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Tuning of PI, PD, and PID Controllers Based on Fuzzy Logic Using IoT

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ABSTRACT: Hydroponic plants require nutrients with a certain concentration according to the type of plant to be cultivated. This study aims to maintain nutrient concentration at a predetermined value. If the concentration measured is below set point, nutrients need to be added. Conversely, water is added as a diluent. PI, PD, and PID controllers are used to adjust servo angle on the water and nutrient valve, then compared to determine the type of controller that provides best response. Controller parameter values Kp, Ki, and Kd are then tuned using fuzzy logic. System then uses internet of things (IoT) so that it can be monitored remotely. The variables observed are time required to reach set point and average error generated. Based on testing, PI controller obtained the time to reach set point is t = 50 and the PID controller t = 30. While on PD controller, response did not reach set point during observation. Average error generated on PI controller is 47.95, PD controller 76.55, and PID controller 30.97 where initial concentration value is in range of 70 ppm and target set point is 400 ppm.

KEYWORDS: Control, Hydroponics, PID, Fuzzy, IoT

I. INTRODUCTION

Hydroponic plants require nutrient solutions with a certain level of concentration (Tallei, Rumengan and Adam, 2017). In this study, nutrient concentration was measured using a TDS sensor, if it is too concentrated then water are added and if it is too thin then nutrients need to be added at that concentration.

Research that has been conducted related to hydroponic plants includes monitoring pH and conductivity of solutions using microcontrollers (Gosavi, 2017) (Umamaheswari *et al.*, 2017). The next study is remote control such as the use of microcontroller-based smartphones (Sihombing *et al.*, 2018), arduino using a wi-fi module (Tembe, Khan and Acharekar, 2018), web servers (Suseno, Munandar and Priyono, 2020), and the use of the internet of things (Hadiatna, Dzulfahmi and Nataliana, 2020). Although done remotely, the method used in setting concentration is still using on/off. In this method microcontroller will order nutrient or water valve to open or close completely so that the solution reaches desired concentration.

The use of PID control algorithms (Nurmahaludin, Cahyono and Riadi, 2023) and Fuzzy controllers (Nurmahaludin, Cahyono and Riadi, 2020) has been carried out by the author in hydroponic nutrient settings which were then continued with the use of IoT in the control (Nurmahaludin and Cahyono, 2023). The results obtained were quite good, but there were difficulties in determining the Kp, Kd, and Ki parameters so that trial and error were carried out. In this study, fuzzy logic was used to tune the PI, PD, and PID controller parameters and then observations were made of the resulting responses. The water and nutrient valve opening settings were carried out via a servo motor where servo angle was obtained from the PID controller calculation. The purpose of this study is to observe and analyze the responses produced in the PI, PD, and PID controller parameter tuning method based on fuzzy logic using IoT.

II. METHOD

The design of the hydroponic nutrient concentration control system is shown in Figure 1. The nutrient tank contains a mixture of nutrients A and B types, while the water tank is used as a nutrient diluent. In the solutions tank, adjustments are made to obtain a solution concentration that is in accordance with the reference value for each type of hydroponic plant.

