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DESIGN AND DEVELOPMENT OF A PPM CONTROL SYSTEM FOR AEROPONIC LETTUCE PLANT NUTRIENT BASED ON MICROCONTROLLERS AND INTERNET OF THINGS

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ABSTRACT

This research aims to address the issue of decreasing agricultural land due to the increasing population, which has led to the conversion of farmland into residential areas. One solution to this problem is the use of aeroponic farming, especially in urban areas. This study focuses on an Internet of Things (IoT)-based aeroponic lettuce plant nutrition control system that utilizes various sensors to maintain the stability of the nutrient solution. The TDS sensor in the system is capable of maintaining the ppm value of the solution between 560-840 ppm, which is essential for the growth of lettuce plants. When the ppm value falls below the set point, the peristaltic pump is triggered to fill the nutrient solution actively. The DHT22 sensor is used to detect the temperature and humidity levels in the range of 27-33°C and 70%-95%, respectively. The ultrasonic sensor is used to measure the water level in the box. The system's TDS sensor was able to regulate the nutrient solution's level, and an average reading value of 675.08 ppm was obtained. The duration of watering and the level of the nutrient solution are done automatically, and the system can be monitored via smartphone, eliminating the need for manual checking every day. This IoT-based aeroponic lettuce plant nutrition control system provides an efficient and effective solution for urban farming, where space is limited. The system's ability to regulate the nutrient solution's level and monitor the plant's growth via smartphone makes it an ideal solution for urban farmers who want to maximize their yield while minimizing their effort. This research contributes to the development of sustainable agriculture practices that can help address the challenges of food security in urban areas.

Keywords: *Aeroponics, Internet of Things, TDS, DHT22, Ultrasonic*

INTRODUCTION

The development process in Indonesia, makes the agricultural sector very important in the national economy because almost most of the Indonesian population lives in rural areas with livelihoods as farmers. However, in the current era, the land for farming is decreasing due to the large number of people so that agricultural land is used as residential land (Sari, 2021). To enable people to continue farming, especially in urban areas, one of the existing solutions is to use the aeroponic method.

Aeroponics is a method of farming using air as a media. Aeroponics comes from the words aero which means air and ponos which means power (Iriani & Lazuli, 2018). This method is very suitable for plant cultivation in a place with limited area. In its application, plants planted using this method are placed in a hanging position (Bai et al., 2023). Nutrients are applied using a fogging technique to the roots of the plants (Geovanie, M., Ruslianto, I., & Ristian, 2023). Some of the advantages of this method include: ease of harvesting, controllable nutrients, efficient use of land and sufficient oxygen levels in the nutrient solution to benefit plants.

The aeroponic method can be used to grow various types of plants vegetables (RS Marginingsih, AS Nugroho, 2018). One of them is the lettuce plant. Previous research on IoT-based aeroponic monitoring systems, using a Single Board Computer where the microcontroller used is Atmega 16. In this research only monitors temperature and humidity using a DHT11 sensor (Iriani & Lazuli, 2018).

Next, research on an aeroponic system automatically, but in this system to determine the concentration of nutrients for plants has not used a sensor that can detect the ppm value of the nutrient solution and also the microcontroller used is Arduino Uno.

Apart from that, there is also research regarding the design of prototypes for automatic sprinklers aeroponic plants. In this research, researchers used an Atmega16 microcontroller and the levels of nutrient solution for plants were also not discussed in this research, all that was mentioned was that the provision of nutrients was still not evenly distributed so that plant growth was also uneven (Fadhil & Argo, 2015).

The purpose of this research is to develop an agricultural automation system that utilizes sensor technology to detect and monitor the plant environment in real-time remotely using the Internet of Things. Internet of things is a network concept that can make several devices communicate with each other. The Internet of Things can make communication with each other objects that are around using an internet network that can be operated remotely with wireless technology (Meutia, 2015). Wireless technology is one of the main technologies in improving IoT with the design of transferring data from one place to another without a cable connection (Teguh, 2017). Application Internet of Things can be used in many areas of life, such as agriculture, which can be developed according to existing needs, such as development in improving quality, quantity, resilience, and can make agricultural production costs more effective (Wijaya & Rivai, 2018).

