Vol. 13, No. 4 (2024): 1361 - 1371 http://dx.doi.org/10.23960/jtep-l.v13i4.1361-1371

JURNAL TEKNIK PERTANIAN LAMPUNG

ISSN 2302-559X (print) / 2549-0818 (online)
Journal homepage : https://jurnal.fp.unila.ac.id/index.php/JTP

Comparison of Two Fuzzification Algorithms (EC-pH and EC-pH Error-Error Difference Fuzzifications) of Nutrient Solution Control in Plant Factory

Ardiansyah[1,✉], Bastian Seno Aji[1], Eni Sumarni[1]

[1] Department of Agricultural Engineering, Faculty of Agriculture, Jenderal Soedirman University, Purwokerto, INDONESIA.

Article History:

Received : 15 September 2024
Revised : 23 October 2024
Accepted : 14 November 2024

Keywords:

AB Mix Nutrient,
Arduino,
ESP8266,
Fuzzy Logic Controller,
Plant Factory.

Corresponding Author:
✉ ardi.plj@gmail.com
(Ardiansyah)

ABSTRACT

Plant factory is a model of intensive indoor cultivation with microclimate conditioning and lighting. This research aims to develop a fuzzy-based control and monitoring system for TDS, pH, and EC parameters in hydroponic integrated with Internet of Things (IoT) technology. The research was conducted at the Laboratory of Bio-environmental Management and Control Engineering, Department of Agricultural Technology, Faculty of Agriculture, Universitas Jenderal Soedirman. The research results showed that the monitoring and control system using the Fuzzy control algorithm with EC and pH fuzzification and the Fuzzy control algorithm with error and error difference fuzzification were successfully implemented. The data obtained indicated that the Fuzzy control algorithm with error and error difference fuzzification performed better in terms of accuracy and energy efficiency. The Fuzzy control algorithm with error and delta error difference fuzzification was more accurate because a single set pint value used as a reference resulted in better control, and this algorithm also consumed less energy than the Fuzzy control algorithm with EC and pH fuzzification, with a difference of 30 minutes in EC control and 5 minutes in pH control.

1. INTRODUCTION

The decreasing agricultural land will cause food security problems due to the increasing population that needs food. Land that was originally used as agricultural land, gradually changed into multifunctional use for housing or other purposes. To overcome this challenge and meet the increasing demand for food as the population grows, Plant Factory, is indoor cultivation by intensifying production through microclimate control and lighting and nutrition (Sakamoto *et al*., 2020; Watabe *et al*., 2022). Plant factory, emerged as a promising solution for urban agriculture with minimal land. Growth factors in the plant factory are strictly controlled. Temperature, humidity, lighting, and nutrients are precisely regulated to create optimal growing conditions for plants. Control using artificial light can produce pesticide-free plants, high quality, can be produced all year round and can be done in a closed space so that the environment remains optimal and is not affected by the outside climate (Nagase *et al*., 2016).

EC (Electrical Conductivity), pH, and TDS (Total Dissolved Solids) need to be controlled in hydroponic plants because they affect plant health and growth. The impact of inappropriate EC, pH, and TDS values on hydroponic plants can include nutrient deficiencies and decreased plant growth and development (Marisa *et al*., 2021; Sumarni *et al*., 2022). Lack of absorption in plants can also occur if the pH and EC values of the solution are inappropriate, plants will find it difficult to absorb the required absorption and nutrients, resulting in a lack of plant absorption (Binaraesa, 2017). Therefore, the use of EC, pH, and TDS sensors is very useful for controlling and controlling nutrient balance in hydroponic plants (Paryanta *et al*., 2021).

Internet of Things (IoT) (Lubis, 2020; Ramson *et al*., 2020) is also applied to control plant nutrition to obtain nutrients that are in accordance with plant needs (Wijaya *et al*., 2020). Therefore, based on the problems that have been described, this study will utilize a microcontroller (Arduino Mega 2560) (Anantama *et al*, 2020; Thamrin & Candra, 2023) and ESP8266 with a fuzzy logic control system to control nutrient levels in the plant factory. In addition, in this study, data monitoring can be accessed via the internet using Blynk and the data is displayed using the UI (User Interface). Fuzzy logic is a logic that is able to interpret ambiguous statements into understandings that can be explained logically in a language that humans can understand (Al-Gadri, 2023). This explanation underlines that fuzzy logic has a better reach than Boolean logic which can only interpret yes or no.

Control strategies determines the effectiveness of parameters being controlled. There was control strategy that involved either direct measurement of variables being controlled, or the effect of those variables in the quality of product (Ardiansyah, *et al.*, 2022). The purpose of this study is to develop a fuzzy-based control and monitoring system for Total Dissolved Solids (TDS), pH, and Electrical Conductivity (EC) parameters integrated with Internet of Things (IoT) technology. This system aims to automatically and efficiently measure and control these important parameters in a plant environment. factory. In addition, this study also aims to analyze the comparative effectiveness of the system between the developed algorithms in maintaining and controlling TDS, pH, and EC, to ensure that environmental conditions remain optimal for plant growth.

2. MATERIALS AND METHODS

The research was conducted at the Bio-Environmental Management and Control Engineering Laboratory (TPPBL), Department of Agricultural Technology, Faculty of Agriculture, Jenderal Soedirman University. The research will be conducted from December 2023 to August 2024.

The tools used in this study included: Plant Factory with a length of 90 cm, a width of 60 cm and a height of 200 cm, Arduino Mega 2560, SD Card, RTC sensor, TDS Meter sensor, relay, pump, jumper cable, Arduino IDE, ESP8266, PVC pipe, laptop. The materials needed in this study are red spinach seeds, AB Mix fertilizer, water and secondary data in the form of data on red spinach nutritional requirements such as TDS, EC and pH data (Pertiwi *et al.,* 2021).

There were 4 stages in designing this research system. The first stage was designing a control system which includes creating input, process, output, and real-time database systems. The second stage was designing software using Arduino IDE. Both algorithms used are created at this stage. The third stage was designing hardware as shown in Figure 1. The last stage was testing the system to ensure that the system created runs well.

