Implementation of Real-Time Fuzzy Logic Control for NFT-Based Hydroponic System on Internet of Things Environment

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Abstract—**Nutrient Film Technique (NFT) is one of the methods of hydroponic system which use a circulated water containing nutrient as a growing media of plant. The important parameter in NFT that affect the plant growth are electrical conductivity (EC) and pH that should be maintain in prescribed range that depend on plant types. In this study, we implement the fuzzy logic to control the EC and pH condition of the NFT-based hydroponic system in Internet of Things (IoT) system environment. By using IoT consist of wireless sensor network, data logger, machine-to-machine and actuator (pump), we can remotely controlling and monitoring all parameters through internet network, that can be applied to scattered area. The experiment based on proportional small scale process which consist of four controlled tanks (nutrient A, nutrient B, acid solution, and alkaline solution) and one mixing tank with adjustable flow pump by using 12 rules fuzzy logic. Parameter EC and pH are maintained in range defined according to the input range given. The required time to recover the EC and pH from outside range to within the defined range is about 15 minutes.**

Keywords— **NFT, pH, EC, Fuzzy Logic, Internet of Things**

I. Introduction

The United Nations give a prediction that in 2050 the global population reach 9.7 billion [1]. In 2016, an estimated that 54.5 per cent of the world's population will be lived in urban areas [2]. The number will continue to increase in the future. This large number can influence all sectors of life, including one of them is sector agriculture sector. Population density in urban areas can cause many of land will be used for a home or a settlement. This situation will reduce the agricultural areas, especially traditional agricultural that typically have large area. Therefore, there should be new agricultural model that allows to farm in urban areas, called Urban Agriculture. Urban agriculture can be described as the agriculture sector that optimize the use of land and building in the urban area [3]. One of urban agriculture model is Hydroponic System that can use in the small areas.

In modern agricultural, the use of internet of things has significant role in a smart agriculture [4]. One of the IoT role are controlling and monitoring all parameters that affect the growth of plants, such as providing nutrition and plant environment condition. In providing nutrition, the content which must be controlled are pH, temperature and EC (Electrical Conductivity) [5]. The plant environment, temperature condition, moisture and lighting room are parameter that also important to control and monitor [6]. By use of IoT, it allows in controlling, communicating and monitoring that can be worked remotely in real-time through internet network. The performance of controlling can be seen from ability to respond and recovery quickly because the condition is suddenly changed, accurately and precisely to achieve optimal and efficient performance [7]. One of the intelligent control method that can be used is fuzzy logic control. Fuzzy logic control is a good alternative method and suitable because it could mimic the control performed process by human being [8] and it is simpler than using an analysis model [9].

The fuzzy logic control algorithm is implemented using embedded microcontroller ATMega328 including I/O hardware. The design algorithm has rules (inference rule) to control plant parameter pH and EC. Fuzzy logic to pH requires input parameter of pump A (alkaline solutions) and pump B (acid solutions), while EC requires input parameter of pump C and pump D (ABmix solutions: fertimix) and adjustable output via IoT. Then, output fuzzy in process or that was achieved will be shown to IoT web-based through reading pH sensor or EC sensor. Examined analyze is tested to the performance of the response time of fuzzy logic process to the system by using IoT.

II. RELATED WORK

A. Development and Simulation of an Agriculture Control System Using Fuzzy Logic Method and Visual Basic Environment

In research [10], agriculture control system by using fuzzy logic method via visual basic was completely designed and simulated. A fuzzy expert system was successfully design in order to control the lighting intensity and temperature of the hydroponic farm environment and maintained at a permissible level. Ths system contructed in form of the prototype of an agriculture control room. In this system, author that fuzzy logic fulfil the need of the lighting intensity control in agriculture environment. As for the parameter that controlled is the changes in temperature, humidity and environment illumination. This will the plants to growth perfectly when the variation of the temperature, humidity and illumination were control at an adequate level. Its result, the fuzzy expert system was successfully interfaced with the prototype via port communication to take consideration on the variation of changes in the environment temperature, humidity and illumination.

