Original Article

IMPLEMENTATION OF FUZZY LOGIC CONTROLLERS TO MAINTAIN WATER TEMPERATURE IN HYDROPONICS NFT FOR LOLLO VERDE LETTUCE (*LACTUCA SATIVA* L.)

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ABSTRACT

Objective: The purpose of this study was to maintain the nutritional water temperature in the range of 25-27 °C for Lollo Verde lettuce (*Lactuca sativa* L.).

Methods: The method was the Fuzzy Logic Mamdani (FLM) with two inputs, i.e. real time clock and temperature. The output was crisp speed PWM with the center of area method.

Results: The results showed that Fuzzy logic was succeeded in reducing water temperature in the NFT system from 28-32 °C to 26-27 °C, with an average delta of 3.5 °C. Fuzzy logic maintained the nutrient water temperature in the Lollo Verde lettuce with an average of 26.57±0.5 °C. Water temperature affected the yield of Lollo Verde lettuce.

Conclusion: The yield of NFT FLM system was better compared to the conventional NFT system.

Keywords: Nutrient film technique, Temperature maintenance, Fuzzy logic mamdani

INTRODUCTION

Hydroponics is an effective way to preserve water and planting space [1]. Hydroponic culture with the application of nutritional media, has become the second generation of the fastest growing crop production system and agricultural industry [2]. Planting vegetables hydroponic methods lead to economic value. Moreover, the market has begun to grow in accordance with the growing demand [3]. There are several hydroponic systems, including Nutrient Film Technique (NFT) [4]. There are several factors that affect the growth of hydroponic plants, including nutrient levels, acidity and water temperature in the system [5].

Water temperature affects the physiological processes during plant growth and development [6]. Hydroponic growth requires an ideal temperature system container, because the increased oxygen demand is proportional to plant growth [7-9]. An increased temperature around the plant roots will decrease dissolved oxygen levels in water. This causes the increased the pathogen growth, such as *Pythium sp.* [10-12] The ideal temperature of the nutrient solution is in the range of 18.3-26.6 °C [13] and for tropical plants in the range of 25-30 °C [14, 15].

Bandung, Indonesia, has two seasons, i.e. tropical heat/rain climate. The air temperature is 23.7±0.5 °C, with the lowest temperature is 17.9 °C and the highest is 32.4 °C [16]. The temperature in our hydroponic system ranges from 28 to 32 °C. In this study, the water temperature was cooled by utilizing the air environment temperature [17, 18]. The purpose of this study was to maintain the nutritional water temperature in the range of 25-27 °C for Lollo Verde lettuce (*Lactuca sativa* L.) [19].

MATERIALS AND METHODS

Materials

This study was conducted in Sariasih, Bandung, West Java, Indonesia. The study used Lollo Verde lettuce as a plant sample, rockwool, reservoirs, pipes, fans, and Arduino.

Methods

Hydroponic system design

Hydroponic system was modified design which described by Fauzan and Saptarini [20]. Reservoir or container of 20 L for 30 Lollo Verde lettuce filled with 15 L of water (75%). The NFT hydroponic system (fig. 1a) consists of 3 pipes filled with 10 pots that have input-fan and exhaust pipe with exhaust-fan of water flow. The volume of nutrient water per pipe (2.5 inch) with a length of 2 m was filled with 30%, i.e. 2.1 L. Three fans (12v, 0.15A) were parallel arranged to cool the nutrient water temperature with an environment air temperature of 23.7±0.5 °C. Arduino UNO r3 microcontroller (fig. 1b) control fan speed via PWM [21] with input set of DS3231 real time clock (RTC) at 0-23 and DS18B20 waterproof temperature sensor to read temperature values in Celsius units.
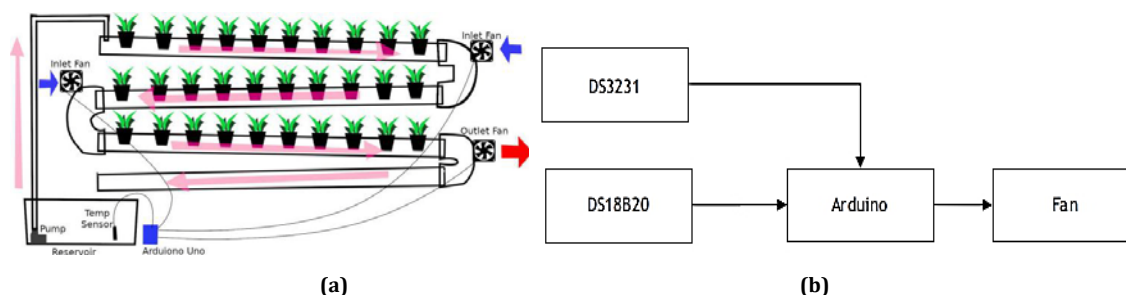

