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DEVELOPMENT OF AUTOMATED PH CONTROLLER SYSTEM FOR NFT HYDROPONIC

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ABSTRACT

In a hydroponics system, pH level is one of the most important parameters that affect the way plants respond to a hydroponic nutrient solution. The range of pH levels depends on the type of plants in the hydroponic system. The plant can uptake nutrients efficiently if the nutrient solution needs to be consistently controlled within the pH range. It is important to ensure a balanced pH level in nutrient solutions to maintain the proper growth of plants. Therefore, the pH level in the nutrient solution will automatically be controlled in this Arduino-based system. A mini NFT hydroponic system was used as a project set up to measure the performance of a pH sensor. Utilizing the pH sensor, it measures the pH level of the nutrient solution and send the data to Arduino. Then, the Arduino will receive, process and send the output signal to the peristaltic pump to transfer the pH adjuster solution into the nutrient solution tank until the desired pH level is achieved. The data of the pH, Electrical Conductivity (EC) and temperature of the nutrient solution for the Amaranth plant growing period of 23 days are collected. The result obtained shows that the system is capable of automatically maintaining the pH level in the nutrient solution.

Keywords: *Amaranth round leaf, Arduino, temperature, EC value*

INTRODUCTION

By 2050, the human population is expected to reach 9 billion [1], and a major challenge for the increased population is maintaining the supply of fresh products to ensure diets that are high in nutrients. Therefore, the hydroponics technique of urban farming is one of the techniques that are getting more attention to serve the needs of urban citizens [2]-[3]. Over the last few years, hydroponics has become important as a way to produce food with a higher yield and less use of land, water and energy. In reference to Sustainable Development Goals (SDG), urban farming and its speciality explicitly aids in ending hunger, achieving food security and improved nutrition and promoting sustainable agriculture (Goal 2) thus achieving other targets in SDGs. SDG-2 highlights the complex interlinkages between food security, nutrition, rural transformation and sustainable agriculture [4]. Furthermore, the government targets to create 20,000 urban farming communities around the country by 2020 as an initiative programme to secure a complete food supply chain and boost food security in the country [5].

Hydroponics is a method to grow plants by supplying nutrients through a water solution without soil [6]. This technique ensures the plant gets all nutrients needed from the water solution. Generally, there are six basic types of hydroponics techniques and one of them is the nutrient film technique (NFT) [7]-[9]. The nutrient film technique is a hydroponic system technique that has a design of a very shallow nutrient solution pouring down through the tubing. The principle of NFT is to continuously re-circulate a thin layer of nutrient solution past the plant roots providing nutrients and oxygen [10]. The bare roots of the plants would absorb the nutrients in the solutions when they come into contact with the water. This method would ensure that the plant root consumes the nutrient in the water solution to grow wisely and it offers many benefits, including faster growth, great productivity, ease of handling and higher efficiency of water usage [11]. By using a hydroponics system, pH, EC value and temperature are among the important parameters that need to be observed and controlled as they affects the ability of the plants to absorb all the nutrients to ensure the growth of the plants [12]-[13]. The plants can absorb the nutrients more easily from the solution by keeping the pH at the optimum level. Research done in [14] has shown that pH can have an adverse effect on plant growth, particularly on those that are being cultivated in hydroponic cultures.EC value of the nutrient solution indicates the amount of dissolved nutrients and whether they need to be replenished. A higher EC value hinders nutrient absorption due to an increase in osmotic pressure, whereas a lower EC may severely affect plant health and yield [15]. Besides, the temperature of the nutrient solution also influences the uptake of water and nutrients differentially by the plants [16]. It is essential to check pH, EC values and temperature of nutrient solution regularly, preferably daily, since they have a huge impact on the amount of nutrition a plant can absorb. Therefore, pH, EC values and temperature are considered to be the most important determining factors of crop yield and quality [17].

