Controlling pH and temperature aquaponics use proportional control with Arduino and Raspberry

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Abstract. In planting plants using an aquaponic system. Plants are very dependent on nutrients found in water, pH and water temperature. pH and temperature become one of the parameters that determine the yield. pH must be maintained in conditions 6.5–8.0 and temperature must be maintained at 18–30° Celcius. Therefore, an automation system designed in order to keep the pH and temperature always at a predetermined range. Automation system designed using ARDUINO and RASPBERRY Pi microcontrollers with proportional control method. From the results of experiments that have been carried out, it is found that the designed device can control the temperature condition in the water by activating Peltier elements and fans or heaters to maintain the temperature conditions in water with fastest response time is 25.5 seconds for pH and 473.5 seconds for temperatures reaching setting determined.

1. Introduction

1.1. Aquaponics
An method that combines of cultivating fish and farming in a limited environment is called aquaponics method, where this method is the development of hydroponic and aquaculture techniques that are constructed with a symbiotic principle of mutualism for plants and fish in the artificial ecosystem[1]. The benefit of aquaponics are: low in the consumption of water; growth of plants faster; vegetables are highly organic, bigger and healthier; reduction of use of artificial fertilizer; reduction in disposal of fish waste; reduction in land is required to grow the same crops; easier to set up; reduced damaged from pets and disease; and no weeding and bending down [2].

1.2. Water Quality Parameters in Aquaponics cultivation system
Water quality is very important thing for aquaponics cultivation. There is five parameters that must be considered in aquaponics cultivation systems. The five most important water quality parameters are: Oxygen, pH (Hydrogen Power), Water temperature, Total nitrogen (ammonia, nitrite, nitrate) and Water hardness [3]. From that five water quality parameters in aquaponics cultivation system, this paper only studied about pH and Water Temperature parameters. pH of the water in aquaponics cultivation systems acceptable is between 6.0 until 8.0 with the ideal level is 7.0 and water temperature is between 18°C until 30°C [2].
1.3. Problem in field
There are still many shortcomings of this aquaponics technique because the handling of plants must be more intensive than traditional planting using soil media [4]. One of the problems is pool water. Rarely replaced pool water will increase the pH and temperature in the water. It can make plants and fish eventually die because the turbid water is not well maintained [5]. The question is how to maintain pH and water temperature at an acceptable condition in aquaponics cultivation system. So we need an effective, efficient way and bring a solution for agricultural and aquaculture actors. Therefore, automation is carried out on aquaponics system cultivation by designing a device that can control pH and temperature in the water so that the harvest of fish and plants is as expected. This research aims to create a device that is able to maintain pH and temperature in ideal conditions so that fish and plants can develop well. This tool uses a mega Arduino microcontroller and raspberry pi, pH sensor, temperature sensor, with a proportional control system.

2. Methodology

2.1. Architecture of monitoring and control system
The design of monitoring systems and controls on aquaponics is conducted by controlling the pH and temperature in water as the main media for aquaponics cultivation. The monitoring and control system is divided into three parts: the aquaponics system, data acquisition, and control equipment. The aquaponics monitoring and control system are shown in figure 1.

![Figure 1. Block diagram of aquaponics monitoring and control system.](image)

Figure 1 shows that the aquaponics system is a parameter in the aquaponics environment especially about the temperature and pH in the water. Data acquisition is about how to collect real-time environmental information such as pH and temperature. Data acquisition process uses two sensors: a pH sensor and temperature sensor. Both of these sensors are used to detect real-time pH and temperature aquaponics environment and the data obtained will be compared to a pH and temperature setpoint that is good for plants and fish.

Control equipment is the control and management center of the whole system, which manages all datasheet. The control equipment use is microcontroller Arduino Mega and Raspberry Pi with a proportional control system to control circulation water pump, chemical water pump and Peltier...
element. To make it easier monitoring and data logging about pH and temperature in aquaponic environment use LCD display and USB.

