Comparison between PID and Fuzzy Controller to Hydroponic Temperature

Yosefine Triwidyastuti, Ira Puspasari, Harianto
Computer Engineering Department, Faculty of Information Technology
Institut Bisnis dan Informatika Stikom Surabaya
Surabaya, Indonesia
yosefine@stikom.edu

***Abstract*—Nowadays, there are many researches about automatic controlling system of hydroponic temperature. The two most well-known controller systems are PID Controller and Fuzzy Logic Controller. This study discusses and compares the performance of these two main controller systems to control the room temperature of a wick-based hydroponic system for cherry tomato cultivation. In this comparison system, we use an SHT11 module as the sensor and an air conditioner as the actuator. From the test result, PID controller has 2.2 times longer rise time, whereas Fuzzy controller yields 25.3 times larger overshoot in day time measurement.**

Keywords—temperature controlling, PID controller, fuzzy controller, hydroponic system, cherry tomatoes

I. Introduction

Recently, plant cultivation in urban area is more difficult because of the rapid development in housing and industries. Then, many plants are grown using hydroponic system because hydroponic system can be cultivated in various media instead of soil, be resistant to plant diseases, be applied in less space like city area, be irrigated with less water and be harvested in shorter term.

Another advantage of the hydroponic system is that it has greater possibilities to be combined with an automatic system easily and efficiently. There are numerous amount of researches dwelt on automatic hydroponic system because maintaining plant cultivation system manually requires extra power [1]-[3]. One of the control methods that are commonly applied is PID controller. PID has simple concept in using the error value to decide the next control value [2]. In addition, Fuzzy controller is also commonly used due to the uncertainty between the control elements [3].

The purpose of this study is to discuss and compare the performance of the two most well-known control methods, which are PID controller and Fuzzy controller. In this study, the two controller methods are implemented alternately in a temperature controlling system for hydroponic cultivation. The performances of their stability are calculated and analyzed to help characterizing the control methods and deciding the suitability of the control methods with the system characteristics, especially in the hydroponic temperature controlling system.

Authors would like to thank to DRPM Ditjen Penguatan Risbang from Ristekdikti Ministry for the funding of "Penelitian Dosen Pemula" in 2017.

II. Hydroponic System

A. Wick-based Hydroponic System

Hydroponics is a technique to cultivate plan without soil. Because hydroponics is soilless system, the nutrients needed for the plants are obtained from the distribution of nutrient solution regularly from the nutrient tank to the hydroponic container. As the alternative to the growing medium, we can use perlite, rockwool, vermiculite, sand, clays, sawdust and others.

There are many various types of hydroponic system. The six basic types of hydroponic system are Wick, Deep Water Culture (DWC), Ebb and Flow, Drip Irrigation, Nutrient Film Technique (NFT) and aeroponics. Generally, the various types of hydroponic system implemented in the plant cultivation are the combination or modification from these six basic types [1].

The simplest type that is easily used by beginners in hydroponics is wick system, because it applies passive irrigation for the plants. Wick is a hydroponic technique to grow plants by delivering the nutrient solution using wicks made from flannels. The scheme of a wick-based hydroponic system is shown in Fig. 1.

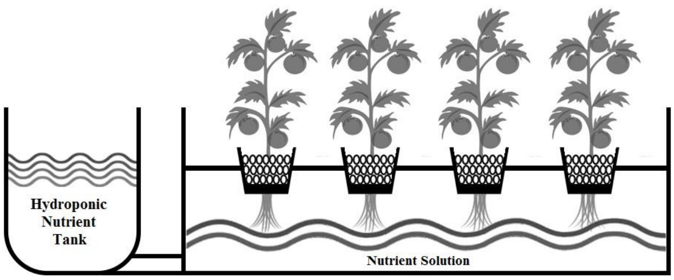


Fig. 1. Wick-based Hydroponic System

Wick system contains a nutrient solution tank connected to the hydroponic container through a pipe. The hydroponic container in wick system consists of several pots with flannels to absorb the nutrient solution beneath it. Wick system uses the principle of capillarity [4].

