plant monitoring and irrigation system that integrates fuzzy logic and WSN. The system consists of sensor nodes monitoring soil moisture and a sink node receiving and processing data from the sensor nodes. The soil moisture data is processed using fuzzy logic to determine soil conditions (dry, moist, or wet), which then automatically activates the water pump for irrigation. Testing results show that the soil moisture sensor values are successfully transmitted to the sink node, activating the relay and water pump according to the detected soil conditions. Additionally, the system utilizes the Blynk platform for real-time data monitoring. Thus, this system successfully automates horticulture plants' monitoring and irrigation process.

Keywords: *Verticulture Plants, WSN, Irrigation System, Smart Farming, Fuzzy Logic*

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1. INTRODUCTION

Currently, many agricultural lands in urban and suburban areas are being converted into residential areas, leading to a reduction in available farmland [1]. This situation limits the land available for food crop production [2]. One solution to address this issue is the development of the verticulture method [3]. Verticulture is an effective approach to gardening activities [4]. It helps overcome land limitations, is easy to implement, and can utilize recycled materials [5].

The verticulture technique is a multi-tiered plant cultivation system carried out vertically [6]. This technique can be applied to various types of containers, depending on creativity [7]. It utilizes a method that involves vertical planting indoors or in limited spaces [8].

One of the challenges in implementing verticulture is providing water based on plant needs [9]. Watering is done when the moisture level decreases, typically in the morning or afternoon [10]. It is carried out routinely, once a day [11]. Other studies suggest that watering should be done in the morning and evening, ensuring that water is not excessive, as certain plant types are sensitive and may rot. Additionally, the water must be appropriately distributed and absorbed by the growing medium to be effectively utilized by the plants [12].

This condition demands significant time and effort from verticulture farmers, as watering must be done daily with extra caution to ensure it meets the specific needs of the cultivated plants. Therefore, one of the essential technologies for verticulture farmers is an automatic and precise irrigation and monitoring system. The integration of sensors and technology for water and plant management enhances productivity efficiency [8].

The development and research on smart farming, particularly in irrigation systems, have been widely conducted. For example, a study by Defi Pujianto and Kadarsih in 2021 developed an automatic plant irrigation system based on a predetermined schedule using an RTC (Real-Time Clock), where the volume of water released by the pump depends on the pump's specifications [13].

Furthermore, research by Andi Priyono and Pandji Triadyaksa in 2019 created an irrigation system based on soil moisture information and demonstrated the ability of the Telegram application to provide remote commands to the system [14].

Additionally, a study conducted by Pamuji Setiawan and Elisabet Yunaeti Anggraen in 2019 successfully developed an irrigation system utilizing copper plates as sensors to detect soil moisture while incorporating a scheduled watering mechanism [15].

The novelty that serves as a comparison and development from previous research includes the application of the Fuzzy Logic algorithm to design an irrigation model based on soil moisture sensor data, the implementation of soil moisture sensors as inputs so that the system can irrigate based on predetermined time and soil moisture conditions, the development of a general-purpose system allowing various types of plants to be cultivated instead of being limited to a specific one—since irrigation settings can be adjusted via a smartphone according to the planted crop, and the utilization of Wireless Sensor Network (WSN) technology, enabling the system to collect sensor data from each verticulture plant and send it to a smartphone for remote monitoring and control.

The reason for conducting this research is that the irrigation of verticulture plants by farmers is still done manually and must be carried out daily, which is very time-consuming and labor-intensive.

The purpose of this research is to develop a home plant monitoring and irrigation system using a verticulture system with a fuzzy logic algorithm based on a Wireless Sensor Network (WSN). This research aims to assist farmers in monitoring and irrigating verticulture plants, eliminating the need for manual and periodic watering, as the system will automatically handle irrigation.

2. RESEARCH METHOD

2.1 Research Stages

This research is conducted through several key stages. It begins with problem identification, focusing on the application of technology in verticulture plant cultivation. A literature study is carried out to understand the concepts of Wireless Sensor Network (WSN), automatic irrigation systems, and the verticulture method.

Next, data collection is conducted by gathering information on verticulture plant care, particularly in the irrigation stage. The system design and development phase includes WSN design, the creation of a User Interface (UI) for the application, the development of an automatic irrigation system, and the construction of the verticulture system.

Subsequently, analysis and testing are performed to assess the system's effectiveness. In the evaluation phase, the system is tested to measure the accuracy of the sensors and the success of automatic irrigation. The research stages can be seen in Figure 1.