2.2. Flowchart Aquaponics monitoring and control system

The working principle of the aquaponics monitoring and control system is shown in figure 2.

![Flowchart of Aquaponics monitoring and control system](image)

Figure 2. Flowchart of Aquaponics monitoring and control system.

The working principle of aquaponic control and observation systems begins with signals by pH and temperature sensors. Both of these sensors will send data regarding the conditions in real time to the aquaponics environment to the Arduino Mega and Raspberry Pi microcontroller. The output signal from Arduino Mega will be passed to the circulation pump to circulate the water in the aquaponics environment and to the Raspberry Pi. Raspberry Pi output will be delivered to the LCD display to inform the temperature and pH of the aquaponic environment in real-time so that it can be seen directly by the observer. In addition, the output of Raspberry Pi is also delivered to the chemical water pump and Peltier elements. The chemical water pump will work when the pH level in the aquaponic environment is not less than 7 or over than 7 by pumping the pH solution (pH-Up or pH-Down) into an aquaponic environment so that the pH corresponds to the setting value (SV) which is at pH = 7. The chemical water pump will supply pH solution (pH-Up) when pH level in the aquaponic environment is less than 7 and will provide pH solution (pH-Down) when pH level in the aquaponic environment is over than 7. While the Peltier element will work when the temperature is more than 28°C and will turn on the fan and Peltier element will turn off when the temperature is less than 28°C. Each real-time condition about pH and temperature will be saved in USB data logging.

3. Result

In designing the pH and temperature control at Aquaponics, several analyzes were carried out to find out whether the system was working properly or not. An analysis is carried out namely pH sensor
analysis, temperature sensor analysis, proportional control system analysis on DC water pump, network communication analysis, overall system analysis.

3.1. pH sensor analysis

pH sensor analysis is conducted by comparing the measurement results of the pH sensor with the measurements result of the digital pH meter using a pH solution (pH-Buffer). In this analysis, six random samples were tested at pH 2, 4, 7, 9, 10 and 13. The purpose of this analysis was to determine the deviation of pH sensor readings against other comparable devices namely digital pH meters so that error correction can be done reading through the Arduino program. Sensor reading error data for the comparator is shown in table 1.

| pH Liquid Buffer | pH Meter Digital | Litmus Paper | pH Sensor | Error Value Sensor pH to pH Meter | Digital | Sampling Time (Menit) |
|------------------|-----------------|--------------|-----------|----------------------------------|---------|----------------------|
| 2.00             | 1.77            | 2.00         | 1.938     | 0.20                             |         | 10                   |
| 4.00             | 4.03            | 4.00         | 4.135     | 0.11                             |         | 10                   |
| 7.00             | 7.00            | 7.00         | 7.028     | 0.12                             |         | 10                   |
| 9.00             | 9.27            | 9.00         | 9.211     | 0.09                             |         | 10                   |
| 10.00            | 10.03           | 10.00        | 9.889     | 0.14                             |         | 10                   |
| 13.00            | 13.06           | 13.00        | 13.11     | 0.16                             |         | 10                   |

From table 1, it was informed that the measurement error of the pH sensor that had been compared with the measurement results by the digital pH meter obtained a minimum pH sensor measurement error 0.09, an average sensor pH measurement error 0.15 and a maximum sensor pH measurement error 0.20. Chart of the sensor pH measurement error is shown in figure 3.

![Figure 3](image3.png)

**Figure 3.** The result of the error value pH sensor.

3.2. Temperature sensor analysis

Temperature sensor analysis is done by comparing the measurement results of the temperature sensor with the measurements result of the digital thermometer using water. In this analysis, the test is carried out on several temperature values, six samples were tested at temperature 0°, 10°, 20°, 30°, 40° and 50°C. The purpose of this analysis was to determine the deviation of DS18B20 temperature sensor readings
against other comparable devices namely digital thermometer so that error correction can be done at the Arduino program. Sensor reading error data for the comparator is shown in table 2.

