Fuzzy Logic Based Nutrient Concentration Control System Using the Internet of Things

Nurmahaludin Nurmahaludin[1] and Gunawan Rudi Cahyono[2]

[1] Dept. of Electrical Engineering, Politeknik Negeri Banjarmasin
Banjarmasin, Indonesia
[2] Dept. of Electrical Engineering, Lambung Mangkurat University
Banjarmasin, Indonesia
mahaludin@poliban.ac.id[1], gunawan.cahyono@ulm.ac.id[2]

Abstract. Hydroponic plant cultivation was developed as a solution to limited land, especially in urban areas. The most important thing in hydroponic cultivation is water and nutrients, where each type of plant requires a different concentration of nutrients. Plants that are given a nutrient solution that is too concentrated or too dilute will not grow optimally, so the nutrient concentration needs to be maintained and regulated so that it remains within a predetermined value. In this research, the control system was built using the internet of things (IoT) where set point values and nutrient concentrations can be monitored via a web server. The system uses a control algorithm based on fuzzy logic with error and delta error as input. The control output is the opening of the nutrient tap and water tap which is driven by a servo motor. The variables observed are the error rate produced at steady state, settling time, and also the maximum spike. The test results show that at a set point of 700 ppm, the system reaches a settling time of 2% at the 260th second. The average error rate when the system reaches steady state is 3.42. The maximum spike produced was 0.75% where the density value at that time was 705.28.

Keywords: nutrient concentration control; fuzzy; internet of things.

1 Introduction

Hydroponic plants were developed as an alternative solution to overcome the problem of limited planting space in urban areas. There are several types of vegetable plants that can be developed using hydroponic media, where each type of plant requires a different concentration of nutrients so that they can grow well [1]. The required concentration of the nutrient solution needs to be adjusted to achieve a concentration that is in accordance with the recommended values.

There is a number of studies related to hydroponic plants, including monitoring pH and light in hydroponic growth [2] and controlling pH and water levels [3]. In both studies, the use of control methods in achieving the desired set point has not been discussed. Other research is regarding the use of fuzzy logic in control to regulate

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nutrient concentrations [4][5]. Both studies were carried out via a programmed microcontroller and were not carried out remotely.

The next development is controlling the flow of nutrient solutions wirelessly with a smart phone using if-else logic [6] and via a web server [7]. The K-Nearest Neighbor algorithm is used to predict the classification of nutritional conditions where the results are used to adjust the nutritional valve opening (on/off) [8].

Another control algorithm has also been used in regulating nutrient concentration, namely PID [9][10], where quite good control results were obtained. However, determining the controller parameters leaves its own problems because it is done by trial and error. So in this research a control algorithm based on fuzzy logic will be designed by providing set points and monitoring processes remotely using IoT. The use of a fuzzy logic controller will produce output in the form of better servo motor movements, so that the desired density can be achieved more quickly compared to the on-off method.

2 Methods

The design of the nutrient solution concentration control system in hydroponic cultivation using the internet of things is shown in Fig. 1. Before nutrients of a certain concentration are given to plants, nutrients A and B are mixed with water as a diluent to obtain a solution with a concentration that matches the reference value.

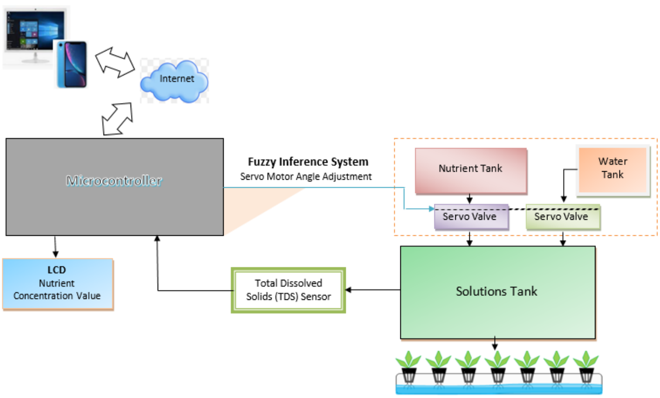


Fig. 1. System design.

