Development of Nutrient Film Techniques on Solar-Powered Internet of Things Devices for Aeroponic Planting

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Abstract. Cultivation by replacing soil media with charcoal or other media, known as the hydroponic method, is now very popular. This hydroponic cultivation method then developed further into an aeroponic one, namely the cultivation of plants in the air without using any soil at all. This method aims to use water optimally, maximize the use of space, and reduce the human resources involved in its management because it is equipped with automatic control equipment. However, aeroponic cultivation techniques are very dependent on electric power, so if the power source is cut off, the system cannot work. Similarly, in the process of plant care. Control devices must be properly arranged in such a way as to ensure the plant gets nutrients from the roots so that the growth process can occur properly. This study aims to provide solutions to overcome the problems experienced by plant cultivators with this aeroponic system. The proposed solution is to create a nutrient film technique (NFT) on a solar-powered control device to spray nutrient solution on the plant roots on a regular basis. This controller device was developed using ESP32 so that the device can work automatically and can still be monitored by factory managers from anywhere and anytime by utilizing internet of things technology. This module utilizes temperature sensors, proximity sensors, and water quality sensors to support the automation of aeroponic plant cultivation. Based on the test results, it was found that each sensor works well with a small error: the temperature sensor has a reading accuracy rate of 96.54%, the proximity sensor is 97.2%, and the nutrition sensor is 96.8%. Based on the permissible error standard, which is a maximum of 5%, the performance of this aeroponic cultivation control device deserves to be in the proper category.

Keywords: aeroponic, nutrien film technique, ESP32, automation and control, solar power.

1 Introduction

The cultivation of crops with limited land has now become a trend for people in urban areas and farmers who want increased production [1]. This method of plant cultivation replaces the role of soil as a growing medium, even without any media at all [2]. Currently, there are two types of planting methods: hydroponics and aeroponics. The aeroponic method is a planting method without media where plant roots are left hanging in the air and nutrients are distributed using a spraying technique. The process of spraying nutrients on plants should be done automatically and arranged in such a way as to ensure that the plants get the nutrients they deserve [3]. Another advantage is that the planting process can be carried out in stages, as

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shown in Figure 1 [4]. So, with the same planting area, the harvest volume can be greater according to the number of planting levels.

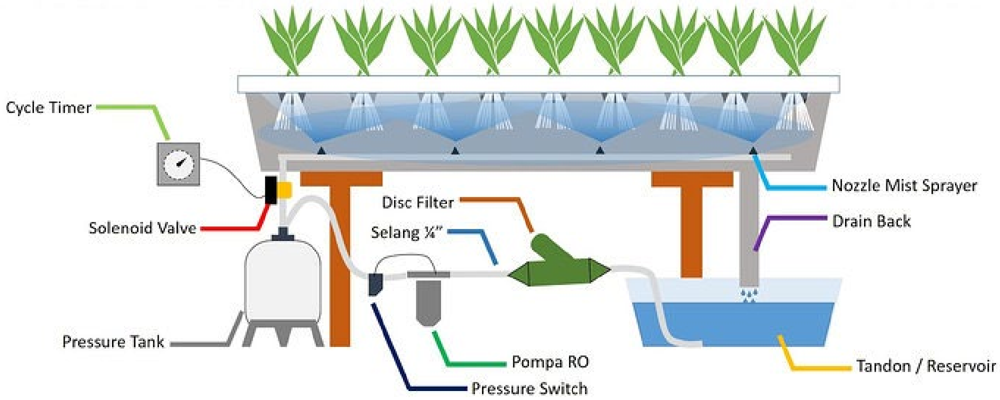


Figure 1. Aeroponic planting design [5]

The provision of nutrients by spray aims to optimize the number of nutrients received by each plant [6]. Spraying is carried out based on the nutritional value of the roots, which is read by a nutrient solution sensor in the air, known as a total dissolved solids (TDS) sensor, and a proximity sensor to ensure the air volume is maintained. Automated work processes are beneficial for farmers because they can reduce the need for human resources for their management [7]. This technique of spraying nutrients on the roots is called nutrient film technique (NFT) [8]. This technique is commonly used in hydroponic growing methods where nutrients are mixed into water and flowed in a channel where, above, plants are placed whose roots touch the water full of nutrients [9]. Although using the same technique, in the aeroponic planting method, nutrients do not flow into the container but are sprayed in the form of mist onto the plant roots periodically. [10].

