Comparison of PI, PD, and PID Controller in Hydroponic Plant Nutrient Concentration Control System

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Abstract: Hydroponics is a plant cultivation technique by utilizing water media and emphasizing the need for nutrients to grow. Each type of hydroponic plant requires a nutrient solution with different levels of concentration. If the concentration is low, it will reduce the effectiveness of nutrients so that additional nutrients are needed. Meanwhile, if it is excessive, the plant will wither and even die.

In this study, Proportional (P), Integral (I), dan Derivative (D) controller is used. PI, PD, and PID controllers were designed, then tested on a nutrient concentration control system to get the best performance. If the error is positive, it indicates the plant to approach the threshold of excess nutrients, so the controller will move the servo motor to open the water valve. On the other hand, if the error value is negative, it indicates that the plant to approach the nutrient deficiency threshold, so that the nutrient solution valve needs to be opened through servo motor movement.

The observed variables are error rate and delta error. The test results show that the use of a PID controller with Kp=0.5, Ki=1, and Kd=1 gives a fairly good performance with relatively small error rates and delta error, namely 4.997 (0.83%) and 1.804.

1 INTRODUCTION

The hydroponic system is a method of growing plants using a solution of mineral nutrients in water without soil. Each type of hydroponic plant requires a solution with a different level of nutrient concentration (Tallei, Rumengan, & Adam, 2017). The level of concentration of nutrients is measured in units of particles per million (ppm) or by measuring the level of conductivity. If the nutrient solution given becomes too concentrated, it will cause the plant to wither or die, so it is necessary to give water as a diluent in order to reduce the concentration level gradually. On the other hand, if the concentration of the solution is low, then the plant will become deficient in nutrients, so it needs to be added.

Monitoring to maintain the concentration value of the nutrient solution for local hydroponic farmers is still done manually using a TDS (Total Dissolved Solids) measuring instrument at certain times. There needs to be a regulatory system to control nutrient concentrations automatically. Control algorithm is needed to achieve the desired concentration optimally. In this research, PI, PD, and PID controllers will be designed for later analysis of the resulting performance. The observed performance parameters are the resulting error rate as well as oscillations in the system response which are shown through delta error observations.

There are a number of studies on monitoring systems and nutrition for hydroponic plants, including monitoring systems for pH and water conductivity in hydroponic plants automatically using sensors and microcontrollers (Gosavi, 2017) (Umamaheswari, Preethi, Pravin, & Dhanusha, 2017). In this study, the control process is carried out through a programmed microcontroller and is not carried out remotely (wireless).

The next research development is the provision of nutrition to hydroponic plants through remote control, including Arduino which is connected to a Wi-Fi module (P. Sihombing, Karina, Tarigan, & Syarif, 2018), using an Arduino microcontroller controlled via a smart phone (Poltak Sihombing, Zarlis, & Herriyance, 2019), and based on IoT using web technology (Crisnapati, Wardana, Aryanto, & Hermawan, 2017). Although the control system as mentioned above can be done wirelessly, in the

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process of regulating the concentration of nutrients it is still done on-off. Arduino will activate or deactivate (on-off) the tank valve which contains water and nutrients and then flows it to hydroponic plants.

The use of control algorithms in regulating the NFT hydronic system, among others, uses fuzzy logic (Mashumah, Rivai, & Irfansyah, 2018), with input in the form of errors and water volume and output in the form of valve openings. The results obtained are quite good with an error rate of 8.9%. Another research is the control of electrical conductivity (EC) with a PID controller (Ikhlas, T, & Sc, 2018) . The control system output is in the form of a solenoid valve to drain AB mix nutrients or water. Observations were made on the achievement of the predetermined EC set point.

In this research, PI, PD, and PID controllers will be designed and applied to control nutrient solution concentration. Then observations were made on the three controllers to determine the method and parameter values of Kp, Ki, and Kd which had the best performance.

