International Journal on Advanced Science Engineering Information Technology

Vol.10 (2020) No. 6
ISSN: 2088-5334

Development and Performance of a Fuzzy Logic Control System for Temperature and Carbon Dioxide for Red Chili Cultivation in an Aeroponic Greenhouse System

Alimuddin[a,b], Ria Arafiyah[c], Dewa Made Subrata[d], Nurul Huda[ef]

[a]*Department of Electrical Engineering, Faculty of Engineering, Universitas Sultan Ageng Tirtayasa, Banten, 42435, Indonesia*
E-mail: alimuddin@untirta.ac.id; alimuddineeuntirta@yahoo.com

[b]*I-CEFORY, Universitas Sultan Ageng Tirtayasa, Banten, 42435, Indonesia*

[c]*Study Program of Computer Science, Faculty of Mathematics and Natural Science,Universitas Negeri Jakarta, 13220, Indonesia*

[d]*Laboratory of Instrumentation and Control, Departement of Mechanical and Biosystem Engineering, Faculty of Agricultural Engineering and Technology, IPB University, Bogor Indonesia*

[e]*Faculty of Food Science and Nutrition,Universiti Malaysia Sabah, 88400, Kota Kinabalu, Sabah, Malaysia*
E-mail:drnurulhuda@ums.edu.my

[f]*Adjunct Professor, Universitas Sultan Ageng Tirtayasa, Serang, 42124, Banten, Indonesia*

***Abstract*—The use of fuzzy logic-based automatic control systems in aeroponic systems is expected to facilitate farming. This paper proposes a novel integrated fuzzy control system for an aeroponic greenhouse. The real-time method considers temperature and carbon dioxide (CO_2) effects on red chili cultivation, and the controller is based on control performance or an evaluation of the correlation of parameters. The design a fuzzy control system to control red chili plant temperature and CO_2 in an aeroponic system cultivation in a greenhouse based on control performance. The fuzzy control system was developed by using a fuzzy zet, a member function, fuzzification, a set of rules, and defuzzification on a personal computer. Sensors include a DHT11 temperature sensor, a CDM4160 CO_2 sensor and 4 actuators: a 12 V pump fan, a gas valve and a lamp that is connected to the Arduino Mega 2560 microcontroller by a relay, and an L298N motor driver for control, as well as an additional Arduino 16x2 LCD screen that displays the temperature and CO_2 values read by the sensors. The performance results reported for the temperature and CO_2 fuzzy logic control parameters for red chilis cutivation in the aeroponic on greenhouse include the time delay (Td), time rise (Tr), time peak (Tp) and Error steady state (Ess) values. The red chili plants grow well using the proposed method**

***Keywords*— fuzzy control control; temperature; CO_2; red chili; aeroponic; greenhouse.**

I. INTRODUCTION

The red chili (*Capsicum annum* L.) is a herbaceous plant of the nightshade family Solanaceae [1]. From South America, its species have spread to Asia, especially Japan, Korea, China, India, the Philippines and Indonesia [2]. Red chilis contain nutrients, including the major Vitamins A, C and E [3]. Red chilis are a well-known vegetable commodity very widely used throughout the world for household food seasoning and in the food and pharmaceutical industries [4][5]. The optimal temperature for chili cultivation is 24-28°C, and temperature values of less than 15°C or more than 32°C will lower the quality of chili production [6].

The recommended optimal level of CO_2 for red chili plants (and tomatoes, cucumbers and peppers) is 800-1000 ppm [7].

There are five methods of cultivation for horticultural crops. The first, conventional cultivation, uses land [8]; the second uses fertigation [9]; the third uses greenhouses [10]; the fourth uses aeroponics [11]; and the fifth uses combinations of aeroponics and greenhouses [12]. Fuzzy logic systems have been developed in various fields of electrical engineering, management, computer science, biological and agriculture to discuss about; a fuzzy set [13], decision-making [14], A fuzzy algorithm [15], a fuzzy logic controller [16], Fuzzy intelligent systems [17], fuzzy logic to biological and agricultural [18].

The temperature of a closed-type plant factory is harmoniously controlled by heating/cooling devices and air flow fans [10]. One paper reviewed and summarized the optimum temperature for microclimate control in the greenhouse cultivation of tomatoes, including the effects of parameters on tomato quality and yield, and the associated problems with suboptimal values, as well as the effects of high or low temperatures [18]. This method has the most advantages when compared with other planting methods commonly used in Mexico. With aeroponics, one can control temperature and water conductivity in a greenhouse [19]. The system developed in this study is the technology used for the best plant growth with respect to many aspects, compared with conventional cultivation systems, to advance modern cultivation technology in various countries for vegetable production without using agricultural land [20].

An aeroponics system application to control temperature, humidity and pH and water conductivity in a greenhouse is reported in [11]. A new approach to aeroponic and hydroponic system monitoring, fault detection and automation on robotic is given in [21].

In a monitoring system was used to monitor a chamber's parameters, such as temperature, and a control system was used to manage actuators in the delivery of water and nutrients. Temperature data were displayed on an LCD and are transmitted to a computer to facilitate easier monitoring of the plant growing chamber [22].