B. Fuzzy Logic Based Farm Automation Using Arduino and LabVIEW with X-Bee Based Control System

In research [11], the author appoint about the farm automation system to help farmers in increase productivity plants. This system using platform hardware such as arduino and zigbee technology as the transmission medium and platform software such as LabVIEW. System implement fuzzy logic in LabVIEW to process and control input and output parameter. As for input parameter controlled the temperature, humidity, moisture and intensity of the level of light calibrated in the level 0-100 and output parameter controlled the duration drip (rate of flow) and duration spray based on input given. Writer suggested that the main advantage of this system is that with implementation of the fuzzy logic method can be optimize the use of water and therefore the efficient use of the resources is ensured.

C. Smart Farming System Using Sensor for Agricultural Task Automation

In this paper [12], the writer appoint about smart farming system that lingking a smart sensing system and smart irrigator system through wireless communication technology. This system focuses on the measurement of physical parameters such as soil moisture content, nutrient content and pH of the soil. The farmers can controlling system via wireless communication with *Global System for Mobile Communication* (GSM) modul in mobile phone it.

D. AgriSys : A Smart and Ubiquitous Controlled Environment Agriculture System

In this paper [6], the writer appoint about Smart Agriculture System (AgriSys) that can be control environment agricultural ubiquitous as it enable distance access. In this system, they adopted fuzzy inference system to reduce complexity and components used. Parameter of AgriSys system that is temperature, moisture, pH and plant nutrition. The implementation system and method used dependent on tools LabVIEW and developed in webserver to access from a distance and can be monitoring use computer, tablets, smartphones and other.

III. ANALYSIS AND SYSTEM DESIGN

A. Hydroponic

Hydroponic is plant cultivation that use water and without use soil as a planting medium (soilless). Nutrient Film Technique (NFT) system is one of the form of cultivation hydroponic. NFT is a system that constantly to flow nutrient dissolved in water without use timer to pump. This nutrition flow into gully through plant root and therefore returning to shelter water, so on [13]. In this study, the system implemented in urban agriculture with hydroponic NFT model.

B. Fuzzy Logic Control Method

Fuzzy system was first conceived in 1965 by Lotfi Zadeh, a professor at the California University, Berkley. Fuzzy logic is a method has ability to process variable that ambiguous or cannot be described in exact or definitely. Basic of fuzzy logic is fuzzy set theory [14]. Fuzzy logic control is a methodology to presented and implement human knowledge or intelligence about how to control a system [15]. In this research, fuzzy logic control used to control the EC and pH condition on the providing of plant nutrition. PH value and EC value as input and pump activation time (actuator) as output. The design of fuzzy logic control in this research can be seen in fig. 1.

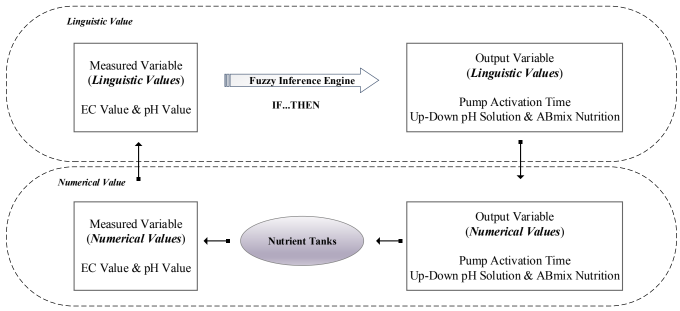


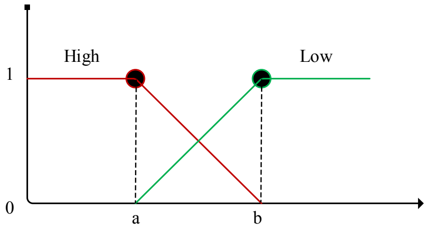
Fig. 1 Design of fuzzy logic control method

Steps the application of fuzzy logic control consist of:

1. The first step is define variable involve in process that will be determined and according to fuzzification functions. In this case, there is six variables that will be modeled, namely:
   - Input variable : pH and EC
   - Output variable: pump A, pump B, pump C and pump D.

