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Design of control system for water quality monitoring system for hydroponics application

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Abstract. In hydroponic farming, optimal pH value is important to regulate nutrient availability for efficient plant growth. This study aims to design an autonomous pH monitoring and control system for maintaining an optimal pH range. The prototype was developed for data acquisition, data processing and data visualization to ensure that the measured nutritional solution parameters are within the specified range: temperature (18–35°C), pH (5.5–8.0), and dissolved oxygen level (>2 ppm). Data collected at sampling rate of 10 seconds utilising temperature sensor, pH sensor, and dissolved oxygen sensor were processed using a microcontroller on a Node-RED interface in a Raspberry Pi. The processed data were stored in InfluxDB before being displayed in Grafana. If the value exceeded the threshold, a Telegram alert was delivered to the end-user. The pH data were used to build a framework to control the pH levels within range. Two peristaltic pumps (DFRobot, DFR0523) were utilized to pump potassium hydroxide or phosphoric acid solution if the pH was out of range. The developed prototype was able to automatically control the pH within the optimum range in the nutrient solution, which will positively impact the nutrient adsorption and subsequent plant growth in a hydroponics system.

1. Introduction

Hydroponics is a well-established method of growing plants utilising a soilless growth medium and a nutrient solution (water) tailored to the crop's needs. Due to the soil-free agriculture method, the plant growth depends highly on large water volumes. Hence, maintaining constant water conditions such as pH, water temperature, dissolved oxygen concentration (DOC), electrical conductivity, and nutrient concentration in the nutrient solution is a critical feature of a hydroponic system to ensure the plant's ability to adsorb the nutrients [1]. pH level is an important parameter that impacts the plant development.

The pH of the nutrient solution must be maintained at optimal level. This is because a solution with a low pH level may contribute to plant toxicity. In contrast, a solution with a high pH level can lead to macronutrient and micronutrient deficiencies in plants. Toxicity and nutrient deficiencies in plants are physically visible through browning of the leaves, brittle leaves or loss of plant weight [2]. For example, research conducted by Krumrei (2019) had suggested that the growth of cucumber in an alkaline hydroponic solution will reduce the solubility of copper, zinc and iron in the nutrient solution, causing the cucumber to undergo chlorosis and reduce the plant yield [3]. Therefore, it can be concluded that a suboptimal pH level does not only affect a single plant but could affect the whole crop cycle.

As the nutrient solution is the main medium growth for the plants, the requirement of water quality index is stringent which indicates the need for data monitoring and control. This is in-line with

Agriculture 4.0, which applies the principles of Industrial Revolution 4.0 (IR 4.0) which applies technology such as sensors, smart tools, the Internet of Things (IoT) and remote sensing to agriculture practices to maximize productivity and quality. Also known as precision agriculture, IR 4.0 elements such as big data, cloud computing as well as artificial intelligence can be applied in precision agriculture management to for complete automation of the agricultural processes [4].

Therefore, a precise water quality monitoring and automated system, focusing on pH control had garnered attention in the management of water quality in the agricultural industry. Recent works in developing control system utilizes fuzzy logic controller for the automating the pH, electrical conductivity and humidity values [5,6]. Alternatively, the control system could also be developed using a microcontroller using the logic ‘if else’ [7]. However, the technologies currently available for an automated hydroponic system have complex control logic, difficult to program, and is unable to regulate to the desired pH level without human intervention. In addition, an improper designed pH control system could cause accidental overdosing or underdosing of pH buffer solution, which could cause non-linear pH changes that causes a chemical shock to the plants leading to detrimental plant growth [8].

This research therefore, aims to develop and test a completely automated pH level monitoring and control system with a visualization system, utilizing a micropump control system, microcontroller and sensors in order to create an ideal pH environment for plant growth in a hydroponics system.

2. Materials and methods

2.1. Materials

The nutrient solutions were prepared with two sets of commercially available mineral fertilizers with varying macro and micronutrients (Set I: N: 15.5%, CaO: 26%, Fe-EDTA: 13.2% (1g); Set II: NO_3: 7%, P2O5: 9%, K_2O: 37%, MgO: 3%, SO_3: 13%, B: 0.02%, Cu-EDTA: 0.004%, Fe-DTPA: 0.14%, Fe-EDDHA: 0.01%, Mn-EDTA: 0.033%, Mo: 0.003%, Zn-EDTA: 0.021%). The nutrient solution was prepared by dissolving both the set I and set II mineral fertilizers with 1L of water respectively to produce two different stock solutions. The ratio of the mineral fertilizers to the water is 1:100. Then, 200 mL from each stock solution were added into another 40L of water to obtain a 1.25 mS/cm of electrical conductivity (EC) reading. The pH buffer solutions were prepared for the control system by diluting pH up solution containing 25% potassium hydroxide and pH down solution containing 50% food grade phosphoric acid (City Farm, Malaysia) at a dilution factor of 1:8 and 1:6 respectively.