Hence, this project aims to develop an automated system equipped with a sensor to measure the pH level in nutrient solution and transmit the compatible signal to an Arduino Uno microcontroller for processing and deliver an output signal to the actuator (peristaltic pump) to dose the pH adjuster solution if required. The real-time data collections determine the pH level from the value of the sensor. This project also proposed the data collection for the EC value and temperature of nutrient solution to determine their relationship while maintaining the quality of the nutrient solution in the hydroponics system by controlling the pH level automatically using Arduino.

METHODOLOGY

The development of an automated pH controller system consisting of two parts: software and hardware. The methodology involved is discussed as follows:

Blok Diagram

Figure 1 shows the overall block diagram of the system. Firstly, the Arduino Uno microcontroller acts as the brain of the system used in this project. It is attached with an analogue pH sensor and a waterproof temperature sensor. The pH sensor functions as the main input to measure the pH level, while the waterproof temperature sensor, DS18B20, measures the temperature of the hydroponic nutrient solution. Then, the data will be transmitted to the Arduino and displayed on the I2C LCD. The primary and secondary peristaltic pump will be triggered based on the condition of the input sensor that has been set.

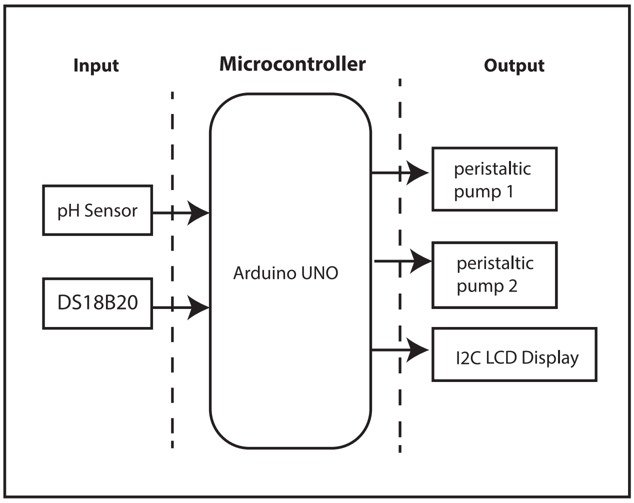

Figure 1 Block diagram of the system

In this project, the Arduino microcontroller is used to control the whole operating system. The Arduino is chosen because it can operate within a low supply of voltage and even use a simple C++ language to code the program. The set point is the desired value initiated by the user, as in Figure 2. Based on the optimum pH value for the plants [18], the pH level is set to a range of 5.5 to 6.5 and the pH sensor is used as a measurement device. Then, the Arduino receives the information from the analysis of the sensor and generates a response as the feedback action. The action is based on the actuator that will react towards the signal received until it reaches the desired pH level measurement. Therefore, this closed-loop control for the project development system is completed.

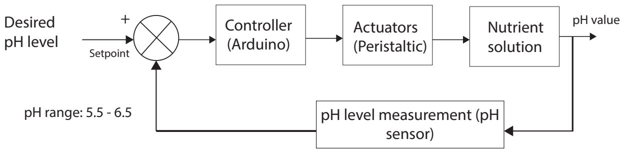

Figure 2 The closed-loop control of the proposed system

Prototype

Figure 3 shows the setup of the NFT hydroponic system. It has a dimension of 78 cm in length, 36 cm in width and 60 cm in height. The design concept of the hydroponic set is built based on the principle of a closed recirculating system where nutrient solution flows down a set of growing channels. The system consists of two hydroponic trays 60 cm in length each and 8 holes are prepared for the hydroponic plants' placement. Nutrient film technique (NFT) is the most popular culture for growing green vegetables. In this project, Amaranth's round leaf is used as a plant sample. Eight samples of Amaranth plants were placed inside the 47 mm net pots. A reservoir tank is used to hold 10 litres of nutrient solution.