The variables measured in this study were TDS, EC and pH in the plant factory. The variables to be controlled and monitored in this study were only EC and pH values, while TDS was only monitored. Measurement and data storage were carried out every cycle. The hardware system diagram was portrayed in Figure 1. There were two fuzzy control

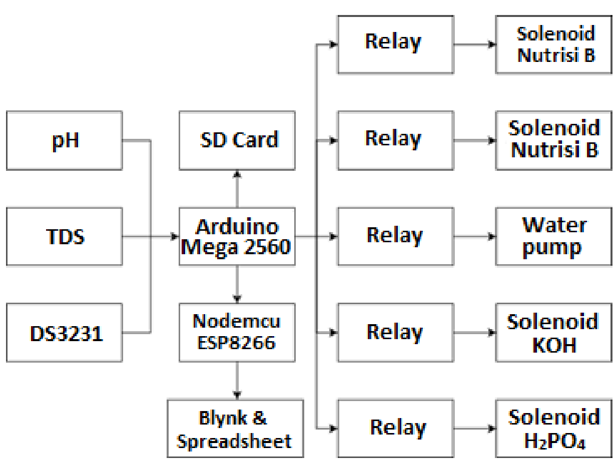


Figure 1. Hardware system diagram

algorithms that was used, namely algorithm 1 with direct fuzzification (Siskandar *et al.,* 2023) on EC and pH variables, and algorithm 2 with fuzzification on the error and error difference of each EC and pH. Algorithm 2 is applied to the PID control method, where the error (difference between set point and actual value) is the basis for control action.

3. RESULTS AND DISCUSSION

3.1. Hardware Design

The hardware design for the nutrient monitoring and control system for the plant factory consists of a microcomputer, microcontroller, sensors, and actuators. The hardware circuit is made using Fritzing software version 0.9.3b for Windows 64-bit (Figure 2). Then the hardware of the nutrient tank itself is made with a circuit like Figure 3.

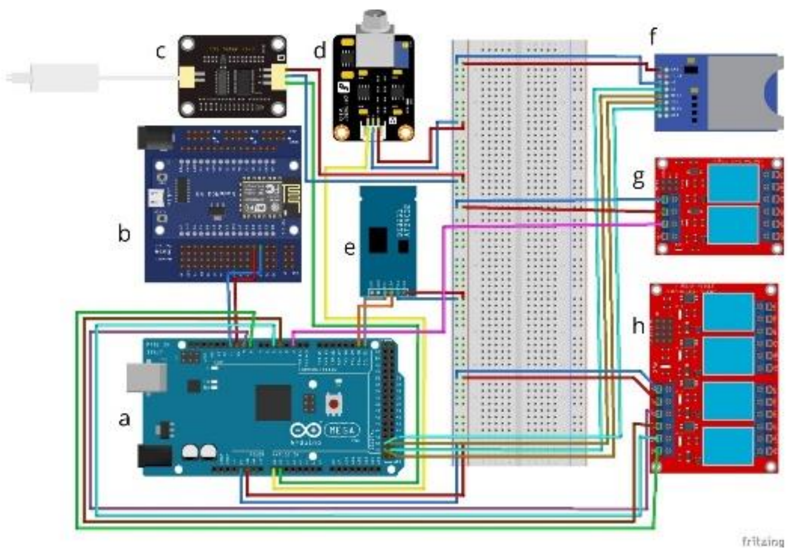


Figure 2. Hardware circuit design using fritzing : a. Microcontroller, b. IoT unit (Nodemcu ESP8266), c. TDS Sensor, d. pH Sensor, e. Real Time Clock DS3231, f. SD Card Module, g. 2 Channel Relay, h. 4 Channel Relay

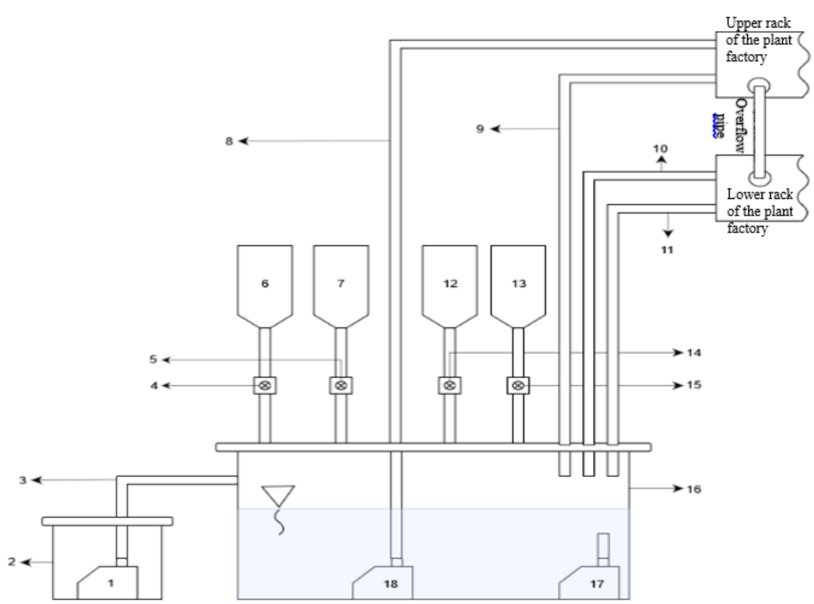


Figure 3. Hardware circuit. [2: Water reservoir; 16: Nutrient reservoir; 1, 17, 18: Pumps; 3: Inlet pipe to rack: 3, 8, 10; Drain pipe: 9 (upper rack), 11 (lower rack); Solenoid valve: 4, 5, 14, 15; Nutrient reservoir: 6 (Nutrient A), 7 (KOH), 12 (H_2PO_4), 13 (Nutrient B)]

3.2. Software Design

There are two algorithms used in this study. The two algorithms are fuzzy which uses error and delta error and the second is fuzzy which does not use error and delta error as input. Both algorithms have the same programming structure, the only difference is in the fuzzy decision-making section based on input and its rules. The flowchart of this program can be seen in the Figure 4.