The benefit of wick system is the equality in nutrition distribution because all of the pots are in the same hydroponic container. Thus, the plants could get the same amount and quality of the hydroponic nutrient solution. This simplicity and uniformity is the main advantages of the wick system.

B. Hydroponic System for Cherry Tomatoes

Cherry Tomato is a tropical fruit that has high economic value in agriculture. Its price is ranging from 20,000 to 30,000 rupiahs per kilogram [5], so cherry tomato cultivation could be rated as a perspective business in agroindustry.

Generally, cherry tomatoes are cultivated using hydroponic system. It can produce more fruit than traditional culture. Tomato cultivation using traditional method needs intensive maintenance system, while only produces 1.5-2 kilograms per plant. On the other hand, hydroponic system could produce 5.1-5.8 kilograms per plant [6]. This high production rate makes hydroponic system becomes preferable among farmers.

However, there are five sources of risk in cherry tomato production, which are the weather condition, pest infection, plant disease, seed quality and human skills. The highest production risk comes from the bad weather condition with the probability of 44%. This high weather effect could cause a production risk until 9,722,492 rupiahs [7].

Hence, the hydroponic cultivation room of cherry tomatoes should be sophisticated controlled to fulfill the weather requirement of the plants to grow, especially the temperature requirement. The required room condition to cultivate cherry tomatoes should have a temperature of 24ºC [8].

III. Temperature Controlling Methods

In this study, PID controller and Fuzzy controller are implemented alternately in a temperature controlling system for cherry tomatoes cultivated using hydroponic technique.

A. Hydroponic Temperature Controlling System Design

The temperature controlling system is designed to maintain the room temperature of hydroponic system around the temperature target which is 24ºC. In order to achieve good performance, the control system should be able to adjust the actuator precisely based on the control methods, so the temperature value has less error from the target and stable. The block diagram of the temperature controlling system for the hydroponic cultivation is shown in Fig. 2.

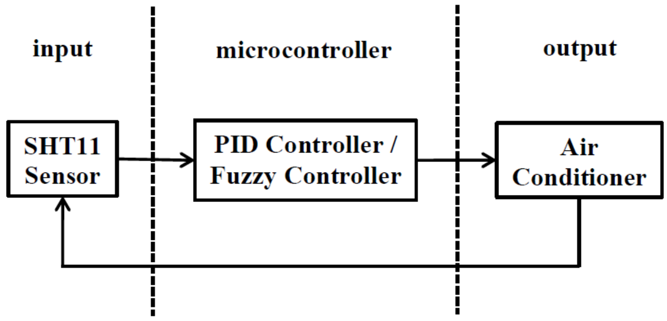
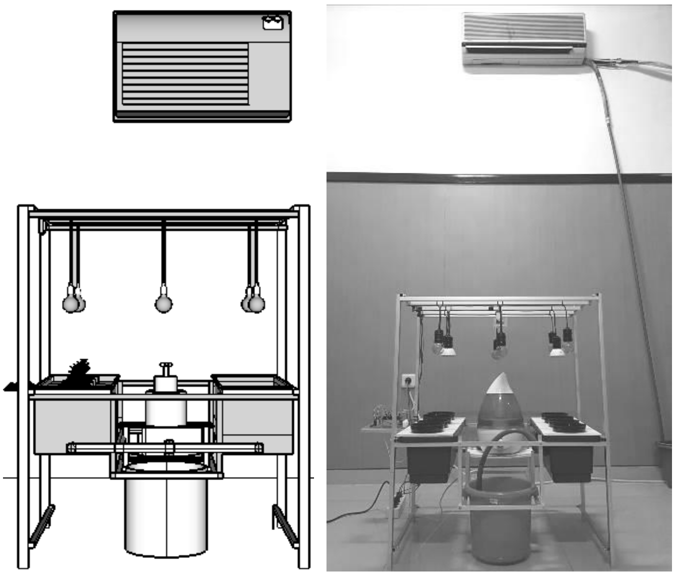


Fig. 2. Block Diagram of the Hydroponic Temperature Controlling System

In Fig. 2, the temperature controlling system contains a DT sense SHT11 sensor as its input, a microcontroller to implement the control methods and a room air conditioner as the output. Every time the control system obtains an input data, it should calculate the controlling adjustment as its output. The output value from the control methods is used to set the controlling actuator via infrared communication and turn the temperature recent value into the target value. Then, the next temperature value is measured and inserted again as the input of the control process.