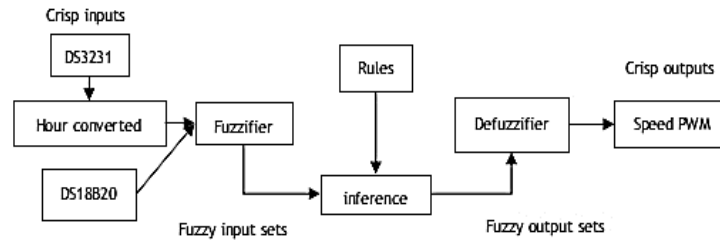**Fig. 1: NFT system design (a) and arduino UNO r3 block (b)**

Fig. 2: Fuzzy logic controller

Fuzzy Logic Controller (FLC) [22] (fig. 2) was used to read two input parameters, i.e. (a) RTC input to convert hours 0-23 to 3-26, then entered into the time membership (table 1) and (b) temperature sensor input, then entered into the temperature membership (table 2). Both inputs produce outputs according to the PWM membership speed (table 3) through rules (table 4). Output in the form of speed PWM crisps value with the Center of Area (COA) method which is calculated by equation 1 [23].

$$z_0 = \frac{\sum_{j=1}^{n} \mu(w_j).w_j}{\sum_{j=1}^{n} \mu(w_j)} \dots (1)$$

The defuzzified value was denoted as z_0. Here w_j was indicate the sample element, $\mu(w_j)$ was the membership function, and n was representing the number of elements in the sample [23].

Table 1: Time membership

Membership	Time	Time conversion
Time1	21.00-3.00	21-26
Time2	3.01-20.59	3-21

Table 2: Temperature membership

Membership	Temperature (°C)
Cool	0-25
Normal	25-27
Hot	27-50

Table 3: Speed membership

Membership	PWM speed
off	0
mid	100,128,140
max	255

Table 4: Fuzzy logic rules

Membership	Time1 (21-26)	Time2 (3-21)
Cool	Off	Off
normal	Off	Mid
Hot	Mid	Max

Time inputs were made into two memberships to simplify the calculations. The system was applied rules for time, i.e. if the hour value was less than 3, the hour value was added to 24 to produce its conversion (table 1). Temperature inputs were divided into three memberships (table 2). The PWM speed output was 2 singletons and 1 triangular membership (table 3). Fuzzy logic was used the rules in table 4. The weight comparison of Lollo Verde lettuce between conventional NFT and NFT with FLC systems was done at harvest, i.e. 45 d after the seeding.

Statistical analysis

The Python 3.8.2 program was used for data plotting and statistical analysis.

RESULTS AND DISCUSSION

The Lollo Verde lettuce was used in this set-up to be tested with the hydroponic circuit as shown in fig. 1a to maximize the planting space. The Lollo Verde lettuces were planted on the rockwool slave with 3 hills per slave and implementing the NFT system. In this study, the temperature of nutrient water was considered the factors to be maintained. The temperature maintenance can achieve with compressed refrigeration techniques with the lowest temperatures was 5 °C [24]. Controlling vent fans and growlight can achieve an optimal temperature range of 10 to 35 °C [25]. Light and temperature affected the final internode lengths (FIL) [26]. In the Cold Storage System Temperature study, Fuzzy produced crisp outputs which suitable for hot fan speeds and cold fan speeds of 6.55% and 70%, respectively [27]. The considered factor was the temperature, which plants acceptable, i.e. 25-27 °C for Lollo Verde lettuce [19].

In this study, a microcontroller was used to implement a fuzzy logic-based temperature control system. The purpose of the system was to control the water temperature by regulating the speed of a fan (fig. 1b). There were many ways to describe the variables linguistically, we choose the simple linguistic to simplify the task of the controller using fuzzy logic (fig. 2). Plots in fig. 3 and 4 were obtained from the Python program by entering the membership input and output parameters. Membership inputs, outputs, and rules were obtained from field observations (Sariasih, Bandung) and literature studies. The temperature membership plot was described the group of input values which read by the DS18B20 sensor (fig. 3a). The membership time plot was described the group of input values which read by RTC DS3231 (fig. 3b). The membership output plot was a variation of the PWM speed value from the range 0 to 255 (fig. 4).
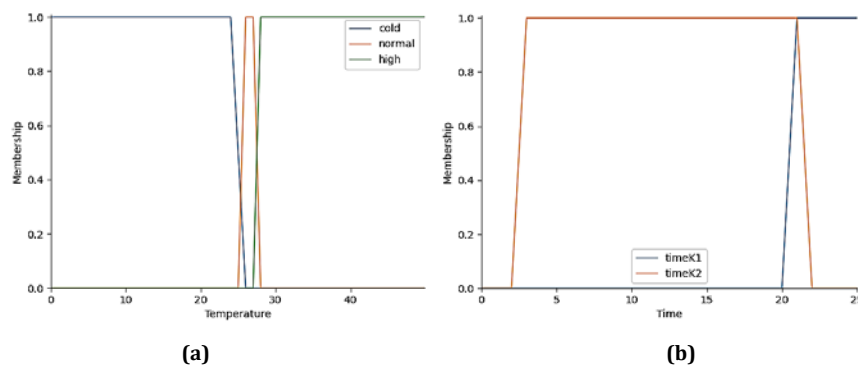

(a)

(b)