2. The second step (*Fuzzification*) is step mapping input crisp into fuzzy sets that presented in form membership function. The purpose of fuzzification is get degree of membership. The following computation of value membership functions (μ) for each input variable and output variable.

a. PH Acid (x), consist of two linguistic values, namely: High and Low. The membership function was formulated as follows :

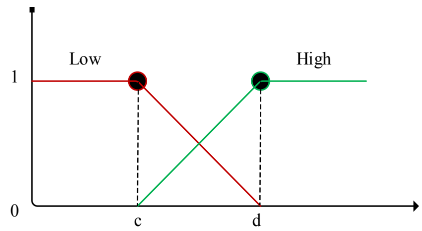


Value degree of membership:

$$\mu phAcid\_HIGH[x] = \begin{cases} 1 & x \leq a \\ \frac{b-x}{b-a} & a \leq x \leq b \\ 0 & x \geq b \end{cases}$$

$$\mu phAcid\_LOW[x] = \begin{cases} 1 & x \geq b \\ \frac{x-a}{b-a} & a \leq x \leq b \\ 0 & x \leq a \end{cases}$$

b. PH Alkaline (x), consist of two linguistic values, namely: Low and High. The membership function was formulated as follows :

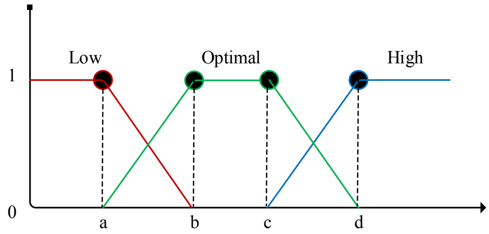


Value degree of membership:

$$\mu phAlkaline\_HIGH[x] = \begin{cases} 1 & x \leq c \\ \frac{d-x}{d-c} & c \leq x \leq d \\ 0 & x \geq d \end{cases}$$

$$\mu phAlkaline\_LOW[x] = \begin{cases} 1 & x \leq c \\ \frac{d-x}{d-c} & c \leq x \leq d \\ 0 & x \geq d \end{cases}$$

c. EC (x), consist of three linguistic values, namely: Low, Optimal and High. The membership function was formulated as follows :



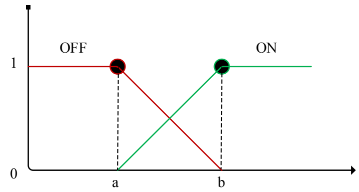
Value degree of membership:

$$\mu ecLOW[x] = \begin{cases} 1 & x \leq a \\ \frac{b-x}{b-a} & a \leq x \leq b \\ 0 & x \geq b \end{cases}$$

$$\mu ecOPTIMAL[x] = \begin{cases} 0 & x \leq 1a \text{ atau } x \geq 4d \\ (x-a)/(b-a) & a \leq x \leq b \\ 1 & b \leq x \leq c \\ (d-x)/(d-c) & c \leq x \leq d \end{cases}$$

$$\mu ecHIGH[x] = \begin{cases} 1 & x \geq d \\ \frac{x-c}{d-c} & c \leq x \leq d \\ 0 & x \leq c \end{cases}$$

d. Pump A (z), Pump B (z), Pump C (z) and Pump D (z), each consist of two linguistic value, namely: OFF and ON. The membership function was formulated as follows :



Value degree of membership:

$$\mu pump\_OFF[z] = \begin{cases} 1 & z \leq a \\ \frac{b-z}{b-a} & a \leq z \leq b \\ 0 & z \geq b \end{cases}$$

$$\mu pump\_ON[z] = \begin{cases} 1 & z \geq b \\ \frac{z-a}{b-a} & a \leq z \leq b \\ 0 & z \leq a \end{cases}$$

3. The third step (Fuzzy Inference Engine) is set rules fuzzy use Tsukamoto model, which is by counting value α-predicate for each rule with using implication system MIN function and value of z in pump variable value for each rule fuzzy. The following rule-based in this system :

- The first rules :

IF-THEN	pH Acid High	pH Acid Low
EC Low	pump A ON AND pump C ON AND pump D ON	pump A OFF AND pump C ON AND pompa D ON

EC Optimal	pump A ON AND pump C OFF AND pump D OFF	pump A OFF AND pump C OFF AND pump D OFF
EC High	pump A ON AND pump C OFF AND pump D OFF	pump A OFF AND pump C OFF AND pump D OFF

- The second rules :

IF-THEN	pH Alkaline Low	pH Alkaline High
EC Low	pump B OFF AND pump C ON AND pump D ON	pump B ON AND pump C ON AND pump D ON
EC Optimal	pump B OFF AND pump C OFF AND pump D OFF	pump B ON AND pump C OFF AND pump D OFF
EC High	pump B OFF AND pump C OFF AND pump D OFF	pump B ON AND pump C OFF AND pump D OFF

4. The fourth step (*Defuzzification*) is convert fuzzy sets into a firm number. The method used in defuzzification process in composition rule Tsukamoto that is weighted average. Calculate crisp value Z using formula the following:

$$\text{Pump activation time (Z)} = \frac{\sum_{i=1}^{n} w_i \cdot z_i}{\sum_{i=1}^{n} w_i}$$

C. Internet of Things

Internet of Things (IoT) is a network that connect things to internet network for communicate or exchange data or information via sensing devices with protocol that agreed [16]. As for topology that used in this system can be seen fig.2.