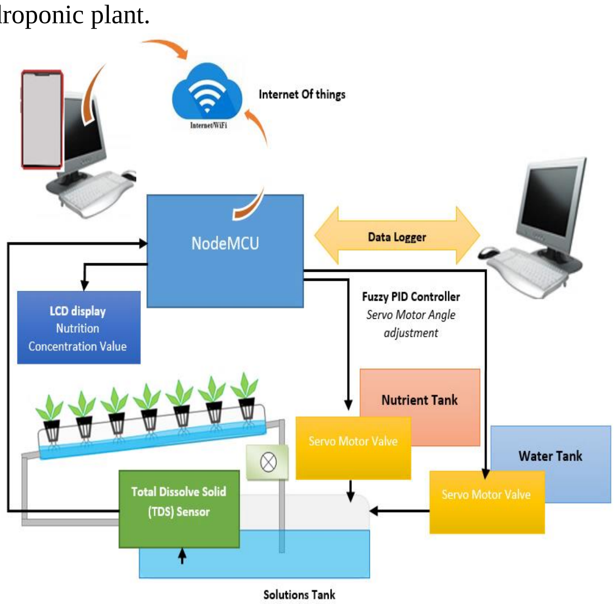

Figure 1. Control System Design

Alternately, PI, PD, and PID control algorithms are used to regulate the opening of the servo valve on the nutrient tank and the servo valve on the water tank. Fuzzy logic is used to tune the Kp, Ki, Kd parameters on the controller. The process of regulating the concentration of the nutrient solution is shown in the flow diagram as shown in Figure 2.

Figure 3 explains the process in fuzzy system to produce PID control parameter values, namely Kp, Ki, Kd. After the concentration of the solution required by the plant is achieved, nutrients are sprayed onto hydroponic plants.

Output of PID controller will adjust the angle of the servo motor to open the nutrient solution or water valve. If error value is positive, it indicates that plant is in a state of lack of nutrients (below the set point value) so that nutrient valve needs to be opened through the movement of the servo motor. Conversely, if error value is negative, it indicates that plant is approaching the threshold of excess nutrients. So the controller will move the servo motor to open the water valve to dilute the solution.

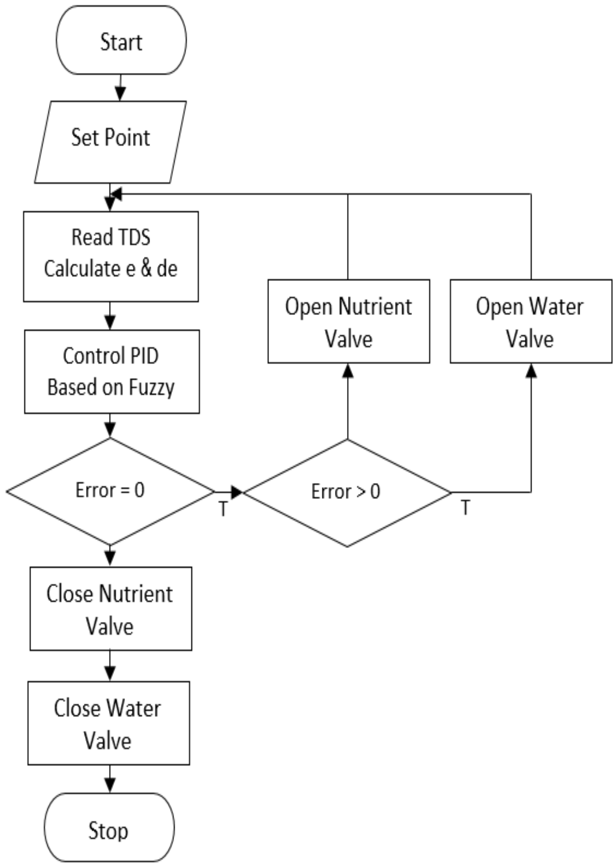

Figure 2. Flowchart of Control Process

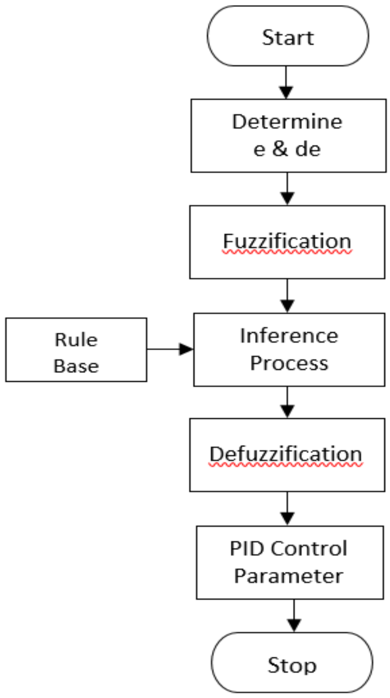

Figure 3. Flowchart for Controller Parameter Tuning

Controller Design

PI control algorithms in controlling nutrient concentration are shown in Figures 4. The fuzzy logic function in the design is to tune the Kp and Ki parameters used in the PI controller. This can be a solution where generally the determination of these parameters is done by trial and error until the best performance is produced from a series of tests. Another advantage is that the tuning mechanism becomes more adaptive because it is based on the error and delta error generated each time.