The many advantages offered by this aeroponic planting method are, of course, accompanied by obstacles as well. The obstacle that is often faced is that this method relies on electric power to operate it [11–12]. If a power source is not available, then the process of providing nutrients to plants will be disrupted, which can interfere with plant growth. Another barrier is that the control system must be configured in such a way that plants can rely on it to provide the nutrients they require without delay [13]. In this study, an aeroponic plant care automation tool was developed using a microcontroller-based nutrient film technique, namely the solar-powered ESP32 module. This development aims to provide solutions to the constraints experienced in aeroponic cultivation activities, such as the need for intelligent control systems, supervision, and reliable power sources. This automation device can provide further opportunities for aeroponic plant management in remote and inaccessible locations via the electricity grid [14].

2 Literature Review

2.1 Aeroponic

Aeroponics is a method of growing plants without using soil or growing media but instead using water in the form of mist. Judging from the constituent words, these consist of aero and phonic. Aero means air, and phonic means cultivation method, which literally means growing crops in the air without using soil media for the growth process and meeting nutritional needs by spraying it on plant roots [15]. Aeroponics is an extension of hydroponics. In hydroponics, the nutrient solution is made to flow and circulate to meet the nutritional needs of the plant; in aeroponics, the nutrient solution is converted into a mist or sprayed on the plant's roots. The aeroponic system is one of the modern agricultural systems currently used by farmers because it has advantages compared to traditional farming systems or using soil media. There are different types of soilless farming systems, such as hydroponic and aeroponic systems [16]. This aeroponic system has the advantage that it can be applied to a place that is not too wide or lacks land because it can be done with a structured system. In general, aeroponics cultivation is placed in a greenhouse that can manage oxygenation in each fine mist of nutrient solution so that the roots of plants get enough nutrients to grow optimally.

2.2 Solar Panel

A solar panel or solar cell is a device that can convert energy from sunlight into electrical e16 volthroughergy from the photovoltaic,rocess or also called the technology of converting solar energy into elenergy,al energy in the form of solar cells arranged in series or parallel into a solar module[17]. The electrical voltage obtained from the solar cell is not large enough, appro0.6 voltstely 0.6V without a0.45 volts or 0.45V using a load. To receive a stable voltage, several solar cells are designed in series. With 36 pieces of solar cells arranged in series,producewill make a voltage of approximately 16V. This voltage is capable of powering a 12 V battery.To produce the optimal current and voltage needed for daily use, it is necessary to arrange about 20 or more solar cells to become solar panels [18].

Aside from saving energy because it is derived from the sun, the use of solar panels in aeroponics systems is not hazardous because it differs from the use of fossil fuels, which emit greenhouse gas emissions.The use of solar panels has a significant impact on climate change, so the use of aeroponics systems with solar panels can help create clean air from the most abundant energy source on earth, namely the sun.The solar charge controller is a tool of the solar power generation system that acts as a regulator for electric current according to the incoming current to the solar panel or the load current used. The use of a solar charge controller also functions as protection to prevent overcharging or overloading the battery. The charge controller can regulate the voltage and current from the solar panel that flows into the battery. This tool also has several features, including dual 5V USB ports and the ability to automatically detect 12V or 24V voltage.The function of this tool is almost similar to that of a fuse, namely, when the battery charging has reached the specified limit or is full, this tool will work automatically to stop the electric current flowing in the battery, so that the battery can last longer. When the battery is almost empty, the charge controller will stop the consumption of electric current from the battery at the load to maintain the quality of the battery so that the cells contained in the battery are not damaged.In general, solar panels with a voltage of 12 volts produce an output voltage of around 16 volts to 20 volts; however, if the charging settings are not used, the battery will be damaged if the charging voltage is too high.A battery with a voltage of 12 volts requires a voltage when charging of around 13 to 14.8 volts, depending on the type of battery used, to be fully charged so it can be used [19].

