Smart hydroponic based on nutrient film technique and multistep fuzzy logic

Prabadinata Atmaja[1], Nico Surantha[1,2]
[1]Computer Science Department, Bina Nusantara University, Jakarta, Indonesia
[2]Department of Electrical, Electronic and Communication Engineering, Faculty of Engineering, Tokyo City University, Tokyo, Japan

Article Info

Article history:

Received Jun 12, 2021
Revised Jan 19, 2022
Accepted Feb 7, 2022

Keywords:

Arduino
Automation
Fuzzy logic
Hydroponic
Nutrient film technique
Raspberry Pi

ABSTRACT

Automation in hydroponics is have been a great change. Research with fuzzy logic control it is designed to add to each parameter one by one. In a way microcontroller will activate one by one relay to regulate the parameters with fuzzy logic. While parameter calibration is done, calibration is needed for the next checking if the parameter were not optimal, until it is parameter optimal. Multistep fuzzy is used to counter measure the same activation of the relay. With adding real time data monitoring to the system. From test result evaluating multistep fuzzy logic method were 100% works as expected. With another testing approach for best module for sending real time data monitoring for hydroponics. From the real time data transmission method, the success of sending data is 30% from the ESP82166 and 75% of the NRF24L01 with a shortage of the NRF24L01 data loss. For the relay activation can be accommodate with dynamic programming. As for multistep fuzzy logic for hydroponic tested to reach optimal water condition for kale crops resulting in average 12.8 iterations calibration from condition where researches add water only from the start.

Corresponding Author:

Nico Surantha
Computer Science Department, Bina Nusantara University
K. H. Syahdan Street, No 9 Kemanggisan/Palmerah, West Jakarta 11480, Indonesia
Email: nico.surantha@binus.ac.id

1. INTRODUCTION

Nowadays, agriculture is a traditional way to produce vegetable to meet our needs. With the rate of resource needs is more than 70% [1] and the solution to reduce resource in agriculture is develop smart irrigation system [2]. Other method is using hydroponics for growing and producing vegetable to meet our daily needs with an efficient land and resource use. As now there are two types of hydroponics that can be implemented to grow crops. There are deep flow technique (DFT) [3] that requires roots to be fully submerged in the water. On one method called nutrient film technique (NFT) [4], [5] used to grow crops without submerging the roots like in DFT technique, so roots will be just flowed with water not submerged.

Previous research calculated parameter from water level [6], pH level [7]. [8] and electrical conductivity (EC) level in hydroponics water [9] others research will add some humidity, light and temperature sensor to test watercress crops. Some of them create automation with monitoring system [10], [11] which would help to automate or manually control actuators to maintain threshold. With automation system frequently build with Arduino or Raspberry Pi as main processing system or with another parent [6] for accommodating long range [10] monitoring system. Recent method fuzzy [12]–[15] were used for fully automated monitoring system in hydroponics system. With fuzzy logic controller it is know best application for defining detail between true or false and in hydroponics it is better to use fuzzy logic controller as it is method to support decision making. Differentiation in fuzzy logic clearly define the range between a hot and cold situation it can be specified to hot, medium hot, normal, medium cold, and cold. As these properties in fuzzy logic method, it can adjust properly for calculating time needed to add some parameters in hydroponics. For example, in defining a gray area between hot and cold other research use fuzzy logic for estimating contact force for railway application [16] to make pantograph connection reliable with less calculation time. Evaluation of previous research some are using detailed comparison till length of leaf produce with this method [12] other evaluate by progressing it is growability in controlled environment.

Within hydroponics already using less resource and less land use, it is already progressing towards the efficient resource. When using hydroponics to grow crops daily maintenance can be troublesome like maintaining temperature, pH, parts per million (PPM) to meet the crop needs. As efficient resource can be improved by using an internet of things (IoT) to do some automation to the hydroponics system [17], [18], [19]. There are many hydroponic automations that has been published. Some of them have shown a good progress in using automation to maintain the hydroponic system parameter that leads to great growth rate of the vegetable and prove to be effective with manual [6] or automation control. To summarize the future challenges in hydroponics automation, some are suggesting adding light control to maximize growth rate to overcome weather condition, other suggest technical aspect about activating multiple actuators at the same time. Within that conclusion of other research, the authors proposed of using multistep fuzzy [20], [21] logic to accommodate some of idea in previous research motivation creating a multistep fuzzy logic is to extend the technical aspect to be able activating relay within the same time, after relay were activating the same time it is possible there are some calibrations needed to tune mixed solution to add a difference into the hydroponics main system.

2. RESEARCH METHOD

In this research will use NFT for hydroponics system that claimed to be affecting growth rate which is caused by root can absorbed more oxygen compared to DFT that needs root to be completely submerged in the water. The system can be seen as Figure 1. From Figure 1 the system is controlled by Arduino mega which is used to monitor the parameters like pH [22] sensor, EC sensor, ultrasonic sensor [23]. The value of each parameter from the sensor is send using ESP8266 module for Arduino to connect internet. End receiver is in a web server running to retrieve data send with request from Arduino. While the Arduino mega is monitoring the parameters it also processing fuzzy logic parameter for decision making for maintaining parameters so it still on the threshold. Maintaining the parameters, the Arduino will activate some relay to operate peristaltic pump for the water and nutrition that crops need. Where in this research is used kale crops to grow with optimum pH values were range in 5, 5-6, 5 and in parts per million (PPM) values range in 1,050-1,400.