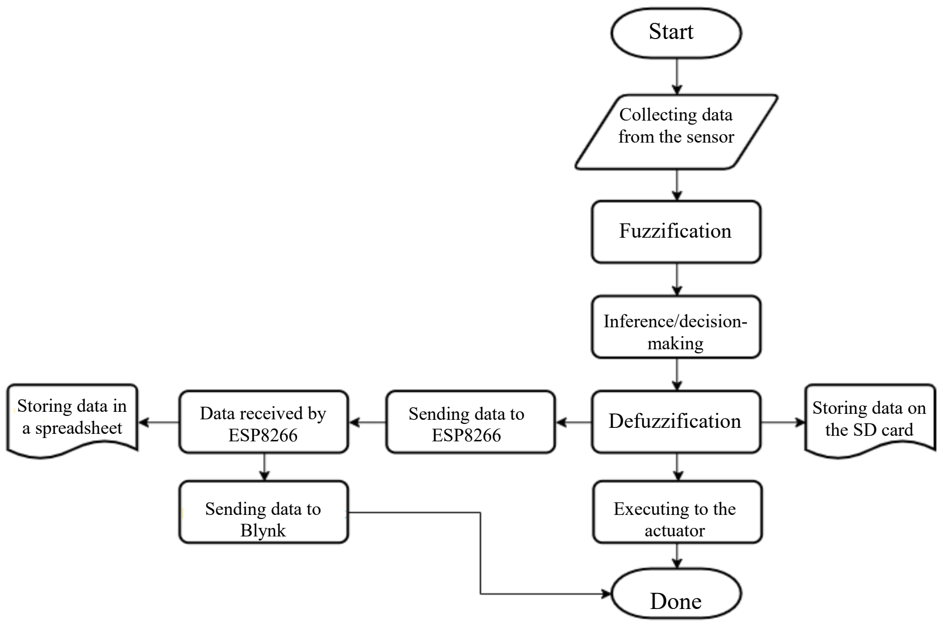


Figure 4. Programming flowchart.

3.3. Designing Data Appearance in Blynk and Spreadsheets

Figure 4 shows the data transmission obtained. First, the data is stored on an SD Card placed on the controlling microcontroller. The data is stored in text (.txt) format. The data stored on this SD card does not require a signal to store it but needs to be removed from the hardware to read it so that data monitoring cannot be carried out simultaneously with the research. This data is then sent to the ESP8266 as an IoT unit, to then be uploaded to a Google spreadsheet. This type of storage requires an internet connection. The advantage of storing it to a Google spreadsheet is that the data

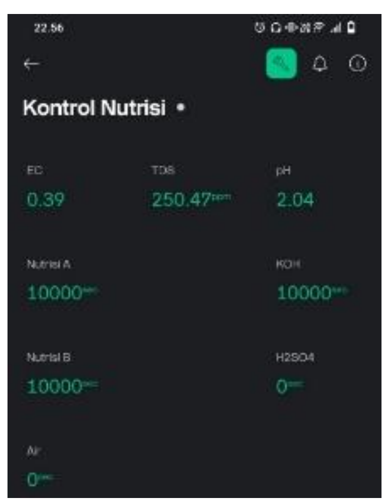


Figure 5. Blynk interface display on a smartphone. (Kontrol = Control, Nutrisi = Nutrient, Air = Water) (Handi *et al*., 2019))

can be monitored simultaneously with the retrieval of research data. The IoT unit, the data is also connected to the Blynk service, which is used to create an interface for Android smartphones.

The use of the Blynk application in this study is due to the simplicity of the implementation of the Blynk program using a microcontroller, ease of installation on a smartphone, the ability to customize the appearance of the application according to preferences, and the fact that the Blynk application is free (Prayitno *et al*., 2017). Blynk provides an easy-to-use interface for creating mobile applications that can connect to various microcontrollers such as Arduino, ESP8266, and others. The interface design is done by creating a template of what sensor values you want to display in the application. These values change in real time because there is an internet connection on the IoT unit that periodically takes data. Figure 5 shows the application interface template created for EC and pH control. It should be noted that the program was inputted in Bahasa Indonesia (the equivalent meaning is marked in the caption).

3.4. Fuzzy Control System

Fuzzy logic is a development of Boolean logic related to the concept of partial truth, where the data used is incomplete, contains uncertainty and ambiguity, which is transformed into classified data. The advantage of this method is that it changes uncertain data into clear data (Rahman & Yanti, 2023; Susanto *et al*., 2020). Common fuzzy methods used in fuzzy inference are the Mamdani method, the Sugeno method, and the Tsukamoto method. In this study, the Mamdani fuzzy method was chosen as the fuzzy inference method. The Mamdani method was chosen because this method is very flexible and tolerant of existing data and can be applied to various types of control systems (Rahman & Yanti, 2023). In

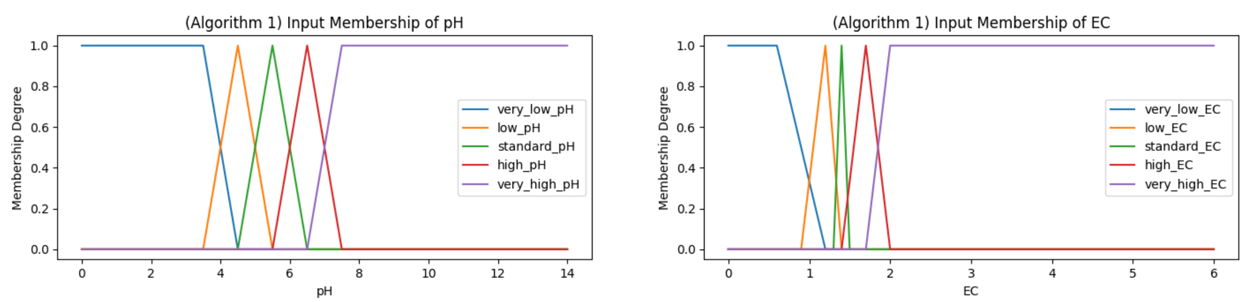


Figure 6. Algorithm 1: pH set function (left), and EC set function (right)