Automatic aeroponic growth systems depend on the temperature variable for bamboo nurseries, and root observations use ultrasonic sprayers to spray nutrient solutions in water. Fertilizer using ultrafine particles that are 1-5 microns in diameter are superior to traditional piezometric automation because they increase the efficiency of the automation of nutrient solutions and the uniform absorption in plant roots [23].

Minitubers with a size of more than 20 mm produced directly from in vitro plantlets using an aeroponic system were used for potato cultivation with minitubers of 20 mm size produced in vitro plantlets with quality potatoes [11] [24].

An intelligent monitoring system with real-time acquisition of temperature, physicochemical input parameters, and cloud platform servers and the deep trust network model (DBN) Softmax has been used to study physicochemical parameters without supervision from input products and to extract input features [25].

A fuzzy logic system has been used to assess room comfort based on sensor readings and an HVAC system efficiency analysis [16]. Another study used an artificial neural network to predict temperatures over a year based on near real-time data loggers by an Automated Environmental Monitoring Network (AEMN)[26].

The fuzzy logic control system functions to control the temperature inside the greenhouse by modeling the thermal dynamics of the greenhouse environment and to predict the temperature inside the greenhouse to achieve the expected climate [27].

One study used a fuzzy control coupling method to study the temperature and humidity greenhouse effect; the controller was based on validated greenhouse physical models and evaluation of the correlation of both parameters [28].

A fuzzy logic control system for environmental parameters of the climate in a greenhouse has been achieved and was more efficient in its operation than conventional methods [17].

After application of the fuzzy logic control method for identification and mitigation, the main limitations of UWB signals in indoor environments were overcome with a high degree of accuracy when both were compared to the level of accuracy in previous work [16].

Based on the cited research, the theory of fuzzy logic control systems can thus be applied to the cultivation of red chili plants using aeroponics in a greenhouse.

In this paper, we present a novel integration of fuzzy control systems, aeroponics, and the greenhouse parameters temperature and carbon dioxide for the cultivation of red chilis. The new system's control performance is described as follows: Materials and methods, the temperature and CO_2 fuzzy control system design, including fuzzy rules, and the experimental activities in this work are described in section II. The results and discussion of the sensor used and the simulation and application of real-time fuzzy control system temperatures and carbon dioxide are discussed in section III, and conclusions are presented in section IV.

II. MATERIALS AND METHOD

II.1 System Design of Fuzzy Control

In Fig. 1 the under block diagram, the aeroponic box is designed to create a system for controlling temperature, and CO_2 in a room. Temperature control in the aeroponic system is accomplished by controlling the amount of heat generated by the lamp and the amount of cold generated by the fan. Control of CO_2 gas levels is accomplished by adding CO_2 gas when needed and using artificial rain treatment to reduce CO_2 gas levels. The regulatory process in the aeroponic box has an output variable that will be processed or measured by the DHT11 temperature sensor and the CO_2 sensor CDM4160. Then, a signal is generated as input feedback for the controller. The controller compares the feedback signal from the sensor with the reference input. The results of the comparison produce error and delta error values to reflect the differences between the reference and the actual measurement values in the aeroponic box. Error and delta error values are processed based on the fuzzy logic control algorithm on a PC implemented in MATLAB.

In Fig. 2. the DHT11 temperature sensor and the CDM4160 CO_2 sensor are connected to the Arduino Mega microcontroller. The VCC, output and GND pins in the DHT11 sensor are connected to the Arduino Mega microcontroller 5 V pin, the input digital pin 8 and GND. A relay is used to connect the lamp to the microcontroller. The lamp operates at 220 V and is controlled by the microcontroller, which has output voltages of 5 V and 3.3 V. Therefore, the relay is required to assist the microcontroller in controlling the lamp. The L298N motor driver has 4 outputs; 2 outputs are used for the 12 V fan, and the L298N input is connected to pin 10 of the microcontroller. The temperature value detected by the DHT11 sensor is displayed on the 16x2 LCD. The pins on the LCD are connected to the I2C 16x2 LCD module to minimize pin usage at the microcontroller. The 16x2 LCD pins that are already connected to the I2C 16x2 LCD module has connected to the microcontroller. The greenhouse has a length of 3.6 m, a width of 3 m and a height of 3 m. The aeroponic greenhouse is constructed with a mild structure and fiber material for the roof and partition. The aeroponic desk placed inside the greenhouse has a 2-m length, 1-m width and a 0.9-m height. The desk used to place the aeroponic system on red chili plants is 1 m in length and 1 m in width, half the size of the aeroponic desk.