The system mechanic design of the temperature controlling system for the hydroponic system is shown in Fig. 3. The prototype has size of 72 x 55 x 90 cm^3. It comprises of eight pots, rockwool, plants, water bucket, hydroponic container, grow lights, fluorescent lights, SHT11 sensor, infrared, air conditioner, humidifier and a control panel.



(a) (b)

Fig. 3. System Mechanic Design; (a) 3-D Design (b) Implemented System Mechanic

The sensor used in this control system is DT-sense SHT11 module that is shown in Fig 4. This sensor can measure the value of air temperature and relative humidity. The temperature range is from -40ºC to +123.8ºC, while the humidity range is from 0% RH to 100% RH [9].

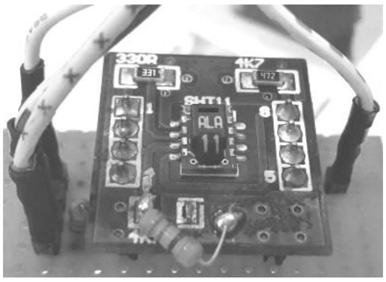


Fig. 4. DT-sense SHT11 Module

The system electronic design to control the hydroponic temperature is shown in Fig. 5 and the pin configuration connected to the microcontroller is shown in Table 1. The data input of the control system is obtained from SHT11 sensor via I2C pin, whereas the output of the control system would be the temperature value addressed to set the air conditioner through the infrared communication.

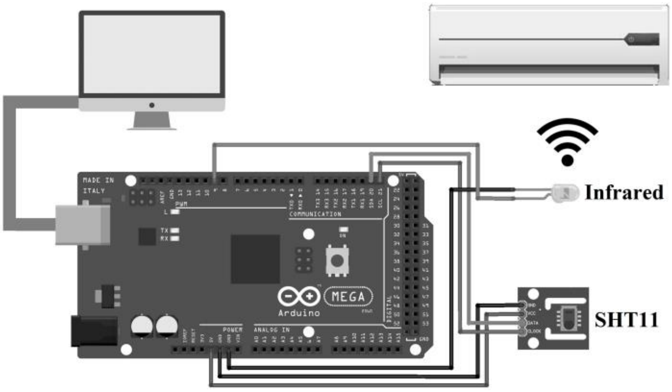


Fig. 5. Electronic Design of the Temperature Controlling System

TABLE 1. PIN CONFIGURATION IN MICROCONTROLLER

Microcontroller Pin Number	Connection
20	SHT11 Data Output (Pin 1)
21	SHT11 Clock (Pin 3)
9	Infrared Data Input

B. PID Controller

The PID controller consists of proportional, integral, and derivative components to calculate the controlling adjustment. The scheme of the PID controller can be seen in Fig. 6. The attribute of the PID controller is the feedback process to address the evolution characteristics of the error signal $e(t)$ throughout the control process.

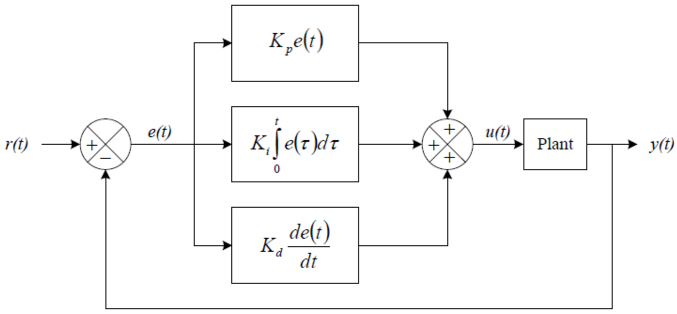


Fig. 6. PID Controller Scheme

In Fig. 6, $r(t)$ is the set point value that would like to be achieved. The parameters that should be set in PID controller are the K_p (proportional constant), K_i (integral constant) and K_d (derivative constant) parameters.

