Designing and Implementing the Arduino-based Nutrition Feeding Automation System of a Prototype Scaled Nutrient Film Technique (NFT) Hydroponics using Total Dissolved Solids (TDS) Sensor

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Abstract* - Hydroponics is a new breakthrough in farming because it no longer uses soil as a planting medium, and uses water instead. In the hydroponic system, the fertilizer used is mixed into water, which is then referred to as hydroponic nutrition or nutrient solution. The nutrient concentration in the solution, which is then indicated by the electrical conductivity (EC), is very influential on crop production. The nutrient concentration usually mixed manually by combining the fertilizer and the water in the right amount. Therefore, through this research, a nutrition feeding automation system of a prototype scaled Nutrient Film Technique (NFT) hydroponics is prepared. The system is designed with a control center using the Arduino UNO R3 board. The system is equipped with GP2Y0A21 proximity sensor as a water level detector, TDS sensor as a detector of electrical conductivity of the nutrient solution, and servo motor as an opening device of the faucet in the nutrient container. The research resulted that the system is capable of performing water delivery automatically when the water level is less than the minimum level, and add the nutrients automatically when the nutrient solution concentration is below 800ppm.
***Keywords* - hydroponics; nutrition; TDS; automatic**

I. Introduction

Extreme weather changes and contaminated soil air are the cause of plant production problems in open field crop production. Hydroponics is applied as a new breakthrough in farming because it no longer uses soil as a planting medium, and uses water instead.

In the hydroponic system, the fertilizer used is mixed into water, which is then referred to as hydroponic nutrition or nutrient solution [1]. The nutrition is distributed to the hydroponic system to be absorbed by the roots of the plant. The concentration of the nutrients in the solution is very influential on crop production [2]. It is related to the amount of EC (Electrical Conductivity) from the nutrient solution. Electrical Conductivity, which is also known as CF (Coductivity Factor), is an indicator of salinity in a nutrient solution. The EC value gives an indication to the farmer about the nutrients contained in the solution and which is absorbed by the roots. A low EC will give a low yield, which then increases to the maximum when EC is increased [3].

EC measurement aims to find out how much concentration of nutrients is absorbed. EC that is too high to cause plants can not absorb nutrients because it is too saturated. The nutrient solution that is flowing only passes without being absorbed by the roots. If the concentration of nutrient EC solution is too high then there will be poisoning and cells will experience plasmolysis. EC nutrient solution can increase along with time. This is presumably because nutrient solution loses some water due to evapotranspiration, so the nutrient solution becomes more concentrated.

The plant growth is affected by the appropriate water and nutrient type and adequate aeration support. These factors can increase nutrient uptake to produce energy. The energy required to produce sufficient oxygen in the solution will be used by the roots to respiration and generate energy to absorb water and nutrients from the solution. This affects the smooth process of respiration so that more nutrients can be absorbed by plants. Excess water will reduce the amount of oxygen in the nutrient solution [4]. Increased nutrient intake will increase plant growth [5].

The development of science and technology, especially computer technology occurs rapidly. The scope of application of technology is also increasingly widespread, covering various aspects of human life so that efforts to meet human needs are increasing and complex. Computer technology can be positively correlated to improving the quality of life and human well-being. Rapid and accurate system automation is an important requirement that encourages the creation of automated tools. Devices that are integrated with various peripherals and other supporting devices make the performance of these technologies become more applicable and functional [6].

Diansari [7] designed a nutritional automation system to regulate the length of activation and disabling of the pumps that would deliver nutrients using the AVR ATMega 8535 microcontroller. However, the system was not designed to add nutrients if they were less than they should be.

In 2014, Qalyubi, Pudjojono and Widodo [8] conducted an experiment on the effects of water discharge and the provision of nutrients to the growth of kale plants (*Ipomoea aquatica forsk*) in the hydroponics NFT system. The results revealed that the EC or the concentration of hydroponic nutrition is very influential on the growth of kale plants. EC amounted to 460 ppm indicates the deficit of solution concentration, so that the kale plants grow slowly.

The weakness in the experiment [7] will be improved, and the ideas in the experiment [8] will be supported by designing the automatic NFT (*Nutrient Film Technique*) hydroponics nutrition system, using the Arduino microcontroller, equipped with SHARP GP2Y0A21 as a water level sensor, servo motor actuators, and TDS (Total Dissolved Solids) sensors. The TDS sensor is used to detect the concentration of the nutrient solution, so it can be precisely detected when the solution requires additional nutrients.

II. METHOD

This section explains the needs and methods used in system development. There are four stages: needs analysis, system design, system implementation, and system testing.