The fuzzy inference system control algorithm will regulate the opening of the servo faucet in the nutrient tank and the servo faucet in the dilution water tank. The set point value is provided via a mobile device using the internet network. The process of adjusting the concentration of the nutrient solution is shown in the flow diagram as in Fig. 2.

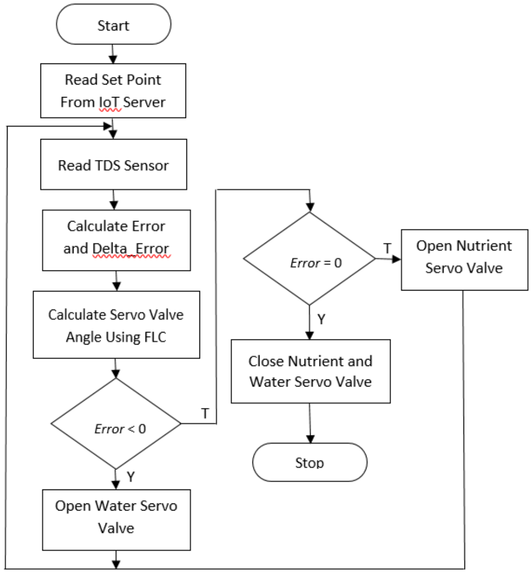


Fig. 2. Flow diagram of the nutrient concentration control process.

Fig. 3 explains the process involved in fuzzy inference and after the desired solution concentration is achieved, nutrients are poured into the hydroponic plants.

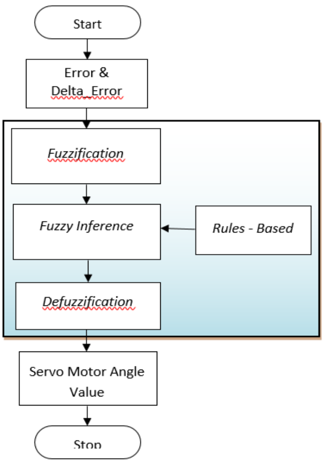


Fig. 3. Fuzzy inference system flow diagram.

2.1 Controller Design

The steps for designing fuzzy logic controller (FLC) are as follows:

1. Determine input and output variables

The controller input is the error at the time of observation e(t) and delta error (δ(t)) which is the difference between the error at time t minus the error at the previous time (t-1). The controller output is a servo motor that moves from an angle of 0 to 90 degrees as shown in Fig. 4.

Fig. 4. Input - Output System.

2. Determine membership function

The error and delta error membership functions are shown in Fig. 5 and Fig. 6.

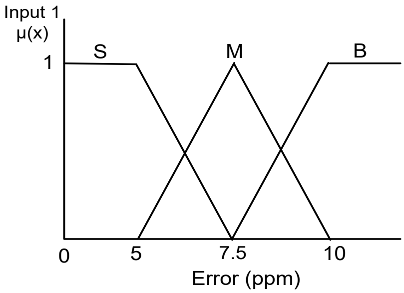


Fig. 5. Membership function of error.

The membership function e (t) in Fig. 6 is given:

$$\mu_{Small}[x]=\begin{cases}1 & ;\ x\leq 5\\ \dfrac{7.5-x}{2.5} & ;\ 5\leq x\leq 7.5\\ 0 & ;\ x\geq 7.5\end{cases} \quad (1)$$

$$\mu_{Medium}[x]=\begin{cases}0 & ;\ x\leq 5\ \ or\ \ x\geq 10\\ \dfrac{x-5}{2.5} & ;\ 5\leq x\leq 7.5\\ \dfrac{10-x}{2.5} & ;\ 7.5\leq x\leq 10\end{cases} \quad (2)$$

$$\mu_{Big}[x]=\begin{cases}0 & ;\ x\le 7.5\\ \dfrac{x-7.5}{2.5} & ;\ 7.5\le x\le 10\\ 1 & ;\ x\ge 10\end{cases} \quad (3)$$

The second input δe (t), consists of small (S), medium (M), and big (B) as shown in Fig. 6.