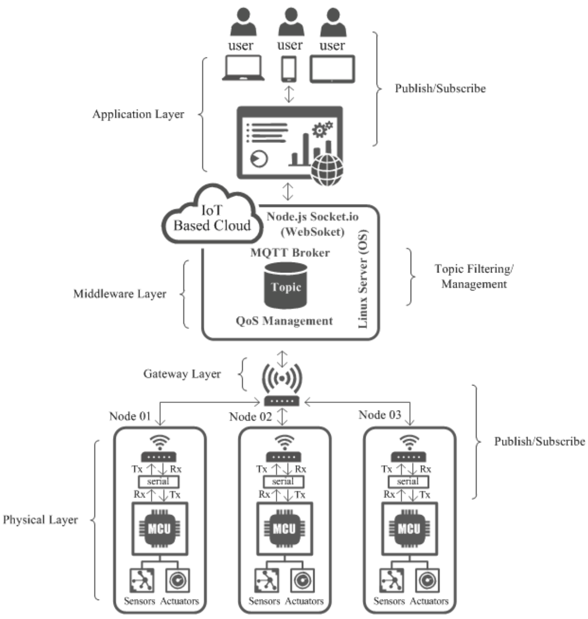


Fig 2. Topology IoT system [15]

In this study, the using of IoT is as interface for monitoring and control the parameter pH and EC and pump water. The following interface in webserver.

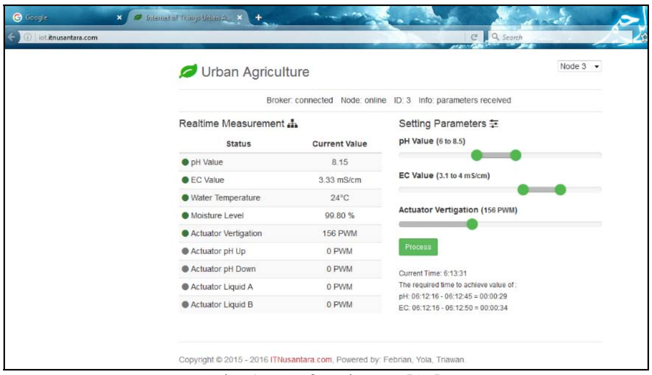


Fig. 3 Interface in IoT [15]

To Control the parameter pH and EC, begin with setting the range pH and EC as parameter input of fuzzy logic and PWM water pump (vertigation actuator). Then run the program. The increasing of pH value process or reduction of pH value process and the increasing of EC value process and pump activation can monitoring via web. So also with other parameters such as water temperature and moisture level. The process result will be displayed with response time that achieved by system.

This system apply soft real-time response that has tolerance time to completing the process. The tolerance time is ± 15 minute by considering some issues such as time of starting pump, reading sensor, absorption process of every nutrients given on solution mixing and absorption process of nutrients dissolved in water by plants because the plant that contain much oxygen on root will able to absorb nutrient quickly [17].

IV. Experiment

A. Experiment Specifications

The experiment model use a proportional small scale process that consist of four controlled tank and one mixing tank with adjustable flow pump. As for pumps that used is:

- pump A that drain alkaline solution (pH Up) to raise pH of nutrient solution;
- pump B that drain acid solution (pH Down) to reduce pH of nutrient solution;
- pump C and pump D that drain nutrient solution ABmix to raise EC.

The following design of hydroponic NFT system in this study.

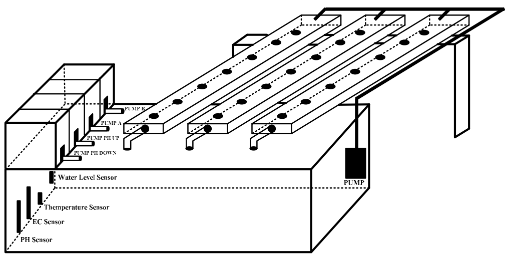


Fig 4. Design of hydroponic NFT system

The sensor and actuator connected to be embedded system. Microcontroler ATMega328 will process the data and display will shown measurement result to IoT.

