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Fuzzy Logic in Determining The Control Temperature and Humidity in Plant Factory for Cultivation of Pak Choy (*Brassica chinensis l.*) Hydroponics

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Abstract

In cultivation of vegetable plants, *plant factory* system requires flexible approach and resolution methods with a high degree of accuracy, considering the main requirement quality of *plant factory* is internal environmental conditions that must be a constant value for a long period, while the value of temperature and humidity environment is fluctuate easily. The purpose of this study is to find out the steps of obtaining *fuzzy* values and knowing the value of *PWM* (Pulse Width Modulation) output in the *plant factory* for a set point temperature of 28^0C and a set point humidity of 75% using the Tsukamoto *fuzzy* approach. Fuzzy logic is an approach method and problem solving by modeling linear and non-linear functions, the main advantages of this method are being very flexible, high tolerance and high-value precision as well natural language use in this method, so it can be understood easily. Pak choy plants (*Brassica Chinensis L.*) can grow ideally at temperatures of 19-30^0C and 75% humidity. The steps of research is, first determine the input and output variables which are firm sets. Second, fuzzy compositions, are the steps of changing input values to the value of functions involve. Third, inference fuzzy set of Tsukamoto with the minimum method. Fourth, defuzzication with re-convert data in fuzzy set to crisp data. The last step is to get the output value of the defuzzification result which converted to PWM (Pulse Width Modulation) value. The calculation results obtained a PWM (Pulse Width Modulation) value of 760.2450 for the set point temperature of 28^0C and humidity of 75% in the plant factory of pak choy's cultivation.

Keywords: Fuzzy Logic, Fuzzy Tsukamoto, High Accuracy, Pak Choy, Plant Factory, PWM.

INTRODUCTION

Plant factory is cultivation system without restriction of any seasons, which means it can farm all year [1]. Based on research [2], Plant factory is a development of greenhouse cultivation systems, where the greenhouse itself is still dependent on seasons, especially in non-tropical countries,mainly considering the sun as main light source. Plant factory can also be interpreted as precision agriculture, in accordance with previous research by [1, 3], the nutritional needs of plants, lighting, and environmental conditions are controlled and maintained according to the needs of plants. In previous studies [4, 5] described in Plant factory farming systems, it is very important to control the intensity of light, temperature and humidity. This will greatly affect the quality of plants when harvesting. The development of a Plant factory will produce high-quality and organic agricultural products, this is a great opportunity especially for farmers in Indonesia.

One of the factors that really determine the quality of Plant factory is the internal environmental conditions, known as temperature and humidity. If this factor cannot be properly maintained, then it is certain that the Plant factory will fail. The main difficulty in controlling temperature and humidity is the variable value that fluctuate easily and hardly to control [2,6]. Precision and flexible control methods are needed.

Fuzzy logic is a study of truth values with a significant number [7]. The method of approach and problem solving in fuzzy logic is by modeling linear and non-linear functions [2], the main advantages of this method are flexibility, high tolerance and high precision value [8] and fuzzy logic also using natural language so it can be easily can be understood. With the fuzzy logic, it is expected to become a solution to control the

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temperature and humidity of the Plant factory conditions. In fuzzy logic there are 3 methods that can be used, Tsukamoto, Mamdani and Sugeno [9]. Each has their own advantages and disadvantages, used according to problems and needs. The inventor of fuzzy logic is an American [10], and in term of usage, a lot of people using it in Japan.

Pak choy plant (*Brassica Chinensis L.*) is one of the vegetables that is popular, contains many nutrients and has a high selling value. This plant was also developed by NASA with a full control system using artificial light in the form of LEDs [11]. The determining factor in the quality of Pak Choy is internal environmental conditions, temperature and humidity. The ideal condition of temperature in the pak choy plant is $19-30^0$ C and humidity is 75%[12].

The purpose of this study is to know the steps of obtaining fuzzy values and knowing the PWM value at set point temperature 28^o C and humidity 75%. Fuzzy logic control for plant factory of Hydroponic Pak Choy is done using the Tsukamoto fuzzy approach.

