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Smart nutrision hydroponic mix Microcontroller-based system with solar power plant integration

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ABSTRACT

Indonesia's agricultural sector faces the challenges of climate change and land constraints that drive the need for sustainable agricultural technology innovation. This research designed a Deep Flow Technique (DFT) hydroponic system based on Arduino Mega 2560 which is integrated with a Solar Power Plant (PLTS). The system uses a DFRobot TDS sensor for nutrient monitoring, an HC-SR04 ultrasonic sensor for water level detection, an ACS712 voltage and current sensor for electrical monitoring, and an I2C LCD for the display. The integration of solar power with solar panels, MPPT, and batteries provides sustainable energy. The test results showed that the TDS sensor had an accuracy with an error of 1.38%-41.11%, the ultrasonic sensor showed good reading consistency, and the electrical sensor gave the results according to the reference. Testing of the overall system proves the integration is successful with real-time monitoring capabilities and automatic controls. The solar power system has succeeded in providing stable energy for independent operations. The research resulted in an automated hydroponic prototype that improves production efficiency with the support of renewable energy.

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1. INTRODUCTION

The agricultural sector is a vital foundation for Indonesia's national food security as an agrarian country. However, the challenges facing the sector are increasingly complex, including uncertain climate change, rapid population growth, decreasing agricultural land limitations, and degradation of water availability. This condition causes a decline in the productivity of conventional agriculture and threatens the stability of the national food supply. Therefore, agricultural technological innovations are needed that are able to increase production efficiency while minimizing dependence on uncontrollable natural factors [1]. The weakness of traditional farming systems lies not only in its dependence on natural conditions, but also in its limitations in precise nutrient control and land-use efficiency. This causes farmers to experience difficulties in optimizing crop production, especially in urban areas or areas with limited land. In addition, the absence of an integrated monitoring system makes agricultural management less efficient and difficult to evaluate performance accurately [2].

The development of Internet of Things (IoT) technology has opened up great opportunities to develop more sophisticated and effective agricultural systems. Hydroponic systems with dual automation that combine two methods such as nutrient sensors and environmental control have been shown to provide much higher productivity levels than conventional farming systems [3]. This concept works on the principle that even if one of the environmental parameters is disrupted, the system can still maintain optimal conditions through compensation from the other parameters. The implementation of this layered system is critical given the increasing need for sustainable food production

Several previous studies have shown the great potential of the application of IoT technology in automated hydroponic systems. Andrianto and Suryaningsih designed an ESP32-based system that is integrated with automatic nutrition monitoring to provide real-time notifications when nutritional parameters are not up to standard [4]. Eridani et al. developed a nutrient authentication system using a combination of TDS sensors and pH control with Arduino integration that allows supervisors to conduct monitoring more effectively [5]. Meanwhile, Setiawan utilizes Arduino Mega to automatically regulate nutrient mixing and send monitoring data through an integrated system [6]. These studies show that the integration of various IoT technologies can create a comprehensive and easy-to-monitor hydroponic system.

Another study conducted by Tryora Inzaghi et al. proposes a hydroponic system with ESP32 and an RFID sensor capable of recording all nutrient feeding activities to a cloud database automatically [7]. Wahyudi et al. developed an Arduino-based system and monitoring that allows administrators to control and monitor nutrition in real-time remotely [8]. Yulianto et al. designed a two-factor authentication system based on TDS sensor and pH control with an alert system to improve the accuracy of nutrition administration [9]. Yuwono developed a system that combines TDS sensors and temperature control with the ability to record activity and send data to the server automatically [10]. Despite a lot of research done, there are still gaps in integrating all ESP32 components, nutrient sensors, pH control, and auto-logging into one optimal system powered by renewable energy.