Control algorithm aims for the system to reach a steady state in a short time with an output value approaching its set point value. The system response data (output) is sent to the database by the microcontroller for monitoring and analysis of the system's transient response.

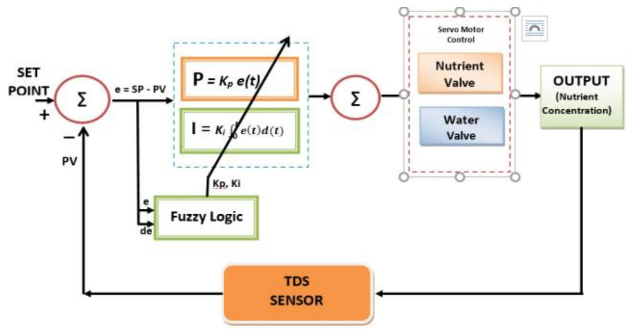

Figure 4. Block Diagram of the PI-Fuzzy

The steps for searching for parameters Kp, Kd, Ki using the fuzzy method are:

1. Determining fuzzy input and output

Fuzzy input is error e(t) and delta error (δ(t)). Delta error is difference between error at time t and previous error (t-1).

Fuzzy logic output is parameter values Kp, Kd, and Ki, as shown in Figure 5.

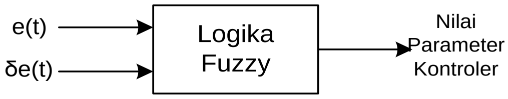

Figure 5. Fuzzy System Input-Output

2. Determining fuzzy sets

Input e(t) is divided into 5 sets, namely negative big (NB), negative small (NS), zero (Z), and positive small (PS), and positive big (PB). Input δe(t) is also divided into 5 sets, namely negative big (NB), negative small (NS), zero (Z), and positive small (PS), and positive big (PB). While fuzzy logic output uses a singleton function and is divided into 5, namely small (S), little small (LS), medium (M), little big (LB), and big (B).

3. Determining membership function

Membership function e(t) is as shown in Figure 6, where:

$$\mu_{NB}[x] = \begin{cases} 1 & ; \; x \le -20 \\ \frac{-10-x}{10} & ; \; -20 \le x \le -10 \\ 0 & ; \; x \ge -10 \end{cases}$$

$$\mu_{NS}[x] = \begin{cases} 0 & ; \; x \le -20 \; or \; x \ge 0 \\ \frac{x+20}{10} & ; \; -20 \le x \le -10 \\ \frac{-x}{10} & ; \; -10 \le x \le 0 \end{cases}$$

$$\mu_{Z}[x] = \begin{cases} 0 & ; \; x \le -10 \; or \; x \ge 10 \\ \frac{x+10}{10} & ; \; -10 \le x \le 0 \\ \frac{10-x}{10} & ; \; 0 \le x \le 10 \end{cases}$$

$$\mu_{PS}[x] = \begin{cases} 0 & ; \; x \le 0 \; or \; x \ge 20 \\ \frac{x}{10} & ; \; 0 \le x \le 10 \\ \frac{20-x}{10} & ; \; 10 \le x \le 20 \end{cases}$$

$$\mu_{PB}[x] = \begin{cases} 0 & ; \; x \le 10 \\ \frac{x-10}{10} & ; \; 10 \le x \le 20 \\ 1 & ; \; x \ge 20 \end{cases}$$

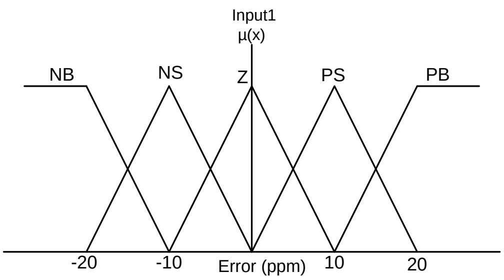

Figure 6. Membership Function e(t)