The control system is the process of setting one or several variables so that they are at a certain price or price range. Besides keeping the system output at the desired price, the control system also aims to obtain optimal performance. The closed loop control system is shown in Figure 1.

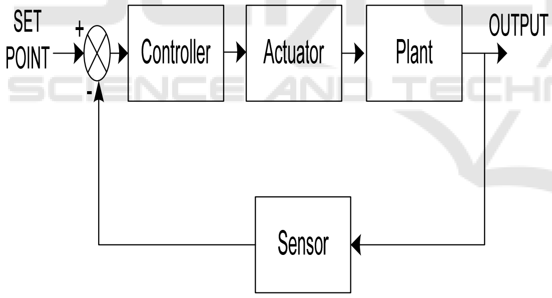

Figure 1: Block diagram of closed loop control system.

The control system starts by assigning a set point value. The system output is measured using sensors and then compared with the set point to determine the resulting error.

$$e(t) = SP - PV \tag{1}$$

where e(t) is the error value at time t, SP is the set point value, and PV (present value) is the sensor's measured output value.

If there is an error, the controller will process it using the programmed control algorithm. The PID (Proportinal, Integral, Derivative) control algorithm is defined as follows:

a. Proportional Controller (P):

$$P = K_p\, e(t) \tag{2}$$

b. Integral Controller (I):

$$I = K_i \int e(t) \tag{3}$$

c. Derivative Controller (D):

$$D = K_d \frac{\partial e(t)}{\partial t} \tag{4}$$

2 METHODS

The design of the hydroponic plant nutrient concentration control system is shown in Figure 2. The nutrient solution bath contains a mixture of nutrient A (5ml) and nutrient B (5ml), while the water tank is used as a diluent for the solution. In the circulation tub, adjustments are made to obtain the nutrient concentration in accordance with the reference value for each type of hydroponic plant.

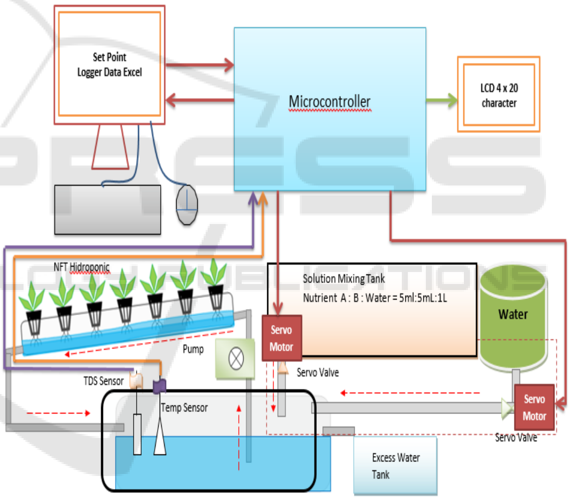

Figure 2: Control system design for nutrient concentration.

To adjust the concentration, a control algorithm is used which will adjust the opening of the servo valve in the nutrient and the valve in the water tank as a diluent. The control algorithms that are simulated are PI, PD, and PID with parameter settings Kp, KI, and Kd to determine the effect of each type of controller and determine parameters that are considered to have good enough performance. The process of adjusting the concentration of the nutrient solution is shown in a flow chart as shown in Figure 3. After the concentration of the solution required by the plant is reached, the nutrients are watered onto the hydroponic plants.

If the error is smaller than zero, the water servo valve will open at the calculated angle value. On the other hand, if the error is greater than zero, the nutrition servo valve will open. When the error condition is equal to zero, the water servo valve and the nutrition servo valve will be closed.

