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

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**Abstract**

Verticulture is a gardening method that addresses land limitations by using a multi-layered vertical planting system. However, there are several issues in verticulture, one of which is providing water based on plant needs. The irrigation of verticulture plants is routinely done every day, either in the morning or during the day. This certainly consumes time and effort for the farmers. Therefore, the objective of this research is to design a monitoring and irrigation system for verticulture plants based on soil moisture sensor data that will be processed using fuzzy logic algorithms and Wireless Sensor Network technology. The result of this research is a system implemented at 16 verticulture planting points. Sixteen sensor nodes successfully read soil moisture data in real time and sent this data to a sink node. The sink node then received and collected the moisture data sent by the sensor nodes. The algorithm used in this system is fuzzy logic, which successfully categorizes the readings from the soil moisture sensors into dry, moist, or wet categories, allowing the system to decide whether to irrigate the plants or not. The monitoring application created successfully displays the soil moisture sensor data as a percentage (%)..

**Keywords**: Vertical Farming, *WSN* , Irrigation System , Smart Farming, Fuzzy Logic



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## 1. INTRODUCTION

Currently, many agricultural lands in urban and suburban areas are converted into residential areas, resulting in a decrease in the availability of agricultural land [1]. This situation narrows the land available for food crop production [2]. One solution to address this issue is the development of verticulture methods [3]. The verticulture method is an appropriate way of gardening activities [4]. Verticulture can overcome land limitations, is easy to implement, and can utilize waste materials [5].

Verticulture techniques are a system of tiered plant cultivation conducted vertically [6]. This technique can be applied in various types of containers depending on creativity [7]. This method involves vertical planting indoors or in limited spaces [8].

One of the challenges in implementing verticulture is providing water based on plant needs [9]. Irrigation is done when the moisture level decreases, typically in the morning or during the day [10]. Watering is carried out routinely, once every day [11]. Other research suggests that watering should be done in the morning and evening, and care should be taken not to overwater, as certain types of plants may not tolerate excess water and could rot. Additionally, the water applied must be precise and accumulated in the growing media to be absorbed by the plants [12].

This condition consumes time and effort for verticulture farmers because watering is done every day, requiring extra caution to meet the watering needs of the planted verticulture plants. Therefore, one of the technologies needed by verticulture farmers is an automated and precise monitoring and irrigation system. The intervention of sensors and technology for water management and plant management increases productivity efficiency [8].

Development and research on smart farming, particularly in irrigation, have been widely conducted. For example, research conducted by Defi Pujianto and Kadarsih in 2021 titled "Design of Automatic Irrigation Scheduling for Home Plants Using an Arduino-Based Vertical System" has created an automatic plant irrigation system based on predetermined time using an RTC (Real-Time Clock) and the volume of water released from the pump depending on the specifications of the pump used [13]. Subsequently, research by Andi Priyono and Pandji Triadyaksa in 2019 titled "Automatic Irrigation System for Chili Plants to Maintain Humidity" has developed a plant irrigation system based on soil moisture information and demonstrated the capability of the Telegram application to provide remote commands to the working system [14]. Then, research conducted by Pamuji Setiawan and Elisabet Yunaeti Anggraen in 2019 successfully created an irrigation system using copper plates as sensors to detect soil moisture and utilizing a watering schedule [15].

The novelty that serves as a comparison and development from previous research is the application of fuzzy logic algorithms to design an irrigation model based on soil moisture sensor data. This study implements soil moisture sensors as input so that the system can irrigate based on the set time and the soil moisture condition. The system to be created is general, allowing for various plants to be grown, as the irrigation settings can be adjusted through a smartphone based on the planted crops, and it employs wireless sensor network technology to gather sensor data from each verticulture plant, which can then be sent 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 manual and must be done daily, which is very time-consuming and labor-intensive.

The objective of this study is to create a monitoring and irrigation system for home plants using a verticulture system with fuzzy logic algorithms based on Wireless Sensor Networks. With this research, it can ease the farmers' task in monitoring and irrigating verticulture plants, eliminating the need for periodic manual watering as the irrigation will be done automatically by the system.

## 2. RESEARCH METHOD

### 2.1 Research Stages

This research will be divided into three stages: the initial stage of the research, the design and data analysis stage, and the final stage of the research. The design, indicators, and status of implementation for each stage can be seen in Table 1.