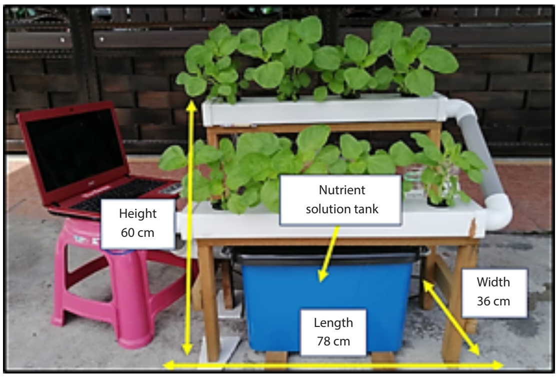

Figure 3 Prototype setup

All plants will grow in the net pot with the roots being hanged down to the bottom of the channel where they get nutrients from the shallow film of nutrient solution flowing by. In addition, the hardware setup of the automated system is placed on top of the reservoir tank, as shown in Figure 4, alongside two peristaltic pumps as actuators. Meanwhile, the water-proof temperature sensor DS18B20 and the pH sensor which have been used as the input, are immersed in the nutrient solution.

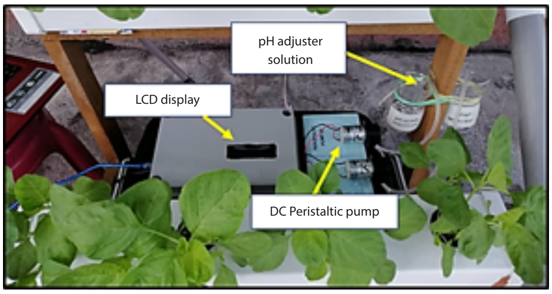

Figure 4 The hardware setup of the automated system

Software Development

To operate the Arduino UNO microcontroller, software is needed. This project used Arduino IDE to run the operation as a command to the controller to run the system automatically. Arduino IDE is a software program that runs on a computer to develop programs for microchip microcontrollers. Figure 5 illustrates the system interface of the Arduino IDE software with the programs written using C++ as the programming language. Then, it connects to the Arduino hardware to upload programs and communicate with them. Once the system is initialised, the project information is displayed on the LCD and ready for the next operation.

```
#include <Wire.h>
#include <LiquidCrystal_I2C.h>
#include <OneWire.h>
#include <DallasTemperature.h>

LiquidCrystal_I2C lcd(0x27, 16, 2);
const int SENSOR_PIN = 13; // Arduino pin connected to DS18B20 sensor's DQ pin
OneWire oneWire(SENSOR_PIN);         // setup a oneWire instance
DallasTemperature sensors(&oneWire); // pass oneWire to DallasTemperature library
float tempCelsius;    // temperature in Celsius
const float phLow = 5.5;
const float phHigh = 6.5;
int phval = 0;
unsigned long int avgval;
int buffer_arr[10],temp;
int ControlPump1 = 10;  //give your arduino pin a name
int ControlPump2 = 3;

void setup() { // the setup routine runs once when you reset the Arduino:

  pinMode(ControlPump1, OUTPUT); // initialize the digital pin as an output.
  pinMode(ControlPump2, OUTPUT);
  Serial.begin(9600); //setup the serial monitor for viewing the active PWM control value
  sensors.begin();    // initialize the sensor
  lcd.init();
  lcd.begin(16, 2);
  lcd.backlight();
  lcd.setCursor(0, 0);
  lcd.print("  Automated pH     ");
```

Figure 5 The system interface of Arduino IDE software

The steps of uploading code or a sketch to Arduino for the system interface, as shown in Figure 5, can be summarized as the following:

Step 1: Connect Arduino using a USB cable

Step 2: Open the Arduino IDE

Step 3: Select the Arduino board and port

Step 4: Prepare the code/ sketch

Step 5: Upload the code/ sketch

Step 6: Run the code/ sketch

Based on the flowchart in Figure 6, the water-proof temperature sensor DS18B20 initially measures the temperature of the nutrient solution, followed by an analogue pH sensor which measures the pH level of the nutrient solution inside the tank. The data sensed by both sensors will be displayed on the LCD, reflecting the temperature as well as the pH value of the nutrient solution. Then, if the value of the pH level measured is higher than the desired range, the microcontroller will send the signal to DC peristaltic pump to dose the pH down the solution to reduce the pH value in the nutrient solution so that the pH value is within the acceptable pH level range for the plant and vice versa.