RESEARCH METHOD

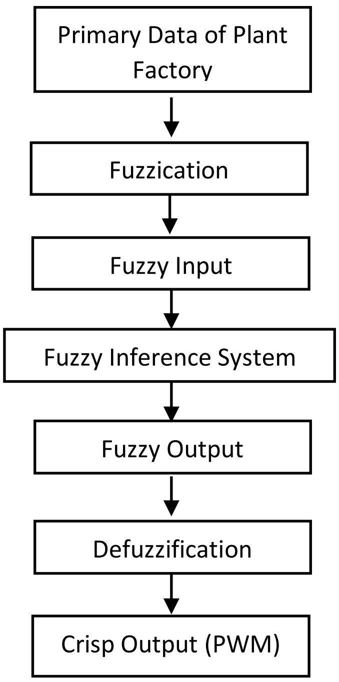

Figure 1. Research Structure

Primary Data of Performance Trial *Plant Factory*

Collecting primary data is done by testing the performance of Plant factory with the state of the temperature actuator and humidity actuator at maximum and minimum conditions. This test is carried out for 60 minutes, the data obtained will be used as the basis for the fuzzification process, namely in determining the universe of conversation, the formation of fuzzy sets and determining the type of fuzzification curve used [6,9].

Fuzzification

This step is the step of converting the exact value from the primary data, converted to fuzzy values. Definition of firm value or it can be called crisp value is a set of numbers that involve value of YES (1) and NO (0), while the definition of fuzzy set value is a set of numbers that involve value between 1 and 0, examples are 0.20 and 0 ; 95, the value is free but remains within the range 0-1[9].

The process that occurs in the fuzzyication step is forming a fuzzy set with certain boundaries / universe of conversation. Fuzzy sets are formed using curves, while the types of fuzzy set curves include: linear curves, triangular curves, trapezoi13 curves, shoulder curves and S curves [2,9,13,14]. The output value of the value fuzzification step is the membership function variable (μ) and will be used as input to the fuzzy inference step.

Fuzzy Inference System

Fuzzy inference system or can be abbreviated as FIS is a processing system of values from fuzzy logic [11], at this step , there is fuzzy / base fuzzy rules that created with several variable values, depending on the problem to be solved. After making the fuzzy rule, the next FIS step is solving the problem, the fuzzy inference system itself has several methods, including: tsukamoto method, mamdani method and sugeno method [9]. Each method has a different method with different problem solving objectives. This study uses the tsukamoto method with the MIN implication function [10].

Defuzzication

The process of mapping fuzzy set quantities in the form crisp/firm values. The Tsukamoto defuzzification method used is the Average Method [2,11]. Other defuzzification methods are: maximum (max-membership) membership method, center of area method (COA method), average of maximum membership method. Average formula of Defuzzyfication tsukamoto :

$$\alpha x = \frac{((PWM\ MAX)-(Zx))}{(PWM\ MAX)}$$

Explanation :

αx : Fuzzy Quantities Set

PWM MAX : 1023

Zx : Defuzzificasition of x

Next is Convertion of Defuzzication value to PWM (Pulse Width Modulation).This Steps adapted according the usage purpose of *fuzzy*. In this reseaarch, Defuzzication valuse must be converted to PWM, so output value of defuzzification can be directly applied to actuator plant factory[9,13]. Convertion formula of PWM :

$$Z_{PWM} = \frac{((\alpha\,1)(Z_1)+(\alpha\,2)(Z_2)+\cdots+(\alpha\,n)(Z_n))}{\sum\alpha}$$

Explanation :

Z_{PWM} : PWM value

α : Fuzzy set value

Z : Defuzzification value

RESULT AND DISCUSSION

According the methoud used in this research, in determining fuzzy value of temperature control dan humidity of plant factory, final value will converted to PWM (Pulse Width Modulation). The steps are [9,10]:

1. Primary Data Collection, the value can be seen in table 1.

Table 1. Plant Factory Performance Test Results

No	TEST TIME	TEMPRATURE		HUMIDITY	
		MAX	MIN	MAX	MIN
1	00:00:01	32⁰C	29⁰C	57%	52%
2	00:02:01	35⁰C	26⁰C	70%	48%
3	00:04:01	35⁰C	26⁰C	84%	47%
4	00:06:01	36⁰C	25⁰C	90%	46%
5	00:08:01	36⁰C	26⁰C	94%	45%
6	00:10:01	36⁰C	27⁰C	90%	45%
7	00:12:01	35⁰C	27⁰C	88%	46%
8	00:14:01	36⁰C	26⁰C	90%	46%
9	00:16:02	35⁰C	25⁰C	89%	46%
10	00:18:01	34⁰C	26⁰C	92%	47%
11	00:20:01	34⁰C	27⁰C	91%	47%
12	00:22:02	35⁰C	26⁰C	87%	46%
13	00:24:01	36⁰C	26⁰C	89%	45%
14	00:26:01	35⁰C	26⁰C	92%	46%
15	00:28:01	35⁰C	27⁰C	90%	46%
16	00:30:01	36⁰C	27⁰C	93%	47%
17	00:32:02	35⁰C	27⁰C	89%	45%
18	00:34:01	34⁰C	25⁰C	88%	45%
19	00:36:01	35⁰C	26⁰C	90%	46%
20	00:38:01	36⁰C	27⁰C	93%	46%
21	00:40:01	35⁰C	26⁰C	88%	44%
22	00:42:01	35⁰C	26⁰C	89%	46%
23	00:44:01	35⁰C	26⁰C	90%	45%
24	00:46:01	35⁰C	25⁰C	94%	47%
25	00:48:01	34⁰C	25⁰C	87%	47%
26	00:50:01	35⁰C	26⁰C	90%	46%
27	00:52:01	34⁰C	26⁰C	88%	45%
28	00:54:01	36⁰C	27⁰C	89%	44%
29	00:56:02	36⁰C	26⁰C	91%	45%
30	00:58:02	35⁰C	27⁰C	9%0	46%
31	01:00:01	35⁰C	27⁰C	91%	46%