Membership function δe(t) is as shown in Figure 7.

$$\mu_{NB}[x] = \begin{cases} 1 & ; \; x \le -10 \\ \frac{-5-x}{5} & ; \; -10 \le x \le -5 \\ 0 & ; \; x \ge -5 \end{cases}$$

$$\mu_{NS}[x] = \begin{cases} 0 & ; \; x \le -10 \; or \; x \ge 0 \\ \frac{x+10}{5} & ; \; -10 \le x \le -5 \\ \frac{-x}{5} & ; \; -5 \le x \le 0 \end{cases}$$

$$\mu_{Z}[x] = \begin{cases} 0 & ; \; x \le -5 \; or \; x \ge 5 \\ \frac{x+5}{5} & ; \; -5 \le x \le 0 \\ \frac{5-x}{5} & ; \; 0 \le x \le 5 \end{cases}$$

$$\mu_{PS}[x] = \begin{cases} 0 & ; \; x \le 0 \; or \; x \ge 10 \\ \frac{x}{5} & ; \; 0 \le x \le 5 \\ \frac{10-x}{5} & ; \; 5 \le x \le 10 \end{cases}$$

$$\mu_{PB}[x] = \begin{cases} 0 & ; \; x \le 5 \\ \frac{x-5}{5} & ; \; 5 \le x \le 10 \\ 1 & ; \; x \ge 10 \end{cases}$$

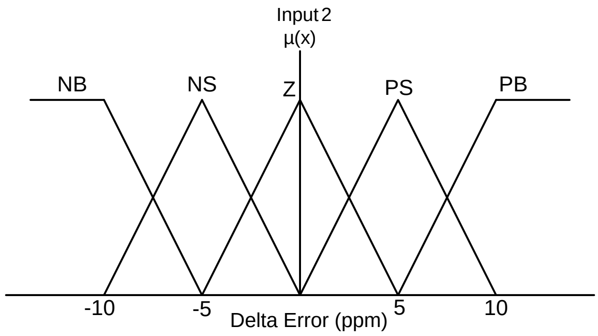

Figure 7. Membership Function δe(t)

Output membership function values of Kp, Kd, and Ki are in the form of singletons as shown in Figure 8.

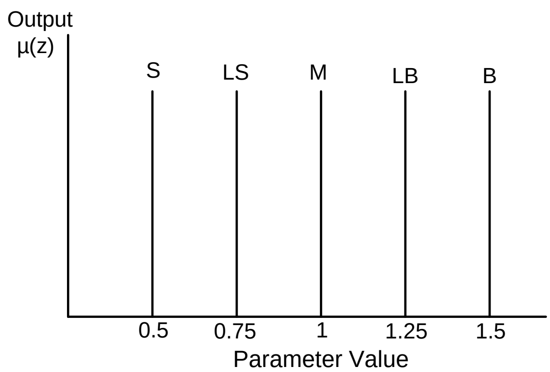

Figure 8. Membership Function Controller Parameter

4. Develop rules

Fuzzy rules have an if-then form, with conjunction operator AND between first input and second input. Rules are prepared to determine the values of Kp, Ki, and Kd respectively.

a. Rules for determining the value of Kp parameter

Table 1 shows a table of fuzzy rules for determining the value of Kp from a previously compiled set.

Table 1. Fuzzy Rule Determines Kp

e(t) \ δe(t)	PB	PS	Z	NS	NB
PB	M	LB	B	B	B
PS	M	LB	LB	B	B
Z	LS	S	S	S	LS
NS	M	LS	LS	S	S
NB	M	LS	S	S	S

b. Rules for determining the value of the parameter Ki
Table 2 shows a table of fuzzy rules for determining the value of Ki from a previously compiled set.