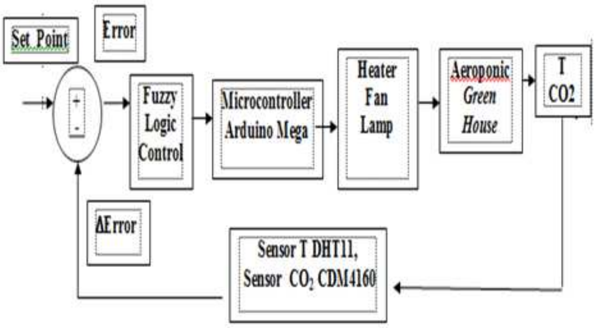

Fig. 1 Block diagram of temperature and CO_2 fuzzy control system on aeroponic greenhouse

II.2 Implementation of Fuzzy Logic Control

In this research, the software design comprises the design of the fuzzy logic using MATLAB software and the Arduino microcontroller program using Arduino IDE software. The fuzzy method used in this research is the Mamdani method with 2 variable inputs and 5 variable outputs.

A. Member Function Input

The fuzzy set for the temperature input variable is divided into three categories: Cold, Normal, and Hot, which are used in the rule base as {D, N, H}. The temperature variable has a membership function from 18°C-45°C and is divided into the three linguistic variables shown in Table I.

TABLE I
MEMBERSHIP FUNCTION TEMPERATURE VARIABLE

Linguistic Variables	Cold	Normal	Hot
Temperature	[18 20 22]	[21 25,5 30]	[30 32 45]

The temperature variable of the membership function in MATLAB, produced by the FIS editor MATLAB function, can be seen in Fig. 2.

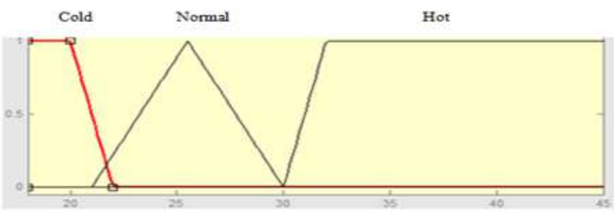

Fig. 2 Variables of temperature input

The trapezoid curve and the triangular curve are chosen to describe the terms of the above linguistic variables. The equation of the temperature membership curve is obtained on the trapezoidal curve and the triangular curve. The temperature for each of the above terms obtained by reducing the function of the equation to its value will result in a membership function with rank 0 to 1 as an input function of the fuzzy logic input.

Then, the membership function for the carbon dioxide variable has an interval of 320 to 1800. The carbon dioxide variable membership function is divided into the three linguistic variables shown in Table II.

TABLE II
VARIABLE MEMBERSHIP FUNCTIONS OF CO2

Linguistic Variable	Low	Medium	High
CO_2	[320 700 800]	[700 900 1100]	[1000 1200 1800]

A membership function of the carbon dioxide variable was created using the FIS editor found in the MATLAB software and can be seen in Fig. 3:

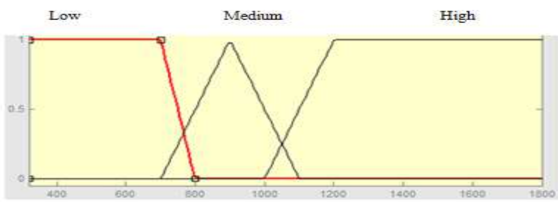

Fig. 3 Variables of CO_2 Input

In Fig. 3, the representations of trapezoid curves and triangular curves are used to describe the terms of linguistic variables. In the representation of trapezoidal curves and triangular curves here, both have similarities. The equation curves of the CO_2 variable membership function for each term used as input are as follows:

$$\mu Low[X] = \begin{cases} 1; & x \le 700 \\ \frac{800-x}{100}; & 700 \le x \le 800 \\ 0; & x \ge 800 \end{cases}$$

$$\mu Medium[X] = \begin{cases} 0; & x \le 700 \text{ atau } x \ge 1100 \\ \frac{x-700}{200}; & 700 \le x \le 900 \\ \frac{900-x}{200}; & 900 \le x \le 1100 \end{cases}$$

$$\mu High[X] = \begin{cases} 0; & x \le 1000 \\ \frac{x-1000}{200}; & 1000 \le x \le 1200 \\ 1; & x \ge 1200 \end{cases}$$

The membership functions of the fan and lamp output variables (Table III and IV) have a range of -1 to 1 and are divided into two linguistic variables. The linguistic variables for fan, lamp, motor B and valve output are shown in Fig. 4 and Fig. 5

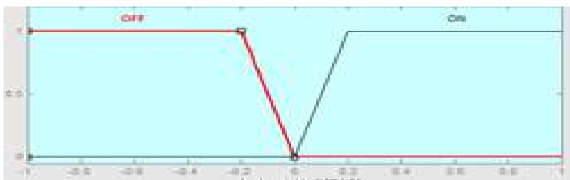

Fig. 4 Fan output variable

TABLE III
MEMBERSHIP FUNCTION OF FAN VARIABLE

Linguistic Variable	OFF	ON
Fan	[-1 -1 -0.2 0]	[0 0.2 1 1]

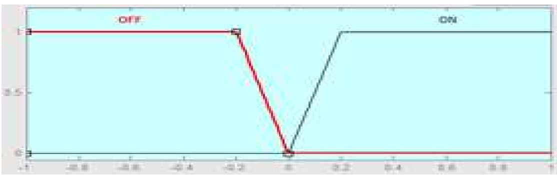

Fig. 5. Lamp output variable

TABLE IV
MEMBERSHIP FUNCTION LAMP VARIABLE

Variable Linguistic	OFF	ON
Lamp	[-1 -1 -0.2 0]	[0 0.2 1 1]

B. Fuzzy Logic Rules

Fuzzy rules consist of several fuzzy logic statements in the form of IF-THEN statements. The preparation of several statements was based on an expert's knowledge or experience, and experiments to make rules were based on the step response of the process. In this study, there are 2 inputs, temperature and carbon dioxide, and 5 outputs, fan, lamp, Motor B, valve and Motor A. The temperature and CO_2 inputs have 2 membership functions, the fan, lamp, Motor B and valve outputs have 2 membership functions, and the Motor A output has 3 membership functions.