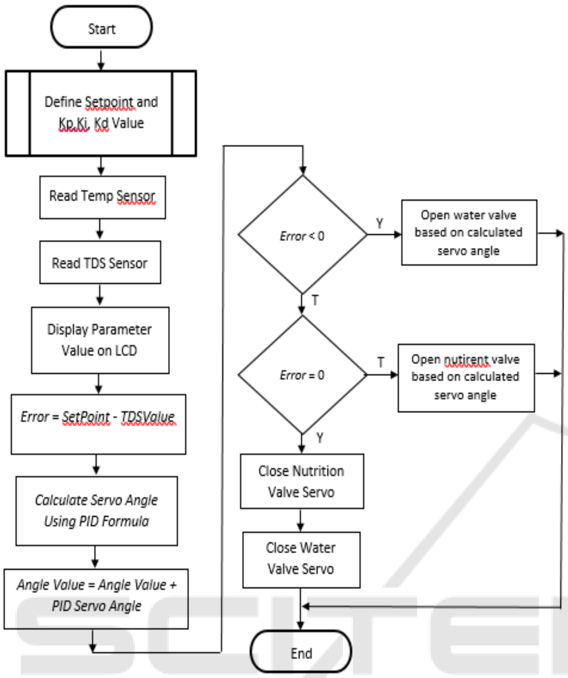

Figure 3: Control process flowchart.

The electronic circuit used for system settings is shown in Figure 4.

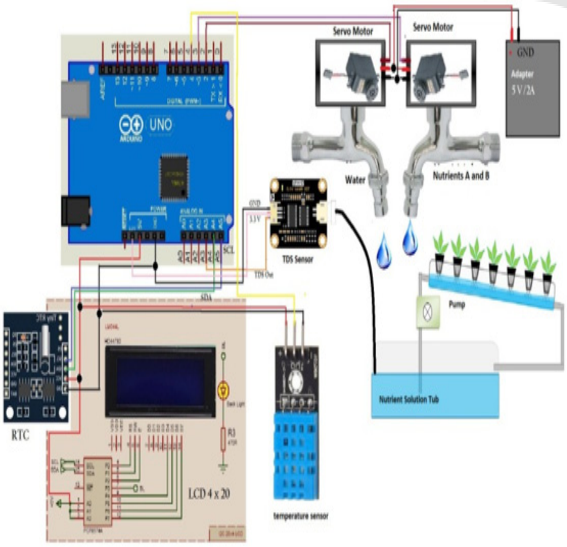

Figure 4: Electronic circuit.

The schematic of the circuit above has the following pin out configuration:

1. The TDS sensor will be connected to pin A4 of the Arduino microcontroller. The sensor probe is placed in a tub of nutrient solution whose concentration will be measured.
2. RTC and LCD use serial I2C, each for SDA data is connected to an arduino microcontroller.
3. Temperature and humidity sensors are connected to the D4 pin of the microcontroller
4. The servo motor is used to rotate the water and nutrition valve connected to the D2 and D3 pins of the Arduino microcontroller.

3 RESULT AND DISCUSSION

Tests were carried out on the PI, PD, and PID control algorithms with variations in the values of Kp, Ki, Kd and a set point of 600 ppm.

3.1 PI Controller

The proportional controller (P) and the integral controller (I) are combined in a cascade and then command the actuator in this case the servo motor to drive the nutrient solution or water valve. The movement of the valve is based on the servo motor angle according to the given control signal.

The results of the PI controller test with values of Kp=0.5 and Ki=0.5 resulted in an error rate of 8.397 (1.4%) and an average delta error |dE| of 12,189. The graph of the system response to the set point is shown in Figure 5.

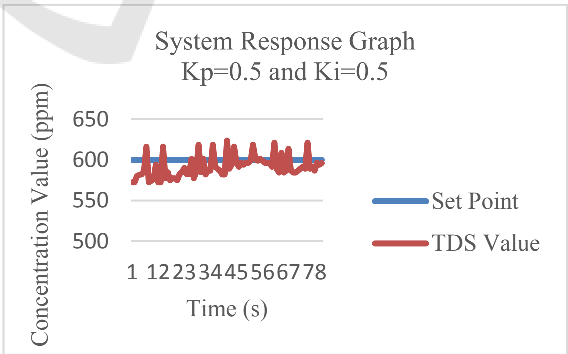

Figure 5: System response with Kp=0.5 and Ki=0.5.