Source: Primary Data Collection Research

2. Formation of the *Fuzzy* Set.

There are 2 types of fuzzy sets, fuzzy set of temperature and fuzzy set of humidity.

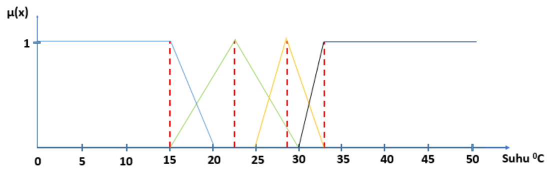

Figure 2. Fuzzy Set in Temperature Variables

Universe of temperature variables: [50]

Fuzzy set domain:

1. Cold : ≤ 20
2. Cool : 15 ≤ x ≤ 30
3. Warm : 25 ≤ x ≤ 33
4. Hot : ≥ 30

the function of Temperature variable membership

$$\mu COLD = \begin{cases} 1\ ;\ x \le 15 \\ \frac{(20-x)}{(20-15)}\ ;15\ \le x \le 20 \\ 0\ \ ;x \ge 20 \end{cases}$$

$$\mu COOL = \begin{cases} 0\ \ ;x \le 15\ atau\ x \ge 30 \\ \frac{(x-15)}{(22.5-15)}\ \ ;15\ \le x\ \le 25 \\ \frac{(30-x)}{(30-22.5)}\ ;\ 22.5\ \le x \le 30 \end{cases}$$

$$\mu WARM = \begin{cases} 0\ \ ;x\ \le 25\ atau\ x \ge 33 \\ \frac{(x-25)}{(29-25)}\ \ ;25 \le x \le 29 \\ \frac{(33-x)}{(33-29)}\ \ ;29 \le x \le 33 \end{cases}$$

$$\mu HOT = \begin{cases} 1\ \ ;x \le 30 \\ \frac{(33-x)}{(33-30)}\ \ ;30 \le x \le 33 \\ 1\ \ ;x \ge 33 \end{cases}$$

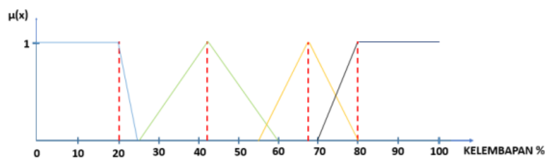

Figure 3. Fuzzy Set in Humidity Variables

Universe of humidity variable: [0 100]. Fuzzy set domain:

1. Dry : x ≤ 25
2. Slighty dry : 25 ≤ X ≤ 60
3. humid : 55 ≤ X ≤ 80
4. Very humid : ≥ 70

$$\mu DRY = \begin{cases} 1 \ ; x \leq 20 \\ \frac{(30-x)}{(30-25)} \ ; 20 \leq x \leq 25 \\ 0 \ ; x \geq 25 \end{cases}$$

$$\mu SLIGHTYDRY = \begin{cases} 0 \ ; x \leq 25 \ atau \ x \leq 60 \\ \frac{(x-25)}{(42.5-25)} \ ; 20 \leq x \leq 42.5 \\ \frac{(60-x)}{(60-42.5)} \ ; 42.5 \leq x \leq 60 \end{cases}$$

$$\mu HUMID = \begin{cases} 0 \ ; x \leq 55 \ atau \ x \geq 80 \\ \frac{(x-55)}{(67.5-55)} \ ; 55 \leq x \leq 80 \\ \frac{(80-x)}{(80-67.5)} \ ; 67.5 \leq x \leq 80 \end{cases}$$

$$\mu VERY\ HUMID = \begin{cases} 1 \ ; x \geq 80 \\ \frac{(x-70)}{(80-70)} \ ; 70 \leq x \leq 80 \\ 0 \ ; x \leq 70 \end{cases}$$

3. Make Fuzzy Rule Base

The function is as a rule in fuzzyfication operations.Given the input variables are 2 and each has 4 membership, the total of fuzzy rules used are 16 [9] can be seen in table 2.