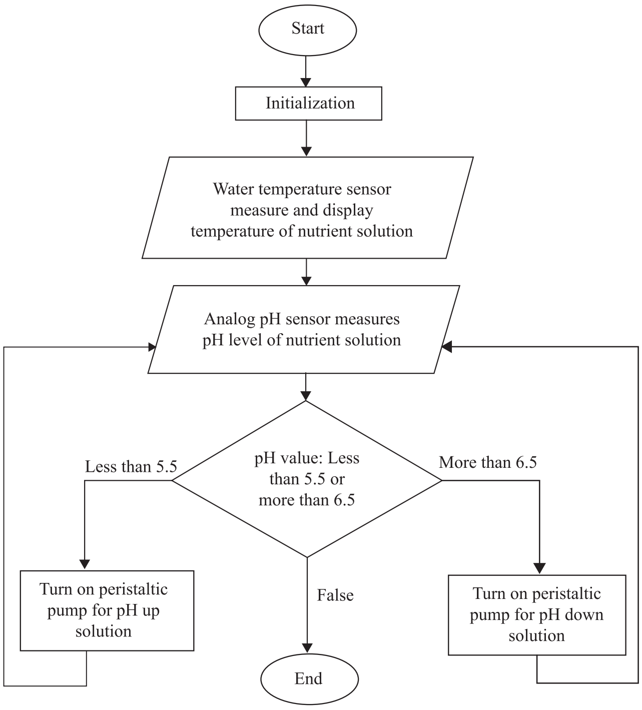

Figure 6 Flowchart of the developed automated hydroponic system

RESULTS AND DISCUSSION

Several experiments have been conducted to find the relationship between the parameters. In this project, the experiments conducted and their results obtained are discussed as follows:

Measurement of pH Adjuster Solution Amount Dosed by the Peristaltic Pump

This experiment was conducted to obtain the amount of pH adjuster solution (pH up and pH down solution) dosed by the peristaltic pumps based on dosing time. The reading was taken until the dosing time reached 100 seconds. The graph from Figure 7 illustrates a relationship between dosing time and the amount of pH adjuster solution. The reading of an amount of pH adjuster solution dosed by the peristaltic pump was taken for 100 seconds. The maximum amount of pH adjuster solution that could be dosed was 25 ml. Based on Figure 7, the amount of pH adjuster is directly proportional to the dosing time, and the amount of pH adjuster needed can be determined by setting up the dosing time. These data were important to find the suitable amount of increment or decrement of pH value when the pH adjuster dosed into the nutrient solution. Besides, these data have been used as a reference in finding the exact dosing time to dose the pH adjuster solution until the desired pH level is achieved.

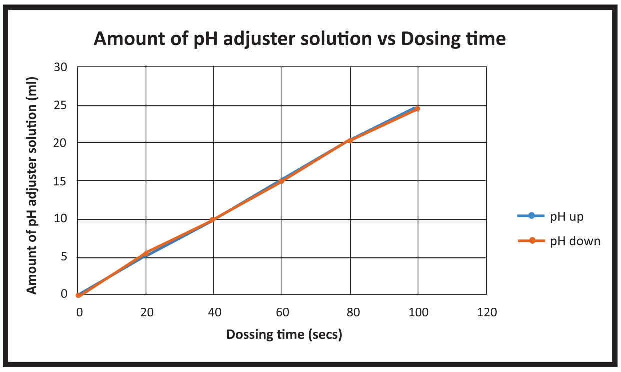

Figure 7 The amount of pH adjuster solution dosed by the actuator

Measurement of pH Value, EC Value and Temperature of Nutrient Solution in the Reservoir Tank

The purpose of this experiment is to study the relationship between pH value, EC value and temperature in the nutrient solution. This experiment also provided the data required to find the time when pH value began to differ, and it was tested for 10 litres of water solution, which has put 100 ml of AB liquid fertiliser in the reservoir tank. The data from the pH sensor, EC meter and temperature sensor were taken for 23 days, and the data for each day was recorded based on the average of five measurements. The pH sensor and the EC meter were dipped into the nutrient solution. The purpose of using a temperature sensor in this experiment was to monitor the temperature of the nutrient solution and display it on the LCD. The nutrient solution temperature was also measured by the EC meter, as it can measure both EC and the temperature.