The next test is by changing the PI controller parameters where the Ki value is increased by 1, while Kp remains at 0.5. The test results are given in Table 5.2. The average error generated is 4,569 (0.76%) and the delta error is 16,194.

When compared with the previous results, error rate is relatively smaller, while the value of the delta error is larger. This is influenced by controller Integral which serves to minimize steady state error. However, the increase in the value of Ki causes the response to experience a slight increase in oscillations which is indicated by a larger delta error. The graph of the system response to the PI controller is shown in Figure 6.

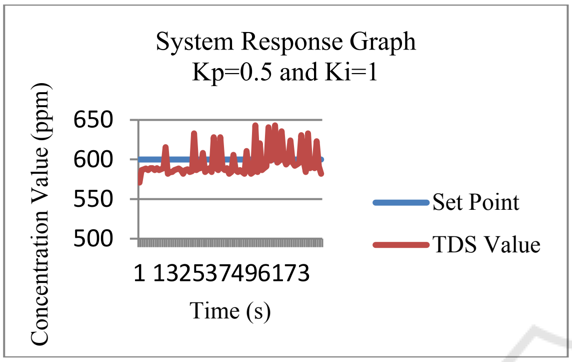

Figure 6: System response with Kp=0.5 and Ki=1.

3.2 PD Controller

The addition of a derivative controller (D) is intended to reduce oscillations in the system response. The results of the test using a PD controller with Kp=0.5 and Kd=1 indicate the error rate generated is larger, namely 50,935 (8.49%). This means that the system output does not succeed in approaching the specified set point value of 600 ppm.

However, if we look at the average delta error |dE| which became smaller by only 1,627, indicating the system became more damped so that the oscillations were successfully reduced. The system response graph is shown in Figure 7.

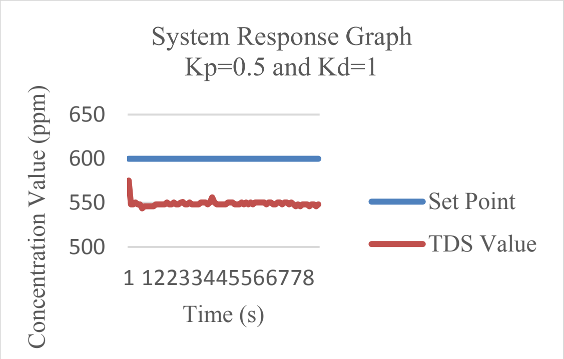

Figure 7: System response with Kp=0.5 and Kd=1.

3.3 PID Controller

Based on the results of previous tests, the use of the PI controller will reduce the error rate, while the PD controller has succeeded in reducing oscillations and overshoot. So that combining the three types of controllers into a PID will result in better performance. Block diagram of the PID controller can be seen in Figure 8.

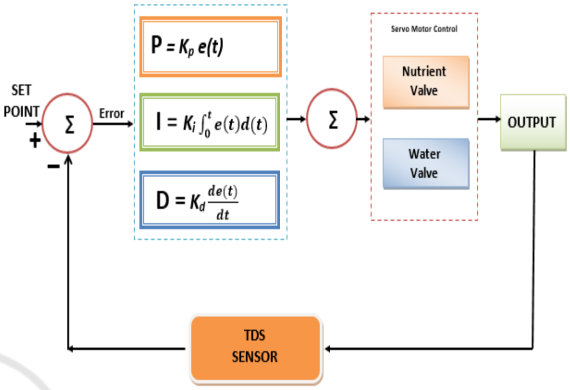

Figure 8: Block diagram of nutrient concentration control using PID controller.

In the first test with values of Kp = 0.5, Ki = 0.5, and Kd = 1, the error rate was 10,491 (1.75%) and average delta error was 5.867. The system response graph is given in Figure 9.