The first stage in system development is the identification of the system requirements. At this stage the data related to the needs of system design is collected, such as selecting the sensors that will be used on the system. This stage is also a stage where the data related to the experiments and literature studies is collected. The result of this stage is the list of functional and non-functional requirements of the system.

The functional requirements in the system design are the system is capable to keep the value of electrical conductivity of the nutrient solution not less than 800 ppm. The system is capable to add water automatically to the A-B Mix nutrient solution for NFT hydroponic. [9]. The system will perform data readings when the water level is sufficient and the sensor plate is immersed in a nutrient solution. The system is capable of adding fertilizer A and B fertilizer automatically to the hydroponic nutrient solution until it reaches sufficient nutrient concentration. The system is capable to detect the electrical conductivity levels in a NFT hydroponic nutrient solution container to determine when nutrients need to be added. The system is able to detect the distance from the sensor to the water level on the NFT hydroponic nutrient solution container to determine when the nutrient solution should be added. The system is able to adjust the amount of nutrients A and B that must be spent to achieve ideal conditions.

Non-functional requirements in designing this system are the system using ATMega 328 microcontroller on Arduino board as control center to read sensor output value. The system runs with a 9V/1A power supply. The system gets input from existing sensors, and does not require input from user. The entire system is one system that installed and connected directly to the NFT hydroponic nutrient solution container. The second stage is system design. This stage is the result of the identification stage of the system needs performed previously. The data obtained is then used as the design of nutritional automation systems on a prototype-scaled NFT hydroponic to fit between the design of software and hardware. The result of this step is the hardware block diagram and the flowchart of the software.

In the system design is also done the determination of an equation to convert analog voltage values to PPM units on TDS sensors. The experiment was carried out by taking 11 solution samples with different amounts of dissolved solids. First, the PPM value of each sample is measured using TDS sensors and TDS meters. Each sample was measured 5 times to determine the average of the value measured. This repetitive reading is done because the value displayed by the sensor or TDS meter is fluctuating or changing very quickly. The comparison of the average data measured by sensors and TDS meter is shown in Table 1.

TABLE I. SOLUTION SAMPLE OF MEASUREMENT DATA

No.	Sample	Average value from Sensor TDS	Average value from TDS Meter
1	I	180.8	488.6
2	II	200.8	680.8
3	III	203.8	736.8
4	IV	214.2	892
5	V	224.8	1031.2
6	VI	233.2	1175.2
7	VII	235.6	1240.2
8	VIII	240.2	1392
9	IX	248.2	1528.2
10	X	251.2	1622
11	XI	253.6	1760

Then from the data is made a quadratic equation graph as shown by Fig.1.

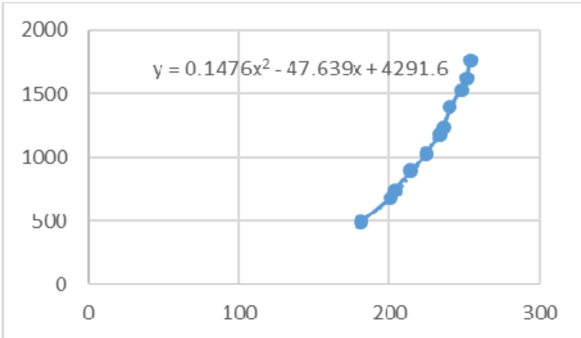

Fig. 1 Comparison graph of data from sensor and TDS meter

From the graph we get the equation 1 to convert the measured voltage value by TDS sensor to PPM unit.

$$y = 0{,}1476x^2 - 47{,}639x + 4291{,}6 \quad (1)$$

where

y = TDS value in PPM

x = voltage value measured by the sensor

The third stage in system development is system implementation. At this stage hardware is assembled and software is created to be uploaded into the system. The hardware used is an Arduino Uno R3 board [10] with an ATMega 328 microcontroller equipped with SHARP GP2Y0A21 proximity sensor [11] [12], TDS sensor [13], and MG996R servo motor actuator [14]. The SHARP GP2Y0A21 output range sensor is used to detects the water level in the hydroponic nutrient solution container which then determines the TDS sensor reading schedule which is when the water level is sufficient to immerse the TDS sensor plate. The TDS sensor is used as the main sensor of the system to detect the electrical conductivity or solute content of the hydroponic nutrient solution in Part per Million (PPM) units. Both of these sensors determine when the servo motor actuators that are mounted on 3 containers of water or fertilizer will move to open the faucet head or close the faucet head. The software used is Arduino IDE version 1.6.5 running on the Windows 10 operating system to program the system hardware.