Based on the analysis of previous research, this study aims to design and develop a Deep Flow Technique (DFT) hydroponic system that integrates dual automation based on nutrition sensors and environmental control with a monitoring system through IoT technology. The system developed will use Arduino Mega as the main microcontroller, TDS sensor for nutrition authentication, TFT keypad as a control input interface, temperature and pH sensor for documentation of environmental conditions, and buzzer as a nutrient access notification alarm. The software will be developed using Arduino IDE with the integration of Solar Power Plants (PLTS) to provide a sustainable and environmentally friendly energy source. With this system, it is hoped that hydroponic solutions can be created that are more robust, easy to monitor, and have complete access documentation for the purpose of productivity audits and independent system investigations.

2. METHOD

The initial step in designing begins with the creation of a block diagram of the system, which describes the workflow of each part in the system in general. Each block in the diagram represents a functional component or set that has its own role in the entire system. By understanding the relationships between blocks and their functions, the implementation process can be carried out in a more structured and efficient manner.

The microcontroller acts as the main control center in the hydroponic system, which is equipped with a variety of sensors and actuators to support automatic operation. The explanation of each block in the system can be described as follows: in the energy source and storage blocks, solar panels function as the main energy source by converting solar radiation energy into electrical energy in the form of direct current (DC) used to charge batteries; MPPT (Maximum Power Point Tracking) is a power control module that optimizes energy absorption on solar panels by adjusting the panel's working point so that it is always at the maximum power point, thereby increasing battery charging efficiency and stabilizing the output voltage according to the battery charging characteristics; Batteries (batteries) act as a storage medium for electrical energy generated by solar panels, where the stored energy is used to supply power throughout the system when there is no solar radiation, such as at night or cloudy weather; and the Power Supply module is responsible for providing stable voltage for control and measurement system devices, such as microcontrollers and sensors, thus ensuring the stability of the overall system's work.

Furthermore, in the control and monitoring system block, the microcontroller is the main control center that works as the brain of all system work, starting from processing sensor measurement data, controlling actuators such as pumps and motors, and regulating relay work based on predetermined programming logic; While the display functions to display important data regarding sensor information and system status, such as voltage, current, and nutrient quality, it becomes a user interface that facilitates monitoring. In the actuator and measurement system blocks, the relay is used as an electronic switch controlled by a microcontroller to connect or disconnect the current to the load according to the instructions of the control system; The pump functions as an actuator that works based on the commands of the microcontroller, where this pump serves as an injector or carrier of nutrients automatically based on data from the sensors set by the microcontroller; and sensors act as inputs to measure physical parameters in the system, using several sensors that have their own functions, namely voltage and current sensors to measure electrical parameters in the system, and TDS (Total Dissolved Solids) sensors to measure the concentration of solutes in water related to plant nutrients.