Table 2. Fuzzy Rule Determining Ki

e(t) \ δe(t)	PB	PS	Z	NS	NB
PB	B	LB	LB	LB	M
PS	LB	LB	LB	M	M
Z	LS	S	S	S	LS
NS	LB	LB	M	LB	LB
NB	B	LB	LB	LB	B

c. Rules for determining the value of the Kd parameter
Table 3 shows a table of fuzzy rules for determining the value of Kd from a previously compiled set.

Table 3. Fuzzy Rule Determining Kd

e(t) \ δe(t)	PB	PS	Z	NS	NB
PB	M	LS	S	S	S
PS	M	LS	LS	S	S
Z	LS	S	S	S	LS
NS	M	LB	LB	B	B
NB	M	LB	B	B	B

5. Determining fuzzy inference method
Fuzzy system here uses the Sugeno inference method to produce the appropriate output.

Fuzzy Design Using MATLAB

Fuzzy logic design to determine the PID controller parameters using MATLAB is intended to perform simulations based on previous designs. Figure 9 shows fuzzy logic with error and delta error inputs, as well as Kp value outputs.

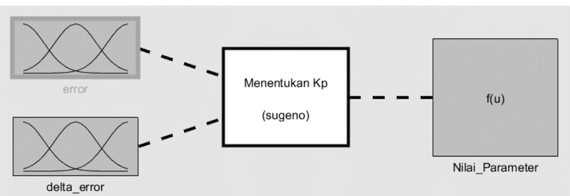

Figure 9. MATLAB Design Determining the Kp Value

The results of the MATLAB simulation are shown in Figure 10, where if the error value = 10 and the delta error value = 5, then the Kp value is 1.25.

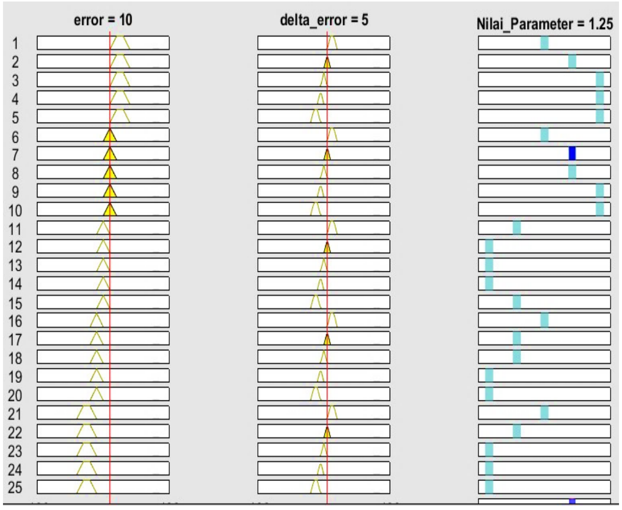

Figure 10. MATLAB Results If Error = 10 and Delta Error = 5

Electronic Circuit Design

Electronic circuit design is shown in Fig 11. The circuit schematic above has the following pin out configuration:

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

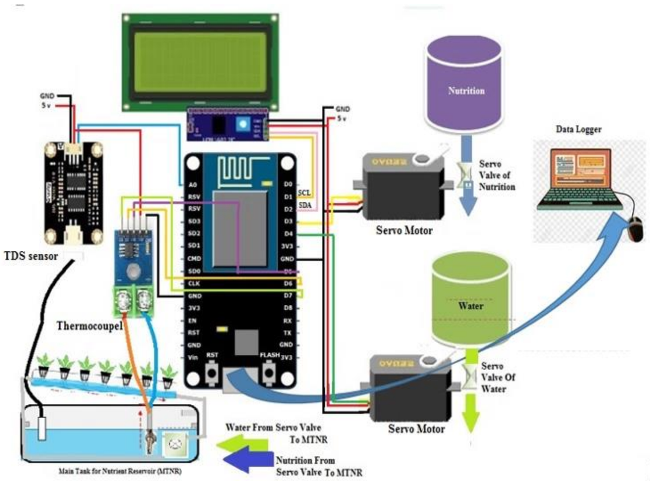

Figure 11. Electronic Circuit Design

III. RESULT AND DISCUSSION

Testing was conducted on three types of controllers, namely PI, PD, and PID whose parameter values Kp, Ki, and Kd were tuned using fuzzy. Set point value is 400 ppm, while data sampling time is every 0.5 seconds.