Table 1. research stages

| Implementation of the Research | Design | Indicator |
|---|---|---|
| Initial Stage of the Research | | |
| Problem Identification | Describing the issues to be addressed, analyzing information needs through journals, and selecting appropriate research methods. | Data needs and research topics |
| Needs Analysis | | Identifying the needs for the system to be developed |
| Preparation of Research Methods | | Research methods have been set |
| Procurement of Research Materials and Equipment | Preparing tools and materials for building the system and cultivating verticulture plants | ools and materials for building the irrigation system and verticulture cultivation are available |
| Data Collection | Collecting data to be used in building the system | Gathering data on verticulture plant care, particularly during the irrigation stage |
| Design Analysis | Analyzing the hardware and software of the irrigation system to be created | Understanding the design of hardware and software |
| Design and Data Analysis Stage | | |
| Design of Wireless Sensor Network Concept | Designing the wireless sensor network concept to be applied to the system | The concept of the wireless sensor network to be applied to the system has been determined |
| Design and Development of User Interface (UI) for the Application | Designing and creating the user interface for the application used to monitor verticulture plants | The monitoring application has been completed |
| Design and Development of the Automatic Irrigation System Device | Designing and creating devices starting from mechanical construction, electronics, and firmware of the system | The automatic irrigation system device has been completed |
| Design and Construction of Home Plant Cultivation with Verticulture System | Building a simple home plant cultivation system with verticulture as a place for the application of the system | A simple verticulture plant cultivation has been established |
| Analysis and Testing of Results | Analyzing and testing the developed system device | The verticulture plant irrigation system device works well |
| Final Stage of the Research | | |
| Journal Publication | Conducting publication of accredited scientific journals | Publication of research results in a National Journal |

### 2.2 System Diagram

The system diagram to be created can be seen in Figure 1, where the implementation of the Wireless

Sensor Network in the data transmission process is illustrated. In the diagram, the soil moisture sensor sends data to the sink node, which acts as a gateway that receives all data from the sensor nodes. This data is then transmitted to the Blynk Cloud in real-time, allowing access through a smartphone via the internet network.

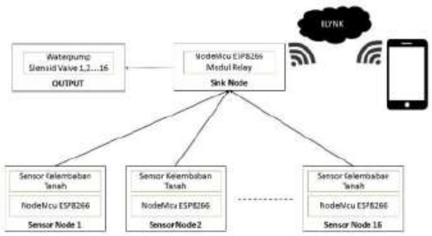


Figure 1. System Diagram

### 2.3 Fuzzy Logic

Fuzzy logic is one of the components that form soft computing, first introduced by Prof. Lotfi A. Zadeh in 1965. The foundation of fuzzy logic is the theory of fuzzy sets, which involves the role of membership degrees as a crucial determinant of the existence of elements within a set. Membership values or degrees of membership, known as membership functions, are the main characteristics 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 in the form of fuzzy sets with specified membership functions [17].

In this study, the fuzzy set formulas used are as follows:

Fuzzy Set Formula for Dry:

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

Fuzzy Set Formula for Moist:

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

Fuzzy Set Formula for Wet:

$$\mu_{dry}(x) = \begin{cases} 1 & if\ x < \min\_wet \\ \frac{\min\_wet - x}{\min\_wet - \min\_wet} & if\ \min\_wet < x \le \min\_wet \ldots (3) \\ 0 & if\ x \ge \min\_wet \end{cases}$$

The three formulas above are for the fuzzy sets of 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 study is used to represent the conditions of wet, dry, and moist in the planting medium, allowing the system to make decisions on whether to irrigate or not.

Furthermore, the composition of the rules designed in this study can be seen in Table 2.

Table 2. 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 the readings from the sensors that have been defined in the fuzzy sets.

## 3. RESULT AND DISCUSSION

After going through a series of research stages as outlined in Table 1, the goal of this study has been achieved, which is the development of a monitoring and irrigation system for home plants using a vertical farming system based on fuzzy logic algorithms and Wireless Sensor Networks..

### 3.1 Hardware Design

#### 3.1.1 Sensor Node Hardware

The results of the sensor node hardware design in the developed system can be seen in Figure 2.

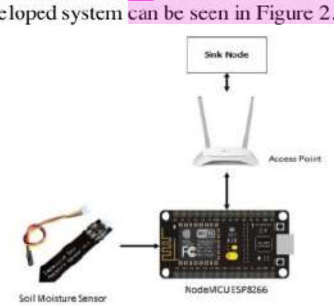


Figure 2. Hardware Design of the Sensor Node

### 3.1.2 Sink Node Hardware

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


Figure 3. Hardware Design of the Sink Node

## 3.2 Software Design

The results of the software design to be implemented in the system can be seen in Figure 4.

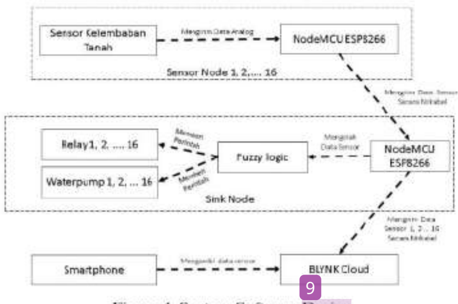


Figure 4. System Software Design

## 3.3 System Implementation

The system implementation stage is a crucial part of the sequential system development process, culminating in a unified system. This begins with the design and construction of an automated monitoring and irrigation system for vertical farming, utilizing Wireless Sensor Network technology with the Arduino IDE application and the Blynk platform.

### 3.3.1 Sensor Node Device

The hardware used in the creation of the Sensor Node circuit includes the Soil Moisture Sensor V.2.0 and NodeMCU ESP8266. The circuit of the Sensor Node can be seen in Figure 5.