B. Experiment Results

The implementation of fuzzy logic algorithm in program can control output pump value according to the input given. In table 1 is testing result from fuzzy control method in various condition.

Table 1. The Testing Results of Fuzzy Logic Control Method

No.	Current Value pH	Set Range pH	Action (Output)	Time (Second)	Current Value EC	Set Range EC	Action (Output)	Time (Second)
1.	1	6-7	Pump A ON	41.75	0.5	2-3	Pump C and Pump D ON	48.74 and 48.74
2.	1.5	6-7	Pump A ON	34.38	1	2-3	Pump C and Pump D ON	32.26 and 32.26
3.	2	6-7	Pump A ON	39.84	1.5	2-3	Pump C and Pump D ON	20.49 and 20.49
4.	2.5	6-7	Pump A ON	42.15	2	2-3	Pump C and Pump D OFF	0
5.	6	6-7	Pump A and Pump B OFF	0	0.15	2-3	Pump C and Pump D OFF	0
6.	6.5	6-7	Pump A and Pump B OFF	0	0.30	2-3	Pump C and Pump D ON	55.18 and 55.18
7.	7	6-7	Pump A and Pump B OFF	0	0.45	2-3	Pump C and Pump D ON	50.35 and 50.35
8.	6	6-7	Pump A and Pump B OFF	0	0.15	2-3	Pump C and Pump D OFF	0
9.	6.5	6-7	Pump A and Pump B OFF	0	0.30	2-3	Pump C and Pump D ON	55.18 and 55.18
10.	7.5	6-7	Pump B ON	20.20	0.6	2-3	Pump C and Pump D ON	43.62 and 43.62
11.	8	6-7	Pump B ON	22.67	0.75	2-3	Pump C and Pump D ON	38.38 and 38.38
12.	8.5	6-7	Pump B ON	24.40	0.9	2-3	Pump C and Pump D ON	34.19 and 34.19
13	9	6-7	Pump B ON	25.60	1.05	2-3	Pump C and Pump D ON	30.76 and 30.76

The testing result from table 1 showed that fuzzy logic method with 12 rules can control output value of pump activation time suitable with given input. Fuzzy control system will instruct the pump A on alkaline solution tank to work when current value pH is smaller than defined pH value. Fuzzy control system will instruct the pump B on acid solution tank to work when current value pH is higher than defined pH value. In EC parameter, fuzzy logic system will instruct pump A and pump D to work when current value of EC is smaller than defined EC value.

The next step is to determine solution volume that can affect pH water condition on the mixing tank with water volume 10 liters, likewise with EC. The solution distributed by pumps according to PWM pump given per unit second. The result can be seen in table 2 and table 3 and illustrates the changes of pH and EC with respect to the time can be seen in fig. 5 and fig. 6.

Table 2. Time response of actuator A & B

No.	PWM Pump A	PWM Pump B	Time (Second)	Volume Solution A (mL)	Volume Solution B (mL)	Raise pH Value	Reduction pH Value
1.	120	120	41.75	117	117	1.17	1.75
2.	120	120	34.38	96	96	0.96	1.44
3.	120	120	39.84	112	112	1.12	1.67
4.	120	120	42.15	118	118	1.18	1.77
5.	120	120	36.2	101	101	1.01	1.52
6.	120	120	30.25	85	85	0.85	1.27
7.	120	120	26.28	74	74	0.74	1.10
8.	120	120	25.79	72	72	0.72	1.08
9.	120	120	19.84	56	56	0.56	0.83
10.	120	120	6.45	18	18	0.18	0.27

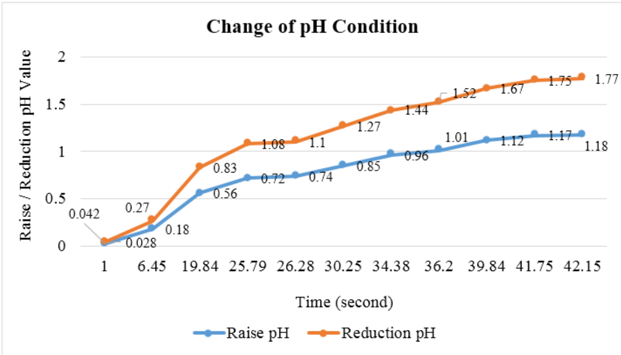


Fig. 5 Comparison of raise and reduction pH

The analyzing of testing result in table 2 is obtained that with addition 1 mL alkaline solution (pH up) can increase pH value ± 0,01 and addition 1 mL acid solution (pH down) can decrease pH value ± 0,015. In fig. 5 is shown that the longer pump activation time the larger raise and reduction of pH value.