In this research, the system is designed to measure air temperature and humidity, water level in the plant box, and ppm value of nutrient solution. With the information obtained from these sensors, this research aims to create a mechanism to automatically spray nutrients on the roots of plants according to a predetermined schedule. In addition, users can monitor the environmental conditions of the plants, including temperature, humidity, ppm value of the nutrient solution, and water level, directly through the Blynk app (Sneineh & Shabaneh, 2023). Thus, this research aims to improve the efficiency and accuracy of crop management, support sustainable agriculture, and provide innovative solutions for modern farming.

METHOD

The method used in this research is creating a design starting from literature study, system design, hardware design, software design, testing and analysis.

1. System Design

The system design starts with making a system block diagram of the tool to be made and the working principle of the tool.

a. Block Diagram

This block diagram explains in general how each component works for the tool to be designed with each block referring to the theoretical basis and based on needs (Galasso et al., 2023). The design of the block diagram simplifies the process when testing and avoids system errors from the tool. The overall system block diagram can be seen in Figure 1.

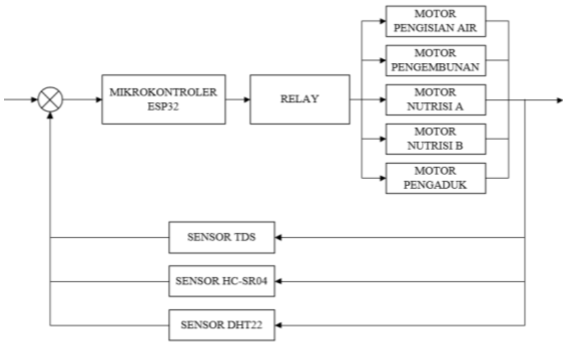

Figure 1. System Blok Diagram

Based on the block diagram in Figure 1, it can be explained as follows:

1) Input Block

The input block consists of the DHT22 sensor, TDS sensor and HC-SR04 sensor, where these sensors have their respective function, namely:

a. DHT22 Sensor
   There is one DHT22 sensor at the input which functions to detect the temperature and humidity of the air around the plant where the temperature value will be detected on a scale of °C and air humidity in units of percentage relative humidity (%RH).
b. TDS Sensor
   There is one TDS sensor at the input which functions to detect the value of the number of dissolved solids or TDS in the nutrient solution. This TDS value is calculated in ppm.
c. HC-SR04 Sensor
   There is one HC-SR04 sensor at the input which functions to detect the availability of solution in the nutrient solution tub. The availability of this nutrient solution will be displayed on a centimeter (cm) scale.
d. Power Supply
   There is a power supply that functions as an energy source for the system to work

2) Process Block

The process block consists of an ESP32 microcontroller that has a function to process or process input data from the DHT22 sensor, HCSR04 and TDS sensor. The data read from the sensors will be sent to the blynk application for monitoring. In addition, the temperature and humidity reading data will be processed by the microcontroller which will then be used to control the condensation pump relay.

3) Output Block

The output block consists of a relay, pump and mist nozzle along with a website and blynk application on a smartphone.

a. Relay, pump and mist nozzle
   In the core tool there are 5 relays connected to several pumps, namely the water filling pump, nutrient filling pump A, nutrient filling pump B, stirring motor and watering pump connected to the mist nozzle so that the nutrients are released in the form of dew
b. Web and Smartphone
   Monitoring can be done by viewing through the blynk web or through a smartphone that hasthe blynk application installed wirelessly via WiFi or internet connection.

b. Working Principle

The working principle of this tool is that the TDS sensor will read or detect the level of nutrient solution for plants where the unit is in ppm, the normal standard ppm value for lettuce plants is 560 ppm to 840 ppm. Where the ppm value of this solution is a mixture of AB mix nutrients with plain water.

Then, to increase the ppm level of the solution, we will add nutrients in the form of AB mix with a ratio of 5ml of nutrient A, 5ml of nutrient B mixed with 1 liter of plain water. When the TDS sensor detects the ppm value of the solution below the setpoint of 560 ppm, the A and B nutrient pumps will activate to add nutrients so that the ppm value of the solution returns to the setpoint. Likewise, when the TDS sensor detects a ppm value above the setpoint of 840 ppm, the regular water pump will be active to add water so that the ppm value of the solution drops and returns to the setpoint.