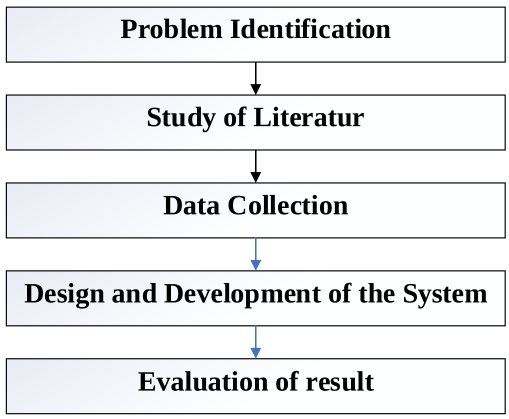

Figure 1. Research Stages

2.2 System Diagram

The system diagram to be developed can be seen in Figure 2. In this diagram, the implementation of the Wireless Sensor Network (WSN) in the data transmission process is illustrated. The soil moisture sensor sends data to the sink node, which acts as a gateway to receive all data from the sensor nodes. The data is then transmitted to the Blynk Cloud in real time, allowing access via a smartphone through an internet connection.

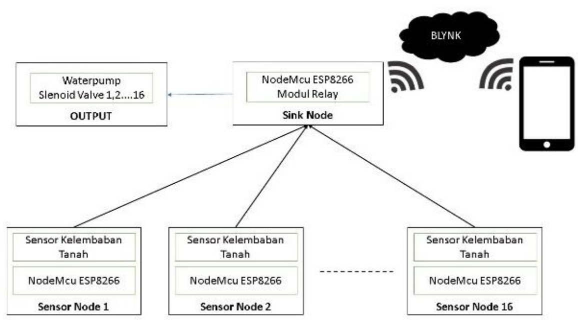

Figure 2. System Diagram

2.3 Fuzzy Logic

Fuzzy logic is one of the components of soft computing, first introduced by Prof. Lotfi A. Zadeh in 1965. The foundation of fuzzy logic is fuzzy set theory, in which the degree of membership plays a crucial role in determining the existence of elements within a set. The membership value or degree of membership, also known as the membership function, is a key characteristic of fuzzy logic reasoning [16].

This research uses the Mamdani fuzzy method, which is one of the most commonly used methods in fuzzy logic applications. The Mamdani method refers to the inference process or drawing conclusions based on rules defined in IF-THEN statements. In this method, input and output variables are expressed as fuzzy sets with predetermined membership functions [17].

In this research, the fuzzy set formula used is as follows:

The fuzzy set formula for Dry is as follows:

$$\mu_{dry}(x) = \begin{cases} 1 & if\ x > \max\_dry \\ \frac{\max\_dry - z}{\max\_dry - \min\_dry} & if\ \min\_dry < x \leq \max\_dry \ldots (1) \\ 0 & if\ x \leq \min\_dry \end{cases}$$

The fuzzy set formula for moist is as follows:

$$\mu_{dry}(x) = \begin{cases} 0 & if\ x < min\_moist \\ \frac{\max\_dry - z}{\max\_dry - \min\_dry} & if\ \min\_moist < x \leq \mathrm{mid}\_moist \\ \frac{\max\_dry - z}{\max\_dry - \min\_dry} & if\ \mathrm{mid}\_moist < x \leq \min\_moist \\ 0 & if\ x > \max\_moist \end{cases} \quad (2)$$

The fuzzy set formula for wet is as follows:

$$\mu_{dry}(x) = \begin{cases} 1 & if\ x < \min\_wet \\ \frac{\min\_\mathrm{wet} - z}{\min\_\mathrm{wet} - \min\_\mathrm{wet}} & if\ \min\_wet < x \leq \min\_\mathrm{wet} \ldots (3) \\ 0 & if\ x \geq \min\_wet \end{cases}$$

The three formulas above represent the fuzzy sets for Dry, Moist, and Wet, where max_dry is the maximum value for the dry category, min_dry is the minimum value for the dry category, min_moist is the minimum value for the moist category, mid_moist is the midpoint value for the moist category, max_moist is the maximum value for the moist category, and min_wet is the minimum value for the wet category.

The application of fuzzy logic in this research is used to determine the wet, dry, and moist conditions of the growing media, allowing the system to decide whether to irrigate or not. The rule composition designed in this research can be seen in Table 1.