2.3 Internet of Things (IoT)

IoT is a system where physical objects can be connected to the Internet using sensor media. IoT also refers to the utilization of connected intelligent devices and systems to use data collected from sensors and drives embedded in a system with other physical objects. With the development of IoT technology, humans no longer need to configure a system on a machine when using it; they can set it up automatically and interact with other systems. In IoT technology, each object must have an IP address, which is its identity or identifier on the network and can be set by other devices on the same network. The IP address of each of these devices is connected to the internet. To maximize the productivity of aeroponic plants, information on environmental conditions such as temperature and humidity levels, as well as the concentration of the solution in nutrients, is required to make decisions about what needs to be done in the aeroponic system [20].

NodeMCU is an IoT platform microcontroller with a wifi module by ESP8266 that connects to electronic devices such as a microcontroller via a wifi connection.The default programming language of the NodeMCU module is Lua. The ESP8266 was developed by Espressif. With the wifi communication module owned by NodeMCU, the development of IoT systems is easy because the module is very helpful, efficient, and optimal for various kinds of technological research. The ESP8266 also features a processor, GPIO, and memory. This module includes a system-on-chip (SOC) module because it does not depend on a microcontroller. The ESP8266 was chosen over the standard wifi module because it can save energy and has a deep sleep mode feature.The DHT11 sensor is a component that can calibrate digital signals so that it can provide information in the form of actual values of temperature and humidity. The DHT11 sensor has digital output, so programming is needed to be able to use it, and there is no need for signal conditioning or ADC. This sensor is a component that has excellent stability and fast response and is equipped with an ATmega8 microcontroller capacity at an affordable price. The TDS sensor is an electronic component in the form of a sensor that operates when it detects the conductivity of a solution or a dissolved substance in a solution that comes from organic and inorganic substances. If the solid of a solution changes, the value will also change; if the liquid contains minerals, the conductivity will increase and the output will be greater; and vice versa, if the liquid contains fewer minerals, the output will be smaller and the conductivity will decrease. Testing the TDS sensor is done by connecting it to the ADC pin on the Arduino to read the change in voltage in the solution. The unit used in this TDS sensor is the PPM, which is a unit for measuring the number of dissolved particles. The HC-SR04 is a type of ultrasonic sensor that has four pins to activate it and apply its function as a controller, sender, and receiver of ultrasonic waves. The HC-SR04 sensor's pins include the VCC pin for power and GND for the sensor's ground, while the other two pins, the echo pin and the trigger pin, are used to capture or receive signals, respectively.This sensor works by reflecting signal waves and receiving reflected signal waves, so the sensor can be used to measure distances within a certain range. The range of this sensor is about 2 cm–400 cm, while the angle range is approximately 15 degrees. The frequency range of waves that can be emitted on the HC-SR04 sensor is around 40.000 Hz . [21]

Blynk is a server service that is currently widely used as a supporting medium for IoT research. This server service can be used and downloaded in the form of an application by smartphone users based on Android and iOS. There are 3 main components in Blynk, including: 1) the Blynk application, which has an interface design with various input and output components that will support displaying, sending, receiving, and representing data. The representation of the data can be in the form of visual numbers or graphics; 2) Blynk Server, a cloud-based back-end service facility that functions to manage communication between applications and hardware; and 3) Blynk Library, which is used for programming code development. The Blynk library is available for multiple platforms on hardware (including the ESP8266 NodeMCU) and offers IoT developers the flexibility to support hardware in the Blynk environment.