In the HC-SR04 sensor, its function is as an input tool for controlling the solution in the plant nutrition tub, which has a height of 40 cm. When the sensor detects the water level below 25 cm, the pump for filling water will automatically turn on.

Furthermore, the DHT22 sensor here functions to detect the temperature and humidity around the planting media, which will affect the duration of watering the plants.

2. Hardware Design

In hardware design for making tools consists of electronic design and mechanical design (Gu et al., 2023). Electronic design is making electronic circuits that are realized into PCB (Printed Circuit Board) form. Mechanical design is the creation of a design form for the mechanical system of the tool.

a. Electronic Circuit Design

This circuit is a series of overall tool systems to control plant nutrient levels that are sprayed using a pump that is connected to a mist nozzle so that the resulting liquid is in the form of dew so that it is more easily absorbed by plants. The data read by the sensors in this system will be processed by the ESP32 microcontroller and will later be sent to the blynk application. Monitoring can be done as long as it is still connected to WI-Fi. The circuit schematic can be seen in Figure 2.

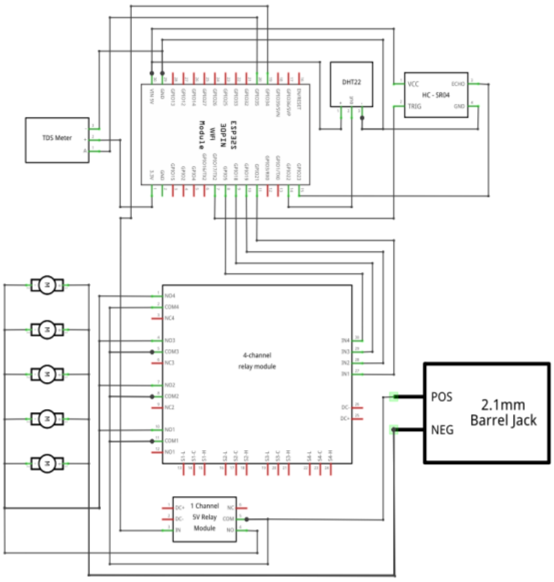

Figure 2. Overall System Schematic

b. Mechanical Design

In this design, the planting medium is made using pipes, and for support, pipes of a smaller size are also used. The planting medium consists of three pipes, namely each pipe has 4 planting holes so that the total number of planting holes is 12 holes.

At the bottom of the planting media pipe, there is a hole to place the mist nozzle which is connected to a hose so that the solution spray from the mist nozzle can reach the plant roots properly

Next, in the Styrofoam box used to store the nutrient solution, an ultrasonic sensor is installed at the top of the box to measure the level of the nutrient solution, and a solution stirrer motor is also installed so that the solution in the box is evenly mixed so that the ppm value can be read by the TDS sensor. more accurate. And the control system is placed on the side of the box. The mechanical design of this tool can be seen in Figure 3 below.

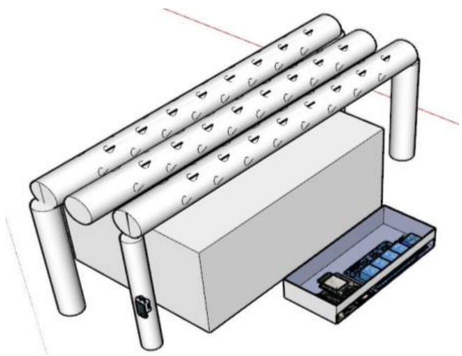

Figure 3. Mechanical Design of the Tool

3. Software Design

In software design is the creation of a system of a tool that will be made.

a. Flowchart

Flowchart is a sequence of instructions for creating a program (Zhang et al., 2023). Making this flowchart functions to make it easier to create programs. The flowchart of the system to be created can be seen in Figure 4 below.