Table 1. Rule Composition Table

Soil Condition	Irrigation
Dry	Irrigate
Moist	Do Not Irrigate
Wet	Do Not Irrigate

The rule composition table is used to determine whether the system will irrigate or not based on sensor readings defined in the fuzzy set.

3. RESULTS AND DISCUSSION

After going through a series of research stages, as shown in Figure 1, the objective of this study has been achieved: a home plant monitoring and irrigation system using a vertical farming system based on fuzzy logic algorithms and Wireless Sensor Network.

3.1 Hardware Design

3.1.1 Sensor Node Hardware

The hardware design results of the sensor node in the developed system can be seen in Figure 3.

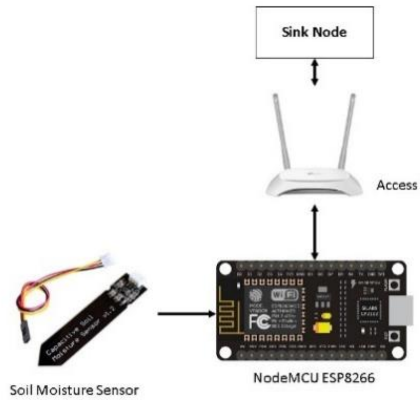

Figure 3. Sensor Node Hardware Design

3.1.2 Sink Node Hardware

The hardware design results of the sink node in the developed system can be seen in Figure 4.

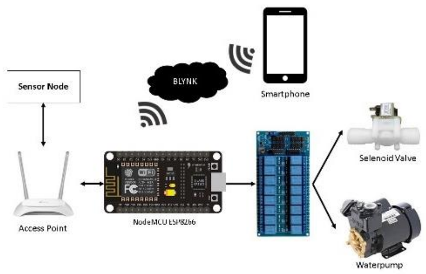

Figure 4. Sink Node Hardware Design

3.2 Software Design

The software design to be implemented in the system can be seen in Figure 5.

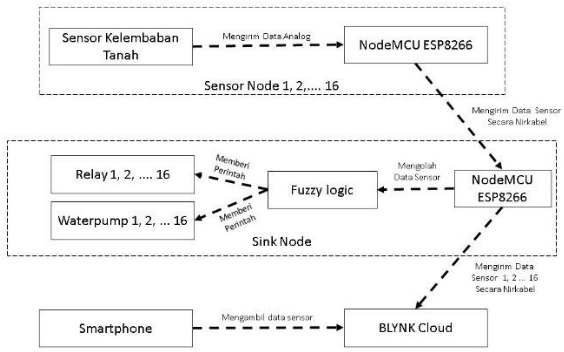

Figure 5. System Software Design

3.3 System Implementation

The system implementation stage is one of the sequential stages of system development, forming an integrated system starting from the design and creation of an automatic vertical farming monitoring and irrigation system using Wireless Sensor Network technology with the Arduino IDE application and the Blynk platform.

3.3.1 Sensor Node Device

The hardware used in the design of the Sensor Node consists of a Soil Moisture Sensor V2.0 and a NodeMCU ESP8266. The circuit diagram of the Sensor Node can be seen in Figure 6.

Figure 6. Sensor Node Circuit

3.3.2 Sink Node Device

The Sink Node functions as the gateway for all sensor nodes. The hardware used in the design of the Sink Node consists of a NodeMCU ESP8266 and a 16-channel relay module. The circuit diagram of the Sink Node can be seen in Figure 7.

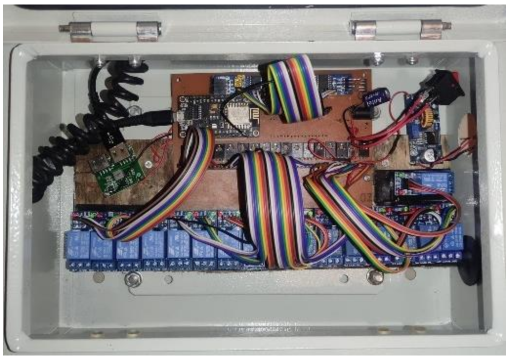

Figure 7. Sink Node Circuit

3.3.3 Software

System Software

The implementation of the system software is intended to test whether each hardware component functions as expected. The system software is developed using the Arduino IDE by writing code that is embedded into each NodeMCU ESP8266, as shown in Figure 8.

Figure 8. System Software

Monitoring Software

The testing of the monitoring software aims to verify whether the developed software can display soil moisture sensor data. The software is built using the Blynk platform, as shown in Figure 9.