PI-Fuzzy Controller Testing

The results of nutrient concentration control test using a PI controller where Kp and Ki parameters are tuned using fuzzy logic are shown in Figure 12. Initial value of solution concentration is at around 70 ppm. The controller output is a command to move servo motor at a certain angle obtained from the calculation results on PI controller. Then water/ nutrient valve will open or close according to size of the angle to reach 400 ppm.

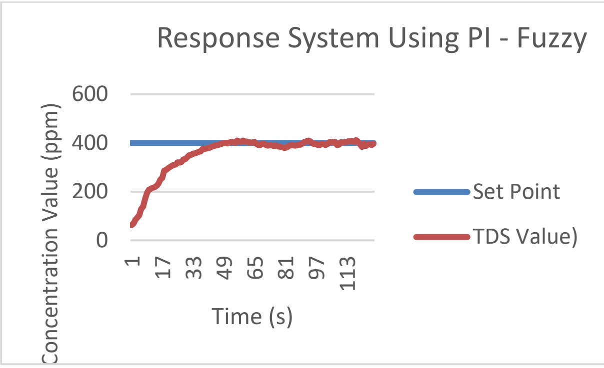

Figure 12. System Response Using PI-Fuzzy

System reaches a settling time of 5% at t = 42 and reaches the set point at t = 50, where t is sampling time for each data collection, which is 0.5 seconds. The average error generated is 47.95 and the delta error is 7.63. When system has entered the steady state area, the average error in the zone is 7.17.

PD-Fuzzy Controller Testing

The test results of nutrient concentration settings using a fuzzy logic-based PD controller are shown in Figure 13.

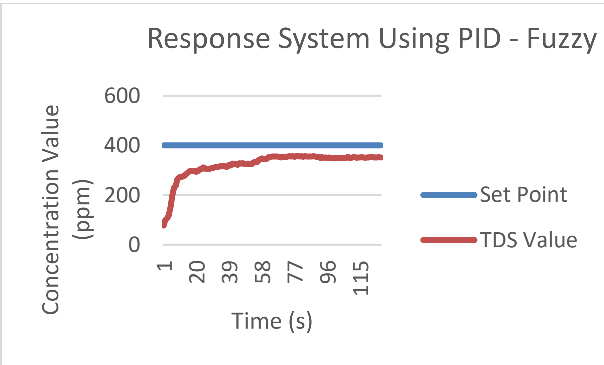

Figure 13. System Response Using PD-Fuzzy

In controlling using PD-Fuzzy, system has not been able to reach the set point value. The system is only in the range of 350 ppm concentration, so there is a steady state error of 50 ppm. The average error produced is 76.55 and delta error is 6.07. When compared to PI-Fuzzy, PD-Fuzzy has a larger average error, but a smaller delta error.

PID-Fuzzy Controller Testing

The results of nutrient concentration control test using a PID controller where Kp, Kd, Ki parameters are tuned using fuzzy logic are shown in Figure 14.

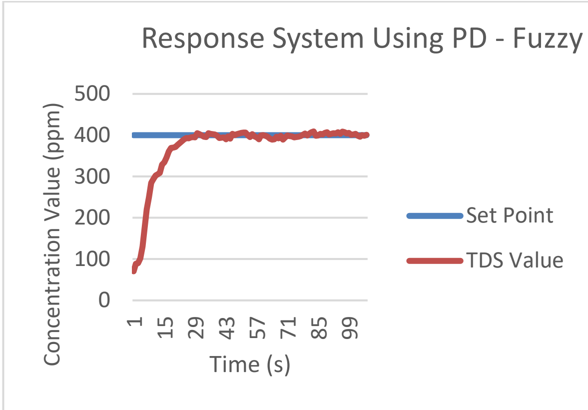

Figure 14. System Response Using PID-Fuzzy

Based on the table, system reaches 5% settling time criteria at t = 22. System reaches set point at t = 30. The average error generated is 30.97 and delta error is 8.62. When system has entered steady state region, average error in the zone is 4.53.