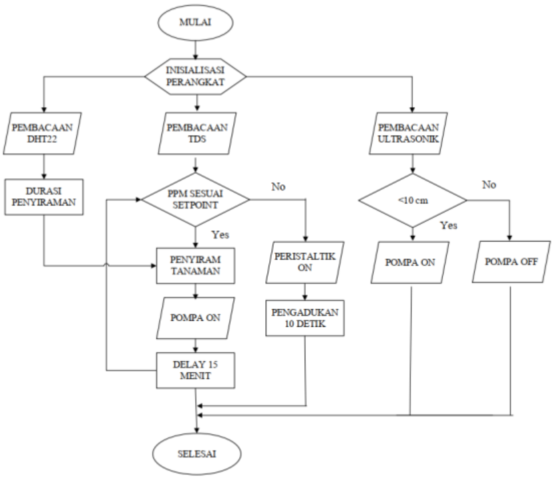

Figure 4. Flowchart

RESULTS AND DISCUSSION

1. Testing and Analysis of TDS Sensor Readings

Testing of the TDS sensor is carried out to see the error in the sensor readings compared with the reference measuring instrument, namely the TDS meter. A comparison graph of the PPM value readings for nutrient solutions can be seen in Figure 5 below.

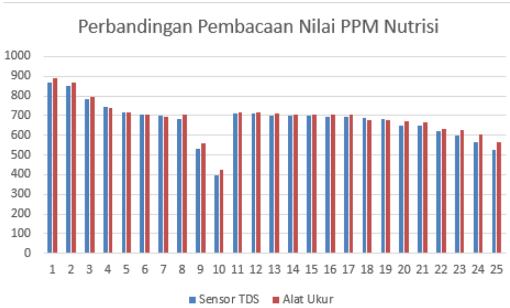

Figure 5. Comparison Chart of Nutrition PPM Values

From the experimental data, to find the percentage error value mathematically is as follows:

$$Error = \frac{|Nilai\ Alat\ Ukur - Nilai\ Sensor|}{Nilai\ Alat\ Ukur} \times 100\%$$

Data was taken from the first 3 experiments

1. $Error = \frac{|892-868|}{892} \times 100\% = 2.69\%$
2. $Error = \frac{|868-852|}{868} \times 100\% = 1.84\%$
3. $Error = \frac{|797-785|}{797} \times 100\% = 1.51\%$

Next, to find the average percentage error value or MAPE (Mean Absolute Percentage Error) TDS sensor readings with a TDS meter measuring instrument from the experimental data are as follows:

$$MAPE = \frac{\sum_{t=1}^{n} \left| \frac{Nilai\ Alat\ Ukur - Nilai\ Sensor}{Nilai\ Alat\ Ukur} \right|}{n} \times 100\%$$

So, the average difference between the percentage error in the TDS sensor reading and the TDS meter reference measuring instrument is 2.29%.

2. **Testing and Analysis of DHT22 Sensor Readings**

a. Temperature Reading

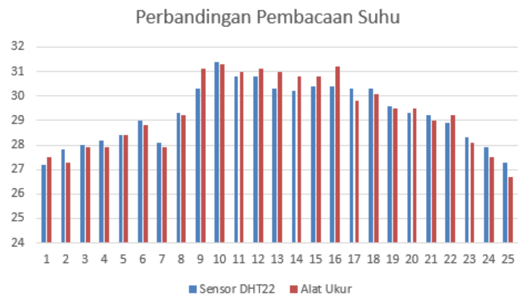

Figure 6. Temperature Reading Comparison Chart

From the experimental data in Figure 6, to find the percentage value Mathematical error is as follows:

$$Error = \frac{|Nilai\ Alat\ Ukur - Nilai\ Sensor|}{Nilai\ Alat\ Ukur} \times 100\%$$

Data was taken from the first 3 experiments

1. $Error = \frac{|27{,}5-27{,}2|}{27{,}5} \times 100\% = 1.09\%$
2. $Error = \frac{|27{,}2-27{,}8|}{27{,}2} \times 100\% = 2.21\%$
3. $Error = \frac{|27{,}9-28|}{27{,}9} \times 100\% = 0.36\%$

Next, to find the average percentage value error or MAPE (Mean Absolute Percentage Error) reading of the DHT22 temperature sensor using a thermohydrometer measuring instrument from the experimental data is as follows:

$$MAPE = \frac{\sum_{t=1}^{n} \left| \frac{Nilai\ Alat\ Ukur - Nilai\ Sensor}{Nilai\ Alat\ Ukur} \right|}{n} \times 100\%$$