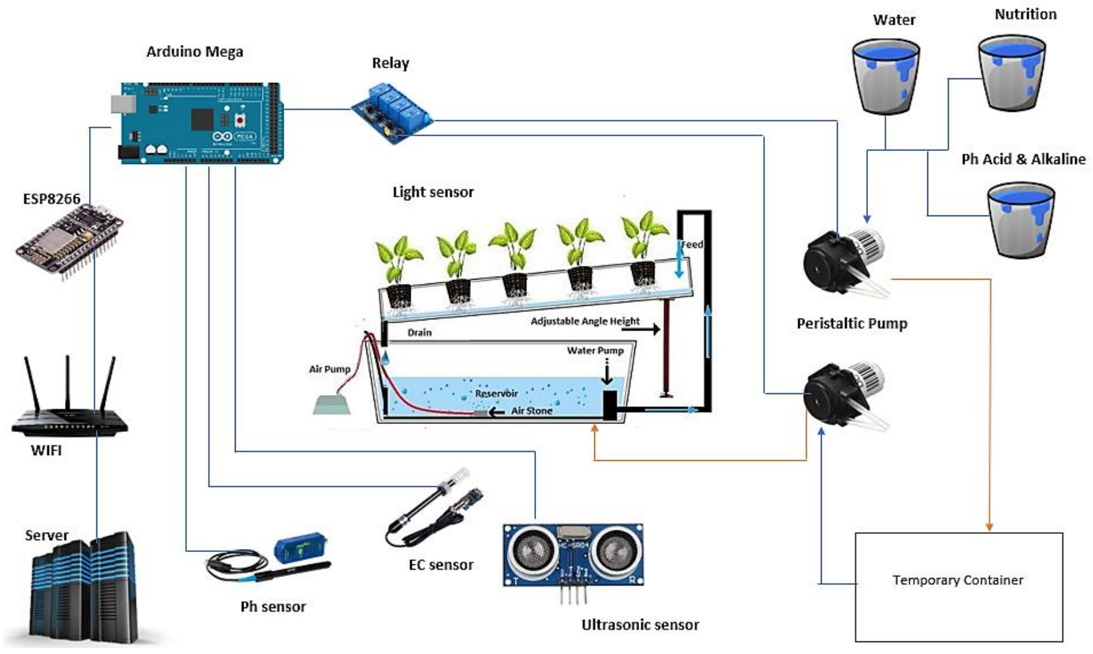

Figure 1. Hydroponic system integrated with IoT

The main process can be seen in Figure 2 of maintaining the water parameters with water level sensor, pH sensor, and PPM sensor is start by reading all the 3 parameters and each of it is reading it operates by fuzzy output that give how long of this pump has to activate within seconds. The pump is driven to pump within seconds to other temporary container. Temporary container is used for accommodating new approach to multistep fuzzy logic. Method that were used in this research and it is use for step 2 check to tune the parameters in temporary container that parameter in temporary container can affect the main container in a right way so the monitoring system can be calculated again after same second relay activation.

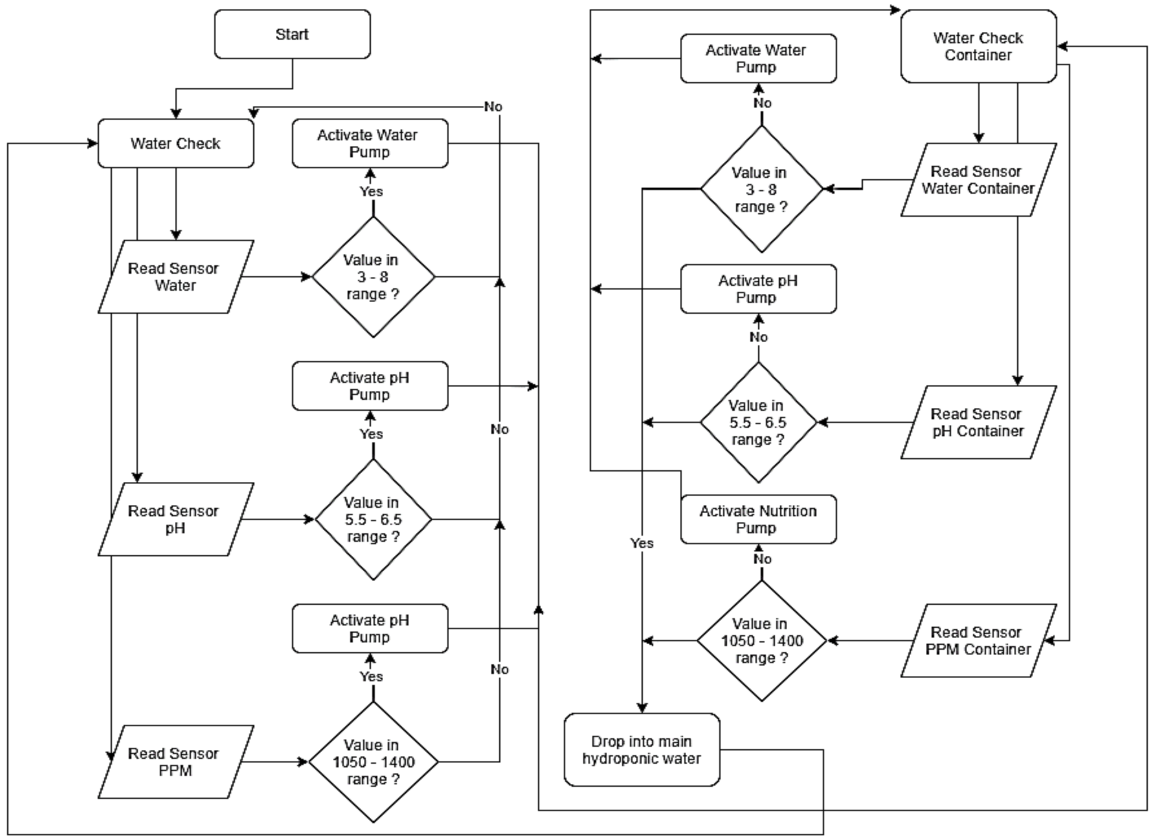

Figure 2. Flowchart to maintain hydroponics parameter

In Figure 2 is detailed how automation with fuzzy logic were used in determining which condition the parameter in works with 3 parameter water, pH, and nutrition to maintain for optimal crops growth. With detailed membership function can be seen in Figure 3 for water level, 4 for pH level and 5 for PPM level. In Figure 3 water level sensor is detected by ultrasonic sensor within range 0-10 and detail is described in Table 1. Maintaining parameters in water, pH, PPM to be in optimal which is water in moderate level, pH in normal level and PPM in normal category are decided by defining a new membership output in Table 2.