Table 2. The result of the error value temperature sensor.

| Water Temperature | Digital Thermometer | Mercury Thermometer | DS18B20 Temperature Sensor | Error Value Sensor pH to pH Meter Digital | Sampling Time (detik) |
|-------------------|---------------------|----------------------|-----------------------------|-------------------------------------------|----------------------|
| 0.00              | 0.10                | 0.00                 | 0.37                        | 0.27                                      | 100                  |
| 10.00             | 10.80               | 10.00                | 10.58                       | 0.38                                      | 100                  |
| 20.00             | 20.40               | 20.00                | 20.56                       | 0.16                                      | 100                  |
| 30.00             | 29.50               | 30.00                | 29.37                       | 0.13                                      | 100                  |
| 40.00             | 40.90               | 40.00                | 40.72                       | 0.18                                      | 100                  |
| 50.00             | 50.50               | 50.00                | 50.25                       | 0.25                                      | 100                  |

From table 1, it was informed that the measurement error of the DS18B20 temperature sensor that had been compared with the measurement results by the digital thermometer obtained a minimum DS18B20 temperature sensor measurement error 0.13, an average DS18B20 temperature sensor measurement error 0.23 and a maximum DS18B20 temperature sensor measurement error 0.20. Chart of the DS18B20 temperature measurement error is shown in figure 4.

3.3. Proportional control system analysis

Control system testing is done by setting the minimum setting value (SVmin) and setting the maximum setting value (SVmax) at pH equal to 7. When the pH is below SVmin, raspberry pi will instruct the chemical pump to supply pH solution (pH-Up) so that the pH value on aquaponics system increases to 7 according to the setting value, whereas if the pH value is above the SVmax value, the raspberry pi will instruct the chemical pump to supply pH solution (pH-Down) so that the pH value of the aquaponics system drops to 7 according to the setting value. Proportional control system response test to the pH is shown in table 3. Table 3 informs that when pH value less than 7 chemical pump pH-Up will turn on and when pH value over than 7 chemical pump pH-Down will turn on. Response time when switch from less than 7 until chemical pump pH-Up turn on is 1 second. Chart of chemical pump response to pH value is shown in figure 5.
Table 3. Proportional control system response test to the pH.

| Water Temperature (°C) | pH Value | Motor Speed pH-Down (%) | Motor Speed pH-Up (%) | Time |
|------------------------|----------|-------------------------|-----------------------|------|
| 28.69                  | 6.62     | 0.00                    | 5.48                  | 13.50.42 |
| 28.69                  | 6.62     | 0.00                    | 5.48                  | 13.50.43 |
| 28.69                  | 6.62     | 0.00                    | 5.48                  | 13.50.44 |
| 28.69                  | 6.48     | 0.00                    | 5.48                  | 13.50.45 |
| 28.69                  | 6.40     | 0.00                    | 7.44                  | 13.50.46 |
| 28.69                  | 6.21     | 0.00                    | 8.61                  | 13.50.47 |
| 28.69                  | 6.12     | 0.00                    | 11.35                 | 13.50.48 |
| 28.69                  | 6.26     | 0.00                    | 12.52                 | 13.50.50 |
| 28.69                  | 6.56     | 0.00                    | 10.57                 | 13.50.51 |
| 28.69                  | 6.86     | 0.00                    | 6.26                  | 13.50.52 |
| 28.69                  | 7.00     | 0.00                    | 1.96                  | 13.50.53 |
| 28.69                  | 7.37     | 0.00                    | 0.00                  | 13.50.54 |
| 28.69                  | 7.82     | 5.28                    | 0.00                  | 13.50.55 |
| 28.69                  | 7.89     | 11.74                   | 0.00                  | 13.50.56 |
| 28.69                  | 8.10     | 12.72                   | 0.00                  | 13.50.57 |
| 28.69                  | 7.64     | 15.66                   | 0.00                  | 13.50.58 |
| 28.69                  | 6.95     | 9.20                    | 0.00                  | 13.50.59 |
| 28.69                  | 2.11     | 0.00                    | 0.78                  | 13.51.00 |
| 28.69                  | 0.01     | 0.00                    | 69.86                 | 13.51.01 |
| 28.69                  | 2.21     | 0.00                    | 99.80                 | 13.51.02 |
| 28.69                  | 8.10     | 0.00                    | 68.49                 | 13.51.03 |
| 28.69                  | 12.30    | 15.66                   | 0.00                  | 13.51.04 |
| 28.69                  | 13.97    | 75.73                   | 0.00                  | 13.51.05 |
| 28.69                  | 13.97    | 99.61                   | 0.00                  | 13.51.06 |
| 28.69                  | 13.60    | 99.61                   | 0.00                  | 13.51.07 |
| 28.69                  | 9.37     | 94.32                   | 0.00                  | 13.51.08 |
| 28.69                  | 7.21     | 33.86                   | 0.00                  | 13.51.09 |
| 28.69                  | 6.99     | 2.94                    | 0.00                  | 13.51.10 |
| 28.69                  | 7.40     | 0.00                    | 0.20                  | 13.51.11 |