The last stage in system development is system testing. At this stage data is taken to test the hardware as well as the system software. Then the data obtained from previous stages (design and implementation system) is analyzed. Tests undertaken at this stage are testing of input devices, testing of external devices, and testing based on functional requirements of the system.

III. Results And Analysis

After conducting the four stages of the system development, the next step is describing all data of the results of the test on the system as a whole. Discussion and analysis of the results also provided in this section.

The design of the system that has been done previously produces a block of hardware diagrams and flow diagrams of software. Fig. 2 shows block diagram of the hardware systems.

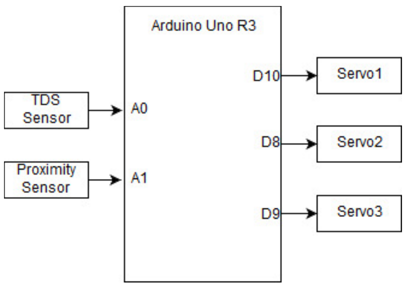

Fig. 2 Hardware Block Diagram

The software design generates a flow chart of void setup(), and void loop(), as well as a flow chart for the function of each sensor and actuator used in the system, namely TDSCheck(), LevelCheck(), system flow diagrams, and FSM diagrams For Servo1move() and Servo23move(). The void setup() function contains only the serial configuration pins and serial communications used on the system at 9600bps. Fig. 3 shows the flow chart of void setup().

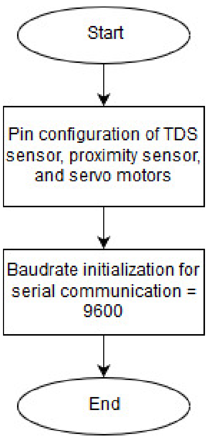

Fig. 3 `Void setup()` Flow Chart

Next, the void loop() function, which is a function that will run continuously, contains a call to drive the main function of the system. Fig. 4 shows the flow chart of the function of the void loop() system.

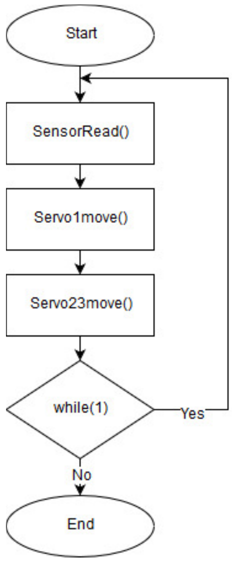

Fig. 4 `Void loop()` flow chart

The void loop() called the SensorRead() function that manages the scheduling of the reading of the distance sensor and TDS sensor. The Servo1move() function controls the conditions governing the movement of servo1 motors mounted on the water container, and the Servo23move() function regulates the servo2 installed on the container of fertilizer A, and the servo3 mounted on the container of the fertilizer B, based on the output data of the distance sensor and TDS. Fig. 5 shows the overall diagram of the systems.

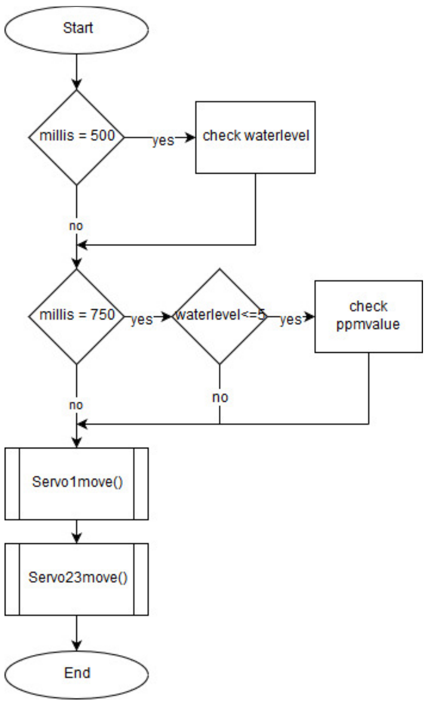

Fig. 5 System Flowchart

The behavior of the Servo1Move() and Servo23move() function is described using the Finite State Machine diagram. The diagram illustrates the movement of conditions or states under certain circumstances as shown in Fig. 6 and 7.