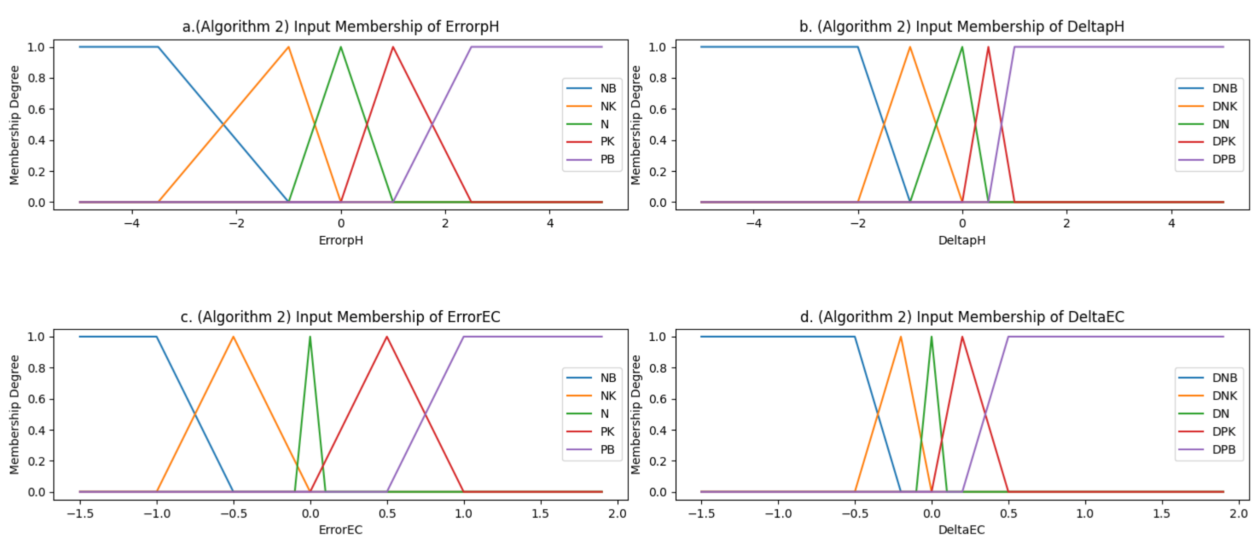


Figure 7. Algorithm 2: (a) Error set function of pH, (b) Delta Error set function of pH, (c) Error set function of EC, and (d) Delta Error set function of EC

this study, there are 2 types of fuzzy research algorithms used, namely the Fuzzy control algorithm using EC and pH fuzzification (Algorithm 1) and the Fuzzy control algorithm using error fuzzification and error difference (Algorithm 2). Both are depicted in Figure 6 and 7.

3.4.1. Fuzzification

The fuzzification stage begins by receiving the sensor input values, consisting of TDS and pH sensors, then the data is used to calculate the degree of membership of the sensor values, then the results will be obtained in the form of degrees TDS and pH. The following are the membership inputs of the two algorithms used.

3.4.2. Inference

Table 1 present rules for control algorithm 1 on nutrition (A & B) and water. Whereas rules for control algorithm 2 on KOH and H_2PO_4 as well as nutrition (A & B) and water are presented in Table 2.

Table 1. Rules for fuzzy control algorithm 1 (direct fuzzification of EC and pH)

pH \ EC		Nutrisi (A & B) ON		Off	Air ON	
		SB	Sedikit	Standar	Tinggi	TB
KOH ON	SB	Lama	Cepat / Lama	Off / Lama	Cepat / Lama	Lama
	Sedikit	Lama / Cepat	Cepat	Off / Cepat	Cepat	Lama / Cepat
Off	Standar	Lama / Off	Cepat	Off	Cepat	Lama / Cepat
H_2PO_4 ON	Tinggi	Lama / Cepat	Cepat	Off / Cepat	Cepat	Lama / Cepat
	TB	Lama	Cepat / Lama	Off / Lama	Cepat / Lama	Lama

Note: The program was written in Bahasa Indonesia. The following list is the equivalent meaning in English.

B. Indonesia	English
lama	long
cepat	fast
sedikit	little
tinggi	high
air	water
SB	
TB	

Table 2. Rules for fuzzy control algorithm 2 (error and error difference (ΔE) fuzzification of EC and pH)

ΔE \ E	Nutrisi (A & B) ON		Off	Air ON	
	NB	NK	N	PK	PB
NB	Lama	Sedang	Berhenti	Sedang	Lama
NK	Lama	Sebentar	Berhenti	Sebentar	Lama
N	Lama	Sebentar	Berhenti	Sebentar	Lama
PK	Sedang	Sebentar	Berhenti	Sebentar	Sedang
PB	Sedang	Sebentar	Berhenti	Sebentar	Sedang

ΔE \ E	KOH ON		Off	H_2PO_4 ON	
	NB	NK	N	PK	PB
NB	Lama	Sedang	Berhenti	Sedang	Lama
NK	Lama	Sebentar	Berhenti	Sebentar	Lama
N	Lama	Sebentar	Berhenti	Sebentar	Lama
PK	Sedang	Sebentar	Berhenti	Sebentar	Sedang
PB	Sedang	Sebentar	Berhenti	Sebentar	Sedang

Note: The program was written in Bahasa Indonesia. The following list is the equivalent meaning in English.

B. Indonesia	English
lama	long_time
sedang	medium_time
sebentar	short_time
berhenti	off
NB	big negative
NK	small negative
N	zero
PK	small positive
PB	big positive
air	water
nutrisi	nutrient (A and B)

3.4.3. Defuzzification

The defuzzification process in the Mamdani fuzzy method is the stage where the fuzzy set is changed into a crisp value. The defuzzification technique used in this method is Centroid or Center of Gravity. This Centroid technique calculates the crisp value as the center point of the area under the fuzzy output curve. After the α value (degree of membership) of the Min-Max method on each variable is calculated, the fuzzy results are evaluated based on the existing rules to produce fuzzy output. This process allows us to get a clear value that represents the output of the fuzzy system based on previously processed information. Both algorithms have different membership values as depicted in Figure 8-12.