Table 3. Time response of actuator C & D

No.	PWM Pump C	PWM Pump D	Time (Second)	Volume Solution C (mL)	Volume Solution D (mL)	Raise EC Value
1.	100	100	48.74	49	49	1.66
2.	100	100	32.26	32	32	1.10
3.	100	100	20.49	20	20	0.70
4.	100	100	55.18	55	55	1.88
5.	100	100	50.35	50	50	1.71
6.	100	100	43.62	44	44	1.48
7.	100	100	38.38	38	38	1.30
8.	100	100	34.19	34	34	1.16
9.	100	100	30.76	31	31	1.05
10.	100	100	27.9	28	28	0.95

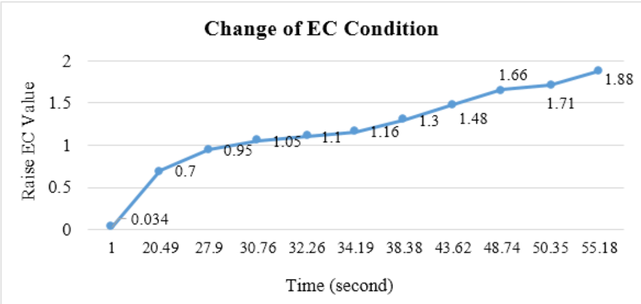


Fig. 6 Change of EC value toward time

The analyzing of testing result on table 3 is obtained that with addition 1 mL nutrient solution A and 1 mL nutrient solution B can increase EC value ± 0,034. In fig. 6 is shown that the longer pump activation time the larger raise of EC.

The next step is observation of system performance. The observation focused on response time that achieved when pH value and EC value defined are fulfilled. Sensor will read current value pH and EC for 60 seconds in order to get result the reading that more stable before execute the computation of fuzzy logic. The following experiment result in IoT can be seen in table 4.

Table 4. Experiment results in IoT

Current Value pH	Set Range pH	Value pH	Response Time	PWM	Current Value EC	Set Range EC	Value EC	Response Time	PWM
3	6-7	6.98	3 minute 12 second	120	0.25	2-3	2.56	3 minute 8 second	100
6.98	7-8	7.42	1 minute 16 second	120	2.56	3-4	3.23	2 minute 20 second	100
7.42	8.5-9	8.86	3 minute 51 second	120	3.23	4-4.5	4.34	2 minute 33 second	100
8.86	5-6	5.69	4 minute 26 detik	120	4.34	1-3	4.30	0	0
5.69	3.7-4	3.91	4 minute 43 second	120	4.30	3-4.30	4.27	0	0
3.91	2-3.7	3.68	3 minute 6 second	120	4.27	3-5	4.25	0	0
3.68	2 - 4	3.73	0	0	4.25	4.4-4.6	4.42	2 minute 6 second	100
3.73	2-4	3.78	0	0	4.42	4.5-5	4.53	2 minute 4 second	100
3.78	2-4	3.82	0	0	4.53	4.6-4.7	4.63	2 minute 3 second	100

The result in table 4 is shown that response time that achieved to recover the EC and pH from outside range to within the defined range is about 15 minutes.

V. CONCLUSION

Based on the experiments, by adding 1 mL of alkaline solution (pH Up) into the mixing tank with the volume of water 10 liter can raise pH ± 0,01 and by adding 1 mL of acid solution (pH Down) can reduce pH ± 0,015. While for EC, by adding 1 mL of nutrient solution A and 1 mL of nutrient solution B into the mixing tank with the volume of water 10 liter can raise EC ± 0,034. The up and down pH value directly proportional to pump activation time, likewise with parameter EC. The greater the raise or reduction pH value then the longer response time system to complete the process in fulfilling input desired. Likewise with EC.