Figure 9. Monitoring Software

The values displayed in Figure 9 represent the soil moisture sensor readings that have been converted into percentage form.

3.3.4 Hardware Installation

The system devices that have been functioning properly will then be installed on each vertical farming pipe to monitor and automatically water the plants, as shown in Figure 10.

Figure 10. System Installation on Verticultural Plants

3.4 Testing Results of Each Component

The overall working principle of this system is to monitor soil moisture and automatically irrigate the vertical farming media using Wireless Sensor Network technology. The system consists of 16 sensor nodes, each sending analog data from the soil moisture sensor to a sink node, which serves as the central unit for collecting all data transmitted by the 16 sensor nodes. The sink node processes the collected data using fuzzy logic to determine whether the vertical farming media is dry, moist, or wet. If any of the planting media is dry, the sink node activates the relay, turning on the water pump to irrigate the dry media. Additionally, the sink node sends real-time sensor data to the Blynk Cloud, which can then be accessed through the monitoring application.

3.4.1 Sensor Node Testing Results

The sensor testing was conducted to observe the values from each sensor node and determine the dry, moist, and wet conditions by comparing the soil moisture sensor readings with previously established sensor data. These sensor values are then sent to the sink node and processed using fuzzy logic. The testing results can be seen in Figure 11.

Figure 11. Testing and Data Collection of Soil Moisture Sensor Values

The results of the sensor node testing can be seen in Table 2.

Table 2. Sensor Testing Results

Sensor Node	Sensor Values in Soil Conditions		
	Dry	Moist	Wet
1	656	594	549
2	602	540	493
3	666	625	578
4	668	614	526
5	649	598	545
6	679	610	555
7	717	680	639
8	649	606	521
9	645	566	536
10	639	597	557
11	663	624	559
12	680	622	578
13	626	700	543
14	662	594	529
15	680	622	567
16	630	570	495

3.4.2 Results of Sensor Node Value Implementation into Fuzzy Set Formula

After the sensor values have been determined, the next step is to apply the fuzzy set formula to each sensor node value to define the maximum and minimum values for wet, moist, and dry conditions within the fuzzy set.

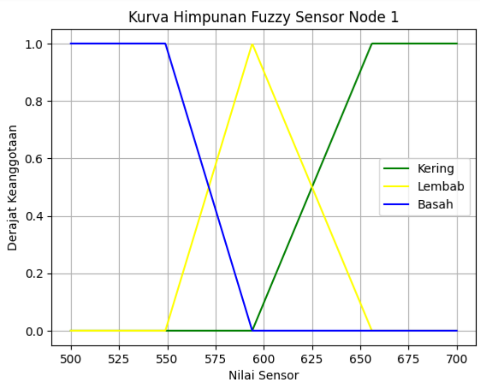

Figure 12. Fuzzy Set Curve for Sensor Node 1

In Figure 12, the results of implementing the sensor node 1 values into the fuzzy set formula are shown, resulting in the curve depicted in the image. This implementation of sensor values is also applied to each sensor node.

Fuzzification

The fuzzification stage aims to convert the numerical values obtained from soil moisture sensor readings into representations in the form of membership degrees for fuzzy categories. The categories used in this study are Dry, Moist, and Wet, with the value ranges shown in Table 3.

Table 3. Range of Sensor Values for Soil Conditions

Soil Condition	Sensor Value Range
Dry	600 - 602
Moist	600 - 650
Wet	650 – 700

Each category has a linear membership function, where the membership value is calculated using the following equations:

Dry Membership Function:

$$\mu Dry(x) = (650-x)/(650-600)$$

Moist Membership Function:

$$\mu Moist(x) = (x-600)/(650-600)$$

Wet Membership Function::

$$\mu Wet(x) = (x-650)/(700-650)$$

Inference and Rule Composition

At this stage, IF-THEN rules are used to determine whether the system should irrigate or not based on soil conditions. The list of rules can be seen in Table 4.

Table 4. List of Rules

No	Soil Condition (Sensor Value)	Fuzzy Category	Irrigation Decision
1	602- 600	Dry	Irrigate (Yes)
2	600 - 650	Moist	Do Not Irrigate (No)
3	600 - 700	Wet	Do Not Irrigate (No)

For example, if the sensor reads a value of 610, the membership calculation is as follows:

$$\mu\_Dry(610) = (650 - 610) / (650 - 600) = 0.8$$

$$\mu\_Moist(610) = (610 - 600) / (650 - 600) = 0.2$$

$$\mu\_Wet(610) = 0$$

Since the membership degree for the Dry category (0.8) is the highest, the system will trigger irrigation.