Process is start from checking how much water needed to reach moderate level. The process is to check the water level height in the main hydroponic system container and calculate it with water fuzzy logic. After that activate pump based on how much time in milliseconds to add the water to the temporary container. Now water was in the temporary container needs to added pH and nutrition based on first level multistep fuzzy logic. With membership function for pH in Figure 4 and PPM in Figure 5 detailed information of membership function can be seen in Table 3 for pH and Table 4 for PPM.

In Figure 4 is defined fuzzy membership function for detecting pH Level based on kale optimal pH level for optimal growth. Table 4 defined fuzzy rule base condition to determine from water level that has been added to temporary container by first water level check and pH level condition in main hydroponics. After first pH level check the proposed system will activate pH alkaline or pH acid to a temporary container and then process it to get the next step of checking PPM level to add it to a temporary container. With fuzzy membership function in Figure 5 with detail in Table 5 and fuzzy rule base in Table 6. After first level calibration based on water level added and pH or nutrition proceed to the next level of multistep fuzzy logic.

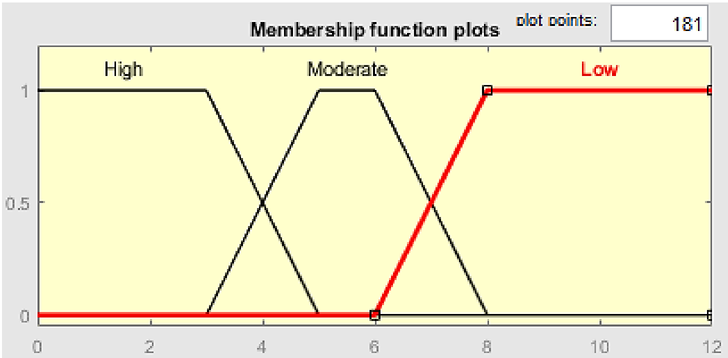

Figure 3. Fuzzy membership function water level

Table 1. Fuzzy membership function water level range

Water Level	Range
Low	0-5
Moderate	3- 8
High	6-10

Table 2. Output duration

Water Volume	Active Duration
Fast	0- 3 seconds
Medium	2- 5 seconds
Slow	4- 7 seconds

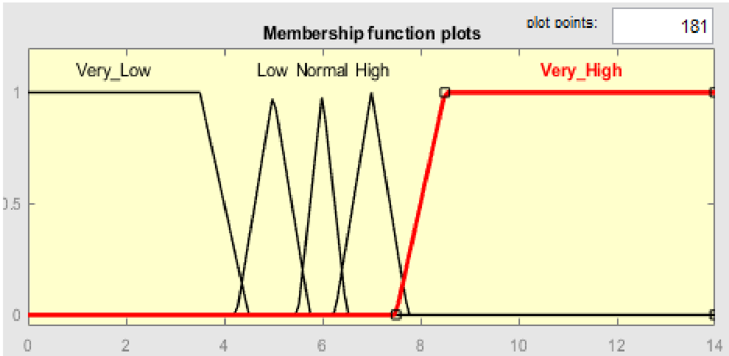

Figure 4. Fuzzy membership function pH level

Figure 5. Fuzzy membership function PPM level

Table 3. Fuzzy membership function pH level range

pH Level	Range
Very Low	0-4.5
Low	4.25-5.75
Normal	5.5-6.5
High	6.25-7.75
Very High	7.5-14

Table 4. Fuzzy rule base pH level

		Main Hydroponic pH Level				
		pH Very Low	pH Low	Normal	pH High	pH Very High
Water Level	Low	Alkaline Medium	Alkaline Fast	None	Acid Fast	Acid Medium
	Medium	Alkaline Medium	Alkaline Medium	None	Acid medium	Acid Medium
	High	Alkaline Long	Alkaline Medium	None	Acid Medium	Acid Long

Table 5. Fuzzy membership function PPM level range

PPM Level	Range
Lowest	0-750
Very Low	650-950
Low	850 – 1150
Normal	1050 – 1400
High	1300 - 1500

Table 6. Fuzzy rule base PPM level

		Main Hydroponic PPM Level				
		Lowest	Very Low	Low	Normal	High
Water Level	Low	Medium	Fast	Fast	None	None
	Medium	Long	Medium	Fast	None	None
	High	Long	Medium	Fast	None	None

After the first level of multistep fuzzy logic in water level, pH level, PPM level is done and added to temporary container. Then proceed to second multistep fuzzy logic is done by another process of fuzzy logic to check the parameter in the container will affected the main hydroponics by 1 more check with rule base can be seen as Tables 7 and 8. The multistep fuzzy logic is to check the pH and the PPM level in the temporary container to adjust the parameter to fully affect and managed to go to the threshold in our optimal growth condition. In membership function to check pH level and PPM level within the next step fuzzy using the same membership functions but with other fuzzy rule base.