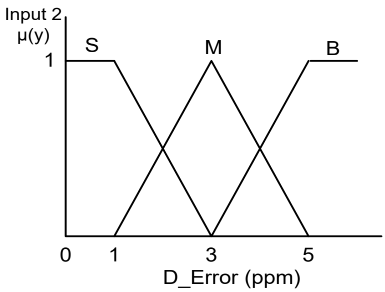


Fig.6. Membership function of delta error.

$$\mu_{Small}[y]=\begin{cases}1 & ,\ x\le 1\\ \dfrac{3-x}{2} & ,\ 1\le x\le 3\\ 0 & ,\ x\ge 3\end{cases} \quad (4)$$

$$\mu_{Medium}[y]=\begin{cases}0 & ;\ x\le 1\ or\ x\ge 5\\ \dfrac{x-1}{2} & ;\ 1\le x\le 3\\ \dfrac{5-x}{2} & ;\ 3\le x\le 5\end{cases} \quad (5)$$

$$\mu_{Big}[y]=\begin{cases}0 & ,\ x\le 3\\ \dfrac{x-3}{2} & ,\ 3\le x\le 5\\ 1 & ,\ x\ge 5\end{cases} \quad (6)$$

Meanwhile, the angular output membership function of the servo motor is in the form of a singleton as shown in Fig. 7

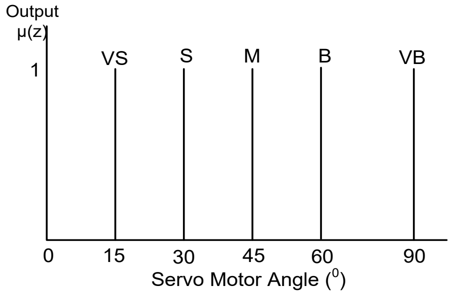


Fig. 7. Servo Motor Angle Membership Function.

3. Design rules

Fuzzy rules have an if-then form, with the AND operator between the first input and the second input. Table 1 shows fuzzy rules from sets that have been compiled previously.

Table 1. Rules Of Fuzzy Controller

δe(t) / e(t)	Small	Medium	Big
Small	VS	S	M
Medium	S	M	B
Big	B	VB	VB

Rule 1 : If error is small and delta error is small, then servo motor angle is very small
Rule 2 : If error is small and delta error is medium, then servo motor angle is small
Rule 3 : If error is small and delta error is big, then servo motor angle is medium
Rule 4 : If error is medium and delta error is small, then servo motor angle is small
Rule 5 : If error is medium and delta error is medium, then servo motor angle is medium
Rule 6 : If error is medium and delta error is big, then servo motor angle is big
Rule 7 : If error is big and delta error is small, then servo motor angle is big
Rule 8 : If error is big and delta error is medium, then servo motor angle is very big
Rule 9 : If error is big and delta error is big, then servo motor angle is very big

2.2 Electronic Circuit Design

A schematic image of the electronic circuit is shown in Fig. 8.

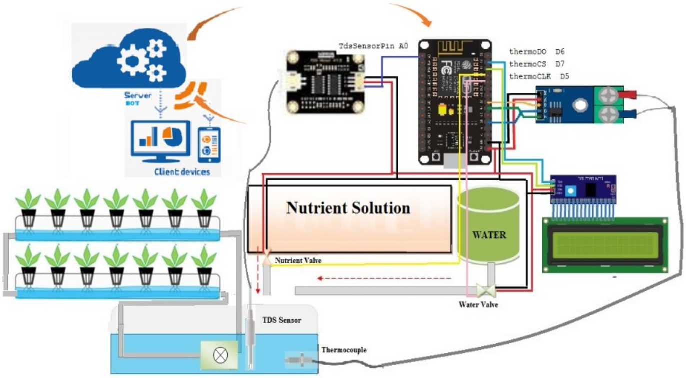


Fig. 8. Electronic Design.