Figure 5. Sensor Node Circuit

### 3.3.2 Sink Node Device

The Sink Node serves as the gateway for all sensor nodes. The hardware used in the construction of the Sink Node circuit includes the NodeMCU ESP8266 and a 16-channel relay module. The circuit diagram for the Sink Node can be seen in Figure 6.

Figure 6. Sink Node Circuit

### 3.3.3 Software Design

#### 3.3.3.1 System Software

The implementation of the system software is intended to test that each component of the hardware functions as expected. The system software is developed using the Arduino IDE application by writing lines of code that will be embedded in each NodeMCU ESP8266.

Figure 7. Perangkat Lunak Sistem

#### 3.3.3.2 System Monitoring Software

The monitoring software testing aims to verify whether the developed software can display soil moisture sensor data. The software is created using the Blynk platform, as shown in Figure 8.

Figure 8. Monitoring Software

The values displayed in Figure 7 are 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 be installed on each vertical pipe to monitor and automatically water the plants, as shown in Figure 9.

Figure 9. Vertikultur Installation of the System on Vertical Plants

## 3.4 Results of Testing Each Component

The overall principle of this system is to monitor soil moisture and automatically water the vertical planting medium using Wireless Sensor Network technology, which consists of 16 sensor nodes. Each sensor node sends analog data from the soil moisture sensor to a sink node that serves as the central hub to collect all the data sent by the 16 sensor nodes. The sink node then processes the collected data using fuzzy logic to determine the condition of the vertical planting medium as dry, moist, or wet. When any of the planting mediums is dry, the sink node commands the relay to activate, thus turning on the water pump to irrigate the dry planting medium. Additionally, the sink node sends real-time data from the sensor nodes to the Blynk Cloud, which can then be accessed through the monitoring application.

### 3.4.1 Results of Sensor Node Testing

The sensor testing was conducted to observe the values from each sensor node and to determine the dry, moist, and wet conditions by comparing the soil moisture sensor values with previously existing sensors. These sensor values will subsequently be sent to the sink node for processing using fuzzy logic.

Figure 10. Testing and obtaining soil moisture sensor values.

The results of the sensor node testing can be seen in Table 3.

Table 3. Results of the Sensor Testing

| Sensor Node | Sensor Values Under 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 Implementation Results of Sensor Node Values to Fuzzy Set Formulas

Once the sensor values have been determined, the fuzzy set formulas are applied to each sensor node value to provide the maximum and minimum values for wet, moist, and dry in the fuzzy set.

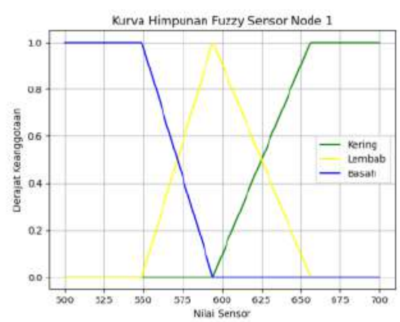


Figure 11. Fuzzy Set Curve for Sensor Node 1

The image above shows the implementation of the sensor node 1 values into the fuzzy set equations, resulting in the curve displayed. This sensor value implementation is also applied to each sensor node. Next, the implementation of the stages of fuzzification, inference, rule composition, and defuzzification will be incorporated into the program code, which will automatically process the sensor reading data based on each fuzzy set

### 3.4.3 Results of Sink Node Testing

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. The sink node also processes the values using fuzzy logic stages based on the fuzzy sets of each sensor and activates the relay and water pump based on the processing results.

Table 4. 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 | ON | ON | 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 | ON | ON | Sent |
| 14 | 662 | Received | ON | ON | Sent |
| 15 | 680 | Received | ON | ON | Sent |
| 16 | 630 | Received | ON | ON | Sent |

Table 5. Sink Node Testing Results 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 | OFF | OFF | 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 | OFF | OFF | Sent |
| 14 | 594 | Received | OFF | OFF | Sent |
| 15 | 622 | Received | OFF | OFF | Sent |
| 16 | 570 | Received | OFF | OFF | Sent |

Table 6. Sink Node Testing Results 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 | OFF | OFF | 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 a monitoring and irrigation system for home plants with a vertical gardening system using a fuzzy logic algorithm based on Wireless Sensor Network, the following conclusions can be drawn: This research has produced a system that can automatically irrigate and monitor home plants with a vertical gardening system using fuzzy logic and Wireless Sensor Network technology. There are 16 vertical plant points, each equipped with a sensor node that reads and transmits soil moisture data in real-time to a gateway known as the Sink node using the Wireless Sensor Network. Based on the results of testing each component, all 16 sensor nodes successfully read soil moisture data in real-time and transmitted that data to the Sink node, which then received and collected the moisture data sent by the sensor nodes. The algorithm used in this system is fuzzy logic, which effectively categorizes the soil moisture readings into dry, moist, or wet categories, allowing the system to decide whether or not to irrigate the plants. The monitoring application developed successfully displays soil moisture sensor data as a percentage (%), enabling farmers to assess the moisture content of the 16 vertical plants.

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