3 Research Methods

This research was conducted at the State University of Medan. After identifying problems, conducting literature studies, and analyzing needs, researchers carried out system design, namely hardware and software design. The hardware that will be used in the development of a solar aeroponic system with the IoT-Based NFT Method and the relationship between each of these pieces of hardware indicate that if the system does not run properly, repairs will be made, and the program will be created using the Arduino IDE application to create a NodeMCU ESP8266 control program and create applications to monitor systems built with the Blynk application. The research design that has been made will be implemented through the implementation phase and tested using hardware and software. The testing phase aims to be able to find out the function of the tool that has been designed to work properly in accordance with the program created. The analysis of the results of system testing is the stage in which the performance of the system and the data generated during the testing phase are analyzed based on the formulation of the problem designed in this study. Research documentation is carried out as evidence of reporting during the research process and to support the preparation of research reports; the summary of this can be seen in Fig. 2 below.

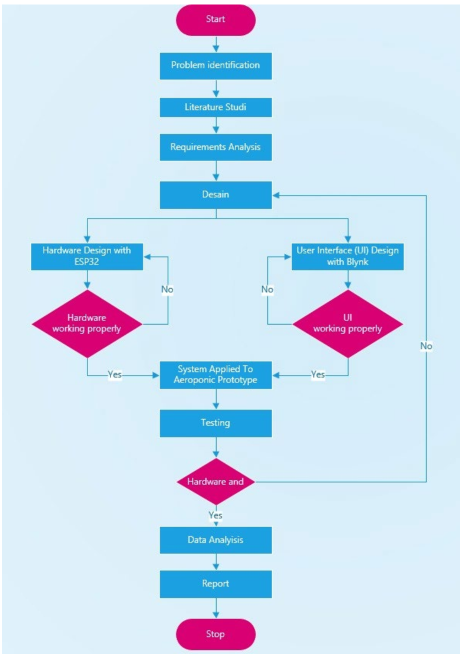


Figure 2. Research method

The system design in this study has five main parts: the hardware system, input, process, output, and system interface. The main source of electrical energy for this system is solar panels, and the system is controlled by the NodeMCU ESP8266, which can adjust the I/O needs of the system, as shown in Fig 3 below.

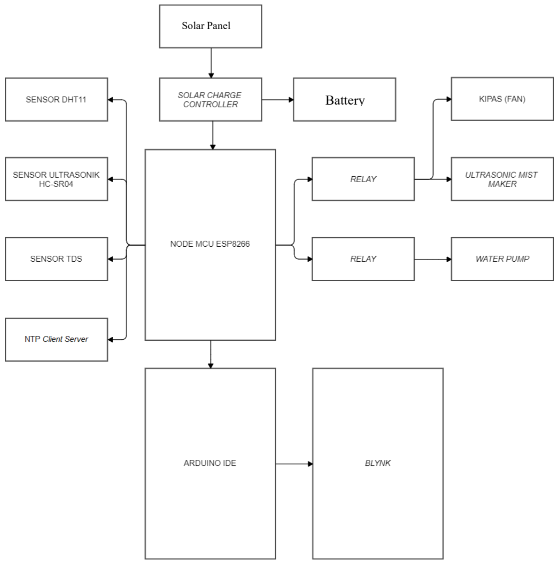


Figure 3. System design

Following the completion of the system design and tool creation processes, the next step is to develop a program algorithm to configure the system on the designed tool.The algorithm uses the C programming language, which is written in the Arduino IDE application, and the program that has been created will be uploaded to the NodeMCU ESP8266. Furthermore, the program will be connected to the Blynk application as a user interface, which aims to make it easier for users to monitor plant growth through the displayed data.