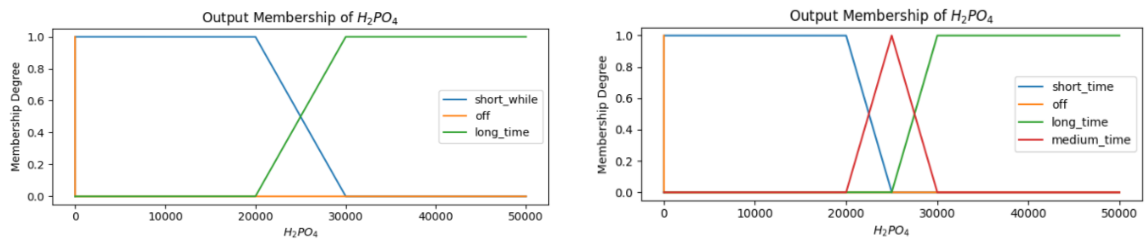


Figure 8. Output member set of H_2PO_4 from algorithm 1 (left) and from algorithm 2 (right)

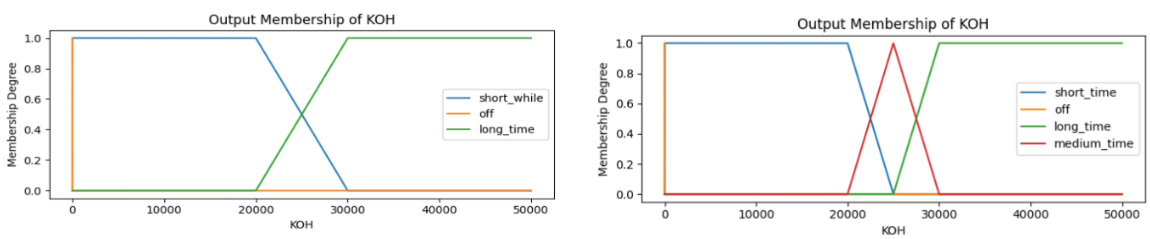


Figure 9. KOH output member set from algorithm 1 (left), and from algorithm 2 (right)

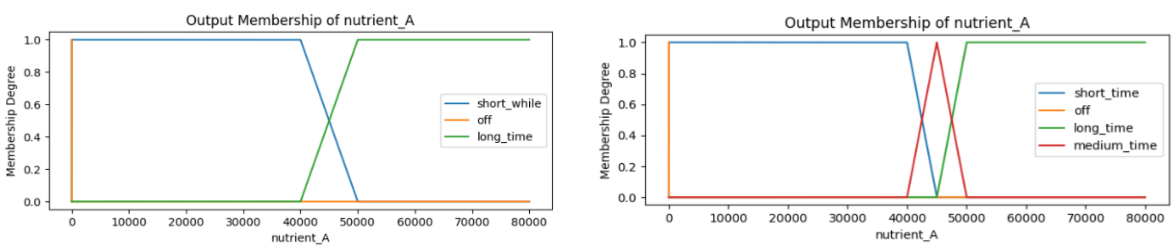


Figure 10. The set of output members of nutrient A from algorithm 1 (left), and from algorithm 2 (right)

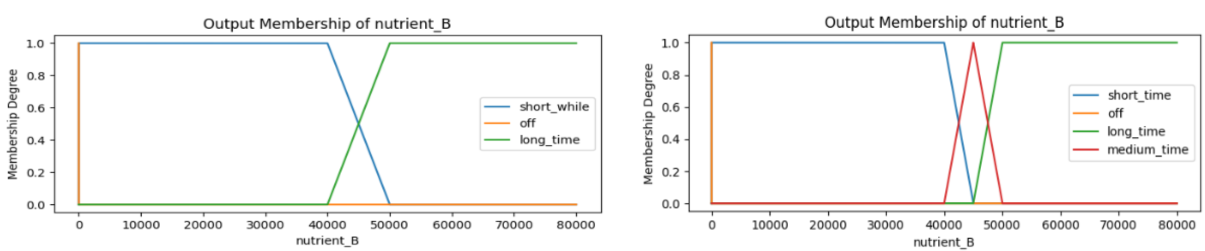


Figure 11. The set of output members of nutrition B from algorithm 1, and from algorithm 2 (right)

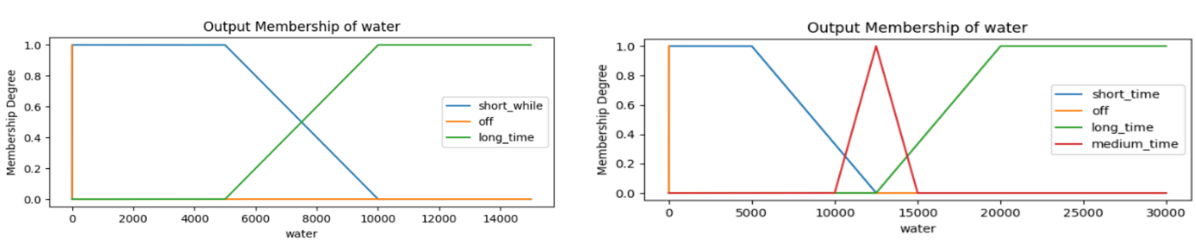
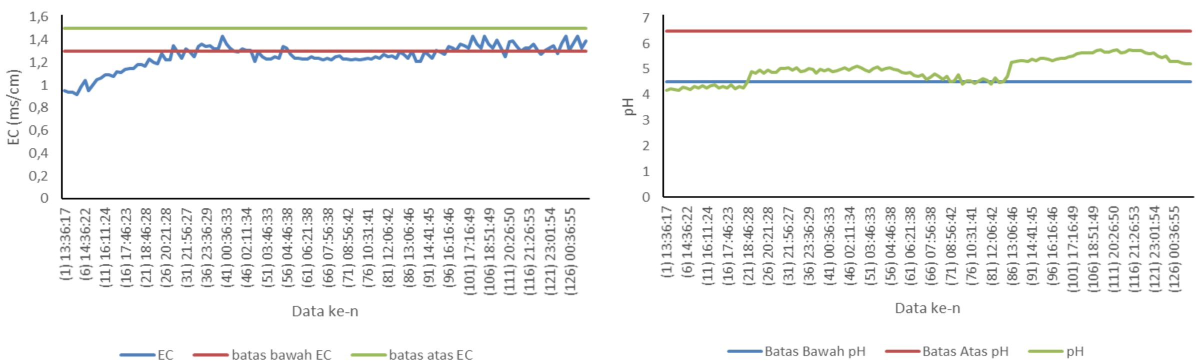


Figure 12. Water output member set from algorithm 1, and from algorithm 2 (right)