Table 7. Fuzzy rule base pH level step 2

		Temporary Container Hydroponic pH Level				
		Very Low	Low	Medium	High	Very High
Main Hydroponic pH level	Very low	Alkaline Long	Alkaline Medium	Alkaline Medium	Alkaline Fast	None
	Low	Alkaline Long	Alkaline Medium	Alkaline Fast	None	Acid Medium
	Normal	Alkaline Medium	Alkaline Fast	None	Acid Fast	Acid Medium
	High	Alkaline Medium	None	Acid Fast	Acid medium	Acid Long
	Very high	None	Acid Fast	Acid Medium	Acid Long	Acid Long

Table 8. Fuzzy rule base PPM level step 2

		Temporary Container Hydroponic PPM Level				
		Lowest	Very low	Low	Medium	High
Main Hydroponic PPM Level	Lowest	Nutrition Long	Nutrition Medium	Nutrition Fast	None	Water Fast
	Very low	Nutrition Medium	Nutrition Fast	None	Water Fast	Water Fast
	Low	Nutrition Fast	None	Water Fast	Water Medium	Water Medium
	Normal	None	Water Fast	Water Medium	Water Long	Water Medium
	High	Water Fast	Water Medium	Water Long	Water Long	Water Long

3. RESULTS AND DISCUSSION

Within this section is a comprehensive explanation how the research result is detailed. In aspect of system coverage, software specification, and comparison in module for sending data to provide real-time monitoring data. Research result will compare with each test with different sets of modules.

3.1. System result

Research system result will be explained in list with the equipped items or modules to hydroponics systems. In purpose the system will help automate monitoring crops growth with multistep fuzzy logic with two steps checking for adding parameters to main hydroponics system. Hydroponics that built in this research still using outdoor sunlight compares in [6] create an automated environment control. The system can be seen in Figure 6.

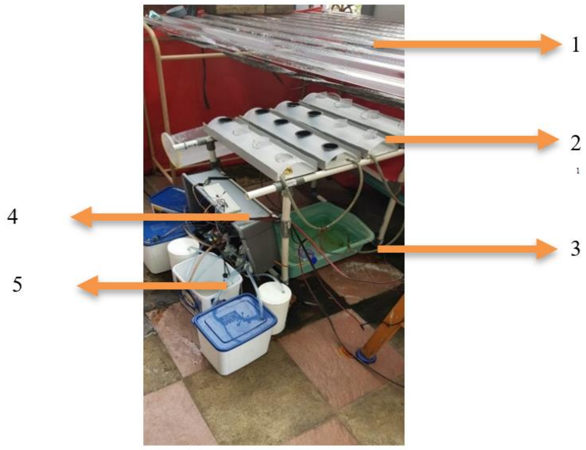

Figure 6. Hydroponics system integrated with automation system

From Figure 6 implementation in author automation system is detailed:

a) Roof preventing hydroponics setup from rainwater.
b) Main place for hydroponics crops growth.
c) Main container for hydroponics water
d) Microcontrollers place includes these item:
   - Arduino mega
   - 2 pH sensor
   - 2 EC sensor
   - ESP8266
   - Ultrasonic sensor
   - 4 channel relay
   - 1 channel relay
   - 6 peristaltic pumps
e) Temporary container with other container for water, nutrition, acid, and alkaline supply
f) Standalone Raspberry Pi as a server for receiving monitoring data.

3.2. Software architecture

Arduino it is the main compute process from reading the sensor values to calculating fuzzy logic result in step 1 and step 2 last but not least sending it to Raspberry Pi by using one of these alternative module ESP8266 [24], [25] or NRF24L01. ESP8266 is better at data transmission and easy to integrate for this system [10]. First step Arduino will read the sensor values frequently by 3 minutes in process with using ultrasonic, pH, EC sensor for calculating fuzzy logic first step and create a decision making for adding water, acid, alkaline, or nutrition parameter to a temporary container by activating relay to activate peristaltic pump. After first step fuzzy logic is done Arduino will go through the second step of multistep fuzzy logic by comparing temporary container sensor values with the main hydroponics system to really compare the mixed solutions in temporary container will greatly affect the main hydroponic parameter. Result in adding and sensor values all will be send with ESP8266 or NRF24L01.

While Raspberry Pi used for receiving data sent by Arduino to be processed and visualized to a graph in monitoring system. In Raspberry were installed Apache/2.4.38 (Raspbian), MySQL Ver 15.1, PHP 7.3.19, and using Laravel Framework for creating web apps. Detail of software function and programs that were used in this research can be seen in Figure 7.