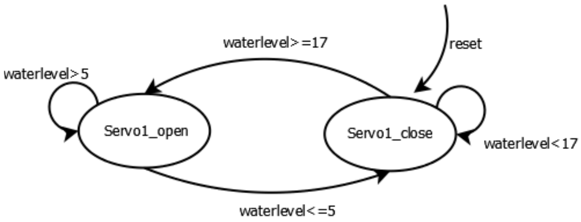

Fig. 6 FSM Diagram of `Servo1Move()`

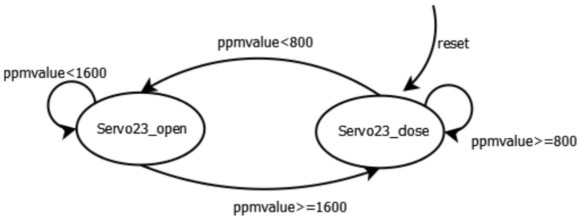

Fig. 7 FSM Diagram of `Servo23move()`

The implementation of the hardware covers all hardware that has been designed and created. This system uses Arduino Uno R3 board that uses ATMega 328 micro controller as the system control center. This system is connected to several sensors, namely electrical conductivity or TDS, SHARP GP2Y0A21 distance sensor as a water level sensor, and three MG996R servo actuators.

The hardware is implemented directly on the prototype-scale of the NFT hydroponic system with 84 holes. The components used are directly connected to Arduino board with the help of prototype shield. The prototype shield for Arduino Uno R3 already provides a sufficient number of pins to fit all the components used in the system. The Arduino board, along with protoshield that has been connected to the system components, are mounted on top of a hydroponic nutrient solution container. Fig. 8 shows the implementation of the NFT hydroponic nutrition systems.

Fig. 8 The Automation System

Implementation of the software is the development of a system program using Arduino IDE version 1.6.5 based on language C. The software is developed by programming the whole system in accordance with the design as prepared, consists of three parts, namely the initial declaration, void setup() function, and the void loop() function. The initial declaration shows the declarations needed in the program, including the required libraries, the pins that need to be initialized and the global variables that need to be declared. The void setup() function declares the required device connection and the communication with the computer. There are three parts of the void setup() that declare pin connections on the Arduino, activation command of the serial communication for TDS sensors, GP2Y0A21 sensors, and the servo motor actuator. The function of voidloop() runs continuously to determine the order of execution of other functions according to the sensor readout schedule in the SensorRead() function, and will move the actuator according to the behavior specified in the Servo1move() and Servo23move() function. In addition, there is also a sensor data reading function, that is a LevelCheck() function, which contains a command of the reading value of the GP2Y0A21 sensor and TDSCheck() function that contains the command to read the value of the TDS sensor.

The illustration of the implementation of the device used in the automation system is shown in Fig. 9 that is then referred to as the system deployment diagram.

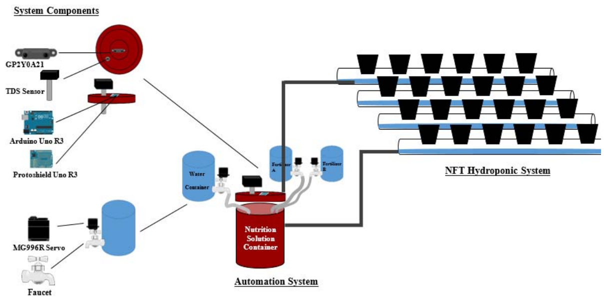

Fig. 9 Illustration of installation of the system components

The testing of the system is conducted by reading the value of each sensor and other input devices. Then, the testing is conducted to the outlet devices of the systems, and the last is a testing of the system as a whole to meet all the functional requirements of the system.

The testing of TDS sensor is conducted by comparing the sensor output with a measuring instrument that is TDS meter. The TDS reading is the conversion value of the analog voltage generated by the sensor to the PPM unit using equation (1) obtained from the observed value of the output voltage of the sensor compared to the value measured by the TDS meter. The variable x in equation (1) is implemented in the software as the measured TDS value, whereas the y variable is inputted with the ppm value in the TDSCheck()function.

The testing of TDS sensor is performed as many as 10 times reading. The sensor and the measuring device are placed close together. The collected data are plotted into a graph as provided in Fig. 10.

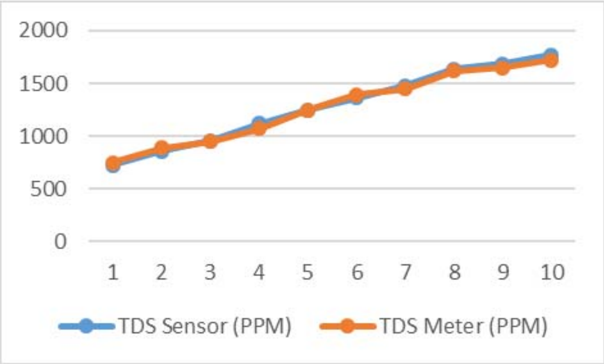

Fig. 10 Comparison of TDS sensor results with TDS Meter

From the data obtained, it can be calculated the percentage of errors caused by the TDS sensor. The error is 2.197% or rounded to 2.2%, so the accuracy of TDS sensor is 97.8%.