Table 1 Measurement of pH value in 10 litres nutrient solution using DFRobot pH sensor and pen type pH

Day	DFRobot analogue	pH Value Pen type pH	Difference	EC value (mS/cm)	Water Temperature (ºC)
1	6.73	7.31	0.58	0.06	30.2
2	6.58	7.19	0.61	0.07	29.5
3	6.81	7.28	0.47	0.05	28.4
4	6.86	7.59	0.73	0.07	31.1
5	6.74	7.31	0.57	0.06	29.2
6	6.92	7.46	0.54	0.05	30.7
7	6.67	7.32	0.65	0.06	26.8
8	6.84	7.58	0.74	0.07	28.9
9	6.71	7.29	0.58	0.06	30.4
10	5.83	6.22	0.39	1.8	27.0
11	5.68	6.05	0.37	1.9	29.0
12	5.72	6.14	0.42	2.0	30.0
13	5.68	6.23	0.55	1.7	28.5
14	5.48	6.09	0.61	2.3	32.2
15	5.64	6.32	0.68	2.0	31.8
16	5.68	6.14	0.46	2.2	31.0
17	5.46	5.78	0.37	1.8	25.5
18	5.96	6.09	.0.63	2.2	31.0
19	5.64	5.96	0.32	1.8	29.0
20	5.88	6.32	0.44	2.0	31.2
21	5.58	6.25	0.67	1.7	26.0
22	5.62	6.23	0.61	2.2	31.0
23	5.71	6.14	0.43	1.9	30.2
	Average		0.54		

This project was performed in a reservoir tank which contains 10 litres of tap water and is mixed with 100 ml fertilisers. Tap water without any mixture of fertiliser was used for the growth of Amaranth plants during the first nine days as they were in the germinating phase and nutrient was not yet required. Thus, fertiliser which contains nutrients was added starting from the 10th day. Two different instruments took the data measurements, mainly using DFRobot analogue pH sensor and next, using pen type pH meter to compare the data measurement differences. Both of the instruments are measurement devices that are claimed by the manufacturer to have ±0.1 pH accuracy.

As shown in Table 1, the reading showed a marginally different value in measurement between the DFRobot pH sensor and pen-type pH meter. Based on Table 1. the DFRobot pH sensor has an average pH value of +0.54 in differences concerning the pen-type pH meter. There does not appear to be a large difference between these two pH value readings. The data was recorded to be used as a reference in monitoring plant growth. The pH sensor can't achieve an accuracy of approximately 0.1 pH because there are many uncertainties and potential measuring errors, such as buffer solution degradation or contamination, calibration procedures, temperature dependencies, junction potential and others.

As shown in Figure 8, the pH value in the nutrient solution started to decrease slightly on the 10th day before steadily maintaining the pH range requirements until the last day. This happened because the nutrient in the fertiliser started to react chemically and influence the pH level in the water solution. Therefore, the pH level must be monitored and controlled before introducing the nutrients inside the water solution. Besides, there was a significant change in electrical conductivity (EC) value. From the 10th to the 12th day, the EC value increased dramatically before averaging at the optimal requirements of EC value until the 23rd day.