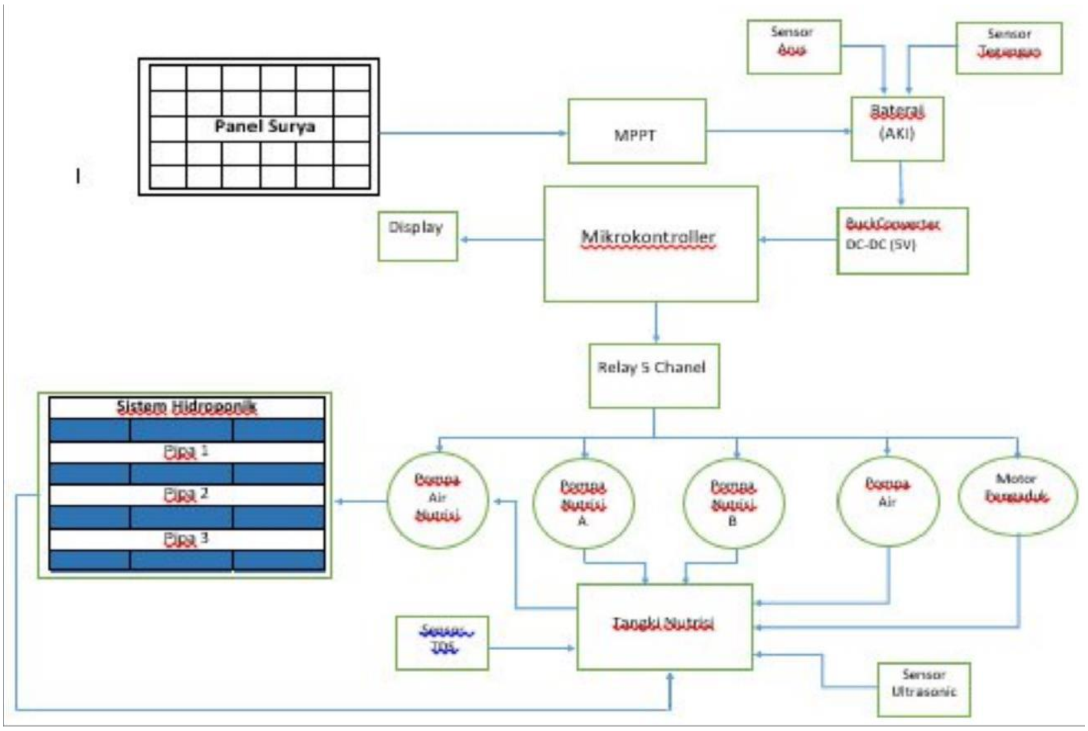


Figure 2. Block diagram

The microcontroller-based Smart Nutrition Hydroponic Mix system design scheme is a strategic step developing an efficient and automated hydroponic farming system. The system is designed to intelligently control and monitor nutrient delivery using microcontrollers integrated with sensors such as total dissolved solids (TDS) sensors. These sensors serve to detect the condition of the nutrient solution, which will then be analyzed by a microcontroller to determine the appropriate dose and timing of nutrient administration. With this approach, the system can maintain the stability of the condition of the nutrient solution so as to support optimal plant growth. This system is also designed with the integration of Solar Power Plants (PLTS) as the main energy source. The use of solar energy aims to improve energy efficiency and support the implementation of environmentally friendly and energy-independent systems. The electrical energy generated by the solar panels will be stored in the battery and then transmitted throughout the electronic components through a voltage regulator circuit.