2.2. Hardware

The temperature, dissolved oxygen concentration and pH values in the hydroponics system were monitored using various sensors for data collection (Table 1). All sensors were calibrated in accordance with the manufacturer’s instructions. A peristaltic pump (DFR0523, DFRobot) was subsequently used to control the addition of buffer solution to adjust the pH in the hydroponics chamber. The selected peristaltic pump includes a pulse position modulation (PPM) motor driver, whereby the control signal is compatible with a standard servo motor which was controlled using microcontrollers. The peristaltic pump which is a positive displacement pump was able to deliver up to 100 mL/min of fluid.

Table 1. Sensors Information for Data Collection.

Sensors	Temperature Sensor	DOC Sensor	pH Sensor
Brand	GI Electronic	DFRobot	Inesa Scientific Instrument
Model Number	DS18B20	SEN0237	E-201-C
Operating Temperature (°C)	-55 to +125	0 to 40	5 to 60
Pressure	-	0 to 50 PSI	-
DOC	-	0 to 20 mg/L	-
Power (V)	3 to 5.5	3.3 to 5	3.3 to 5
Accuracy	±0.5%	±0.1%	±0.1%

2.3. *Testing and Validation*

2.3.1 Peristaltic Pump Volumetric Flowrate. The relationship between the volumetric flow rate and pump rotation speed, as an improperly selected volumetric flow rate may affect the pump to pump insufficient or excess pH up or pH down buffer solution into the nutrient solution. The volumetric flow rate of water was measured at various rotational speeds ranging from 0- 180.

2.3.2 Transient Response of the Pump. A transient response test was designed using the peristaltic pump and pH buffer solutions in order to determine the response of the control system to changes in the pH [9]. A tank containing 50 L of nutrient solution was prepared according to Section 2.1, and the pH sensor was submerged on the opposite side of the peristaltic pump in the tank. The pH of the nutrient solution was manually varied to acidic conditions (pH 4,5) and alkaline condition (pH 9) which was out of the set optimal range (pH 5.5-8.0) using the buffer solutions to artificially simulate a condition when the pH value is out of the optimal range. The peristaltic pumps were then switched on at a rotational speed of 40. A total of two timings were recorded: (1) time taken to dispense out pH up or pH down solution until it reaches the optimal range and (2) time taken to stabilize the pH after the pump is deactivated. The experiments were repeated for rotation speed of 50 and 60 respectively.

3. Design and Development of Control System

Figure 1 details the conceptualization visualization of the design and development of the water quality monitoring and control system design. Data acquisition was conducted by connecting the temperature, pH, dissolved oxygen sensors and peristaltic pumps using hardware wiring to the Arduino UNO, which acts as the microcontroller for the interfacing of the sensors [10]. The command program for this board is written through the Arduino UNO in the C++ language, and then compiled and uploaded for the various components to function in the board. The microcontroller is connected to the Raspberry Pi that contains the Node-RED program (Javascript web hosted), which is a platform for programming hardware, Application Programming Interface (API), and web resources and InfluxDB for data processing and storage. Subsequently, the data is graphically visualized using Grafana as a time-based observability dashboard at a sampling time of 10 seconds.

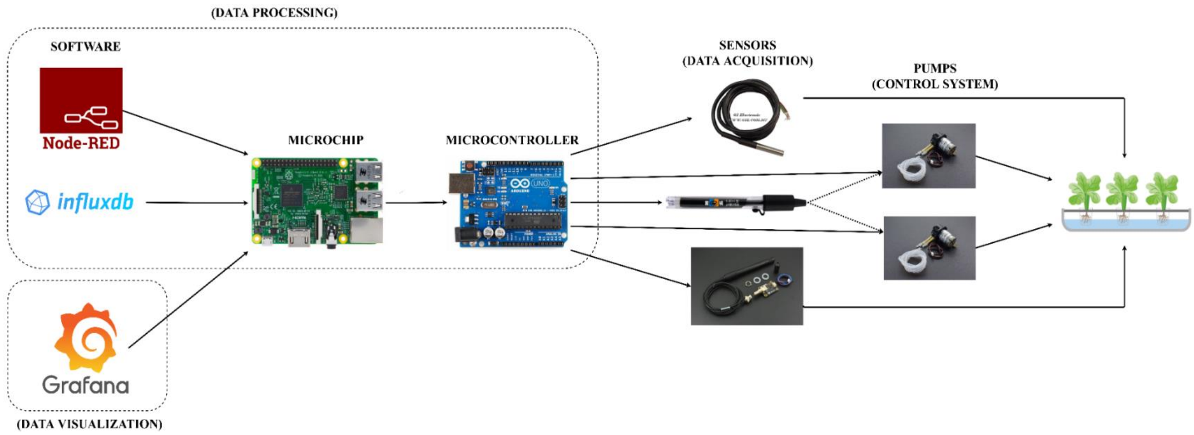

Figure 1. Overall Process Flow Diagram of Data System.