The average value of the error percentage is MAPE

$$\frac{0{,}282}{25} \times 100\% = 1.13\%$$

So, the average difference in percentage error in the temperature reading of the DHT22 sensor and the thermohydrometer reference measuring instrument is 1.13%

b. Humidity Reading

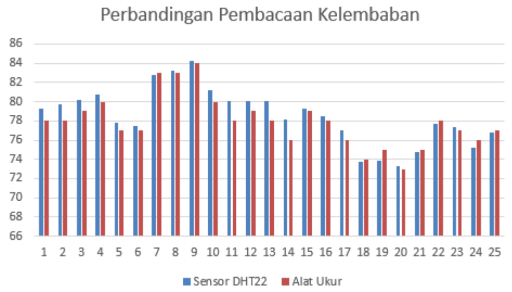

Figure 7. Humidity Reading Comparison Chart

From the experimental data in Figure 7, to find the percentage error value mathematically is as follows:

$$Error = \frac{|Nilai\ Alat\ Ukur - Nilai\ Sensor|}{Nilai\ Alat\ Ukur} \times 100\%$$

Data was taken from the first 3 experiments

$$Error = \frac{|78 - 79{,}3|}{78} \times 100\% = 1.67\%$$

1. $Error = \frac{|78-79{,}3|}{78} \times 100\% = 1.67\%$
2. $Error = \frac{|78-79{,}7|}{78} \times 100\% = 2.18\%$
3. $Error = \frac{|79-80{,}2|}{79} \times 100\% = 1.52\%$

Next, to find the average value of percentage error or MAPE (Mean Absolute Percentage Error) humidity readings by the DHT22 sensor with a thermohydrometer measuring instrument from the experimental data are as follows:

$$MAPE = \frac{\sum_{t=1}^{n} \left| \frac{Nilai\ Alat\ Ukur - Nilai\ Sensor}{Nilai\ Alat\ Ukur} \right|}{n} \times 100\%$$

average value of the error percentage is MAPE

$$\frac{0{,}270}{25} \times 100\% = 1.08\%$$

So, the average difference in percentage error in humidity readings by the DHT22 sensor and the thermohydrometer reference measuring instrument is 1.08%

3. **Testing and Analysis of Ultrasonic Sensor Readings**

Testing of the reading of the water level value by the ultrasonic sensor is carried out to see the error in the sensor reading which is compared with the reference measuring instrument, namely a ruler.

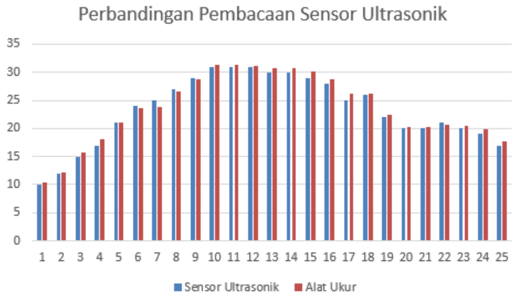

Figure 8. Water Level Reading Comparison Chart

From the experimental data, to find the percentage error value mathematically is as follows:

$$Error = \frac{|Nilai\ Alat\ Ukur - Nilai\ Sensor|}{Nilai\ Alat\ Ukur} \times 100\%$$

Data was taken from the first 3 experiments

1. $Error = \frac{|10{,}3-10|}{10{,}3} \times 100\% = 2.91\%$
2. $Error = \frac{|12{,}2-12|}{12{,}2} \times 100\% = 1.64\%$
3. $Error = \frac{|15{,}8-15|}{15{,}8} \times 100\% = 5.06\%$

Next, to find the average percentage error or MAPE (Mean Absolute Percentage Error) value of the water level reading by the ultrasonic sensor with a ruler measuring instrument from the experimental data is as follows:

$$MAPE = \frac{\sum_{t=1}^{n} \left| \frac{Nilai\ Alat\ Ukur - Nilai\ Sensor}{Nilai\ Alat\ Ukur} \right|}{n} \times 100\%$$

The average value of the error percentage is MAPE

$$\frac{0{,}581}{25} \times 100\% = 2.32\%$$

4. **Testing and Analysis of Watering Duration**

The test on the watering duration was carried out to find out whether the duration of the pump running for watering (spraying) nutrients was in accordance with the temperature and humidity conditions detected by the DHT22 sensor.