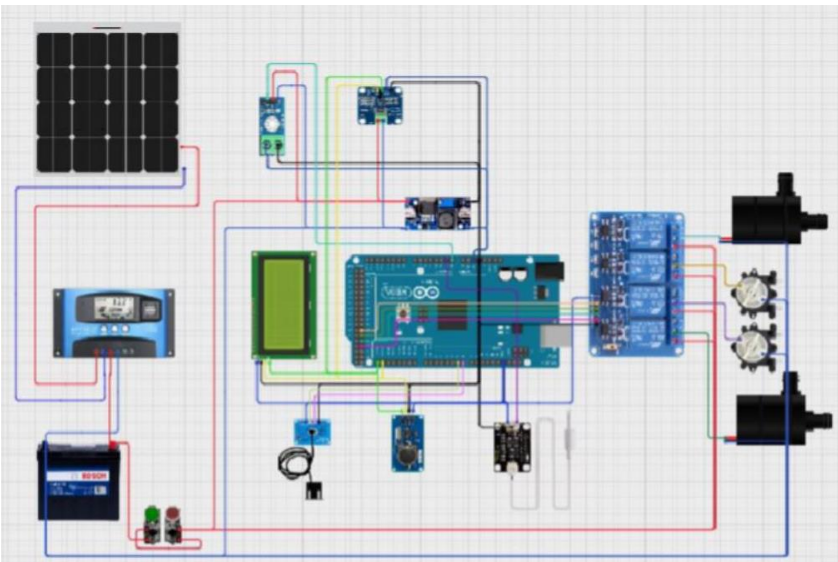


Figure 3. Circuit diagram

The design of the system flowchart shown in the Figure 4, involves several key processes that function to identify data, process data and execute data from sensors. The initial stage begins with the initialization of the system, where the microcontroller activates all connected sensor and actuator components. Next, the system reads the data from the water level sensor (usually using an ultrasonic sensor) placed in the nutrient tank. This sensor will detect the height of the water level to ensure the availability of water as the base material for the nutrient solution. After that, the system also reads data from the TDS (Total Dissolved Solids) sensor to determine the concentration level of nutrients dissolved in the water. This TDS data is an important basis in determining the need to add nutritional solutions to the tank. Once the data from the sensor is obtained, the system enters the processing stage. The data from the water level sensor is processed to determine whether the water level is sufficient or not. If the water is below the threshold, then the system gives a command to activate the water pump to refill the nutrient tank. If the water level is sufficient, the system proceeds to the next stage. Here, the data from the TDS sensor will be compared to the predetermined set point values. If the TDS value is still below the threshold, it means that the concentration of nutrients is still lacking and needs to be increased.