The system to be designed's working principle is that the process begins with initializing programs and systems to ensure NodeMCU is connected to wifi and Blynk.After that, the irrigation process (fogging) will be activated automatically. Furthermore, in the observation process, data will be read on each variable, including temperature and humidity data, water volume, TDS solution content, and time. In standby mode, the system will detect whether the water volume is at a height of 5 cm or less; if it is less than 5 cm, the water pump will be activated to increase the water volume. For standard values of temperature and humidity, the temperature value is around 26°C–32°C, and the humidity value is around 65%–96%. If the value exceeds the standard, the fan will be active to normalize the standard value of temperature and humidity. Meanwhile, the standard value of the TDS solution level will be adjusted based on time, starting with the first week of 500 ppm, the second week of 700 ppm, the third week of 900 ppm, and the fourth week of 1200 ppm. If the ppm value every week is less than the standard value, the nutrient solution pump will be activated to fill the nutrient solution tank so that the ppm value reaches the standard ppm value. If the ppm value exceeds the standard, the nutrient pump will be deactivated. After that, all the data information will be displayed on the Blynk application.

a. Research Implementation Procedure

In the research that will be carried out, the data is obtained by observing the residential environment in the Tangerang City area and each environment in turn in order to find out the problems that exist in the condition of vacant land that no longer exists for farming. Taking some data from the environmental sector, it is necessary to conduct agricultural research in order to be able to grow crops that can be done at home, particularly in the field of modern agriculture. The following are some procedures for the implementation of the research to be carried out, namely as follows:

- Pakcoy mustard planting is done by choosing good seeds for the seeding process before becoming plant seeds using Rockwool media until they reach the age of about 10 days or already have 4 leaves to be transferred to the aeroponic system. Pakcoy mustard plantings are placed in netpot nets so that the plant roots can get sufficient nutrients from misting nutrients in the aeroponic system and placing the plants in sufficient sunlight.
- Plant care will be performed on a daily basis according to real-time using the NTP client server. Observations were made to determine the growth conditions in plants that can grow well and ensure that there are no organisms that interfere with plant growth.
- In the observation process, plants will be monitored once a day with a Blynk application that functions to monitor the state of temperature, humidity, and nutrients in plants. In addition, the observation process carried out aims to ensure that the software and hardware function properly according to the program created.
- Data collection: the data used in the research carried out are temperature data, humidity data, nutrient solution data, and solution height data. Data on temperature and humidity in plants are variables that are used as inputs and taken from the DHT11 sensor, while the nutrient solution data is taken from the TDS sensor to determine the number of dissolved particles.

b. Trial plan

Testing at the initial stage of the trials to be carried out involves calibrating each sensor used in the aeroponics system. In this trial plan, the researcher will identify the percentage error of the system using manual calculations by comparing the values of the readings of the DHT11 sensor, TDS sensor, and HC-SR04 sensor with a digital hygrometer thermometer, a digital TDS meter, and a ruler measuring instrument, so that sensor accuracy can be determined based on the error percentage. The system testing was carried out to determine the system performance of the development of a solar aeroponics system using the IoT-based NFT method.

In the next trial process, namely testing the effectiveness of the system by identifying the length of time for misting plants as a substitute for the irrigation system according to the program, a timer is used to set the misting time on plants, namely 45 seconds active and 15 seconds inactive, so that plants are able to absorb sufficient nutrients. System testing and observations on plants were carried out between 07.00 and 15.00 because the time interval was influenced by the intensity of sunlight, temperature, and humidity in the surrounding environment.

4 Result and Discussion

4.1 Research Testing

In the development and design of this research, testing was carried out by functional testing of each component as well as performance testing on a solar aeroponics system using the IoT-based NFT method. The test to be carried out consists of testing the aeroponic system and the quantitative variables used in the aeroponic system. The goal of the tests is to overcome the failure of each piece of software and hardware so that it can continue to run according to program instructions, as well as to test all system devices so that they can function properly without one uncontrollable factor, particularly on several quantitative variables. with several measuring tools to be able to find out the error value.