3.5. Accuracy of Analysis System

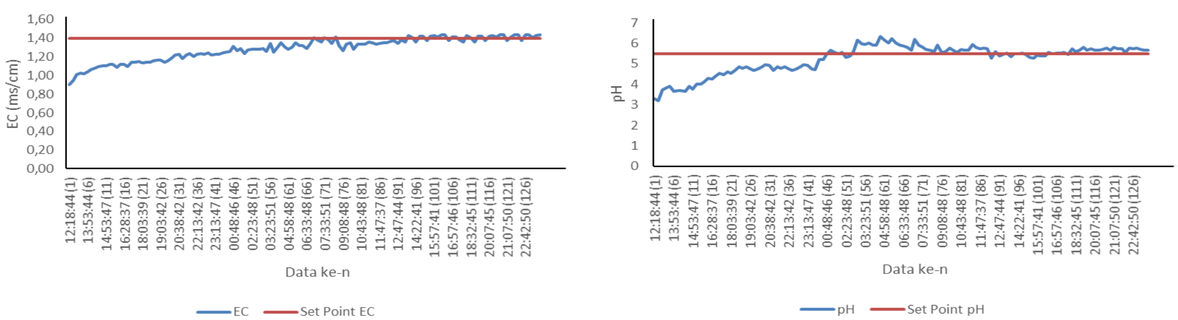
The data shows that the EC value first entered the predetermined range limit on the 29th data or at 21:06 WIB. The EC value began to stabilize within the specified range in the 94th data taken at 14:26 WIB and continued to stabilize within the range until the end of the 131st data collection (Figure 13a). In this EC control algorithm 1, the controlled EC nutrient levels first entered the target range after 450 min and began to stabilize after 1500 min of data collection.

The data shows that the pH value first entered the specified range limit on the 22nd data point or at 18:46 WIB. The KOH pH solution used to increase the pH ran out on July 18 at around 16:00 WIB (Figure 13b). The pH value began to stabilize within the specified range when the 22nd data point was taken at 18:46 WIB. The pH data was relatively stable within the range, although there was a fairly drastic increase from 4.71 to 5.27 at 13:06 WIB. After this increase, the pH value tended to remain relatively stable within the range until the end of the 131st data collection. In the 1st pH control algorithm, the controlled nutrient pH level first entered and stabilized within the target range after 310 min.



(a) (b)

Figure 13. Results of the nutritional conditions of algorithm 1: (a) EC, and (b) pH.



(a) (b)

Figure 14. Results of the nutritional conditions of algorithm 2: (a) EC, and (b) pH.

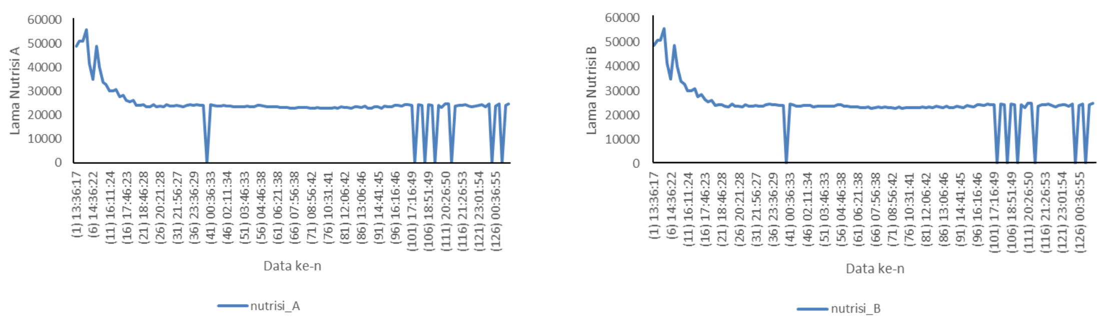
From Figure 14a, it can be seen that the EC value obtained has an initial value of 0.9 $ms.cm^{-1}$ or 576 ppm then increases gradually with some small fluctuations. The EC value then first touches the set point at the 69th measurement interval at 06:43 WIB, and begins to fluctuate around the set point value after that. In the EC control algorithm 2, the controlled nutrient levels A and B first enter and stabilize within the target range after 1105 min.

From figure 14b it can be seen that the initial pH value had a value of 3.29 then increased gradually with some small fluctuations. The pH value then first touched the set point at the 48th measurement interval at 00:53 WIB, and began to fluctuate around the set point value after that. The data increased more than the set point after touching the set point but slowly decreased again at the 81st data at 10:03 WIB. In this algorithm, it was filled with 500 liters of KOH and H_2PO_4 solutions. The KOH and H_2PO_4 solutions ran out at around 16:00 WIB but were continued to see the stability of the nutrient solution to reach the set point. The majority of pH values remained very close to the set point, indicating that the algorithm used was successful in maintaining the pH value close to the desired reference value. In algorithm 2 of pH control, the level of the nutrient was controlled for the first time to touch the set point after 745 min and was stable in the target set point range after 1305 min. The comparison of control system performance can be seen in Table 3.

Table 3. Comparison of system performance between Algorithm 1 and Algorithm 2.

Control System Performance	Algorithm 1		Algorithm 2	
	EC	pH	EC	pH
Accuracy	7.8	4.31	7.34	11.13
Response time to steady state	7 hours	4.5 hours	16 hours	13 hours
Stability	39.2%	81.5%	54.6%	86.2%

Accuracy indicates the total error that occurs during control. Values that are between the upper and lower limits of both EC (1.3 and 1.5 respectively) and pH (4.5 and 6.5 respectively) are not categorized as errors. In this case, algorithm 1 shows better accuracy than algorithm 2 at pH, which is 4.31 compared to 11.13. The response to steady state is achieved faster in algorithm 1, both in EC and pH control. In terms of stability, algorithm 2 shows better stability. In EC control, algorithm 2 shows values that are in the range of 1.3 and 1.5 as much as 54.6% (Table 3). The pH stability in algorithm 2 also shows a value of 86.2%, which means that values that are not in the set point range are only 13.8% of the total measurement data. Apart from the accuracy of the set point, this study also provides data related to the duration of the solenoid on for each during the data collection period.