C. Fuzzification and Defuzzification

In this research, 27 fuzzy rules were used to determine the treatment that must be carried out if the temperature value exceeds or is less than the set point value. The rules are as follows:

1. If (Temperature Is Cold) And (CO_2 Is Low) Then (Fan Is Off) (Lights Are On) (Motor_B Is Off) (Valve_Gas_CO2 Is On) (Motor_A Is Anticlockwise) (1)
2. If (Temperature Is Cold) And (CO_2 Is Medium) Then (Fan Is Off) (Lights Are On) (Motor_B Is Off) (Valve_Gas_CO_2 Is Off) (Motor_A Is Anticlockwise) (1)
3. If (Temperature Is Cold) And (CO_2 Is High) Then (Fan Is Off) (Lights Are On) (Motor_B Is On) (Valve_Gas_CO_2 Is Off) (Motor_A Is Anticlockwise) (1)
4. If (Temperature Is Cold) And (CO_2 Is Low) Then (Fan Is Off) (Lights Are On) (Motor_B Is Off) (Valve_Gas_CO_2 Is On) (Motor_A Is Off) (1)
5. If (Temperature Is Cold) And (CO_2 Is Medium) Then (Fan Is Off) (Lamp Is On)(Motor_B Is Off) (Valve_Gas_CO_2 Is Off) (Motor_A Is Off) (1)
6. If (Temperature Is Cold) And (CO_2 Is High) Then (Fan Is Off) (Lamp Is On) (Motor_B Is On) (Valve_Gas_CO_2 Is Off) (Motor_A Is Off) (1)
7. If (Temperature Is Cold) And (CO_2 Is Low) Then (Fan Is Off) (Lights Are On) (Motor_B Is Off) (Valve_Gas_CO_2 Is On) (Motor_A Is Clockwise) (1)
8. If (Temperature Is Cold) And (CO_2 Is Medium) Then (Fan Is Off) (Lights Are On) (Motor_B Is Off) (Valve_Gas_CO_2 Is Off) (Motor_A Is Clockwise) (1)
9. If (Temperature Is Cold) And (CO_2 Is High) Then (Fan Is Off) (Lights Are On) (Motor_B Is On) (Valve_Gas_CO_2 Is Off) (Motor_A Is Clockwise) (1)
10. If (Temperature Is Normal) And (CO_2 Is Low) Then (Fan Is Off) (Light Is On) (Motor_B Is Off) (Valve_Gas_CO_2 Is On) (Motor_A Is Anticlockwise) (1)
11. If (Temperature Is Normal) And (CO_2 Is Medium) Then (Fan Is Off) (Lights Are On) (Motor_B Is Off) (Valve_Gas_CO_2 Is Off) (Motor_A Is Anticlockwise) (1)
12. If (Temperature Is Normal) And (CO_2 Is High) Then (Fan Is Off) (Lights Are On) (Motor_B Is On) (Valve_Gas_CO_2 Is Off) (Motor_A Is Anticlockwise) (1)
13. If (Temperature Is Normal) And (CO_2 Is Low) Then (Fan Is Off) (Lamp Is Off) (Motor_B Is Off) (Valve_Gas_CO_2 Is On) (Motor_A Is Off) (1)
14. If (Temperature Is Normal) And (CO_2 Is Medium) Then (Fan Is Off) (Lamp Is Off) (Motor_B Is Off) (Valve_Gas_CO_2 Is Off) (Motor_A Is Off) (1)
15. If (Temperature Is Normal) And (CO_2 Is High) Then (Fan Is Off) (Lamp Is Off) (Motor_B Is On) (Valve_Gas_CO_2 Is Off) (Motor_A Is Off) (1)
16. If (Temperature Is Normal) And (CO_2 Is Low) Then (Fan Is Off) (Lights Are Off) (Motor_B Is Off) (Valve_Gas_CO_2 Is On) (Motor_A Is Clockwise) (1)
17. If (Temperature Is Normal) And (CO_2 Is Medium) Then (Fan Is Off) (Lights Are Off) (Motor_B Is Off) (Valve_Gas_CO_2 Is Off) (Motor_A Is Clockwise) (1)
18. If (Temperature Is Normal) And (CO_2 Is High) Then (Fan Is Off) (Lights Are Off) (Motor_B Is On) (Valve_Gas_CO_2 Is Off) (Motor_A Is Clockwise) (1)
19. If (Temperature Is Hot) And (CO_2 Is Low) Then (Fan Is On) (Light Is On) (Motor_B Is Off) (Valve_Gas_CO_2 Is On) (Motor_A Is Anticlockwise) (1)
20. If (Temperature Is Hot) And (CO_2 Is Medium) Then (Fan Is On) (Lights Are On) (Motor_B Is Off) (Valve_Gas_CO_2 Is Off) (Motor_A Is Anticlockwise) (1)
21. If (Temperature Is Hot) And (CO_2 Is High) Then (Fan Is On) (Lights Are On) (Motor_B Is On) (Valve_Gas_CO_2 Is Off) (Motor_A Is Anticlockwise) (1)
22. If (Temperature Is Hot) And (CO_2 Is Low) Then (Fan Is On) (Lamp Is Off) (Motor_B Is Off) (Valve_Gas_CO_2 Is On) (Motor_A Is Off) (1)
23. If (Temperature Is Hot) And (CO_2 Is Medium) Then (Fan Is On) (Lamp Is Off) (Motor_B Is Off) (Valve_Gas_CO_2 Is Off) (Motor_A Is Off) (1)
24. If (Temperature Is Hot) And (CO_2 Is High) Then (Fan Is On) (Lamp Is Off) (Motor_B Is On) (Valve_Gas_CO_2 Is Off) (Motor_A Is Off) (1)
25. If (Temperature Is Hot) And (CO_2 Is Low) Then (Fan Is On) (Lights Are Off) (Motor_B Is Off) (Valve_Gas_CO_2 Is On) (Motor_A Is Clockwise) (1)
26. If (Temperature Is Hot) And (CO_2 Is Medium) Then (Fan Is On) (Lights Are Off) (Motor_B Is Off) (Valve_Gas_CO_2 Is Off) (Motor_A Is Clockwise)
27. If (Temperature Is Hot) And (CO_2 Is High) Then (Fan Is On) (Lights Are Off) (Motor_B Is On) (Valve_Gas_CO_2 Is Off) (Motor_A Is Clockwise) (1)