The utilization of IoT in this system as input parameter to fuzzy logic process, monitoring to parameter and display the process result and response time that achieved by system. Response time of system can be influenced by several factor that is distance between current value pH with set range pH, current value EC with set range EC, PWM pump value, reading sensor time and delay of IoT communication. By implement this method, the required to complete the process and achieve the desired value does not exceed the limit tolerance given is ± 15 minutes, so it can reduce the time and optimize the use of water and nutrient.

ACKNOWLEDGEMENT

Thanks to Dr. Ir. Reginawanti from Agriculture Faculty, Padjajaran University for advising and discussing on NFT-based Hydroponic System.

REFERENCES

[1] United Nations, "World Population Prospects (Key Finding and Advance Tables)," 2015, Available: https://esa.un.org/unpd/wpp/publications/files/key_findings_wpp_2015.pdf , diakses 17 September 2016.

[2] United Nations, "The World's Cities in 2016," 2016, Avalable: http://www.un.org/en/development/desa/population/publications/pdf/urbanization/the_worlds_cities_in_2016_data_booklet.pdf, diakses 17 September 2016.

[3] Aqeel-ur-Rehman, *Smart Agriculture: AN Approach Towards Better Agriculture Management*, OMICS Group eBooks, 2015.

[4] Na'asah Nasrudin, "Evaluating the Suitability of Urban Farming Programme Case Stuy: Ipoh City," In *Colloquium on Humanities, Science and Engineering Research (CHUSER) IEEE* (2011): 217-222.

[5] Emerson C. Christie, "Water and Nutrient Reuse within Closed Hydroponic Systems", In *Electronic Theses & Dissertations College of Graduate Studies (COGS),* pp. 1-91, 2014.

[6] Aalaa Abdullah, Shahad Al Enazi, and Issam Damaj, "AgriSys: A Smart and Ubiquitous Controlled Environment Agriculture System," In *Big Data and Smart City*, IEEE, 2016.

[7] H.R. Jayetileke, W.R. de Mel, and H.U.W. Ratnayake, "Real-Time Fuzzy Logic Speed Tracking Controller for a DC Motor Using Arduino Due," Dept. of Mechanical Engineering, The Open University of Sri Lanka, IEEE, 2014.

[8] M. Jamshidi, *Fuzzy Logic and Control, Software and Hardware Applications,* University of New Mexico, PTR Prentice-Hall, Inc. Ch 1-4, 1993.

[9] Mohamed Slim Masmoudi, "Hardware/Software Approache for the FPGA Implementation of a Fuzzy Logic Controller," In *METS Research Group-National Engineers School of Sfax*, Tunisia, IEEE, 2006.

[10] Mohd Azlan, and Mohammad Yusri Yacob, "Development and Simulation of an Agriculture Control System Using Fuzzy Logic Method and Visual Basic Environment," *Robotics, Biomimetics, Intelligent Computational Systems (ROBIONETICS)*, pp. 135-142, IEEE, 2013.

[11] Bharatwaj G.S, Prasanna S., Ramakrishnan R., Sanjay Raam M., and Vignesh S., "Fuzzy Logic Based Farm Automation Using Arduino and LabVIEW with X-Bee Based Control System," In *International Journal of Engineering and Advanced Technology (IJEAT)*, vol.3, (2013): 1-6.

[12] Chetan Dwarkani M, Ganesh Ram R, Jagannathan S, and R. Priyatharshini, "Smart Farming System Using Sensor for Agriculture Task Automation," In *International Conference on Technological Innovations in ICT for Agriculture and Rural Development (TIAR),* pp. 49-53, IEEE, 2015.

[13] Keith Roberto, *How-To Hydroponics*, the Futuregarden Press, New York, Edisi 4 pp 1 – 100, 2003.

[14] Timothy J. Ross, *Fuzzy Logic with Engineering Applications*, McGraw-Hill, 1995.

[15] Kevin M. Passino, "Intelligent Control: An Overview of Techniques," In *Neil Evenue, Department of Electrical Engineering*, pp. 2, 2015.

[16] M. Agus Triawan, Hilwadi Hindersah, Febrian Hadiatna, and Desta Yolanda, *Internet of Things Communication using Publish and Subscribe Method with Cloud Computing Based (Case Study Providing Nutrition Hydroponic)*, Draft Thesis of Magister Program, Institut Teknologi Bandung, 2016.

[17] Keith Roberto, *How-To Hydroponics*, the Futuregarden Press, New York, Edisi 4 pp 1 – 100, 2003.