(a) (b)

Figure 15. Long time graph of solenoid under algorithm 1: (a) nutrition A, and (b) nutrition B

Figure 15 shows the duration of nutrients A and B was initially above 50,000 ms due to the small EC value, but then experienced a gradual decrease until it stabilized at around 20,000 ms starting from the 30th data which means that the EC value has started to rise approaching the specified range. The data that dropped to 0 occurred because the EC value obtained was in the range where the water distributed was not nutrients. The energy efficiency of algorithm 1 in EC control turns on the solenoid with a total duration of nutrients A of 52 min, nutrients B of 52 min and water of 1 min.

Under algorithm 2, the duration of nutrients A and B was initially above 20,000 ms due to the small EC value, but then it experienced a gradual decrease until it stabilized around the 67th data, which means that the EC value had started to rise approaching the specified range. The data that dropped to 0 occurred because the EC value obtained was in the range where the water distributed was not nutrients. The energy efficiency of algorithm 2 in EC control turns on the solenoid with a total duration of nutrients A of 36.5 min, nutrients B of 36.5 min, and water of 1 min.

Initially, the on time of the H_2PO_4 solenoid is stable at 0 ms and the on time of the KOH solenoid starts with a high value due to the small pH value. The H_2PO_4 solenoid starts to turn on at data 101 and the KOH solenoid turns off, meaning that the pH value is high and needs to be lowered. The energy efficiency of algorithm 2 in pH control turns on the solenoid with a total KOH time of 14 min and H_2PO_4 of 13 min.

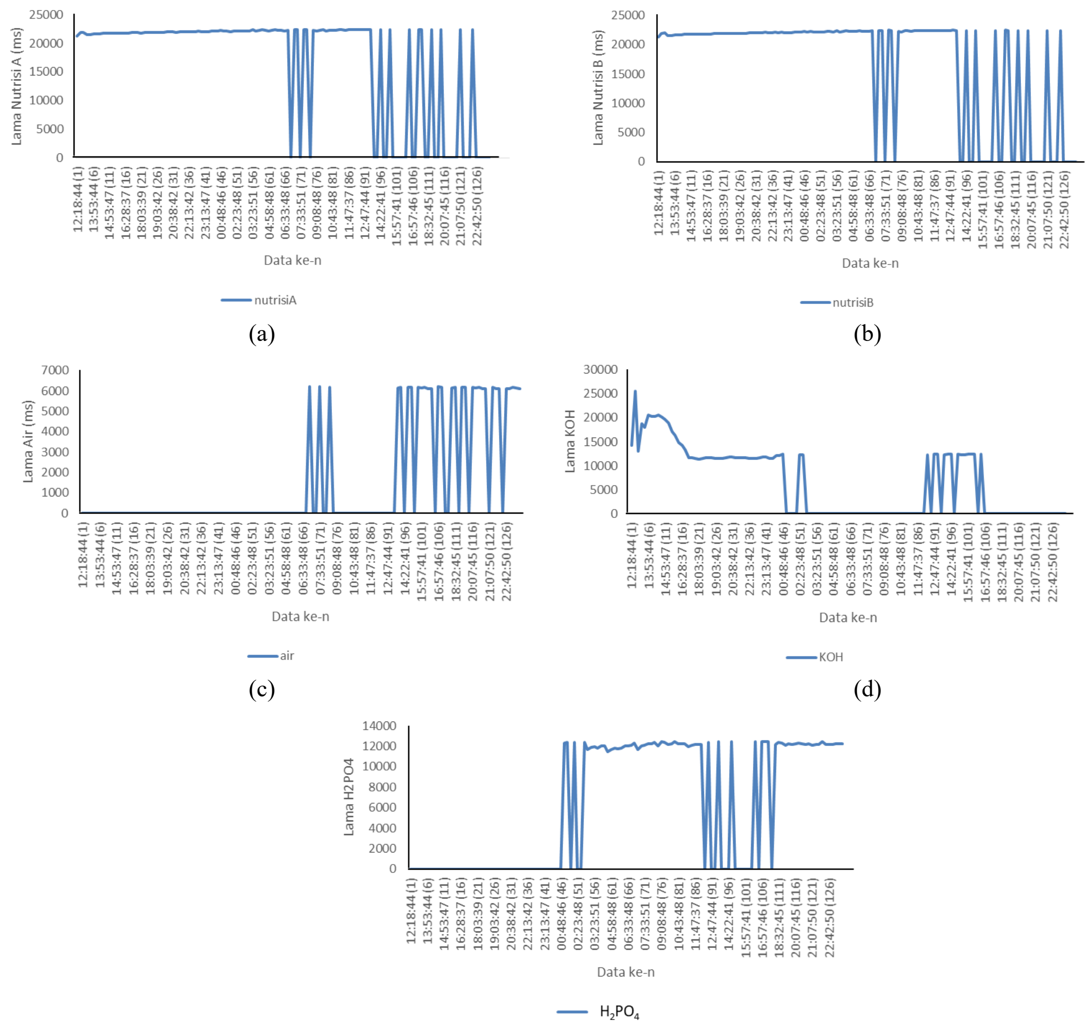


Figure 16. Long time graph of solenoid on algorithm 2: (a) nutrition A, (b) nutrition B, (c) water, (d) KOH, and (e) H_2PO_4

4. CONCLUSION

Based on the results and discussion, some conclusion points are derived. First, the creation of a program for a nutritional control and monitoring system using fuzzy logic has been successfully carried out. Data can be stored well on SD Cards and Google Sheets. The Blynk monitoring system is made for users android application interface for remote control successfully implemented. Second, in algorithm 1, data was generated that to stabilize nutrients in the specified range it takes 1500 minutes for EC and 310 minutes for pH. Then in algorithm 2 it takes 1105 minutes for EC and 1305 minutes for pH. Third, in terms of algorithm 2 is better than algorithm 1 where the value is more than algorithm 1. However, this does not significantly affect the level of accuracy. Last, in terms of energy efficiency, algorithm 1 in EC control turns on the solenoids of nutrient A, nutrient B, and water with a total time of 106 minutes, in addition, pH control in algorithm 1 turns on the solenoids of KOH and H_2PO_4 with a total time of 32 minutes. Algorithm 2 turns on the solenoids with a total of 76 minutes in EC control and 27 minutes in pH control. This shows that algorithm 2 uses less energy than algorithm 1 with a difference of 30 minutes in EC control and 5 minutes in pH control.