Proportional output is the result of multiplication between the proportional constant K_p and the current error value. If the value of K_p is too small, proportional control is only capable of making minor error correction, so it will produce slow system response. If the value of K_p is too large, the control system could oscillates around the set point.

In Integral control, the system response increases the error value continuously until the limit of the integral part. Integral controls have the characteristics of reducing rise time, adding overshoot and eliminating steady state error.

Derivative control affects the amount of control signal generated in proportional to the error change. The faster the error changes, the greater the control signal generated. The differential control output has properties as well as a derivative operation. Sudden changes in the controller input will result in enormous changes. In the transition period, the derivative control causes a damping in the system to further reduce the spike.

The three components of the PID controller would form the control signal $u(t)$ as described in (1).

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau)d\tau + K_d \frac{de(t)}{dt} \quad \ldots (1)$$

In the temperature controlling system, the control signal denotes the temperature adjustment value that is sent to the air conditioner to stabilize the current room temperature around the required hydroponic temperature. The error signal is the difference between the current temperature value measured from the sensor and the target temperature value required in the cherry tomato cultivation.

In order to be applicable in the microcontroller system, the formation of the control signal and the processing of the proportional, integral and derivative parts should be transformed into discrete form as in (2).

$$u(t_k) = K_p e(t_k) + K_i \Delta t \sum_{i=1}^{k} e(t_i) + \frac{K_d}{\Delta t}\left(e(t_k) - e(t_{k-1})\right) \quad \ldots (2)$$

C. Fuzzy Logic Controller

Fuzzy logic is a technique to map the input values to the output value based on its degree of membership. In order to be optimum, a fuzzy controller should contain minimum two inputs. Thus, the second input from the DT-sense SHT11 module is used in the control system.

The membership function of the first input which is the temperature value (x) is shown in Fig. 7. It is divided into five levels, which are "Cold", "Cool", "Normal", "Warm" and "Hot". The required temperature which is 24ºC for cherry tomato cultivation is put in the center point in the level of "Normal".

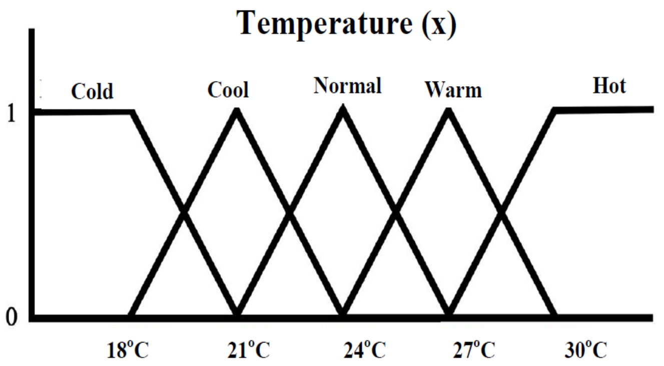


Fig. 7. Membership Function of the Temperature Variable

The membership function of the humidity parameter (y) is shown in Fig. 8. It is divided into three levels, which are "Low", "Normal" and "High". The normal humidity for the growth of cherry tomatoes is 80%.

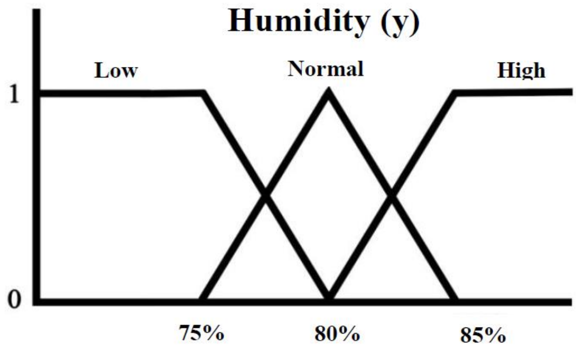


Fig. 8. Membership Function of the Humidity Variable

In the fuzzification process, each input value should be mapped into its membership degree (μ) in all levels based on the membership function. Then in the inference process, we apply the fuzzy rules described in Table 2. Because there are five levels in the first input and three levels in the second input, so there are 15 rules to map the input values into the output [3].