The circuit schematic is divided into 3 main parts.

1. Minimum system circuit
   a. The TDS sensor component is connected to the NodeMCU ESP8266 microcontroller on pin A0. the temperature sensor component (thermocouple) is connected to the NodeMCU on pin D6 (ThermoD0), D7 (ThermoCS), D5 (ThermoCLK)
   b. Displays TDS sensor data, temperature, water tap opening angle values and nutrients to the LCD display. The LCD viewer uses 40 x 2, and is connected to a NodeMCU on the SDA and SCL pins.
   c. Adjust the opening angle of the water and nutrition valve based on fuzzy. The nutrient and water taps use a servo motor connected to the NodeMCU on pins D3 and D4
   d. Sending TDS and temperature sensor data to the server,
   e. Receive reference nutritional value data from an IoT-based server as a set point for processing by the fuzzy system.
2. The IoT web server, is responsible for:
   a. User media in setting up plant types, planting dates, reference nutritional values within a certain time period.
   b. Receives TDS sensor data from the minimum series of systems into the database.
3. Hydroponic plant
   Planting media with an NFT system, with a pump that continues to work to deliver nutrients to plants. These nutrients are stored in tanks equipped with TDS sensors and temperature sensors.

3 Result And Discussion

The design of the internet of things (IoT) is intended to provide set point values for the system based on the type and time of planting via the IoT server. This reference value is used by the NodeMCU microcontroller in the nutrient concentration control system. The density value data measured by the TDS sensor is then sent back via IoT which can be observed via a web display.

3.1 Internet of Things Design

Mechanism of the IoT system is as follows.

1. Users can access web via PC or gadget and the display that appears when logging in is shown in Fig. 9 The user then enters the account in the form of a username and password into the menu provided.

Fig. 9. Display when login.

If the password entered is correct, the user will enter the menu display as in Fig. 10.

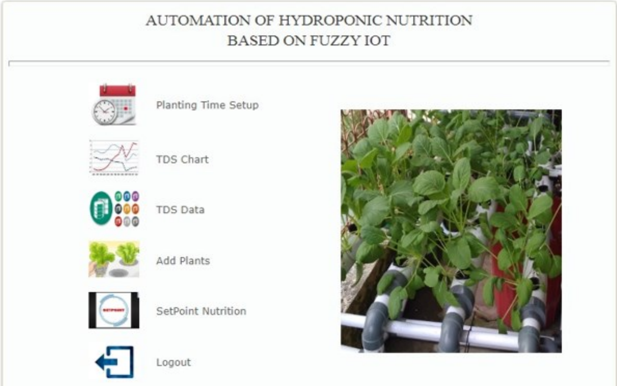


Fig. 10. IOT web application menu display.

There are a number of menu options with the following features.

1. Add Plants menu, used to add the types of plants that will be planned for the hydroponic plant. The selected plant type will be displayed as in Fig. 11.

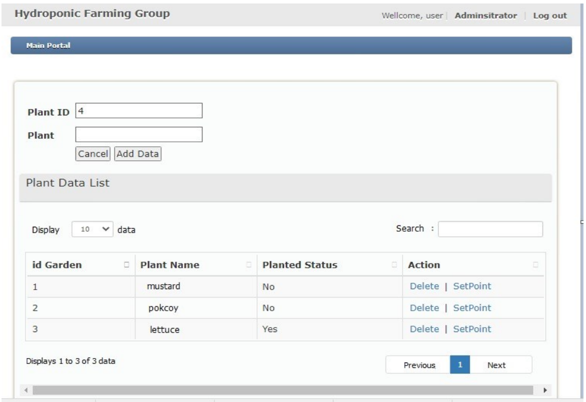


Fig. 11. Add Plant Menu.

2. Setpoint Nutrition menu, functions to add reference nutrient concentration values according to the type of plant selected. This value can be obtained through references/libraries or through experts in hydroponic plants. The menu display is shown in Fig. 12.