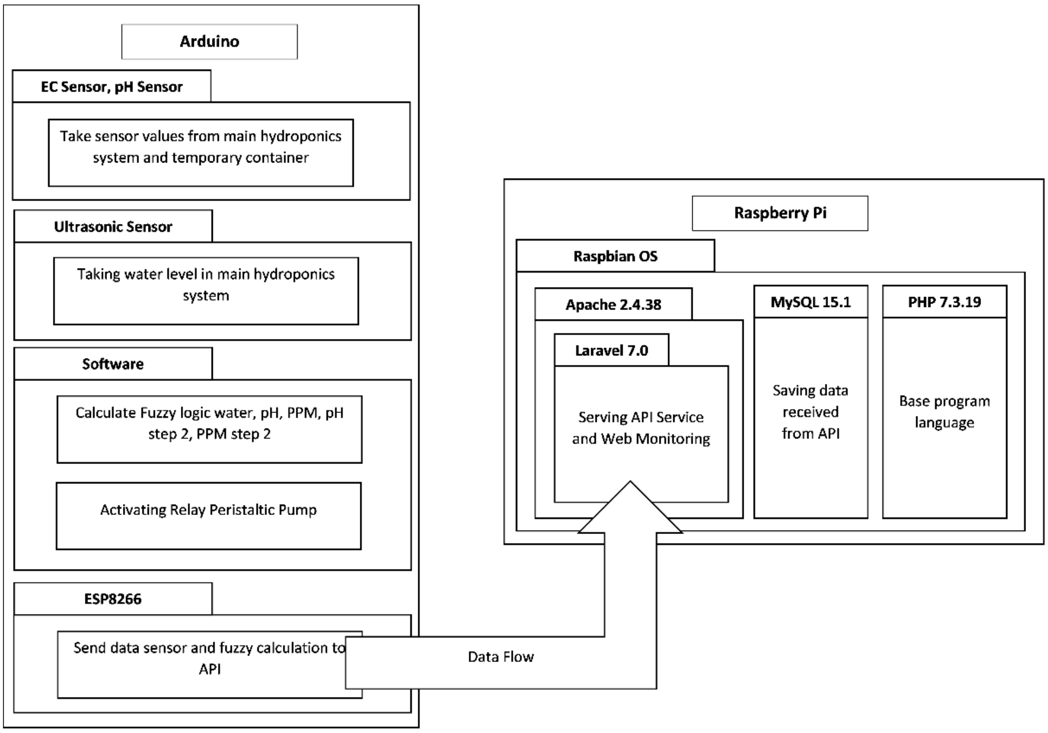

Figure 7. Software architecture

3.3. Method result evaluation

Result were tested by how accurate multistep fuzzy logic in range of the fuzzy rule and a comparison of ESP8266 and NRF24L01 for sending data to be visualized in graphs for monitoring purposes. In each test fuzzy, it is tested with 30 test cases for multistep fuzzy logic sample is represented with Tables 9 to 13. Summary of conducted testing in all fuzzy logic in this research shown in Table 14. As far from Tables 9, to 14 concluded to method implementation to be as expected from the fuzzy rule that were designed to manage hydroponics parameter.

Table 9. Sample fuzzy logic water result

No	Water Level	Expected in Seconds	Arduino Fuzzy in Seconds	Result
1	0.4	OFF	OFF	In Range
2	7.2	2-5	4.836	In Range
3	7.6	4-7	5.264	In Range
4	8	4-7	5.733	In Range
5	8.4	5-8	5.733	In Range

Table 10. Sample fuzzy logic pH result

No	pH level	Water Level	Expected Fuzzy in Seconds		Arduino Fuzzy in Seconds		Result
			Acid	Alkaline	Acid	Alkaline	
1	3.88	3.2	0	4-7	0	5.364	In Range
2	4.34	3.6	0	2-5	0	4.475	In Range
3	4.8	4	0	2-5	0	3.500	In Range
4	6.18	5.2	0	0	0	0	In Range
5	14	12	2-5	0	3.500	0	In Range

Table 11. Sample fuzzy logic PPM result

No	PPM Level	Water Level	Expected Fuzzy in Seconds	Arduino Fuzzy in Seconds	Result
1	650	5.2	4-7	5.500	In Range
2	700	5.6	2-5	4.500	In Range
3	800	6.4	0-3	3.047	In Range
4	1100	8.8	0-3	1.500	In Range
5	1150	9.2	0	0	In Range

Table 12. Fuzzy logic pH step 2 result

No	Temporary Container pH Level	Main Hydroponics pH Level	Expected Fuzzy in Seconds		Arduino Fuzzy in Seconds		Result
			Acid	Alkaline	Acid	Alkaline	
1	3.88	10.78	0	0	0	0	In Range
2	4.34	10.32	0-3	0	1.470	0	In Range
3	7.1	7.56	2-5	0	3.910	0	In Range
4	8.02	6.64	4-7	0	5.625	0	In Range
5	14	0.66	0	0	0	0	In Range

Table 13. Fuzzy logic PPM step 2 result

No	Temporary Container pH Level	Main Hydroponics pH Level	Expected Fuzzy in Seconds		Arduino Fuzzy in Seconds		Result
			Acid	Alkaline	Acid	Alkaline	
1	200	1350	0-3	0	1.378	0	In Range
2	650	900	0	2-5	0	2.413	In Range
3	950	600	0	0-3	0	1.266	In Range
4	1300	250	0	0	0	0	In Range
5	1500	50	0-3	0	1.266	0	In Range

Table 14. Summary fuzzy logic testing

No	Testing Aspect	Result
1	Fuzzy Water	100% in range
2	Fuzzy pH	100% in range
3	Fuzzy PPM	100% in range
4	Fuzzy pH step 2	100% in range
5	Fuzzy EC step 2	100% in range

3.4. Send data module result

With the purpose to make monitoring in this research try to test 2 modules to send data to API. Using ESP8266 that connect directly to Wi-Fi and NRF24L01 to act as a bridge to receive from main hydroponics Arduino and connect ESP8266 to direct Wi-Fi. This testing evaluation is done because in implementing ESP8266 there is some issue assuming it was a serial connection issue.

First test with first design planned architecture conducted using ESP8266 to create a comparison between the two modules. Schema can be seen in Figure 8. In this schema, it is connected directly through the ESP8266 to Raspberry Pi resulting a valid data received in Raspberry Pi. Activating Relay in this test case is activate one by one not in synchronous activation. After some time running the module will failed so it is a problem to generating a valid monitoring data and detailed test result can be seen in Table 15. Testing first design planned architecture in ESP8266 got 6 data received in 1 hour test time resulting in 30% data sent and valid with 100% percentage. Testing with synchronous activation relay resulting in Arduino cannot send the first data to API with ESP8266.

With testing in a revised plan using NRF24L01 with radio is done by adding 2 NRF24L01 module and an Arduino Nano to act as a bridge to receive and forward data that send from Arduino in main hydroponics system. This test is conducted to know if the ESP8266 module was the root cause of failed send data. Within Figure 9 can be seen detailed of the schema and detailed test result in Table 16.