TABLE 2. FUZZY RULES

Hmd.[a] / **Temp.**[b]	**Low**	**Normal**	**High**
Cold	Cool[1]	Cool[2]	Normal[3]
Cool	Cool[4]	Cool[5]	Normal[6]
Normal	Cool[7]	Normal[8]	Normal[9]
Warm	Cold[10]	Cold[11]	Cool[12]
Hot	Cold[13]	Cold[14]	Cold[15]

a. Hmd = Humidity
b. Temp = Temperature

In the inference process, we use the minimum inference function. We produce the fire strength (α) of each rule by choosing the minimum value of the membership degrees (μ) from the two inputs based on Table 2. For example, the 10th fuzzy rule states that if the temperature is "Warm" and the humidity is "Low" then the adjustment of the air conditioner would be "Cold" can be described as in (3).

$$\alpha_{10} = \min(\mu_{Warm}, \mu_{Low}) \quad \text{K (3)}$$

Next, we calculate the output value (z) for all of the 15 fire strengths (α) based on the membership function of the air conditioner temperature adjustment shown in Fig. 9. The output membership function is divided into 3 levels, which are "Cold", "Cool" and "Normal". We use maximum composition rule to obtain a single value of z.

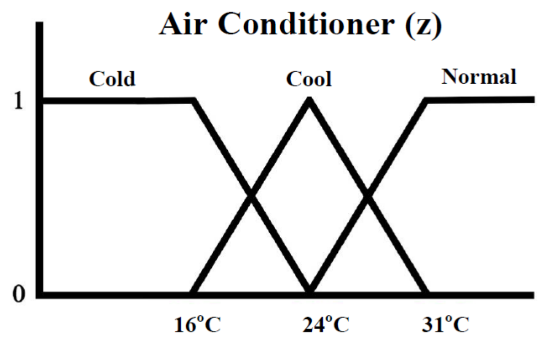


Fig. 9. Membership Function of the Air Conditioner Variable

In the defuzzification process, we use Tsukamoto method. The output value (z) is obtained using weighted average calculation as described in (4).

$$z = \frac{z_1\alpha_1 + z_2\alpha_2 + \Lambda + z_{15}\alpha_{15}}{\alpha_1 + \alpha_2 + \Lambda + \alpha_{15}} \quad \text{K (4)}$$

Then, this output value (z) is sent to the air conditioner to stabilize the current room temperature of the hydroponic system.

IV. RESULTS AND DISCUSSION

A. Temperature Controlling Actuator

Fig. 10 shows the result of temperature controlling actuator when it is given a threshold of 24ºC without using any control method. The purpose of this experiment is to find the characteristics of the actuator which is the room air conditioner solely.