Figure 2 shows the design of an open-loop control system for the pH control system, designed to control the pH level to an optimum range of pH 5.5-8.0 for hydroponics application. The pH sensor is therefore an important regulated input data. These data are stored and processed in the Arduino UNO microcontroller device, where the range of the pH data were evaluated if it falls within the optimal range. If the pH value exceeds out of the optimal range, the microcontroller sends a trigger signal to activate the peristaltic pumps which contains the pH up and pH down buffer solution respectively until the pH sensor detects that the solution reaches the desired range. In addition, a warning message system would also be sent to the end-user via Node-RED through the Telegram program when the following parameters: temperature (18°C - 35°C), dissolved oxygen concentration (DOC) (above 2 ppm) and pH (pH 5.5 -8.0) level are not within the specific range. Figure 3 demonstrates the Grafana dashboard which consists of real-time visualization of the pH, temperature and DOC data.

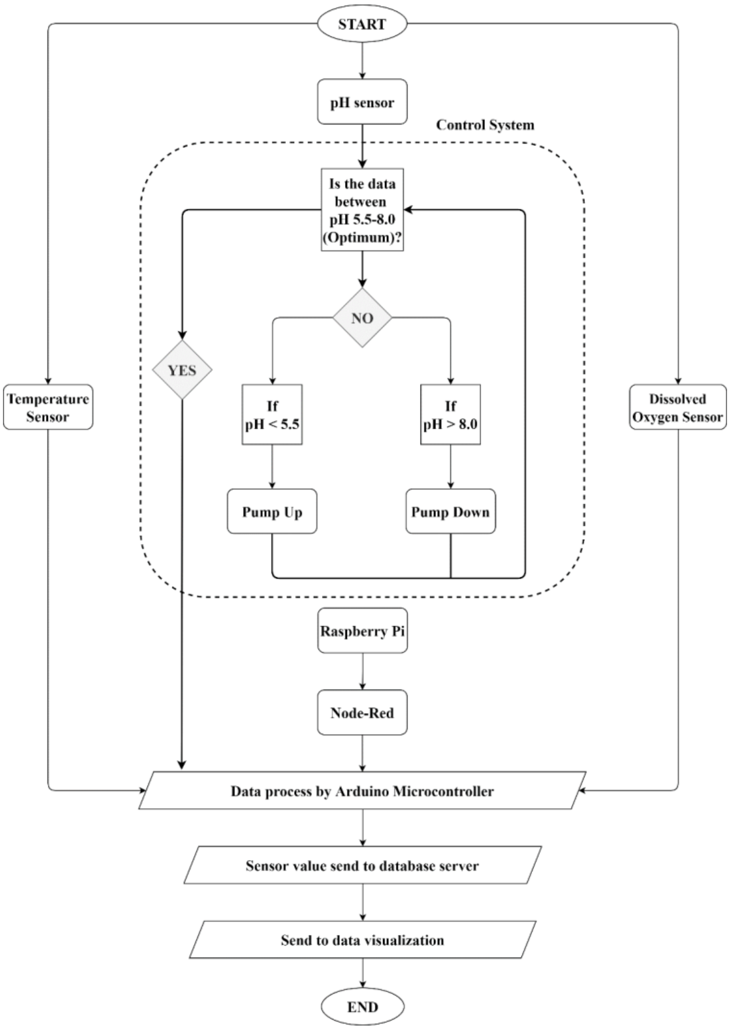

Figure 2. Block Diagram of the Overall Hydroponics System.

Figure 3. Grafana Dashboard.

4. Results and Discussion

4.1 Peristaltic Pump Volumetric Flowrate

Figure 4 demonstrates the volumetric flow rate at various angles of rotation of the pump. The maximum flow rate recorded was 102 mL/min, at rotational angle of 0 and 180. The rotation direction of the peristaltic pump is clockwise for rotation angle of 0-89, and anticlockwise for rotation angle of 91-180. At rotation speed of 90, the pump does not rotate. The volumetric flow rate data provides an indication on the transient response of the pump and the volume dispersed to control the pH to an optimum level.