Comparison of errors generated from the three controllers is shown in Figures 15 to 17. Control using PID-Fuzzy reaches set point faster and produces smaller errors than the others.

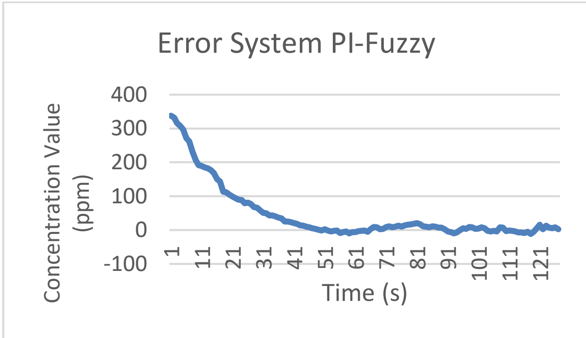

Figure 15. PI-Fuzzy Controller Error Graph

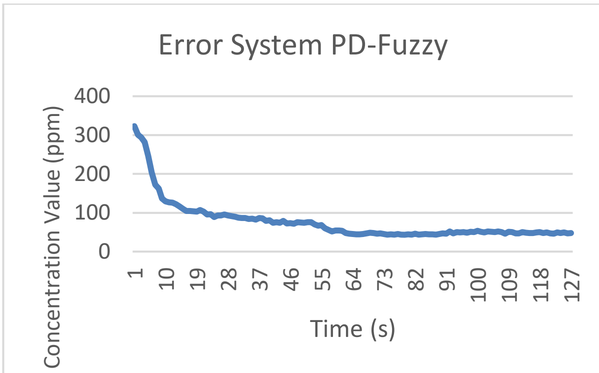

Figure 16. PD-Fuzzy Controller Error Graph

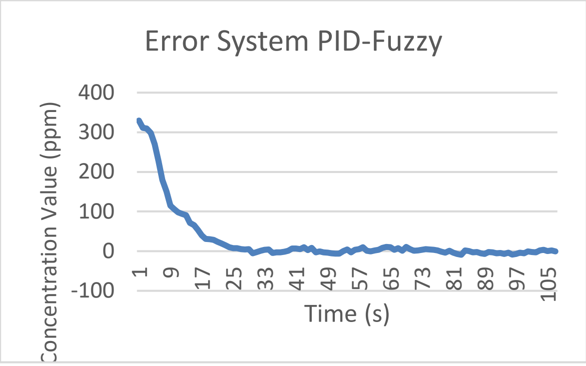

Figure 17. PID-Fuzzy Controller Error Graph

Internet of Things Testing

The mechanism for using the tools and programs is as follows:

1. Activate the WiFi access point that will be connected to the NodeMCU microcontroller.
2. After logging in, a display will appear as shown in the Figure 18.

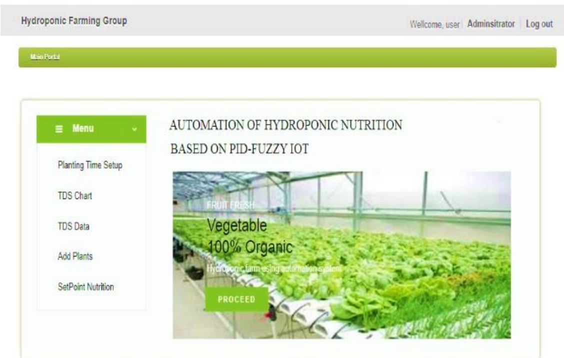

Figure 18. Main Menu Display

3. TDS Data menu to display the measured concentration data by the TDS sensor sent via the internet. Figure 19 is the measured TDS data using the PID-Fuzzy controller.
4. TDS Chart menu provides system response in achieving specified set point as shown in Figure 20 when using PID-Fuzzy controller.
5. Add Plant Menu

This menu is for adding types of hydroponic plants as shown in Figure 21.