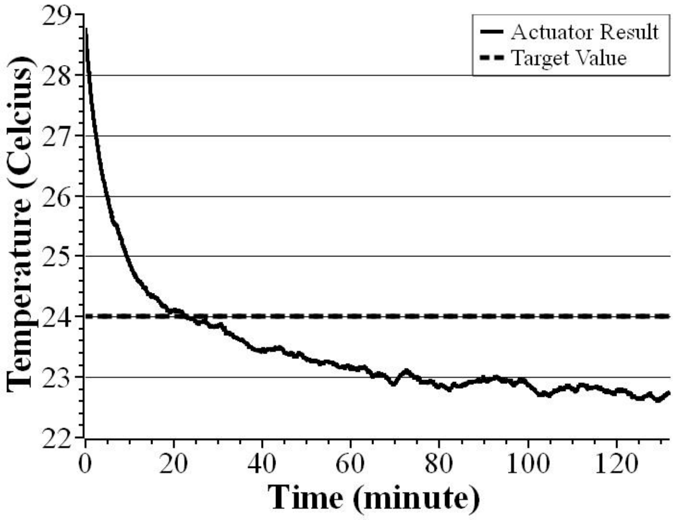


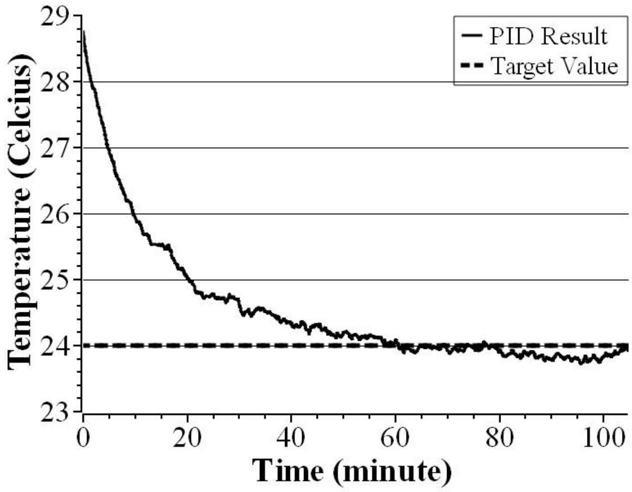
Fig. 10. The Result of the Temperature Controlling Actuator

As we can see in Fig. 10, the actuator of air conditioner could not maintain the temperature target. It cools the room without noticing the current value. The error gets bigger until 1.4ºC. If this condition is stayed for a long time, the room temperature will not suit the growth requirement for the plants. Thus, the need of a control method implementation is important in hydroponic system.

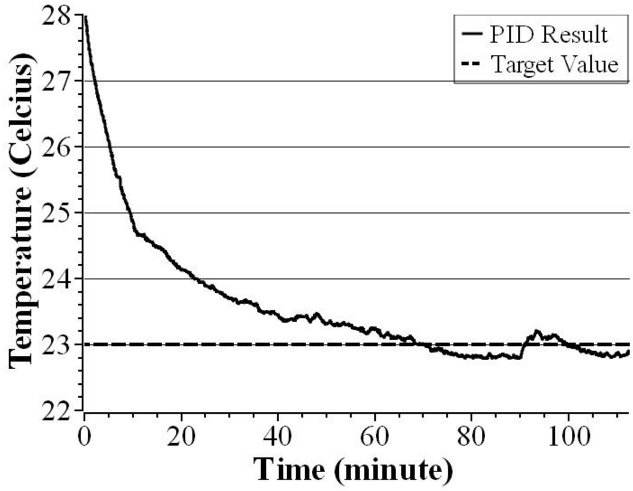
B. PID Parameter Setting

One of the control methods that are commonly used in a controlling system is PID. As the PID controller is the combination of proportional, integral and derivative process, the parameters related with these three components should be set first. Generally, the parameters are set with trial and error process.

In this study, we set K_p, K_i and K_d as 3, 2 and 10 respectively [2]. We tried these parameter settings into the hydroponic temperature controlling system. Fig. 11 shows the results of temperature controlling using the PID's parameter setting with different temperature target.



(a)



(b)

Fig. 11. PID Controlling Result; (a) Temperature Target 24ºC; (b) Temperature Target 23ºC

In Fig. 11a with the parameter setting of 3, 2 and 10, PID controller can maintain the temperature becomes stable at 24ºC. The error is only 0.28ºC or 1.16%. Furthermore, in Fig. 11b PID also results a stable temperature around the target which is 23ºC. The error is 0.23ºC or only 1%.

Hence, with the low error level, the PID parameter setting of 3, 2 and 10 is suitable for the hydroponic temperature controlling system. The high value of the derivative constant (K_d) could tackle the slow change in the temperature value and avoid a large overshoot to occur.

C. Comparison Result in Day Time

The final experiment in this study is to implement the PID controller and Fuzzy controller alternately in order to compare their characteristics in a hydroponic temperature controlling system. Fig. 12 shows the result of temperature controlling using PID and Fuzzy in day time, whereas Table 3 shows their characteristics in producing rise time, overshoot and settling time.