Summary for ESP8266 is better at sending valid data to the API served in Raspberry Pi than NRF24L01. While NRF24L01 give more results data sent than ESP8266 were much more received but there is some lost data in water level values that affecting data to be replaced with water add duration, this occurs on Table 17 at 21:30 water level values should be around 6 and water add duration replacing water level. The summary shown in Table 17.

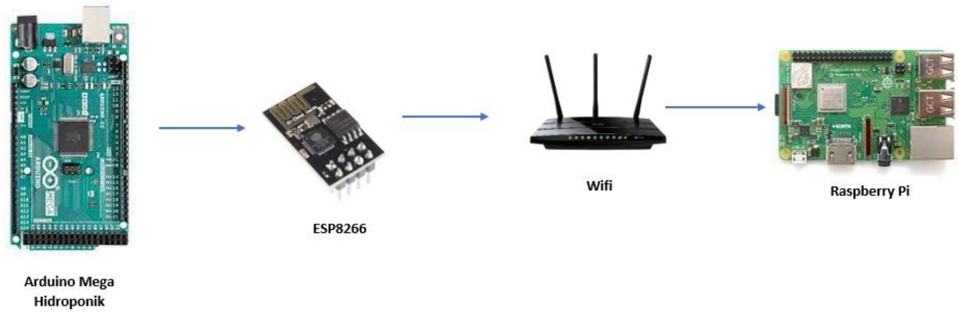

Figure 8. ESP8266 schema

Table 15. Testing result using ESP8266 schema

Date	22/05/2021 16:00	22/05/2021 15:57	22/05/2021 15:55	22/05/2021 15:52	22/05/2021 15:49	22/05/2021 15:47
Water Level	0.92	10.74	10.74	10.64	10.74	10.64
Water Add Duration (Second)	0	5.733	5.733	5.733	5.733	0
pH Level	7.51	10.09	8.38	8.65	8.36	9.1
pH Acid Add Duration (Seconds)	3.567	3.500	3.500	3.500	3.500	3.500
pH Alkaline Add Duration (Seconds)	0	0	0	0	0	0
PPM Add Duration (Seconds)	5.733	3.500	3.500	3.500	3.500	3.500
Container pH Level	2.22	7.56	7.69	7.56	7.69	2.22
pH Step 2 Acid Add Duration (Seconds)	0	5.563	5.547	5.563	5.547	0
pH Step 2 Alkaline Add Duration (Seconds)	3.499	0	0	0	0	0
Container PPM Level	111	0	0	0	0	111
PPM Step 2 Add Duration (Seconds)	5.733	5.733	5.733	5.733	5.733	5.733

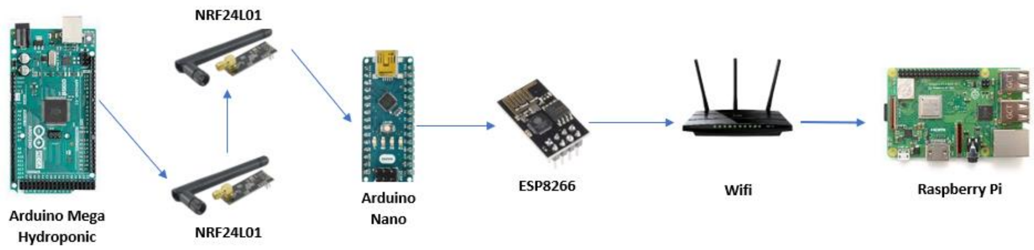

Figure 9. NRF24L01 schema

Table 16. Sample testing result using NRF24L01 schema

Date	16/05/2021 21:36	16/05/2021 21:33	16/05/2021 21:30	16/05/2021 21:27	16/05/2021 21:24	16/05/2021 21:21
Water Level	6.6	6.48	4.145	6.53	6.53	6.6
Water Add Duration (Second)	4.215	4.091	11.47	4.145	4.145	4.215
pH Level	11.71	11.52	3.500	11.58	11.58	11.68
pH Acid Add Duration (Seconds)	3.500	3.500	0	3.500	3.500	3.500
pH Alkaline Add Duration (Seconds)	0	0	0.04	0	0	0
PPM Add Duration (Seconds)	5.054	5.181	6.65	5.127	5.127	5.054
Container pH Level	6.68	6.68	5.628	6.7	6.57	6.59
pH Step 2 Acid Add Duration (Seconds)	5.636	5.636	0	5.645	5.602	5.611
pH Step 2 Alkaline Add Duration (Seconds)	0	0	908.08	0	0	0
Container PPM Level	893.2	908.08	2.233	908.08	922.97	922.97
PPM Step 2 Add Duration (Seconds)	2.526	2.233	0	2.233	1.949	1.949

Table 17. Summary result comparison for ESP8266 and NRF24L01

	ESP8266	NRF24L01
Received data	6 Data	15 Data
Percentage success send data	6/20=30%	15/20=75%
Received data not valid	0 Data	3 Data
Received data valid	6 Data	12 Data
Percentage data valid	6/6=100%	12/15=80%

3.5. Relay activation

Same relay activation is calculated by sorting from smallest to the biggest water add duration, ppm add duration, pH acid add duration, pH alkaline add duration. Make sure each individual value was unique to sorting it in an array. After that we assign the pin from where the relay was used for water, pH, and nutrition. Sorting has been done and then loop through the array with each array identifies with each relay and calculate the differentiation by using this formula and start within array index 1 not 0.

$$Array[n] = Array[n] - Array[n-1] \tag{1}$$

Calculation has been done and resulting an array it may look like 2500, 400, 100, 25 and then loop from index 0 to set delay in to 2.5 seconds and then turn it off and it goes on till the end of array.