Next, the implementation of the fuzzification, inference, rule composition, and defuzzification stages will be integrated into the program code, which will automatically process sensor readings based on each fuzzy set curve.

3.4.3 Sink Node Testing Results

The results of the Sink Node testing can be seen in Table 4, where the testing was conducted to determine whether the Sink Node successfully collected sensor values from each sensor node and transmitted the data to the Blynk Cloud. Additionally, it processed the values using fuzzy logic stages based on the fuzzy sets of each sensor and activated the relay and water pump according to the processing results.

Table 5. Results of Sink Node Testing on Dry Soil

Sensor Node	Sensor Value	Sink Node Status	Relay Condition	Water Pump Condition	Blynk Status
1	656	Received	ON	ON	Sent
2	602	Received	OFF	OFF	Sent
3	666	Received	ON	ON	Sent
4	668	Received	ON	ON	Sent
5	649	Received	ON	ON	Sent
6	679	Received	ON	ON	Sent
7	717	Received	ON	ON	Sent
8	649	Received	ON	ON	Sent
9	645	Received	ON	ON	Sent
10	639	Received	ON	ON	Sent
11	663	Received	ON	ON	Sent
12	680	Received	ON	ON	Sent
13	626	Received	OFF	OFF	Sent
14	662	Received	ON	ON	Sent
15	680	Received	ON	ON	Sent
16	630	Received	OFF	OFF	Sent

Table 6. Test Results of Sink Node on Moist Soil

Sensor Node	Sensor Value	Sink Node Status	Relay Condition	Water Pump Condition	Blynk Status
1	594	Received	OFF	OFF	Sent
2	540	Received	OFF	OFF	Sent
3	625	Received	OFF	OFF	Sent
4	614	Received	OFF	OFF	Sent
5	598	Received	OFF	OFF	Sent
6	610	Received	OFF	OFF	Sent
7	680	Received	ON	ON	Sent
8	606	Received	OFF	OFF	Sent
9	566	Received	OFF	OFF	Sent
10	597	Received	OFF	OFF	Sent
11	624	Received	OFF	OFF	Sent
12	622	Received	OFF	OFF	Sent
13	700	Received	ON	ON	Sent
14	594	Received	OFF	OFF	Sent
15	622	Received	OFF	OFF	Sent
16	570	Received	OFF	OFF	Sent

Table 7. Test Results of Sink Node on Wet Soil

Sensor Node	Sensor Value	Sink Node Status	Relay Condition	Water Pump Condition	Blynk Status
1	549	Received	OFF	OFF	Sent
2	493	Received	OFF	OFF	Sent
3	578	Received	OFF	OFF	Sent
4	526	Received	OFF	OFF	Sent
5	545	Received	OFF	OFF	Sent
6	555	Received	OFF	OFF	Sent
7	639	Received	ON	ON	Sent
8	521	Received	OFF	OFF	Sent
9	536	Received	OFF	OFF	Sent
10	557	Received	OFF	OFF	Sent
11	559	Received	OFF	OFF	Sent
12	578	Received	OFF	OFF	Sent
13	543	Received	OFF	OFF	Sent
14	529	Received	OFF	OFF	Sent
15	567	Received	OFF	OFF	Sent
16	495	Received	OFF	OFF	Sent

4. CONCLUSION

After going through several stages of research, including designing, building, and testing the monitoring and irrigation system for home gardening using a vertical farming system with a fuzzy logic algorithm based on a Wireless Sensor Network, the conclusion obtained is as follows:

This research has resulted in a system capable of automatically irrigating and monitoring home garden plants in a vertical farming system using fuzzy logic and a Wireless Sensor Network. The system consists of 16 vertical farming points, each equipped with a sensor node that continuously reads and transmits soil moisture data in real-time to a gateway called the Sink Node via a Wireless Sensor Network.

Based on the test results of each component, all 16 sensor nodes successfully read soil moisture data in real time and transmitted the data to the Sink Node. The Sink Node successfully received and aggregated the soil moisture data from the sensor nodes. The system uses a fuzzy logic algorithm, which effectively classifies soil moisture readings into dry, moist, or wet categories, allowing the system to determine whether irrigation is needed.

The monitoring application developed in this research successfully displays soil moisture sensor data in percentage (%) format, enabling farmers to monitor the moisture levels of all 16 vertical farming plants.

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