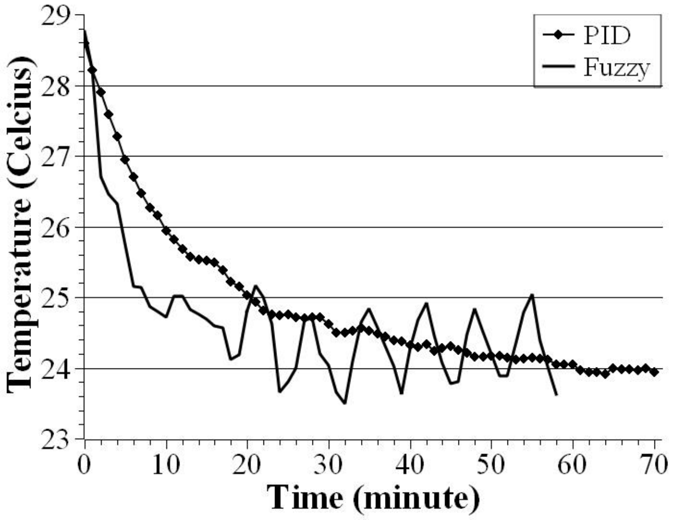


Fig. 12. PID and Fuzzy Performance in Day Time

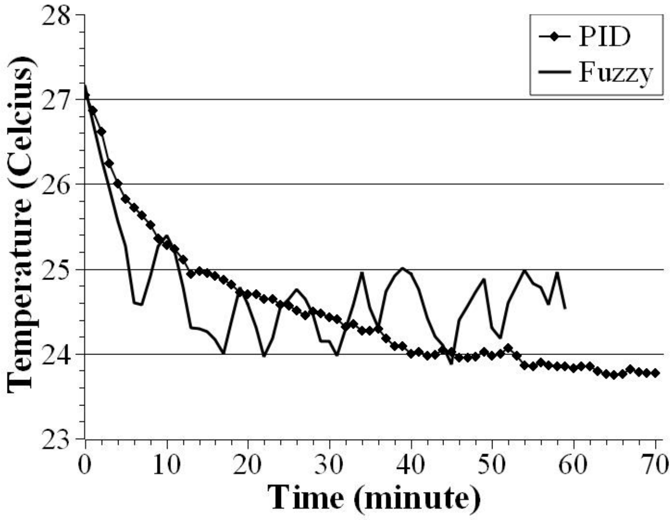


Fig. 13. PID and Fuzzy Performance in Night Time

TABLE III. PID and Fuzzy Performance in Day Time

Controller	Rise Time	Overshoot	Settling Time
PID	35 minutes	0.87 %	18 minutes
Fuzzy	16 minutes	22 %	22 minutes

TABLE IV. PID and Fuzzy Performance in Night Time

Controller	Rise Time	Overshoot	Settling Time
PID	35 minutes	5.6 %	11 minutes
Fuzzy	12 minutes	32 %	12 minutes

Based on Fig. 12 and Table 3, PID controller has longer rise time, smaller overshoot and shorter settling time. On the other hand, Fuzzy controller yields shorter rise time, larger overshoot and longer settling time. Other difference between PID and Fuzzy controller is that Fuzzy controller produces more oscillations to reach the target, because the output decision in Fuzzy controller depends on the classification in the membership function and the complexity of the rules. However, PID controller could produce smoother result because PID controller contains derivative component to help reducing the oscillation.

D. Comparison Result in Night Time

Fig. 13 shows the result of temperature controlling using PID and Fuzzy in night time, meanwhile Table 4 shows their characteristics of rise time, overshoot and settling time.

As in day time, in night time PID controller still has longer rise time, smaller overshoot and more stability. The high derivative constant helps the controller to be smoother. On the other hand, in night time Fuzzy controller also results shorter rise time, larger overshoot and more oscillations. The oscillation results in Fuzzy are related with the classification in the membership function and fuzzy rules during the defuzzification process.

E. Comparison Ratio

The last comparison result is the performance ratio between PID and Fuzzy controller both in day time and night time. Table 5 shows the ratio of the performance of PID and Fuzzy controller during the same time duration which is 60 minutes.