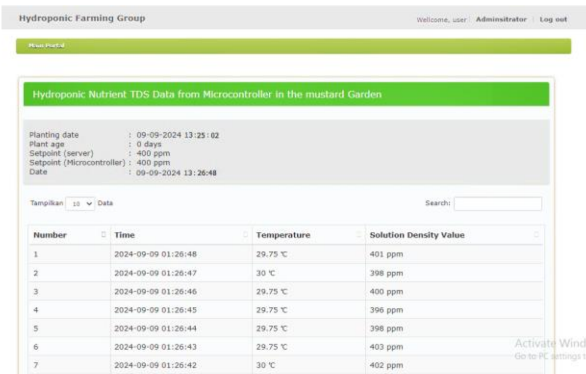

Figure 19. Sending Data to Website

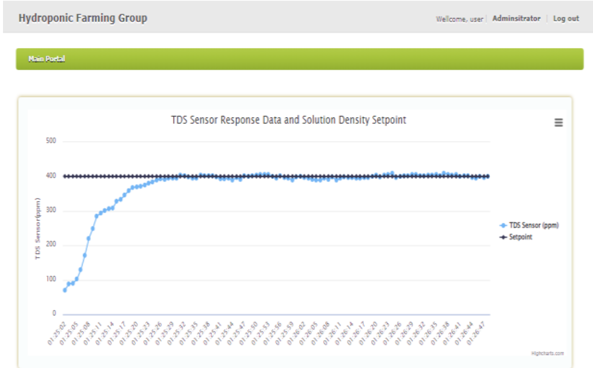

Figure 20. Graph of PID-Fuzzy System Response

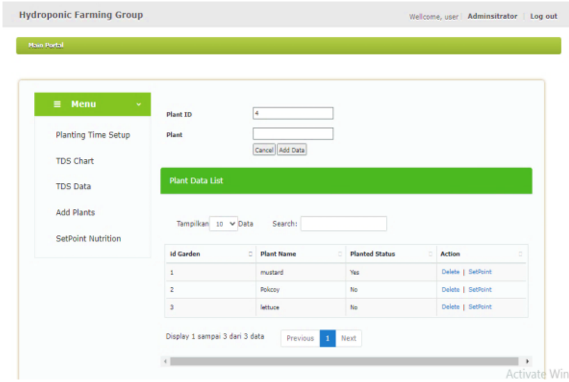

Figure 21. Add Plant Menu

6. Nutrition Setpoint Menu

This menu is used to set set point value of plant type (Figure 22). Set point data will be sent to the microcontroller.

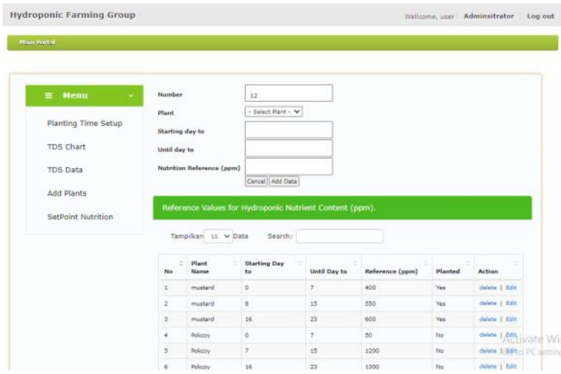

Figure 22. Set Point Value Menu

CONCLUSIONS

From this study it can be concluded that in testing the PI controller tuned using fuzzy, system achieved a settling time of 5% at t = 42 and reached set point at t = 50. Where t is sampling time for each data, which is 0.5 seconds. The average error generated is 47.95. Using PD controller based on fuzzy logic, system was unable to reach the set point. The average error generated is 76.55. However, the PD controller produces the smallest average delta error, this is due to the low error changes at each step. And finally PID controller that parameter tuned using fuzzy, system achieved a settling time of 5% at t = 22 and reached set point at t = 30. The average error generated is 30.97.

Compare of the three types of controllers, the PID-Fuzzy produces a better response where it is able to reach settling time and set point faster. The average error generated is also lower than PI-Fuzzy and PD-Fuzzy controllers.

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