4.2 System Testing

In this test, the solar panel circuit that is used as a voltage source will be tested for the circuit at the input and output voltages which aims to determine the feasibility of the circuit to be applied and to avoid damage to other supporting components. The input of this circuit is adjusted to the battery used, namely 12V which is connected to the solar charge controller which can detect the input voltage and stabilize the output voltage for the needs of the microcontroller, namely 5V using the USB port and for load needs, namely 12V using the output from the solar charge controller. To ensure the voltage from the USB port for the microcontroller remains 5V and the output for the load is 12V. The calculation in the 2nd test is carried out with a load where the value of the solar charge controller's USB port is 5.08V and the value of the multimeter measuring instrument is 4.53V. Meanwhile, the value of the output of the solar charge controller is 12.01V and the value of the multimeter measuring instrument is 11.85V. The results of measuring the voltage value from the solar charge controller and multimeter measuring instrument without load and with load have obtained an average error value of 6.95% from the USB port. While the average error value of the output is 0.71%. NodeMCU identification has been carried out for the type of NodeMCU ESP8266 microcontroller using the Arduino IDE application as a medium for making programs and uploading them to the specified microcontroller board. Programming is carried out using ISP (In System Programming) mode which can be programmed directly on the microcontroller circuit so that it can be identified if an error occurs in the program created to ensure the program functions properly.

4.3 Overall Testing

This overall test aims to be able to find out whether the system is running well or not. The working principle of this aeroponics system starts with a system that simultaneously detects temperature and humidity, water volume, nutrient solution PPM levels, and time information from the NTP client server, which will then be displayed on the blynk application so that it can be monitored in real-time. After testing as a whole, data will be obtained from each variable used as shown in the following figure.

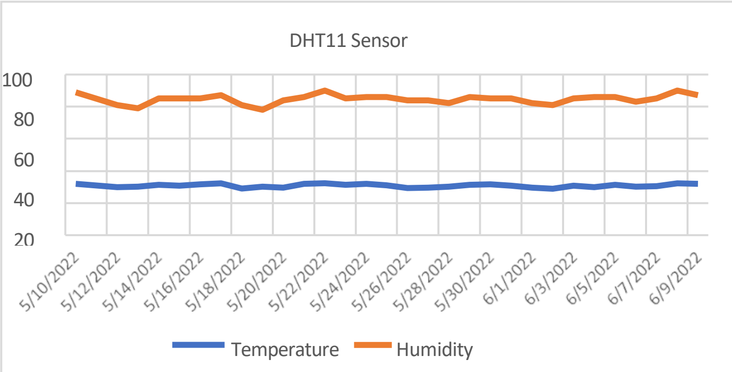


Figure 4. DHT11 sensor sensor test data graph.

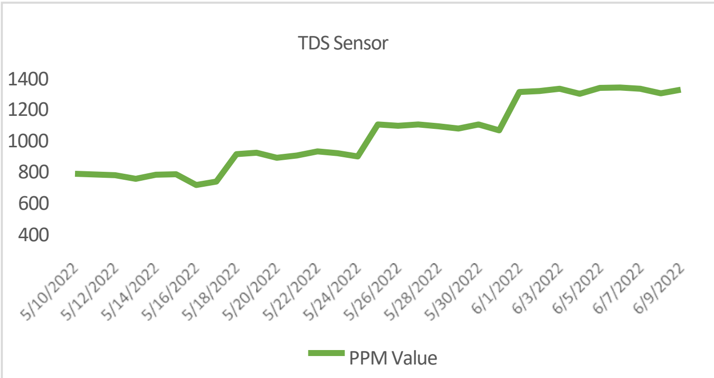
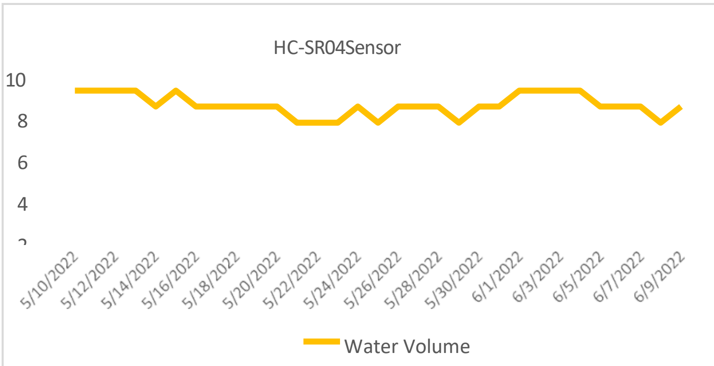


Figure 5. TDS sensor test data graph.