Table 3. Comparison Ratio of PID and Fuzzy Controller

Measurement Time	Ratio of PID to Fuzzy		
	Rise Time	Overshoot	Settling Time
Day Time	2.2 : 1	1 : 25.3	1 : 1.2
Night Time	2.9 : 1	1 : 5.7	1 : 1.1

Based on Table 5, we can see the characteristics of each method. Fuzzy controller has better rise time which is 2.2 times faster but yields larger overshoot that is 25.3 times higher. However, PID controller is more stable but needs longer rise time. The highest overshoot difference between PID and Fuzzy controller happens in day time due to the high value of the initial temperature in day time which is 28.75ºC. Whilst, the initial temperature in night time is 27.15ºC while both time has the same target temperature value that is 24ºC.

Regarding the slow changes in the temperature of hydroponic room, PID controller is found to be more reliable in the hydroponic temperature controlling system. Fuzzy controller could be better to be implemented in a system that needs shorter rise time but can compromise on the overshoot. Meanwhile, PID controller would be viably applied in a system that needs good stability but can compromise its long rise time.

V. Conclusion

There are many methods that could be implemented to make an automatic controlling system for hydroponic room temperature. From the comparison result between PID and Fuzzy controller, PID controller has 2.2 times longer rise time, whereas the Fuzzy controller produces 25.3 times larger overshoot in day time measurement. PID controller is found to be more reliable in maintaining a good stability in the hydroponic temperature controlling system.

References

[1] M.F. Saaid, N.A.M. Yahya, M.Z.H. Noor, M.S.A. Megat Ali, “A Development of an Automatic Microcontroller System for Deep Water Culture (DWC),” IEEE 9th International Colloquium on Signal Processing and its Applications, 2013, pp. 328-332.

[2] Y. Triwidyastuti, I. Puspasari, and Harianto, “Kendali PID untuk Pengaturan Suhu pada Budidaya Tomat Ceri,” SNTEKPAN V, ITATS, Surabaya, 19 October, 2017, pp. C97-C102.

[3] R. N. N. Ichsan, “Pengaturan Temperatur dan Kelembaban untuk Hidroponik Tomat Cherry dengan Metode Wick,” Essay, Computer System Department, Faculty of Information Technology, Institut Bisnis dan Informatika Stikom Surabaya, 2017.

[4] M. Kusumah, “Pengaruh Berbagai Macam Sumber Nutrisi terhadap Pertumbuhan dan Hasil Tanaman Tomat (Licopersicum esculentum Mill) pada Sistem Hidroponik Sumbu,” Essay, Agrotechnology Department, Faculty of Agriculture, University of Muhammadiyah Yogyakarta, 2016.

[5] D. Afandi, “Pengaruh Konsentrasi Nutrisi dan Macam Media Substrat terhadap Pertumbuhan dan Produksi Tomat Cherry (Lycopersicon esculentum var. cerasiforme) dengan Sistem Hidroponik,” Essay, Agrotechnology Department, Faculty of Agriculture, University of Jember, 2016.

[6] A. D. Susila, S. Suarni, H. Pramono, and O. Aksari, “Aplikasi Zat Pengatur Tumbuh pada Budidaya Tomat Cherry (Lycopersicon esculentum Var. Cerasiforme) Secara Hidroponik,” PERHORTI National Seminar, Lembang, 23-24 November, 2011, pp. 393-406.

[7] A. Yamin, “Analisis Risiko Produksi Tomat Cherry pada PD Pacet Segar Kecamatan Cipanas, Kabupaten Cianjur, Provinsi Jawa Barat,” Essay, Department of Agribusiness, Faculty of Economics and Management, Institut Pertanian Bogor, 2012.

[8] W. Prabawati, “Pengusahaan Sayuran Pakchoi Baby dan Tomat Cherry di PT Saung Mirwan, Megamendung, Bogor,” Essay, Department of Agronomy and Horticulture, Faculty of Agriculture, Institut Pertanian Bogor, 2011.

[9] Innovative Electronics, “Manual DT-Sense Temperature & Humidity Sensor,” http://innovativeelectronics.com/innovative_electronics/download_files/manual/Manual _DT-Sense_Temperature_Humidity_Sensor_rev.pdf, 20