3.6. Calibration result

In new proposal of using multistep fuzzy logic, researchers tested method from how efficient multistep fuzzy logic in calibration to optimal condition in growing kale, where optimum pH values were range in 5, 5-6, 5 and in PPM values range in 1050-1400. Test were conducted in adding water only which pH value were average 7.32 and PPM value were 187.5 to start calibration process to it is optimal condition and done in 30 tests. From 30 test concluded average iterations of 12.8 and it is standard deviation is 3.02176 details of summarization in conducted testing in Figure 10.

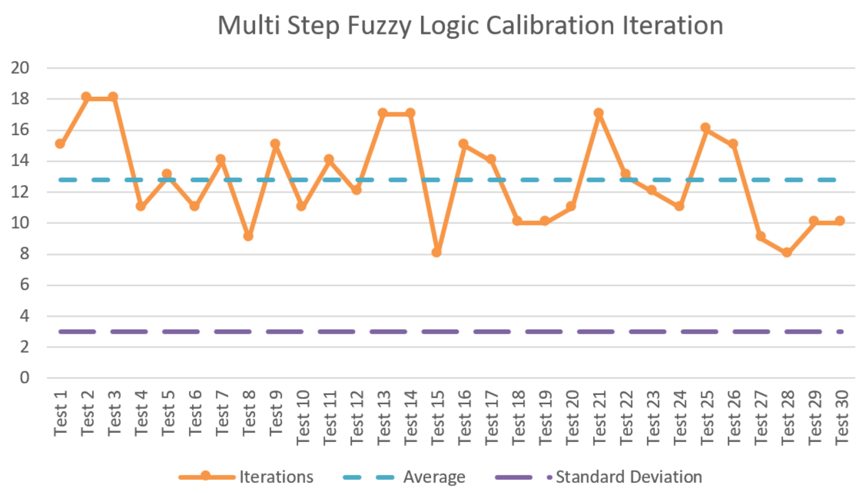

Figure 10. Multistep fuzzy logic calibration graph

4. CONCLUSION

From testing multistep fuzzy logic can be concluded method have worked as expected in fuzzy rule that has been made by the author. This system plan to have an impact to automate hydroponics real-time in real life. This system has an impact to automate hydroponics real-time in real life with the result of calibrate iteration average were 12.8 and it is compared to previous research were using one step fuzzy logic were stated to have 25 iterations for reaching optimal condition in their research. This method proves to be a better calibration performance in controlling hydroponic parameters. From author perspective multistep fuzzy logic were used to have a great impact with calibration process in water condition. Second calculation within the temporary container used to correct furthermore before adding mixed solution to main hydroponics water.

In sending data to make a real-time monitoring system by comparing ESP8266 and NRF24L01 the result was not good as expected to be in this research. In ESP8266 get 30% in receiving 6 data from expected 20 data in 1 hour testing but in validation data the ESP8266 showed better performance than NRF24L01 with radio protocol. NRF24L01 have a better significant in sending data in this research with results 75% but in validation data there are some loses in data presumably with sending data over radio it will cause some lost data. For future research can be digging deeper on other module for sending data that can provide a better result in monitoring website. After new send module has been installed can improve more by adding lights to the parameter. So, it can give another insight of how lights would work to maximize hydroponics crops growth.

ACKNOWLEDGEMENTS

This publication is fully supported by Bina Nusantara University.

REFERENCES

[1] T. A. Khoa, M. M. Man, T.-Y. Nguyen, V. Nguyen, and N. H. Nam, "Smart agriculture using IoT multi-sensors: a novel watering management system," *Journal of Sensor and Actuator Networks*, vol. 8, no. 3, pp. 1–22, Aug. 2019, doi: 10.3390/jsan8030045.

[2] Herman and N. Surantha, "Smart hydroculture control system based on iot and fuzzy logic," *International Journal of Innovative Computing, Information and Control*, vol. 16, no. 1, pp. 207–221, 2020.

[3] J. D. Stevens and T. Shaikh, "MicroCEA: developing a personal urban smart farming device," in *2018 2nd International Conference on Smart Grid and Smart Cities (ICSGSC)*, Aug. 2018, pp. 49–56, doi: 10.1109/ICSGSC.2018.8541311.

[4] C. Kamienski *et al.*, "Smart water management platform: IoT-based precision irrigation for agriculture," *Sensors*, vol. 19, no. 2, Jan. 2019, Art. no. 276, doi: 10.3390/s19020276.

[5] S. Ruengittinun, S. Phongsamsuan, and P. Sureeratanakorn, "Applied internet of thing for smart hydroponic farming ecosystem (HFE)," in *2017 10th International Conference on Ubi-media Computing and Workshops (Ubi-Media)*, Aug. 2017, pp. 1–4, doi: 10.1109/UMEDIA.2017.8074148.

[6] J. Bhar, S. Barouni, and I. Bouazzi, "Multi-level fuzzy logic controller over different parameters variations," *International Conference on Automation, Control Engineering and Computer Science*. 2016.

[7] A. Munandar *et al.*, "Design and development of an IoT-based smart hydroponic system," in *2018 International Seminar on Research of Information Technology and Intelligent Systems (ISRITI)*, Nov. 2018, pp. 582–586, doi: 10.1109/ISRITI.2018.8864340.

[8] T. A. Izzuddin, M. A. Johari, M. Z. A. Rashid, and M. H. Jali, "Smart irrigation using fuzzy logic method," *ARPN Journal of Engineering and Applied Sciences*, vol. 13, no. 2, pp. 517–522, 2018.

[9] A. Ullah, S. Aktar, N. Sutar, R. Kabir, and A. Hossain, "Cost effective smart hydroponic monitoring and controlling system using IoT," *Intelligent Control and Automation*, vol. 10, no. 4, pp. 142–154, 2019, doi: 10.4236/ica.2019.104010.