3.4. Network communication system analysis
There are 2 parts of communication network testing, namely testing of I2C and serial communication networks. The I2C network is used to display data from the sensor to the LCD display. The I2C test results are shown in figure 6. Figure 7 shows serial communication testing by sending sensor data from Arduino to Raspberry Pi. Sensor data transmitted from the pH sensor and the temperature sensor used, then the data is recorded to USB as a data logger.
3.5. **Overall system analysis**

Overall system analysis aims to see the response time of the control system that has been designed, by knowing the response that is given, it can be known the success of the system designed to answer the
problem formulation, in table 4 shows the changes conditions in the device currently used for testing in prototype form (after) and the previous device in the form of the original scale (before).

Table 4. Device comparison testing.

| Item                | After       | Before      |
|---------------------|-------------|-------------|
| Water Volume        | ±50 Liter   | ±10 Liter   |
| Water pH Setting    | 7.5/6.0     | 7.5/6.0     |
| Temperature Setting | 29/27°C     | 29/27°C     |
| Scale of real-time  | 1:20        | 1:4         |

Table 5. Final data of test results.

| Data     | Steady State Time | Maximum Overshoot Time | Peak Time | Error Max | Error Average | Error Min | accuracy | precision |
|----------|-------------------|------------------------|-----------|-----------|---------------|-----------|----------|-----------|
| pH-Up    | 29                | 14                     | 10        | 0.2       | 0.15          | 0.09      | Yes      | No        |
| pH-Down  | 22                | 9                      | 7         | 0.2       | 0.15          | 0.09      | Yes      | No        |
| Temperature Up | 138           | 0                      | 0         | 0.38      | 0.23          | 0.13      | Yes      | Yes       |
| Temperature Down | 759          | 0                      | 0         | 0.38      | 0.23          | 0.13      | Yes      | Yes       |

From table 5 can be known the success of the prototype made on a scale of 1:20 from the scale of the original tool, taking into account all the errors and weaknesses that exist in the prototype makes the success rate of the tool cannot reach 100%. So the success rate that can be achieved is 80% for pH control and 80% for temperature control.

4. Conclusion

Based on the design, implementation and testing of the device it can be concluded that actual information about pH and temperature of the water can be seen directly through LCD display, pH sensor and temperature sensor has worked properly. It is shown by the error percentage of calibration measurement sensor. Error pH sensor 1.07% and error temperature sensor 0.89%. The device can automatically control pH condition by operating pH liquid supply pump if pH conditions are outside setpoint and can control the water temperature conditions by activating Peltier elements and fans or heaters to maintain temperature conditions in the water with fastest response time is 25.5 seconds for pH and 473.5 seconds for temperatures reaching setting determined.

References

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