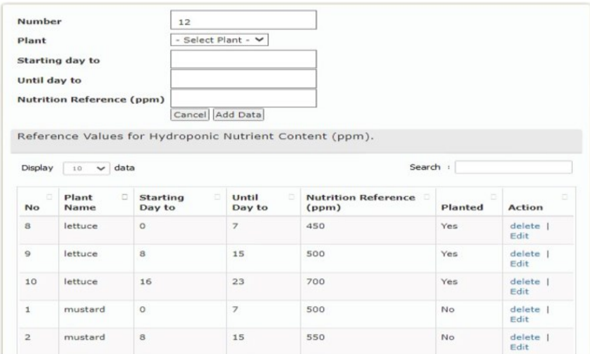


Fig.12. Reference Concentration Value Setting.

3. Planting Time Setup menu, to determine the type of plant and when the plant will be planted. The resulting display is as shown in Fig. 13.

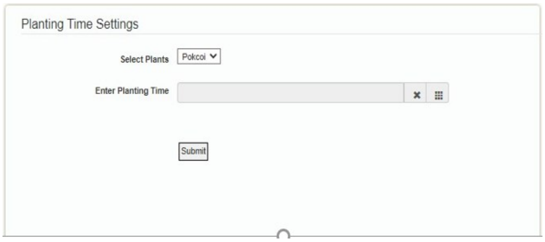
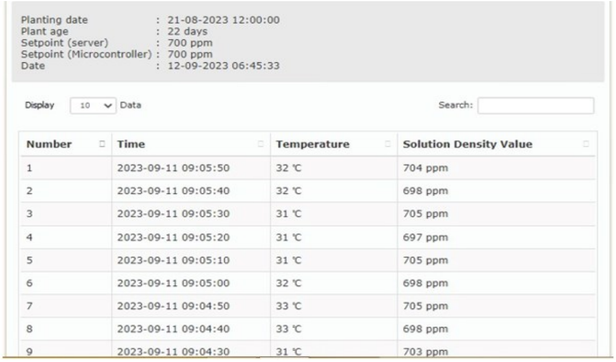


Fig. 13. Planting Time Setup Menu.

4. TDS data, functions to display data from the TDS sensor and temperature sensor. This menu is used to monitor the concentration value of the solution. Figure 5.6 shows the monitoring results of TDS and temperature sensor measurements.



Planting date : 21-08-2023 12:00:00
Plant age : 22 days
Setpoint (server) : 700 ppm
Setpoint (Microcontroller) : 700 ppm
Date : 12-09-2023 06:45:33

Display 10 Data Search:

Number	Time	Temperature	Solution Density Value
1	2023-09-11 09:05:50	32 ℃	704 ppm
2	2023-09-11 09:05:40	32 ℃	698 ppm
3	2023-09-11 09:05:30	31 ℃	705 ppm
4	2023-09-11 09:05:20	31 ℃	697 ppm
5	2023-09-11 09:05:10	31 ℃	705 ppm
6	2023-09-11 09:05:00	32 ℃	698 ppm
7	2023-09-11 09:04:50	33 ℃	705 ppm
8	2023-09-11 09:04:40	33 ℃	698 ppm
9	2023-09-11 09:04:30	31 ℃	703 ppm

Fig. 14. TDS Data Display Menu.

5. TDS graph, functions to display a graph of the measured TDS value based on the specified set point value. In the system being built, the settings use fuzzy (FLC) on the microcontroller to stabilize the nutrient concentration in the hydroponic plant.

3.2 Fuzzy Logic Controller Testing

Fuzzy Logic Controller (FLC) testing on lettuce plants was carried out with a set point value of 700 ppm. The initial value of the solution concentration is 450 ppm, data is taken in real time every second. Table 2 shows the system output data with a data presentation period every 10 seconds.