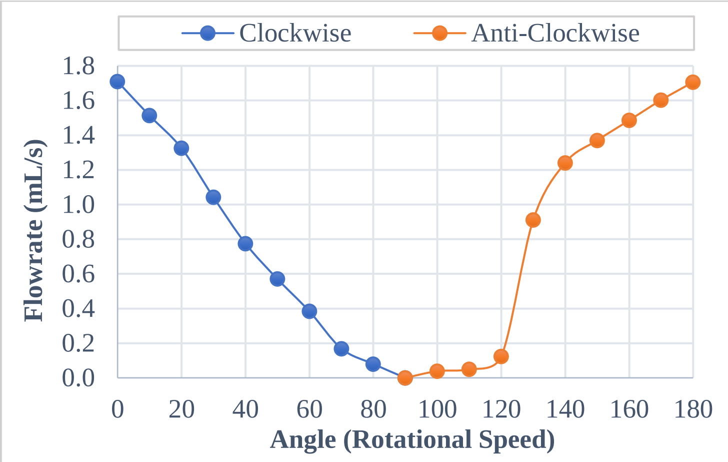

Figure 4. Volumetric Flow Rate of Pump at Different Rotational Angle.

4.2. Transient Response of the Pump

Table 2 summarizes the transient response of the peristaltic pump at varying rotational speed angle of 40,50 and 60. These speeds was able to dispense the buffer solution at controllable volumetric flowrates. At varying initial nutrient solution pH of 4, 5 and 9, the pH control system successfully control the pH values until it reaches the optimal range. For all rotational speed angles and initial pH solution, the final pH after the addition of the pH buffer lies in the mildly acidic region, averaging between pH 6.0 – 6.5.

Table 2. Transient Response at Different Speed.

Rotational Speed Angle	Initial pH	Final pH	Time Taken to Dispense pH buffer (seconds)	Time Taken to Stabilize (seconds)
40	4	6.5	190	150
	5	6.5	130	70
	9	6.3	180	240
50	4	6.2	310	80
	5	6.3	140	250
	9	6.2	80	310
60	4	6.5	450	180
	5	6.0	210	330
	9	6.5	190	250

Koehorst, Laubscher, and Ndakidemi (2010) reported that the highest chlorophyll was produced at pH 6.5 by *Artemisia Afra Jacq.* [11]. Similarly, Anderson et al. (2017) had showed butterhead lettuce grown in hydroponics system at pH 5.8 gave a higher fresh and dry weight by 26% and 18% respectively as opposed to plants grown at pH 7.0 [12]. Seyfferth et al. (2008) also indicated that butterhead lettuces grown under pH 5.5 – 6.5 demonstrated a higher nutrient uptake [13]. Hence, the final pH value after pH control was in-line with the optimal pH of pH 5.0-7.0 for hydroponics plant growth.

Based on the results, the optimal rotational speed angle for the pH control was 40 as this setting resulted in the lowest average time taken to dispense the pH up/down solution into the tank, at approximately 167±32 seconds, as opposed to 177±119 seconds and 283±144 seconds for rotational speed angle of 50 and 60 respectively. In addition, the average time taken to stabilize the pH data after the pump reaches optimal range for rotational speed angle of 40 is the shortest at 153 seconds, followed by 213 seconds and 253 seconds at rotational speed angle of 50 and 60. The results suggested that at the rotational angle of 40 was able to dispense the pH buffer solution swiftly to meet the desired pH range.

5. Conclusion

This study utilizes an Internet of Things (IoT) based control system for monitoring water quality in a hydroponic system. The Arduino UNO microcontroller effectively acquires pH, temperature, and dissolved oxygen sensor data, which is displayed in Grafana through the InfluxDB database. In addition, an alert message was successfully implemented whereby an alert message was sent to Telegram when the temperature, dissolved oxygen concentration (DOC) and pH level were not within the range. The control system was developed by analyzing the data obtained from the pH sensor. If the pH data was not within the desired range, pH up or pH down buffer solution will dispense out into the nutrient solution until the pH sensor detects that the pH value is within the optimal range. The transient response test of the peristaltic pump suggested for an initial nutrient solution pH value of 4, 5 and 9, the final pH after the addition of the pH buffer solution averages between pH 6.0 – 6.5 which is advantageous for hydroponics plant growth. It is suggested that the optimal rotational speed angle for the pH control is 40 as this setting resulted in the lowest average dispense and stabilization time. Results indicated that the control system was able to successfully control the pH value of the nutrient solution but further work is necessary to further optimize the physical setup for hydroponics application.

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