The 27 rules were related to the microcontroller by programming them in the Arduino IDE software. These rules turn on the temperature-based fan, lamp, motor B in actual conditions, Motor A, and the CO_2 gas cylinder valve.

III. RESULT AND DISCUSSION

The temperature and CO_2 fuzzy control system in the aeroponic system for red chili cultivation are shown in Fig. 1. Testing integrated the hardware and the MATLAB software in the application of the fuzzy logic. Testing of the fuzzy logic control system temperature and CO_2 parameters of the aeroponic system in the greenhouse were divided into 3 conditions every morning, daytime and afternoon for 3 weeks. The set point temperature of 30℃ is based on the optimal conditions of red chili cultivation temperatures between 15-32℃ [6].The carbon dioxide setpoint value of 850 was based on the recommended level of 800-1000 ppm [7]. During the test there was an evaluation of the response of the control performance in terms of Td, Tr, Tp and Ess.

The Fuzzy Logic Control Experiment was conducted in the morning, daytime and afternoon for 3 weeks. The different timing was expected to illustrate the change of the temperature condition with respect to the setpoint. The setpoint value determined was 30℃. If the sensor detects detected that the temperature was less than the setpoint, the lamp was turned on to increase the temperature of the aeroponic, whereas if the temperature value was higher than the setpoint, the fan was turned on to decrease the temperature. The following is the fuzzy control experiment result:

A. Temperature Control

The temperature control experiments aeroponic red chili cultivation on greenhouse conducted several tests for 3 weeks in the morning, daytime and afternoon. The results of the temperature experiment are shown in Fig.6, Fig. 7 and Fig. 8.