ACKNOWLEDGEMENTS

The author would like to thank the BLU Universitas Jenderal Soedirman for research funding in 2024.

REFERENCES

Al-Gadri, P.F.Z. (2023). TA: Sistem Auto Light Dimmer pada Hidroponik Indoor Berbasis IOT menggunakan Fuzzy Logic Controller [*Undergraduate Thesis*]. Universitas Dinamika.

Anantama, A., Apriyantina, A., Samsugi, S., & Rossi, F. (2020). Alat pantau jumlah pemakaian daya listrik pada alat elektronik berbasis arduino uno. *Jurnal Teknologi dan Sistem Tertanam*, ***1***(1). https://doi.org/10.33365/jtst.v1i1.712

Ardiansyah, A., Naufalin, R., Arsil, P., Latifasari, N., Wicaksono, R.,Aliim, M. S., Kartiko, C., & Waluyo, S. (2022). Machine learning model for quality parameters prediction and control system design in the kecombrang flower (*Etlingera elatior*) extraction process. *Processes,* ***10***(7), 1-13. https://doi.org/10.3390/pr10071341

Binaraesa, N.N.P.C. (2017). Nilai EC (Electro Conductivity) berdasarkan umur tanaman selada daun hijau (*Lactuca sativa* L.) dengan sistem hidroponik NFT (Nutrient Film Technique). [*Undergraduate Thesis*]. Universitas Brawijaya.

Handi, H., Fitriyah, H., & Setyawan, G.E. (2019). Sistem pemantauan menggunakan blynk dan pengendalian penyiraman tanaman jamur dengan metode logika Fuzzy. *Jurnal Pengembangan Teknologi Informasi dan Ilmu Komputer*, ***3***(4), 3258–3265. Diambil dari https://j-ptiik.ub.ac.id/index.php/j-ptiik/article/view/4907

Lubis, H.R. (2020). Rancang bangun smart system ruang greenhouse berbasis IoT dengan menggunakan arduino UNO. [*Undergraduate Thesis*]. Fakultas Teknik, Universitas Islam Indonesia, Yogyakarta.

Marisa, M., Carudin, C., & Ramdani, R. (2021). Otomatisasi sistem pengendalian dan pemantauan kadar nutrisi air menggunakan teknologi NodeMCU ESP8266 pada tanaman hidroponik. *Jurnal Teknologi Terpadu*, ***7***(2), 127-134. https://doi.org/10.54914/jtt.v7i2.430

Nagase, K., Shiraki, T., & Iwasaki, H. (2016). Plant factory solution with instrumentation and control technology. *Fuji Electric Review*, ***62***(3), 160-164.

Paryanta, P., Wendanto, W., & Mulyani, P. (2021). Purwarupa deteksi pH dan ec larutan nutrisi hidroponik berbasis internet of things. *Go Infotech: Jurnal Ilmiah STMIK AUB*, ***27***(1), 1-12. https://doi.org/10.36309/goi.v27i1.139

Pertiwi, A., Kristianti, V.E., Jatnita, I., & Daryanto, A. (2021). Sistem otomatisasi drip irigasi dan monitoring pertumbuhan tanaman cabai berbasis internet of things. *Sebatik*, ***25***(2), 739-747. https://doi.org/10.46984/sebatik.v25i2.1623

Prayitno, W.A., Muttaqin, A., & Syauqy, D. (2017). Sistem monitoring suhu, kelembaban, dan pengendali penyiraman tanaman hidroponik menggunakan blynk android. *Jurnal Pengembangan Teknologi Informasi dan Ilmu Komputer*, ***1***(4), Article 4.

Rahman, M.F., & Yanti, F. (2023). Aplikasi logika fuzzy dalam optimisasi produksi mebel menggunakan metode Mamdani. *Jurnal Informatika Multi*, ***1***(3), Article 3

Ramson, S.R.J., Vishnu, S., Shanmugam, M. (2020). Applications of Internet of Things (IoT) – An overview. In *2020 5th International Conference on Devices, Circuits and Systems (ICDCS)*, 92–95. https://doi.org/10.1109/ICDCS48716.2020.243556

Sakamoto, M., & Suzuki, T. (2020). Effect of nutrient solution concentration on the growth of hydroponic sweetpotato. *Agronomy*, ***10***(11), 1708. https://doi.org/10.3390/agronomy10111708

Siskandar, R., Mandang, T., Hermawan, W., & Irzaman, I. (2023). Engineering of information monitoring system sensor reading data based on smart wireless using NVDIA Jetson Nano and Arduino Mega on agricultural spraying machines. *Jurnal Teknik Pertanian Lampung*, ***12***(4), 921-936. http://dx.doi.org/10.23960/jtep-l.v12i4.921-936

Sumarni E., Priswanto, Irayani, Z. (2022). Application of electrical conductivity (EC) for some potato varieties in the aeroponically seed production with Root Zone Cooling and Evaporative Cooling in Tropical Lowlands. *Jurnal Teknik Pertanian Lampung*, ***11***(2), 184-194. http://dx.doi.org/10.23960/jtep-l.v11i2.184-194

Susanto, S., Hikmayanti, H., & Indra, J. (2020). Implementasi fuzzy logic pada tambak ikan bandeng berbasis internet of things (IoT). *Scientific Student Journal for Information, Technology and Science*, ***1***(1), 26–32.

Thamrin, S., & Candra, O. (2023). Perancangan sistem pengontrolan dan monitoring pengaliran nutrisi pada tanaman hidroponik berbasis arduino secara otomatis. *JTEIN: Jurnal Teknik Elektro Indonesia*, ***4***(2).

Watabe, T., Nakano, Y., & Ahn, D.H. (2022). The effect of electrical conductivity on fruit growth pattern in hydroponically grown tomatoes. *Crops*, ***2***(3), 323-335. https://doi.org/10.3390/crops2030023

Wijaya, R., Hariono, B., & Saputra, T.W. 2020. Pengaruh kadar nutrisi dan media tanam terhadap pertumbuhan bayam merah (*Alternanthera amoena voss*) sistem hidroponik. *Jurnal Ilmiah Inovasi*, ***20***(1).