Table 1. Watering Duration Testing

DHT22 Reading		Watering Duration (Minutes)
Temperature (°C)	Humidity (%)	
30.3	68.1	6
29.6	71.1	6
27.6	72.2	5
26.8	74.7	5
27	76.8	5

Based on the tests in the table, it can be seen that the jet pump for watering can work well and the duration of watering is in accordance with the temperature and humidity conditions detected by the sensor. The table shows that when the temperature detected by the sensor is high and the humidity is low, the duration of the pump watering is long and when the temperature detected is normal and the humidity is normal, the duration of the pump watering is also normal.

5. Nutrient Pump Testing and Analysis

This test on the nutrient pump is carried out to find out whether the nutrient pump will be active according to the ppm value of the nutrient solution detected by the TDS sensor. Nutrient pump testing can be seen in table 2.

Table 2. Nutrient Pump Testing

TDS Sensor Reading (ppm)	Nutrient Pumps A and B
522	ON
590	OFF
669	OFF
737	OFF
812	OFF

Based on the tests in the table, it can be seen that the nutrient peristaltic pumps A and B for filling nutrients into the box can work well according to the ppm value required by the plant, namely the nutrient pump does not turn on when the ppm value detected by the TDS sensor matches the plant's needs (560 ppm – 840 ppm) and will light up when the ppm value detected by the sensor is below that range.

6. Testing and Analysis of Water Filling Pumps

The test on the water filling pump was carried out to find out whether the pump for filling the water in the box would turn on according to the water level conditions detected by the ultrasonic sensor. Water filling pump testing can be seen in the following table.

Table 3. Water Filling Pump Testing

Water Height (cm)	Water Filling Pump
15	ON
20	ON
22	ON
26	OFF
27	OFF

Based on the tests in the table, it can be seen that the jet pump or pump for filling water in the nutrient solution box can work well according to the water level detected by the ultrasonic sensor. The table shows that the pump will be ON when the water level is <25 cm and will be OFF when it is ⩾ 25 cm.

7. Blynk Application Testing and Analysis

This blynk application test was carried out with the aim of finding out whether the blynk application as a device used to display results can work well (Faisal et al., 2023). The blynk application is used to display results that have been processed by the microcontroller, where the reading results can later be monitored via the blynk application.

Figure 9. Sensor Readings on the Blynk Application

In Figure 9 we can also see that the Blynk application can also display graphs of changes in sensor value readings in real time as long as the device is connected to the internet network.

8. Overall Analysis

This tool uses 3 sensors as input, namely the TDS sensor which is used to detect the ppm value of the nutrient solution given to plants. In this tool, after calibrating the sensor, this sensor is good enough to be used in this tool because it has a fairly small percentage error value. This sensor will trigger the nutrient pumps A and B to turn on if it detects that the ppm level of the nutrient solution is below the set point, and after the nutrient pump is active, the stirring motor will then be active to stir so that the nutrient solution level in the box is evenly mixed. Next, the ultrasonic sensor is used to detect the level of the nutrient solution in the box. When the water is detected below the set point, it will trigger the water filling pump to refill until it reaches the set point. And finally, the DHT22 sensor is used to detect the temperature and humidity around the planting media to regulate the duration of watering the plants which is set to turn on once every 15 minutes with a duration divided into 3 conditions, namely short (4 minutes), normal (5 minutes) and long. (6 minutes). The temperature and humidity that is often read by the DHT22 sensor ranges from 27-33°C and humidity 70% - 95%.

9. Plant Response

10. Table 4. Water Filling Pump Testing

No.	Nutritional Value (ppm)			Plant Response
	Day 1	Day 2	Day 3	
1	503	499	494	 Plants appear yellow
2	705	700	698	 The plants appear to be growing well and are fresh green in colour
3	902	898	895	 The edges of the plant's leaves look like they are burned and the roots turn brown and rot

CONCLUSION

From the results of the research that has been carried out, conclusions can be drawn:

1. This tool can take sensor readings quite stable with a fairly small average percentage error value, namely a TDS value reading error of 2.29%, a temperature reading error of 1.13%, a humidity reading error of 1.08% and a water level reading error of 2.32%.
2. This tool can control plant nutrient levels according to the range required by plants (560-840) ppm with an average value of TDS sensor readings of 675.08 ppm and can also carry out watering with a duration determined based on the temperature and humidity readings in the surroundings. planting medium by the DHT22 sensor.
3. The TDS sensor on this tool can trigger ¬the nutrient pump to actively fill nutrients into the box so that the level of the plant nutrient solution in this tool is maintained.
4. Differences in the ppm value of the nutrient solution can affect plant growth. Plants grow well when the ppm value meets the standards required by plants (560-840) ppm. When the ppm value of the nutrient solution is below standard, the plant's leaves will turn yellow. And when the ppm value of the nutrient solution is above standard, the growth of the plant leaves will look like they are burning and the plant roots will become rotten and brown.