Tabel 2. Basic of fuzzy rule

Fuzzy Rules	D	SD	HM	VH
CL	R1	R5	R9	R13
BZ	R2	R6	R10	R14
WR	R3	R7	R11	R15
H	R4	R8	R12	R16

Information :

CL : Cold — D : Dry
BZ : Cool — SD :Slightydry
WR: Warm — HM: Humid
H : Hot — VH : Very Humid

Can be seen in Table 2, can be accepted as follows:
1. The signal setting with a white background is a predicate α = 0, after being entered according to Fuzzy rules using the AND function.
2. The signal setting with a yellow background is a predicate α ≠ 0, the value will be used and appreciated in the form of PWM (Pulse Width Modulation), which will be used as the output value.

It can be seen in the table above, explaination as follows:

1) The control signal with a green background has a value of α = 0, after entering it into fuzzy rules using the AND function.
2) Control signal yellow background worth ≠ 0, its value will be used and converted in the form of a PWM (Pulse Width Modulation), which will serve as the output value.

Rule *Fuzzy* :

R1. α predicate 1 = µKG ∩ µCL
= (MIN (0.00),(0.00))
= 0.00

R2. α predicate 2 = µKG ∩ µBz
= (MIN (0.00),(0.2667))
= 0.00

R3. α predicate 3 = µKG ∩ µWR
= (MIN (0.00),(0.75))
= 0.00

R4. α predicate 4 = µKG ∩ µH
= (MIN (0.00),(0.00))
= 0.00

R5. α predicate 5 = µAKG ∩ µCL
= (MIN (0.00),(0.00))
= 0.00

R6. α predicate 6 = µAKG ∩ µBz
= (MIN (0.00),(0.2667))
= 0.00

R7. α predicate 7 = µAKG ∩ µWR
= (MIN (0.00),(0.75))
= 0.00

R8. α predicate8 = µAKG ∩ µH
= (MIN (0.00),(0.00))
= 0.00

R9. α predicate 9 = µLP ∩ µCL
= (MIN (0.4),(0.00))
= 0.00

R10. α predicate 10 = µLP ∩ µBz
= (MIN (0.4),(0.2667))
= 0.2667

R11. α predicate 11 = µLP ∩ µWR
= (MIN (0.4),(0.75))
= 0.4

R12. α predicate 12 = µLP ∩ µH
= (MIN (0.4),(0.00))
= 0.00

R13. α predicate 13 = µSLP ∩ µCL
= (MIN (0.5),(0.00))
= 0.00

R14. α predicate 14 = µSLP ∩ µBz
= (MIN (0.5),(0.2667))
= **0.2667**

R15. α predicate 15 = µSLP ∩ µWR
= (MIN (0.5),(0.75))

= 0.5

R16. α predicate 16 = µSLP ∩ µH
= (MIN (0.5),(0.00))
= 0.00

4. Defuzziffication process

The defuzzyfication method used is AVERAGE. The average value taken from the results of the fuzzyfication stage is ≠ 0.

$$\alpha x = \frac{((PWM\ MAX)-(Zx))}{(PWM\ MAX)}$$

- α predicate 10
  Z_{10} = 750.1659
- α predicate 11
  Z_{11} = 613.8
- α predicate 14
  Z_{14} = 750.1659
- α predicate 15
  Z_{15}= 511.5

5. Conversion of Defuzzyfication Value to *PWM* (Pulse Width Modulation) Form.

$$Z_{PWM} = \frac{((\alpha\ 1)(Z_1)+(\alpha\ 2)(Z_2)+\cdots+(\alpha\ n)(Z_n))}{\sum\alpha}$$

$\boldsymbol{Z_{PWM}}$ **= 628.8515**

By using the Tsukamoto fuzzy approach, the above pwm values can be changed and modified using the actual advent. Thus the fuzzy value upon and the pathway are very suitable for the needs of temperature control and factory plant humidity where the value is very volatile [9,13] .

CONCLUSION

The stages of fuzzy logic are primary data collection, the formation of fuzzy sets, the basis of fuzzy rules, defuzzification and conversion of defuzzification to PWM. The PWM output value at the temperature and humidity control is **628.8515** with a set point temperature of 28° C and a set point of humidity of 75%.

Fuzzy approximation method compared to the other, tsukamoto fuzzy methods very appropriate used in the case of the control of temperature and humidity. Considering the tsukamoto fuzzy methods simple and value is easily adjustable. Control of temperature and humidity are very sensitive and easy to change the value.

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