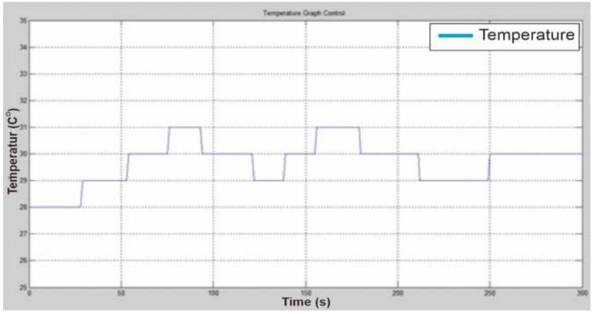

Fig. 6 Morning fuzzy control temperature

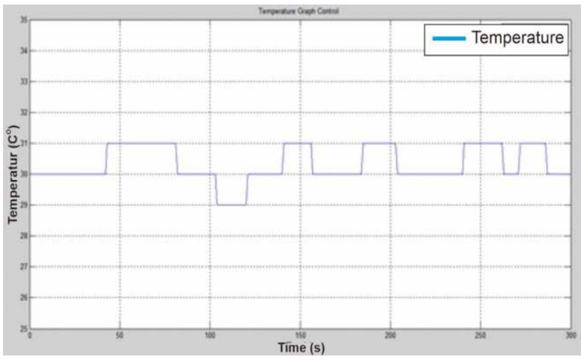

Fig. 7 Daytime fuzzy control temperature

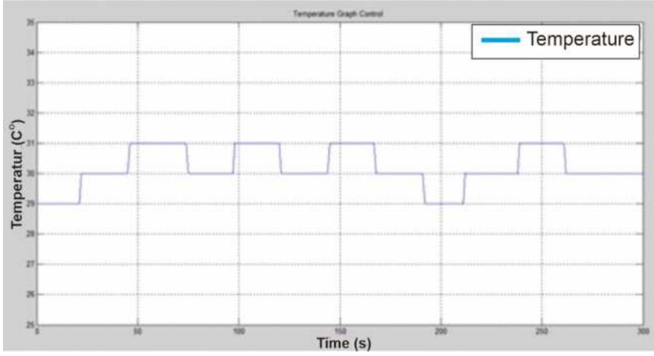

Fig. 8 Afternoon fuzzy control temperature

The following Table V is the response of fuzzy logic control from Fig.6, Fig. 7 and Fig. 8:

TABLE V
SYSTEM RESPONSE CONTROL PERPORMANCE ON TEMPERATURE

Control	Time	Set Point Temperature	Temperature Testing	Td (s)	Tr (s)	Tp (s)	Ess (%)
Fuzzy logic	Morning	30°C	31°C	9.5	19	122	0.03
	Daytime	30°C	34°C	20	40	185	0.13
	Afternoon	30°C	31°C	15.5	31	98	0.03

The temperature experimental results show the normal conditions following the setpoint in the fuzzy rule for 30℃. This condition was caused by the rainfall in the third week, which was higher than that in the first and second week and thus made the temperature surrounding the greenhouse lower and affected the temperature of the red chili aeroponic system inside the greenhouse. Although there was a slight increase of temperature due to human activities inside the greenhouse, the system was still able to control the temperature value to reach the setpoint value.

B. CO2 Control

The CO_2 control experiments aeroponic red chili cultivation on greenhouse conducted several tests for 3 weeks in the morning, daytime and afternoon. The results obtained illustrate the performance of fuzzy logic control in controlling CO_2. The CO_2 setpoint specified was 850 ppm. The results of CO_2 control testing in can be seen in Fig. 9, Fig. 10 and Fig. 11.

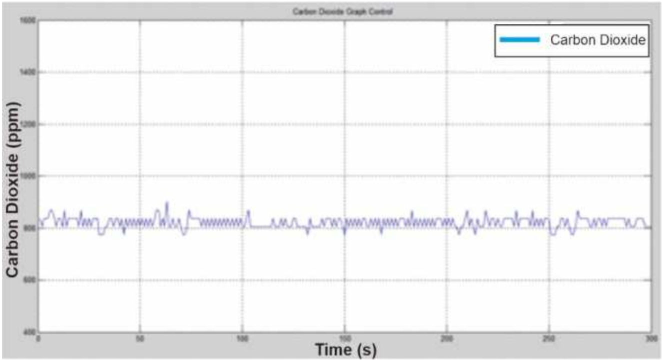

Fig. 9 Morning CO_2 fuzzy control

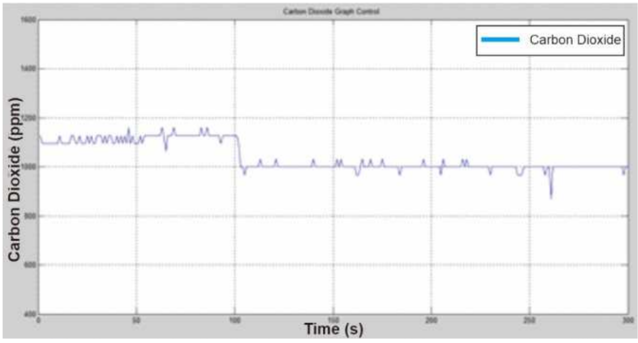

Fig. 10 Daytime CO_2 fuzzy control

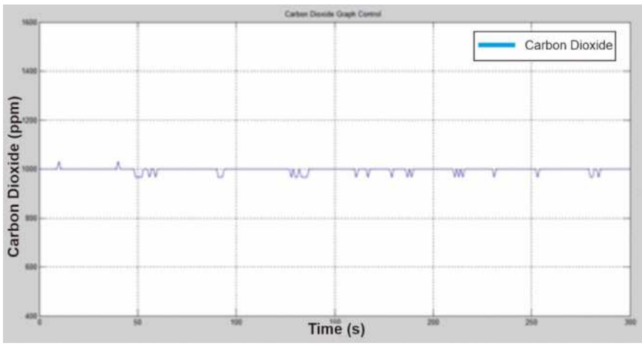

Fig. 11 Afternoon CO_2 fuzzy control

Fig. 9 shows the results of the morning fuzzy logic CO_2 control test. The initial value read by a CO_2 sensor was 837 ppm, a normal condition because the CO_2 value is in accordance with a predetermined setpoint and the graph shows a changing CO_2 value even though it is still within the setpoint range needed by the chili plant. Changes occurred due to the CO_2 levels in the environment around the plant area, which were in the setpoint range. The system maintains CO_2 at the setpoint range by feedback.