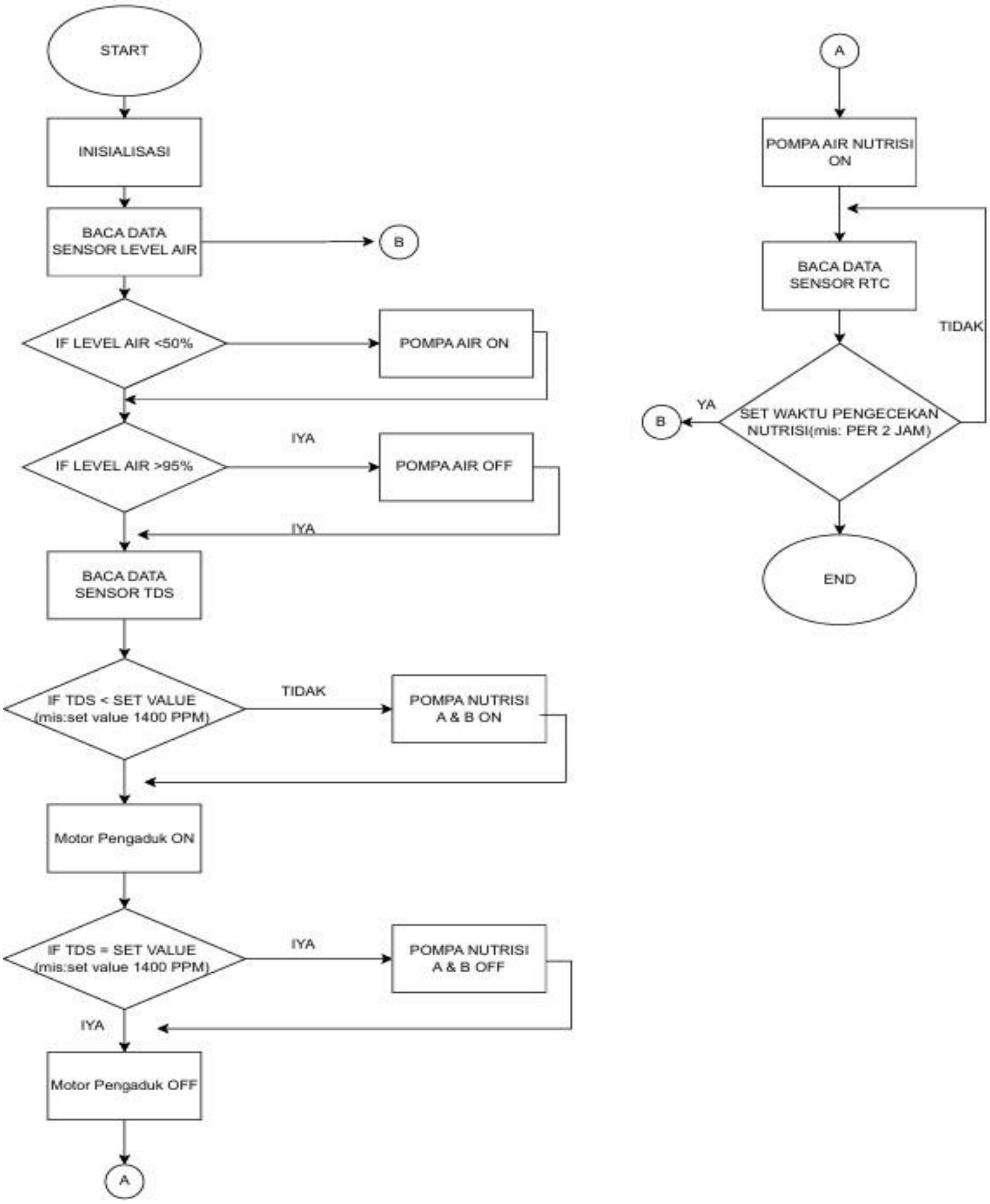
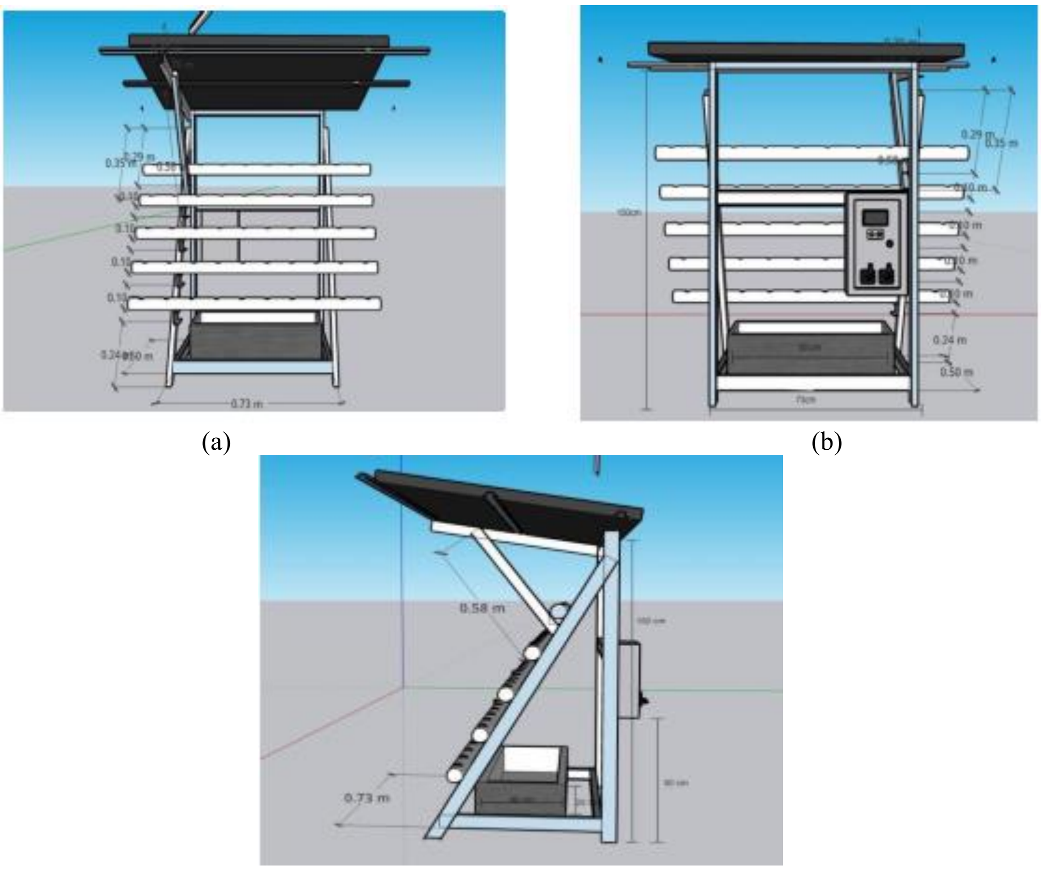