REFERENCES

A. Wijaya and M. Rivai. (2018). "IoT-Based Monitoring and Control of Irrigation Systems Using Banana PI,." *J. Tek. ITS*. https://doi.org/doi: 10.12962/j23373539.v7i2.31113.

Bai, G., Ge, Y., Leavitt, B., Gamon, J. A., & Scoby, D. (2023). Goniometer in the air: Enabling BRDF measurement of crop canopies using a cable-suspended plant phenotyping platform. *Biosystems Engineering*, *230*, 344–360.

Faisal, M., Hidayat, S. A. M., Basrida, A. R., & Fazrin, M. T. (2023). Prototype of Water Level and Rainfall Detection System as Flood Warning Based On Blynk Iot Application. *International Transactions on Education Technology*, *2*(1), 1–10.

Galasso, L., Calogiuri, G., Castelli, L., Mulè, A., Esposito, F., Caumo, A., Montaruli, A., & Roveda, E. (2023). Theoretical construct into blocks of actigraphic-derived sleep parameters. *Chronobiology International*, *40*(2), 174–185.

Geovanie, M., Ruslianto, I., & Ristian, U. (2023). Aeroponic Media Potato Plant Monitoring and Control System Internet of Things Based. *CESS (Journal of Computer Engineering, System and Science)*, 8(1), 235. https://doi.org/https://doi.org/10.24114/cess.v8i1.42432

Gu, Q., Tian, J., Yang, B., Liu, M., Gu, B., Yin, Z., Yin, L., & Zheng, W. (2023). A novel architecture of a six degrees of freedom parallel platform. *Electronics*, *12*(8), 1774.

Iriani, J., & Lazuli, I. (2018). Sistem Monitoring Ruang Bercocok Tanam Aeroponik Berbasis Iot (Internet Of Things) Menggunakan Single Board Computer. *IT (INFORMATIC TECHNIQUE) JOURNAL*, 6(2), 184. https://doi.org/https://doi.org/10.22303/it.6.2.2018.184-195

M. Fadhil, BD Argo, and Y. H. (2015). "Design of a Prototype of an Automatic Sprinkler with an RTC DS1307 Timer System Based on an Atmega16 Microcontroller for Aeroponic Plants," J. Agricultural Engineering. *Trop. and Bassist.*, vol. 3, no. 1, pp. 37–43.

Meutia, E. (2015). *"Internet of things–Security and Privacy," p. (Vol. 1, N.*

RS Marginingsih, AS Nugroho, and M. D. (2018). "The Effect of Liquid Organic Fertilizer Substitution for AB Mix Nutrition on the Growth of Caisim (Brassica juncea L.) in a

Hydroponic Drip Irrigation System," J. Biol. *The Learning*, vol. 5, no. 1, pp. 44–51.

Sari, D. P. (2021). Prototype Alat Monitoring Suhu, Kelembaban dan Kecepatan Angin Untuk Smart Farming Menggunakan Komunikasi LoRa dengan Daya Listrik Menggunakan Panel Surya. *KILAT*, 10(2), 370–380. https://doi.org/https://doi.org/10.33322/kilat.v10i2.1376

Sneineh, A. A., & Shabaneh, A. A. A. (2023). Design of a smart hydroponics monitoring system using an ESP32 microcontroller and the Internet of Things. *MethodsX*, *11*, 102401.

Teguh, N. I. and K. M. (2017). "Wireless Network Design as a Redundancy Link in the Telkom Bandung Health Foundation (YAKES) WAN Infrastructure Using Network Development Life Cycle (NDLC) Methodology,." *BMC Public Health, 5, no*.

Zhang, J.-H., Meng, B., Zou, L.-C., Zhu, Y., & Hwang, G.-J. (2023). Progressive flowchart development scaffolding to improve university students' computational thinking and programming self-efficacy. *Interactive Learning Environments*, *31*(6), 3792–3809.