In Fig. 10 are the results of daytime CO_2 testing in the second week. Initial CO_2 was read by a sensor at 1127 ppm. This condition controls the system of CO_2 to reach the setpoint. Decreasing the initial value of CO_2 to the setpoint took 103 seconds. When the value of CO_2 reached the setpoint, there was a slight change due to CO_2 levels in the environment outside the plant being higher than in the plant; however, the system could control CO_2 under the specified setpoint range conditions.

In Fig. 11 shows the results of the afternoon CO_2 test in the second week. The testing CO_2 value read by the sensor was 999 ppm. This condition is a normal condition or condition needed by chili plants in the plant. In fuzzy logic this condition belongs to the normal set of CO_2 where no treatment occurs.

TABLE VI
SYSTEM RESPONSE CONTROL PERFORMANCE ON CO_2

Control	Time	CO_2 Set Point (ppm)	CO_2 Testing (ppm)	Td (s)	Tr (s)	Tp (s)	Ess (%)
Fuzzy logic	Morning	850	900	40	60	70	0.058
	Daytime	850	1127	51.5	113	371	0.325
	Afternoon	850	1005	5	10	40	0.1823

From the results of CO_2 control testing in the second week conducted in the morning, afternoon and evening, we can determine the response of fuzzy logic control of CO_2 to chili plants by looking at several criteria that are shown in Table VI.

IV. CONCLUSIONS

This paper presented the results of tests of an integrated fuzzy control system for temperature and CO_2 for red chilis in a greenhouse with an aeroponic system and described the control method, including software and hardware.

The fuzzy control system for optimum red chili temperature and CO_2 growth requirements was designed and tested at an aeroponic greenhouse in real time. Performance of the fuzzy logic control of temperature and CO_2 in the aeroponic greenhouse for red chili cultivation was measured by Td, Tr, Tp and Ess values. The tests showed that the red pepper plants grew well using the proposed method over the observational period.

ACKNOWLEDGMENT

This research was supported by the Directorate of Research and Community Service, Directorate General of Research and Development Strengthening Ministry of Research Technology and Higher Education, Republic of Indonesia, through a national applied cluster research grant in 2019 and was supported by Smart Control and Artificial Intelligence Research Group, Electrical Engineering, Universitas Sultan Ageng Tirtayasa and all expertise assistance and technical contributions on the research projects.

REFERENCES

[1] B. Pickersgill, "Genetic Resources and Breeding of Aubergine.pdf," *Euphytica*, vol. 93, pp. 129–133, 1997.

[2] L. Perry *et al.*, "Starch fossils and the domestication and dispersal of chili peppers (Capsicum spp. L.) in the Americas," *Science (80-.).*, vol. 315, no. 5814, pp. 986–988, 2007, doi: 10.1126/science.1136914.

[3] B. and E. J. Votava and P. W. Bosland, *Vegetable and Spice Capsicums*. .

[4] A. N. Hardiansyah, E. Sulistyaningsih, and E. T. S. Putra, "Effects of Pyraclostrobin on Growth and Yield of Curly Red Chili (Capsicum Annum L.)," *Ilmu Pertan. (Agricultural Sci.*, vol. 2, no. 1, p. 009, 2017, doi: 10.22146/ipas.12841.

[5] R. S. Ferniah, S. Pujiyanto, and H. P. Kusumaningrum, "Indonesian red chilli (Capsicum annuum L.) capsaicin and its correlation with their responses to pathogenic Fusarium oxysporum," *NICHE J. Trop. Biol.*, vol. 1, no. 2, p. 7, 2018, doi: 10.14710/niche.1.2.7-12.

[6] D. U. Siswanti and M. F. Lestari, "Growth Rate and Capsaicin Level of Curly Red Chili (Capsicum annum L.) on Biofertilizer and Biogas Sludge Application," *J. Biodjati*, vol. 4, no. 1, pp. 126–137, 2019, doi: 10.15575/biodjati.v4i1.4216.

[7] T. J. Blom, W. A. Straver, and W. Ingratta, F. J., Khosla, S., Brown, "Carbon Dioxide in Greenhouses," *Carcinogenesis*, vol. 33, no. 11. p. NP, 2012, doi: 10.1093/carcin/bgs042.

[8] C. A. Wirasti, C. Listyowati, and K. Yolanda, "Improvement of Red Chili Pepper Production in Dry Land Area Through Introduction of High Yielding Variety," no. 3, pp. 87–91, 2018.

[9] Y. S. Mohd, A. M. Arshad, N. Farah, H. Muhamad, and N. J. Sidek, "Potential and Viability of Chilli Cultivation Using Fertigation Technology in Malaysia," *Int. J. Innov. Appl. Stud.*, vol. 17, no. 4, pp. 1114–1119, 2016.

[10] C. Kittas; N. Katsoulas; T. Bartzanas, "Fao Plant Production And Protection Paper," in *Good Agricultural Practices for greenhouse vegetable production in the South East European countries*, 230th ed., D. G. Wilfried Baudoin, Avetik Nersisyan, Artur Shamilov, Alison Hodder, Ed. Roma: FAO, 2017, p. 434.