Figure 4. System Flowchart

Based on the processing results, the system then executes certain actions. If there is a lack of water, the water pump will be turned on to fill the tank. If the nutrient concentration is lacking, then pumps A and B (nutrient pumps) will be activated to automatically add nutrient solutions to the tank. After the addition is complete, the solution is drained into the hydroponic system. This entire process is carried out automatically by the microcontroller based on programming logic and real-time sensor readings. Once all parameters are in normal conditions (enough water and nutrients are suitable), the system will enter the mode of distributing nutrients to the plants.

Flowcharts are also used to represent the conceptual structure of complex software systems, serving as design documents used by systems analysts to communicate, negotiate and represent the complexity of a process Working principle The system designed is an automation system based on renewable energy that utilizes solar power as the main source of electrical energy.this system is used to manage hydroponic installations automatically, starting from regulating nutrient injection, monitoring water quality, to controlling electrical loads through microcontrollers. The working principle of the system in general can be explained as follows: The electrical energy generated from solar panels will enter through MPPT (Maximum Power Point Tracking), so that it can optimize the electrical power produced by the solar panel to match the needs of the battery content. The electrical energy emitted by the MPPT will be stored in the battery. When the intensity of the sun absorbed by the solar panel is in maximum condition, the energy can be channeled to the load, while the excess energy will be used to charge the battery as energy storage, so that at night the energy previously stored in the battery can be used. The energy from the battery is channeled to the Buck Converter which functions to lower the voltage according to the work needs of the Arduino ATmega 2560 and sensors (usually 5-3.3Volts). The Arduino ATmega 2560 serves as a control center that receives inputs from various sensors and provides outputs to control the pump and stirring motor. The control of water pumps, nutrient mix water pumps, A&B nutrient pumps, as well as stirring motors use relays as automatic electronic switches controlled by Arduino ATmega through logic commands programmed according to plant needs based on data from sensors. The nutrient water that has been mixed in the nutrient tank will then be channeled to the hydroponic system. All processes occur automatically based on Microcontroller programming to ensure optimal quality and nutrient flow for plants.



(a) (b)

(c)

Figure 5. Hydroponic Construction Design, a) Front view, b) Rear view, c) Side view

The design of hydroponic hardware in the Smart Nutrition Hydroponic Mix System is designed with the main structure consisting of a frame made of 3-inch diameter PVC pipe arranged vertically, forming an integrated system (Deep Flow Technique). At the bottom is the main nutrient tank that serves as a reservoir for nutrient solutions before being distributed throughout the system. DFT uses a container with a depth of 5-10 cm for plants with higher nutrient needs.

3. RESULTS AND DISCUSSION

Total Dissolved Solids (TDS) sensor testing is carried out to evaluate the performance of the sensor in measuring the concentration of dissolved solids in water with a level of accuracy and precision in accordance with the set standards. The testing process is carried out under controlled laboratory conditions to minimize interfering variables, such as temperature and environmental pressure, that may affect the measurement results. The TDS sensor used in this study is a DFRobot TDS Meter type, which is integrated with an Arduino Atmega 2560 microcontroller for real-time data acquisition. Figure 6 shows the experimental process carried out.

(a) (b)