Table 2. Test Results with a Set Point Value of 700 ppm

Data to-	Se tpoint	TDS	Error
1	700	452.73	247.27
2	700	469.02	230.98
3	700	478.36	221.64
4	700	489.03	210.97
5	700	493.62	206.38
6	700	504.25	195.75
7	700	517.29	182.71
8	700	528.18	171.82
9	700	536.03	163.97
10	700	543.01	156.99
11	700	554.38	145.62
12	700	567.54	132.46
13	700	575.44	124.56
14	700	583.74	116.26

15	700	595.62	104.38
16	700	602.71	97.29
17	700	610.12	89.88
18	700	627.1	72.9
19	700	635.86	64.14
20	700	644.58	55.42
21	700	655.65	44.35
22	700	664.64	35.36
23	700	673.83	26.17
24	700	680.79	19.21
25	700	690.03	9.97
26	700	697.28	2.72
27	700	703.06	-3.06
28	700	697.89	2.11
29	700	705.28	-5.28
30	700	698.36	1.64
31	700	704.85	-4.85
32	700	697.28	2.72
33	700	705.24	-5.24
34	700	697.68	2.32
35	700	704.24	-4.24

At the beginning where the difference between set point and TDS value was still large, microcontroller ordered the nutrient valve to fully open via a servo motor angle of 90 degrees. The nutrient valve opening remains full until the solution concentration approaches the set point. Then the nutrient and water valve alternately open and close to balance so that the concentration remains around the reference value. If the TDS value exceeds the set point, then the water tap opens for dilution, and vice versa, if the TDS value is below the TDS then it is necessary to add nutrients for thickening.

The graph of the system response to the set point is shown in Fig. 14. From Fig. 14 it can be seen that the settling time where the system reaches and stays at around 2% of the final value is 260th second. The average error when the system reaches steady state is 3.42. The maximum overshoot occurs in the 27th data, namely 0.75%, the moment when the output first reaches and passes the reference.

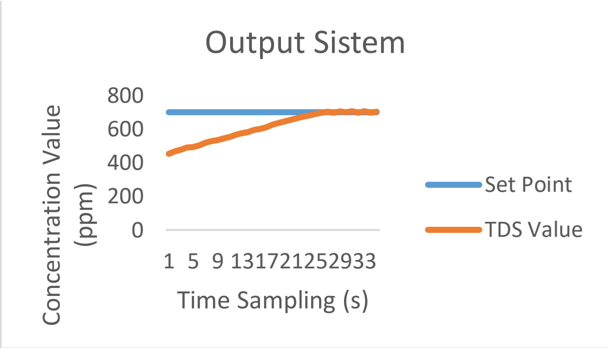


Fig 15. System Response Graph.

Fig. 15 shows a graph for monitoring the concentration of the solution in the system on the web display that presented every 10 seconds which appears in the TDS Chart menu.

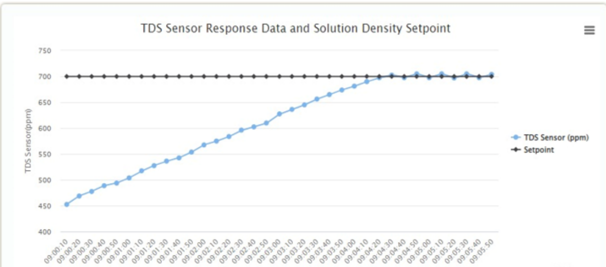


Fig. 16. System Monitoring Graphics.

4 Conclusion

Control using the internet of things (IoT) in this research is carried out by determining set point reference values and monitoring the concentration of the solution which is carried out via the internet network. The control algorithm uses fuzzy logic to regulate the opening of the nutrient and water valves to achieve a predetermined solution concentration.

In testing with a set point of 700 ppm and initial solution conditions of 450 ppm, the system reached a settling time of 2% at the 260th second. The average error when the system reaches steady state is 3.42. The maximum spike (overshoot) that occurred was 0.75% where the density value at that time was 705.28.

When the system has reached the reference value, the nutrient tap and water tap alternately open and close via the fuzzy logic controller so that the system remains at around 700 ppm.

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