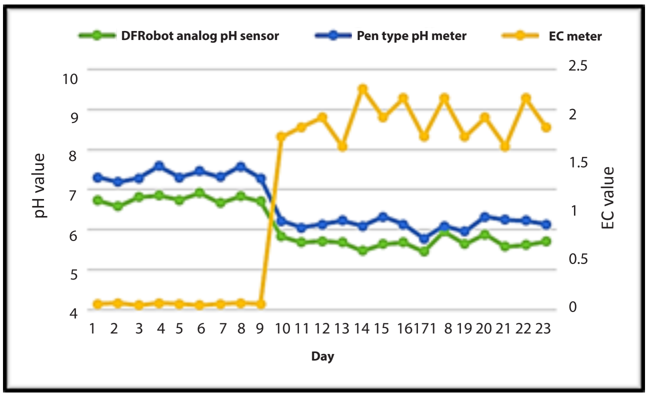

Figure 8 The measurement range graph of pH and EC value using a DFRobot pH sensor, pen-type pH meter and EC meter

Figure 8 shows that the EC value changed every day as the plants absorbed the nutrients and water during growth. When the plants absorb the water, the concentration of the solution becomes higher and the absorption of nutrients lowers the concentration of the nutrient solution. The EC value requirements, as in Table 2, could be maintained by adding fertiliser when levels drop below 1.7 mS/cm as well as adding tap water to dilute the nutrient solution when levels rise more than 2.2 mS/cm. There was a relationship between the EC value and the water temperature based on Figure 9. The EC value started to rise and drop hand in hand with the water temperature on the day of the 10th. The results recorded the highest EC value of 2.3 mS/cm during the highest recorded water temperature which is 32.2°C. Theoretically, the EC value of a solution has an approximately linear relation to the temperature, with a roughly 2% increase of EC for every increasing degree of Celsius.

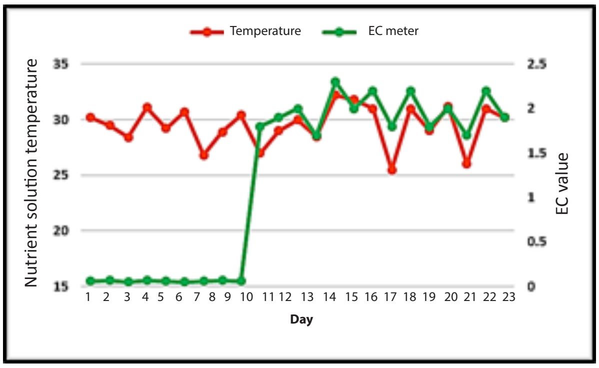

Figure 9 The correlation between temperature and EC value of the nutrient solution

However, the EC value remained approximately constant for the first nine days although there were temperature changes. Thus, the results are not supported by the theory. Even though the EC level may change depending on the temperature, the nutrient content in the solution will not experience any changes.

Table 2 Optical requirements of pH, electrical conductivity, and temperature for hydroponically growth amaranth round leaf

pH	5.5 – 6.5
Electrical Conductivity (EC)	1.7 – 2.3 milliSiemens/cm

The Plant Height Growth Relating to the Measured Parameters

The planting through seeding technique was applied to the plants. After analyzing the results obtained from Table 3 and Figure 10, from observation, the plant height started to increase steadily after the 10th day until the end of the 23rd day.

Table 3 The height and condition of the Amaranth round leaf plant

Day	Plant Height (cm)	Plant Condition
4	1.2	
10	3.4	
13	7.5	
16	10.2	
20	13.5	
23	15.1	

The rapid growth happened due to the averaging of pH and EC values at the optimal requirements, which were influenced by the first addition of liquid fertiliser into the nutrient solution after tenth days. Besides, the good condition of the plant's leaves indicates that they seem to have had enough nutrient intake without showing any sign or symptom of plant disease. Therefore, the control of pH and EC value of the nutrient solution are sorely needed since the growth of the plants is directly influenced by these parameters. However, an increase in height is not the sole factor in defining plant growth. Growth can also be measured by plotting parameters such as length, mass, surface area, volume and number against time.