The testing of the SHARP GP2Y0A21 distant sensor testing is conducted by comparing the sensor response (output) with the measuring instrument (ruler). The tests were conducted as many as 10 times reading. The calculated distance is from the point of the sensor is mounted to the water level. The collected data are the plotted into a graph as provided in Fig. 11.

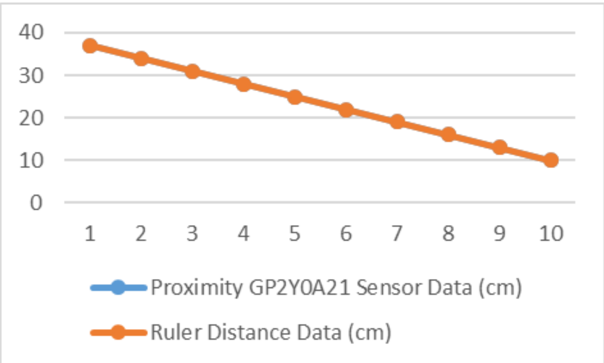

Fig. 11 Comparison of GP2Y0A21 distance sensor results with ruler

The outlet device testing is conducted by comparing the output resulted with the input commanded. In this system, only one outlet device is used, that is a servo motor. The servo motor outlet device testing is performed to ensure that the servo motor is functioning properly. Servo motors are used in the system as a driver of the faucet of the containers (for water and fertilizer). This servo motor testing is conducted by testing the servo motor functionality to move to open the faucet (servo move to position 30^o) and move to close the faucet (servo move to position 100^o). Table 2 is the result of servo motor testing.

TABLE II. SERVO TESTING

Parameters	Servo1	Servo2	Servo3
Servo opens the faucet head	Succeed	Succeed	Succeed
Servo closes the faucet head	Succeed	Succeed	Succeed

After conducted testing on the inlet and outlet devices, the next testing is conducted to the system as a whole. The whole system is a composite of components that have been previously tested. Once all devices are assembled into an integrated system, then the systems can be tested as a whole. Table 3 is the result of testing of the system as a whole.

TABLE III. SYSTEM TESTING RESULT

No	Parameters	Results
1	System detects the water level	Succeed
2	System detect the TDS when the water level is sufficient	Succeed
3	System opens the faucet head of the water container when the water level detected by the sensor is more than 17cm	Succeed
4	System reads the PPM value of the nutrient solution after the water is added.	Succeed
5	System closes the faucet of water container when the water level in the nutrient solution bath is sufficient.	Succeed
6	System opens the faucet of fertilizer A container when the PPM value is less than 800	Succeed
7	System opens the faucet of fertilizer B container when the PPM value is less than 800	Succeed
8	System closes the faucet of the fertilizer A container when the PPM value reaches 1600	Succeed
9	System closes the faucet of the fertilizer B container when the PPM value reaches 1600	Succeed

In this research, the system was able to add A-B Mix water and nutrients to the NFT hydroponics automatically to achieve the ideal concentration of solutions for plants based on data measured by TDS sensors. This is expected to support the ideas in the studies [2], [5], and [8] where such studies generally state that hydroponic nutrient solutions should always be within the ideal level in order to increase plant growth and production. This system was created automatically to support the idea in the research [6] on automation and also improve the research [7] conducted by Muthia Diansari. The system in this research with added witha sensor to detect electrical conductivity (EC) or nutrient in the solution so that the nutrients are given when the level is low, not only given at a certain time using a timer.

On the percentage of error obtained in TDS sensor testing, that is 2.2%, or 97.8% accuracy, it can be arranged a similar research with different methods to get a smaller percentage of error or higher accuracy. To corroborate the idea of the research [8], the system can be added a sensor to detect pH of the nutrient solutions as additional variables before providing nutrients because pH is one of the factors that affect nutrient uptake in plants.

IV. CONCLUSION

This research attempts to examine the design and application of the automatic NFT hydroponic at a prototype-scale using TDS sensors. The research revealed that this system is able to detect the level of electrical conductivity or solute in nutrient solution using TDS sensor in a PPM unit. This prototype-scale NFT hydroponics system could deliver nutrients automatically so that the nutrient content in the solution is not less than the minimum limit of 800 ppm. The accuracy of the TDS sensor based on the voltage unit to PPM conversion formula is 97.8%. The software developed could control the hardware systems according to the results of the system requirement as identified. The design and application of the nutritional automation systems on NFT hydroponics could meet all the functional requirements as planned.

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