Figure 6. Experimental process. A) LCD display, b) Results using TDS Mater

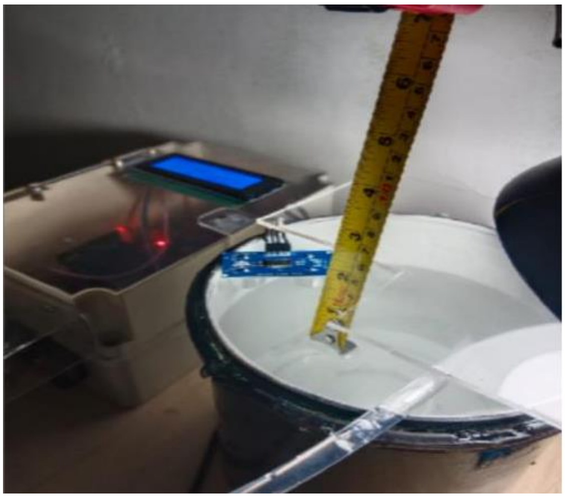
The test was carried out using a solution with a known TDS concentration, which can be seen in the table below, which was made by dissolving to ensure the consistency of the measurement results. The data obtained from the TDS sensor is then compared with the reference values measured using a standard laboratory tool, the TDS meter, to calculate the measurement accuracy level. The results of the measurement of the Total Dissolved Solids (TDS) value obtained from the DFRobot TDS sensor showed a difference in value when compared to the measurement results using the analog TDS meter as a reference tool. These differences can be seen in the table below which presents the reading data of the two devices on various samples of test solutions, ranging from plain water to high-concentration nutrient solutions. Table 1 shows the experimental results.

Table 1. Experimental result of TDS data

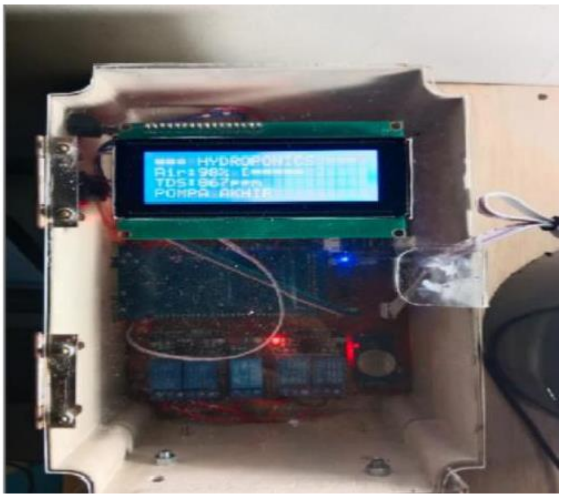
Sample	TDS DFRobot (ppm) R	eference TDS (ppm)	Error (%)
Plain Water	53	90	41.11
Nutrient Water 1	121	139	12.95
Nutrient Water 2	286	290	1.38
Nutrient Water 3	322	342	5.85
Water Nutrition 4	595	633	6.00
Water Nutrition 5	702	846	17.03

From the results of the analysis, it can be seen that the measurement error percentage of the TDS DFRobot sensor varies between 1.38% to 41.11%. The highest error values occur in ordinary water measurements, while the lowest error values occur in nutrient solution 2. This shows that TDS sensors have better accuracy in medium- to high-concentration solutions, whereas in low-conductivity solutions, the reading differences are relatively larger.

The HC-SR04 ultrasonic sensor as a water level detector was tested to determine the accuracy and stability of the water surface distance reading to the sensor. This sensor works on the principle of emitting ultrasonic waves and measures the travel time of the reflected waves from the surface of the water, which are then converted into distances. The distance value is used to calculate the water level in the storage tank. This test aims to evaluate the performance of the HC-SR04 ultrasonic sensor as a water level measuring device in a tub, including the calculation of water volume based on the measured height. The test was conducted to verify the relationship between the distance measured by the sensor and the percentage of water level on the I2C LCD screen, compared to manual measurements using a meter. Mold parameters. Sensor readings were performed at four different water level conditions, where each condition resulted in a different bounce distance. Figure 7 and Table 2 shows the water level control for proposed system.