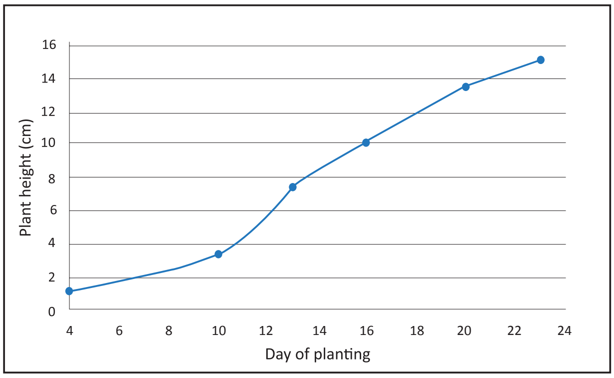

Figure 10 The measurement of plant height for 23 days

Measurement of Changes in pH Value in the Reservoir Tank Using pH Adjuster Solution

Since this project is aiming at keeping the pH levels in the range of 5.5-6.5, the measurements after solution dosing have been taken with intervals of at least 5 minutes which is the time until the system stabilizes after a disturbance. The data were collected from the 10th until the 23rd day of growing Amaranth plants. Based on data collection, Table 4 shows that the average of changes in pH value is approximately 0.482 towards alkalinity. This change requires 5 ml of pH up solution to be dosed into the 10 litres of water solution tank. Therefore, 5 ml of pH up solution is enough to change the 0.482 pH value near alkalinity. However, the differences in pH value before and after the dosing is not constant throughout the measurement. The average of changes in pH value towards the acidity is approximately 0.524, as shown in Table 5. This change requires 5 ml of pH down solution to be dosed into the 10 litres of water solution tank. Hence, 5 ml of pH down solution is also enough to change the 0.524 pH value near acidity. Nevertheless, both results showed the difference between before and after the dosing was not constant for every measurement. The data collected in this project may deviate from the actual values due to a variety of different error sources. A faulty reading may originate from a bad calibration of the pH sensor due to contamination of the calibration fluids. An industrial standard pH sensor would have been preferable to get more precise monitoring of the pH value.

Table 4 The measurement of pH value after pH up solution dosing

pH Value			
pH Up (ml)	Before	After	Difference
5	5.31	5.70	0.39
5	5.42	5.85	0.43
5	5.19	5.70	0.51
5	5.38	5.85	0.47
5	5.27	5.68	0.41
5	5.47	5.80	0.33
5	5.10	5.75	0.65
5	5.18	5.81	0.63
5	5.33	5.79	0.46
5	5.39	5.96	0.57
5	5.44	5.98	0.54
5	5.41	5.76	0.35
5	5.26	5.85	0.59
5	5.35	5.77	0.42
Average			0.482

Table 5 The measurement of after pH down solution dosing

pH Value			
pH down (ml)	Before	After	Difference
5	6.72	6.32	0.40
5	6.65	6.12	0.53
5	6.81	6.45	0.36
5	6.93	6.50	0.43
5	6.58	5.90	0.68
5	6.84	6.38	0.46
5	6.77	6.20	0.57
5	6.65	6.26	0.39
5	6.92	6.46	0.46
5	6.54	6.03	0.51
5	6.68	5.94	0.74
5	6.75	6.37	0.38
5	6.69	5.96	0.73
5	6.83	6.14	0.69
Average			0.524

CONCLUSION

The proposed hydroponics system controls using a microcontroller are excellent for ensuring the pH level remains in the optimum range for the plants. The full integration of controller, sensor and actuators has effectively created a closed-loop control system for the pH level in NFT hydroponics. From the result obtained, the system was capable of automatically adjusting the changes in pH level to the plant requirement by dosing 5 ml of pH adjuster solution. Overall, the developed system was able to monitor the water temperature in nutrient solution and was able to perceive good control performance on the pH level by maintaining its desired range. However, an industrial standard pH sensor would have been preferable to get more precise monitoring of the pH level. For further work, it is recommended to use an industrial pH sensor which can provide the best measurement of the nutrient that is beneficial for advanced analysis.

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