[10] Helmy, M. G. Mahaidayu, A. Nursyahid, T. A. Setyawan, and A. Hasan, "Nutrient film technique (NFT) hydroponic monitoring system based on wireless sensor network," in *2017 IEEE International Conference on Communication, Networks and Satellite (Comnetsat)*, Oct. 2017, pp. 81–84, doi: 10.1109/COMNETSAT.2017.8263577.

[11] P. Sihombing, N. A. Karina, J. T. Tarigan, and M. I. Syarif, "Automated hydroponics nutrition plants systems using arduino uno microcontroller based on android," *Journal of Physics: Conference Series*, vol. 978, Mar. 2018, Art. no. 12014, doi: 10.1088/1742-6596/978/1/012014.

[12] V. Palande, A. Zaheer, and K. George, "Fully automated hydroponic system for indoor plant growth," *Procedia Computer Science*, vol. 129, pp. 482–488, 2018, doi: 10.1016/j.procs.2018.03.028.

[13] A. Dudwadkar, "Automated hydroponics with remote monitoring and control using IoT," *International Journal of Engineering Research and*, vol. 9, no. 6, pp. 928–932, Jun. 2020, doi: 10.17577/IJERTV9IS060677.

[14] U. Nurhasan, A. Prasetyo, G. Lazuardi, E. Rohadi, and H. Pradibta, "Implementation IoT in system monitoring hydroponic plant water circulation and control," *International Journal of Engineering and Technology*, vol. 7, no. 4.44, Dec. 2018, Art. no. 122, doi: 10.14419/ijet.v7i4.44.26965.

[15] I. K. A. Mogi and A. Dharma, "Hydroponic plants monitoring system based on single board computing in order to increase food security in Bali," *IOP Conference Series: Earth and Environmental Science*, vol. 396, no. 1, Nov. 2019, Art. no. 12017, doi: 10.1088/1755-1315/396/1/012017.

[16] P. Koge, N. Deshmane, K. Chhatwani, and P. S. Shetgar, "Development and monitoring of hydroponics using IoT," *International Journal of Recent Technology and Engineering*, vol. 8, no. 6, pp. 4876–4879, Mar. 2020, doi: 10.35940/ijrte.F8710.038620.

[17] R. Lakshmanan, M. Djama, S. Perumal, and R. Abdulla, "Automated smart hydroponics system using internet of things," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 10, no. 6, pp. 6389–6398, Dec. 2020, doi: 10.11591/ijece.v10i6.pp6389-6398.

[18] D. Yolanda, H. Hindersah, F. Hadiatna, and M. A. Triawan, "Implementation of real-time fuzzy logic control for NFT-based hydroponic system on Internet of Things environment," in *2016 6th International Conference on System Engineering and Technology (ICSET)*, Oct. 2016, pp. 153–159, doi: 10.1109/ICSEngT.2016.7849641.

[19] A. Lizbeth J. Rico, "Automated pH monitoring and controlling system for hydroponics under greenhouse condition," *Journal of Engineering and Applied Sciences*, vol. 15, no. 2, pp. 523–528, Oct. 2019, doi: 10.36478/jeasci.2020.523.528.

[20] H. Fakhrurroja, S. A. Mardhotillah, O. Mahendra, A. Munandar, M. I. Rizqyawan, and R. P. Pratama, "Automatic pH and humidity control system for hydroponics using fuzzy logic," in *2019 International Conference on Computer, Control, Informatics and its Applications (IC3INA)*, Oct. 2019, pp. 156–161, doi: 10.1109/IC3INA48034.2019.8949590.

[21] S. Mashumah, M. Rivai, and A. N. Irfansyah, "Nutrient film technique based hydroponic system using fuzzy logic control," in *2018 International Seminar on Intelligent Technology and Its Applications (ISITIA)*, Aug. 2018, pp. 387–390, doi: 10.1109/ISITIA.2018.8711201.

[22] M. Fuangthong and P. Pramokchon, "Automatic control of electrical conductivity and PH using fuzzy logic for hydroponics system," in *2018 International Conference on Digital Arts, Media and Technology (ICDAMT)*, Feb. 2018, pp. 65–70, doi: 10.1109/ICDAMT.2018.8376497.

[23] M. F. Farhan, N. S. A. Shukor, M. A. Ahmad, M. H. Suid, M. R. Ghazali, and M. F. M. Jusof, "A simplify fuzzy logic controller design based safe experimentation dynamics for pantograph-catenary system," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 14, no. 2, pp. 903–911, May 2019, doi: 10.11591/ijeecs.v14.i2.pp903-911.

[24] M. Mohammadian, "Modelling, control and prediction using hierarchical fuzzy logic systems," *International Journal of Fuzzy System Applications*, vol. 6, no. 3, pp. 105–123, Jul. 2017, doi: 10.4018/IJFSA.2017070105.

[25] R. Gunnam, N. Thejaswini, D. Lahari, S. B. Afridi, and R. K, "Monitoring and automated hydroponic system using smart power unit," *International Journal of Control and Automation*, vol. 13, no. 4, 2020.

BIOGRAPHIES OF AUTHORS

Prabadinata Atmaja received the bachelor degree in Computer Engineering in 2018. From 2021 until now, he is graduate student of Information Technology in Bina Nusantara University. His research interest is machine learning. He can be contacted at email: prabadinata.atmaja@binus.ac.id.

Nico Surantha received his B.Eng. (2007) and M.Eng. (2009) from Institut Teknologi Bandung, Indonesia. He received his PhD degree from Kyushu Institute of Technology, Japan, in 2013. Currently, he serves as an assistant professor in Computer Science Department, Binus Graduate Program, Bina Nusantara University. His research interest includes wireless communication, health monitoring, network design, digital signal processing, system on chip design, and machine learning. He is an IEEE member. He can be contacted at email: nico.surantha@binus.ac.id.