(a)



(b)

Figure 7. Experimental process by using HC-SR04. a) Meausuring process, b) LCD display

Table 2. Experimental result for water parameter

Condition	% on LCD	Distance (inch)	Distance (cm)	Water Height (cm)	Volume (cm³)	Volume (L)
Water 1	90	5	12.70	3.30	583.16	0.583
Water 2	94	3	7.62	8.38	1,480.87	1.481
Water 3	96	2	5.08	10.92	1,929.72	1.930
Water 4	98	1	2.54	13.46	2,378.58	2.379

Based on the test results data in the Ultrasonic Sensor Table, the HC-SR04 is able to measure the headspace distance of the water surface consistently with the results of manual measurements. This can be seen from the results of sensor measurements that are in accordance with manual measurements without significant measurement differences. Testing of the entire tool is carried out to ensure that all components that have been individually tested are able to work in an integrated manner in one automated hydroponic monitoring system. This test includes the integration of hardware such as HC-SR04 ultrasonic sensor for water level monitoring, TDS (Total Dissolved Solids) sensor for measuring nutrient concentration, voltage sensor for monitoring power supply system, ACS712 current sensor for equipment power consumption monitoring, RTC (Real Time Clock) module for time recording, I2C LCD for information display, with software running automatic monitoring function, Real-time data display, as well as local notifications.

During the testing process, the system is activated and run under real operating conditions. The ultrasonic sensor is installed in the optimal position above the nutrient tank to continuously measure the water surface level, while the TDS sensor is immersed in the nutrient solution to monitor the concentration of dissolved nutrients. The ACS712 voltage and current sensors are integrated into the main power supply line for real-time monitoring of the system's electrical condition. Data from the four main sensors (water level, TDS value, supply voltage, and current consumption) is continuously displayed through an I2C LCD in an informative and easy-to-read format.

During the test, data from all three sensors is displayed in real-time on the I2C LCD, ensuring that the integration between components runs smoothly. The display of information on the LCD is dynamic and updated according to changes in the data received from the sensor. This shows that the process of reading and processing the data runs simultaneously without interruption. In addition to local monitoring via LCD, the system is also designed to provide automatic control of the relay. The relay regulates the start-up of the peristaltic pump for the addition of nutrients A and B according to the PPM value read by the TDS sensor. The submersible pump will be activated to add water when the volume of liquid is reduced based on the ultrasonic sensor reading, and the stirring motor functions to mix the solution to homogeneity.

Furthermore, the system is also tested to verify that each action performed is in accordance with the specified parameters. For example, if the PPM value of the solution is lower than the set limit, the peristaltic pump will turn on to add the nutrient solution. Similarly, when the water level drops, the ultrasonic sensor detects a change in altitude and triggers the water pump to refill the reservoir. The entire process takes place automatically without manual intervention from the user

Table 3. Overall experimental results

Condition	TDS (ppm)	Water Level (inch)	Water Level (cm)	Height Percentage on LCD (%)	TDS References (ppm)	TDS Relative Error (%)
Water 1 - Experiment 1	800	1	2.5.	98	820	2.44
Water 1 - Experiment 2	800	1	4.2	98	780	2.56
Water 2 - Experiment 1	800	2	5.0	96	850	5.88
Water 2 - Experiment 2	800	2	5.3	96	790	1.27
Water 3 - Experiment 1	800	3	7.62	94	760	5.26
Water 3 - Experiment 2	800	3	8.3	94	830	3.61

4. CONCLUSION

Based on the results of research and the Design of a Microcontroller-Based Hydroponic Plant Mix Control Nutrition System. The hydroponic plant mix control nutrition system was successfully designed using an Arduino ATmega 2560 microcontroller as the control center. This system is able to automatically adjust nutrient concentrations according to the needs of plants with the Deep Flow Technique (DFT) system. Integration of Solar Power Plants (PLTS) to Meet Energy Needs. The solar system with solar panels, MPPT, and batteries has succeeded in providing stable energy for hydroponic system operations. This integration allows the system to operate autonomously, sustainably, and environmentally friendly. Factors Affecting Power Requirements in Solar Power Systems. The power requirements of solar power systems are influenced by electrical loads, operational frequency, solar radiation intensity, system efficiency, and battery storage capacity. These factors determine the stability and operational sustainability of the hydroponic system.

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