[11] I. A. Lakhiar, J. Gao, T. N. Syed, F. A. Chandio, and N. A. Buttar, "Modern plant cultivation technologies in agriculture under

controlled environment: A review on aeroponics," *J. Plant Interact.*, vol. 13, no. 1, pp. 338–352, 2018, doi: 10.1080/17429145.2018.1472308.

[12] M. Lee and H. Yoe, "Analysis of environmental stress factors using an artificial growth system and plant fitness optimization," *Biomed Res. Int.*, vol. 2015, 2015, doi: 10.1155/2015/292543.

[13] Zadeh L.A, "Fuzzy Sets* -," *Inf. Control*, vol. 90, no. 1, pp. 103–107, 1965.

[14] Bellman Re and Zadeh L.A, "Decision-Making in a Fuzzy Environment," *Manage. Sci.*, vol. 17, no. 4, 1970.

[15] C. Lee, "Fuzzy logic in control systems Fuzzy Logic Cntroller-part II," *IEEE Trans. Syst. Man Cybern.*, vol. 20, no. 2, pp. 419–435, 1990, doi: 10.0.4.85/21.52552.

[16] A. Albaidhani and A. Alsudani, "Fuzzy logic control for NLOS identification method in an indoor environment using UWB technology," *Int. J. Intell. Eng. Syst.*, vol. 13, no. 1, pp. 270–281, 2020, doi: 10.22266/ijies2020.0229.25.

[17] Ö. Alpay and E. Erdem, "The control of greenhouses based on fuzzy logic using wireless sensor networks," *Int. J. Comput. Intell. Syst.*, vol. 12, no. 1, pp. 190–203, 2018, doi: 10.2991/ijcis.2018.125905641.

[18] B. Bendjaima, D. Saigaa, and D. E. Khodja, "Fault tolerant control based on adaptive fuzzy sliding mode controller for induction-motors," *Int. J. Intell. Eng. Syst.*, vol. 10, no. 6, pp. 39–48, 2017, doi: 10.22266/ijies2017.1231.05.

[19] R. R. Shamshiri, J. W. Jones, K. R. Thorp, D. Ahmad, H. C. Man, and S. Taheri, "Review of optimum temperature, humidity, and vapour pressure deficit for microclimate evaluation and control in greenhouse cultivation of tomato: A review," *Int. Agrophysics*, vol. 32, no. 2, pp. 287–302, 2018, doi: 10.1515/intag-2017-0005.

[20] J. L. Reyes, R. Montoya, C. Ledesma, and R. Ramírez, "Development Of An Aeroponic System For Vegetable Production," in *Acta Horticulturae*, May 2012, no. 947, pp. 153–156, doi: 10.17660/ActaHortic.2012.947.18.

[21] M. Pala, L. Mizenko, M. Mach, and T. Reed, "Aeroponic greenhouse as an autonomous system using intelligent space for agriculture robotics," *Advances in Intelligent Systems and Computing*, vol. 274. pp. 83–93, 2014, doi: 10.1007/978-3-319-05582-4_7.

[22] I. Idris and M. I. Sani, "Monitoring and control of aeroponic growing system for potato production," *Proceedings of 2012 IEEE Conference on Control, Systems and Industrial Informatics, ICCSII 2012*. pp. 120–125, 2012, doi: 10.1109/CCSII.2012.6470485.

[23] J. Liu and Y. Zhang, "An automatic aeroponics growth system for bamboo seedling and root observation," *Applied Mechanics and Materials*, vol. 307. pp. 97–102, 2013, doi: 10.4028/www.scientific.net/AMM.307.97.

[24] A. H. Calori, T. L. Factor, J. C. Feltran, E. Y. Watanabe, C. C. de Moraes, and L. F. V. Purquerio, "Seed potato minituber production in an aeroponic system under tropical conditions: electrical conductivity and plant density," *J. Plant Nutr.*, vol. 41, no. 17, pp. 2200–2209, 2018, doi: 10.1080/01904167.2018.1497652.

[25] L. Yang, V. Sarath Babu, J. Zou, X. C. Cai, T. Wu, and L. Lin, "The development of an intelligent monitoring system for agricultural inputs basing on DBN-Softmax," *J. Sensors*, vol. 2018, 2018, doi: 10.1155/2018/6025381.

[26] B. Center and B. P. Verma, "Fuzzy Logic for Biological and Agricultural Systems," *Artif. Intell. Rev.*, vol. 12, no. 1–3, pp. 213–225, 1998, doi: 10.1007/978-94-011-5048-4_11.

[27] I. Saraswat *et al.*, "Applications of temperature and humidity monitoring system at aerophonic plants based on IoT," in *MATEC Web of Conferences*, 2018, vol. 218, doi: 10.1051/matecconf/201821803017.

[28] M. Azaza, K. Echaieb, F. Tadeo, E. Fabrizio, A. Iqbal, and A. Mami, "Fuzzy Decoupling Control of Greenhouse Climate," *Arab. J. Sci. Eng.*, vol. 40, no. 9, pp. 2805–2812, 2015, doi: 10.1007/s13369-015-1719-5.