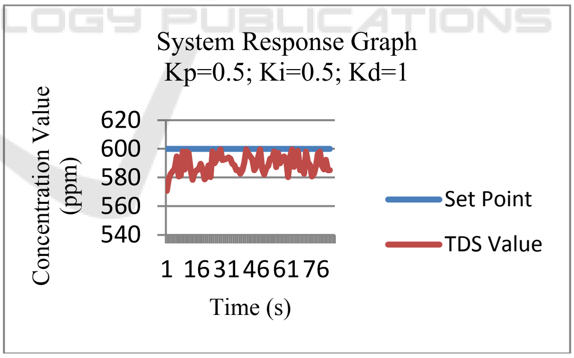

Figure 9: System response with Kp=0.5, Ki=0.5, and Kd=1.

To reduce the oscillations, the value of Kd is then enlarged to 1.5, while the other parameters remain the same. The test results show that the oscillation can be reduced to only 1,798, but the resulting error rate is 57,661 (9.61%). Figure 10 shows a graph of the system response for Kp=0.5, Ki=0.5, and Kd=1.5.

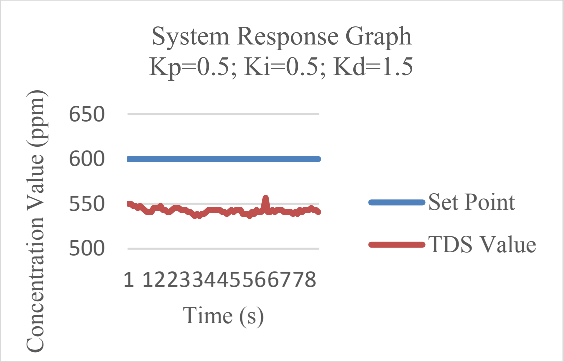

Figure 10: System response with Kp=0.5, Ki=0.5, and Kd=1.5.

Based on previous result, the Kd value should not be too large, although it will provide stability to the system response. To reduce the error rate that occurs, the Ki parameter is enlarged to 1 and the Kd value is returned to its original value to 1. So that the controller parameters are now Kp=0.5, Ki=1, and Kd=1.

From the test results, it can be seen that the average error generated is 4,997 (0.83%), while the average delta error is 1,804. So that there is a compromise value between the control objectives to produce the minimum possible error, with the minimum possible oscillation impact. Figure 11 is a graph of the system response using PID with Kp=0.5, Ki=1, and Kd=1.

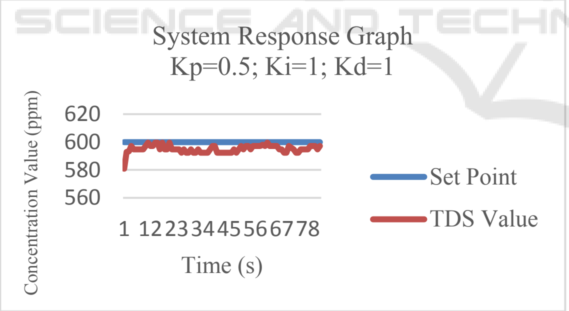

Figure 11: System response with Kp=0.5, Ki=1, and Kd=1.

4 CONCLUSIONS

The control of nutrient concentration in hydroponic plants in this study using PI, PD, and PID controllers aims to observe the performance of each controller and determine the parameters that have the best performance.

There is a compromise in determining the parameters of Kp, Ki, and Kd. By increasing the value of Ki to produce a smaller error rate, it will increase the oscillation and overshoot. Likewise, if increasing the value of Kd in order to obtain a low level of oscillation and overshoot, it will produce a greater error rate.

In testing using a PID controller with Kp = 0.5, Ki=1, and Ki=1, a satisfactory performance was obtained, where the error rate and average delta error produced were quite low, namely 4.997 (0.83%) and 1.804.

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