Figute 6. HC-SR04sensor test data graph.

Based on the overall test data above, the temperature and humidity values have changed based on the intensity of sunlight and the process of misting. The value of the volume of water changes when the water is less than 5 cm and when filling the nutrient solution every 7 days.

Meanwhile, the ppm value in the nutrient solution increased rapidly on May 18, 2022, to 745 ppm. Then on May 25, 2022, it shows the number 986 ppm, and on June 1, 2022, it shows the number 1247 ppm. Changes in the ppm value at 7-day intervals indicate that the system is working according to the program, namely, the specified standard ppm value will change after 7 days, and if the ppm value is below the standard value, the nutrient pump will be active to drain nutrients. And if the ppm value read by the TDS sensor reaches the standard value, the nutrient pump will be deactivated.

5 Conclusions

The use of energy from sunlight as a power source to run an aeroponic system using solar panels with a peak power of 115 watts in one hour when in very good condition with a battery storage capacity of 7.5 Ah or about 7500 mAh is good enough and efficient to use periodically based on the overall test which was carried out for 30 days. The use of NodeMCU ESP8266 in an aeroponic system for IoT-based modern agricultural cultivation can be applied as an actuator controller in the form of an ultrasonic mist maker, fan, and water pump which will be active based on the reading value of the TDS, HC-SR04, and DHT11 sensors. The test results of the system made can detect the level of concentration or nutrient levels in the air using the TDS sensor by testing the TDS sensor in table 4.3 with a percentage value of 6.46% with an accuracy rate of 93.54%. The test results made can observe the plant growth process based on time and at any time as long as the system is connected to a real-time wifi network, temperature level (26℃-32℃) and air humidity level (65%-96%), nutrient solution level (500-1200 ppm), as well as the availability of nutrient solutions in the nutrient solution bath automatically using the blynk application. Based on tests on the aeroponic system, the results of temperature measurements with the DHT11 sensor indicate that the sensor works well because the error value obtained during temperature measurement is 1.52% with an accuracy rate of 98.48%. Meanwhile, the results of humidity measurements from the DHT11 sensor are 4.98% with an accuracy rate of 95.02%. The measurement is done by comparing the measurement of the DHT11 sensor with a digital hygrometer thermometer. Furthermore, the results of measuring the height of the nutrient solution with the HC-SR04 sensor show that the sensor works well because the error value obtained at the time of measurement is 5.66% with an accuracy rate of 94.34%. Measurements are made by comparing the measurements by the HC-SR04 sensor with a ruler. Furthermore, the results of the TDS sensor measurement show that the sensor works well because the error value obtained at the time of measurement is 6.46% with an accuracy rate of 93.54%. Measurements are made by comparing the measurements by the TDS sensor with a digital TDS meter. The results of automatic testing for filling air and nutrient solutions using a water pump are based on the output value of the HC-SR04 sensor which reads the water level in the nutrient solution tank less than 5cm, the water pump will be active and when the ppm value is below the standard ppm value based on the reading TDS sensor, the water pump will be active to fill the nutrient solution into the nutrient solution bath.

The suggestions that can be given by the author so that it can be developed in this study have not used thicker water storage tanks and further so that there is no leakage in the water storage tank. adding an sd card module as a program storage medium on the NodeMCU ESP8266 when it loses internet connection or when the condition does not get electricity so that the program does not reset to the initial program, when it is reactivated the program continues to run according to the research design. Added an OLED display module as direct monitoring of the system so that it can be compared with the blynk application if there is a discrepancy in the data displayed. Further research is needed for the cultivation of other plants such as tubers or fruits using an aeroponic system.

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