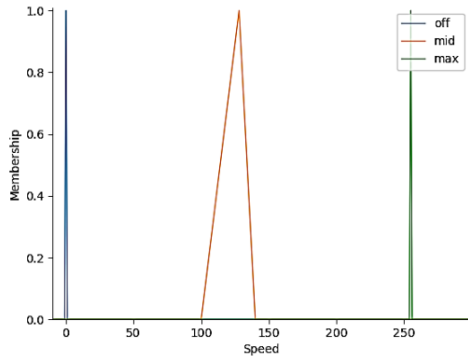**Fig. 3: Input membership of temperature (a) and time (b)**

Fig. 4: Speed membership

Fig. 5 was obtained from the data recorded for 6 d and randomly taken at different hours from the morning to the night. This design was shown the exhausted water collide with the sucked air from the exhaust fan (2.29 inch x 2 m) with a cross-sectional area of about 0.116 m² on the surface. The ideal temperature was reached after 6 d the system first runs (fig. 5). After the 6th day, the water temperature showed a stable value, i.e. 26-27 °C.

Fig. 6 was obtained from the data recorded from 00.00 to 23.59 (converted from 0 to 26) to the response of fan speed output on the 7th day. Fig. 7 was obtained from recorded data in the form of reading the value of the nutrient water temperature sensor to the fan speed output response on the 7th day. The data in fig. 6 and 7 were carried out simultaneously, but processed with different parameters. Table 5 showed the weight comparison between the conventional NFT and NFT with FLC systems performed at harvest, which 10 plus 35 d from seeding.
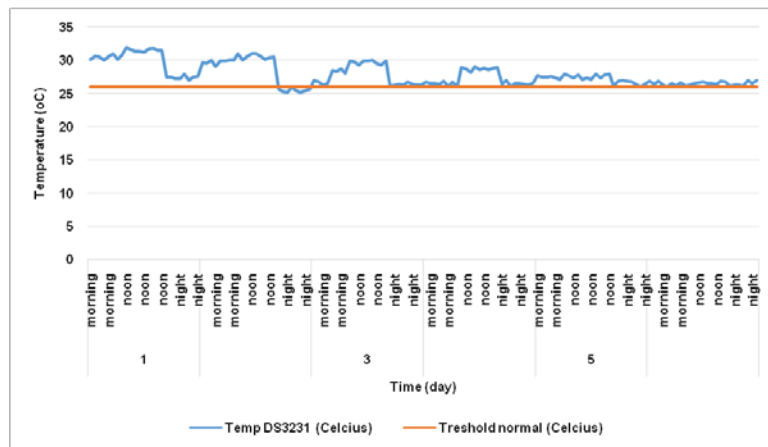
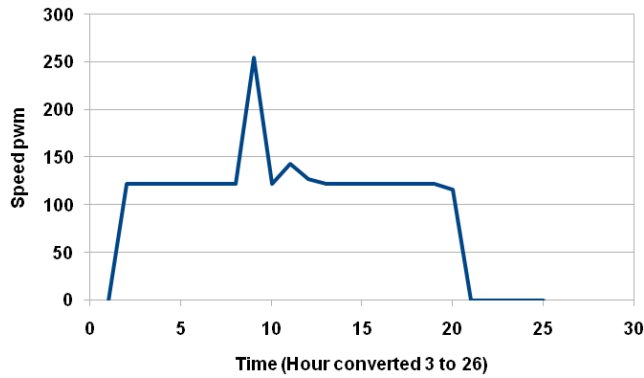

Fig. 5: Graph of time versus temperature
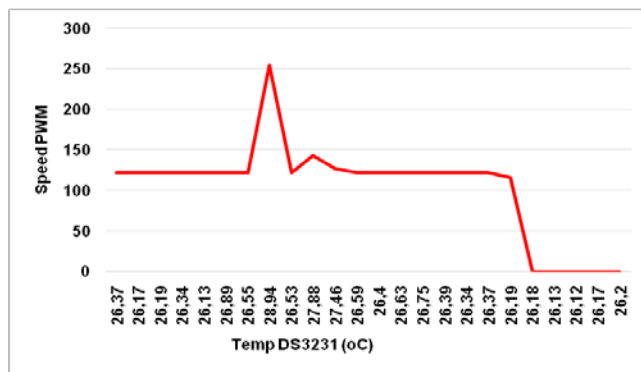

Fig. 6: Graph of time versus speed

Fig. 7: The temperature sensor reading and PWM Speed response

At night, temperatures were 17.9±0.2 °C, the exhaust fan did not work, due to the water temperature in the system was ideal (fig. 6). This was in accordance with the Fuzzy logic rules, so the speed output was 0 or a deadly condition. The results showed that even though the water temperatures were relatively stable, sometimes the DS18B20 temperature sensor was increased. Example, at 28.94 °C, the response of the fuzzy system produced a maximum output speed of 255 (fig. 7).

The fans were rotated according to the constructed rules (table 4). Fuzzy logic was succeeded in reducing water temperature in the NFT system, from 28-32 °C to 26-27 °C, with an average delta of 3.5 °C. Fuzzy logic was succeeded in maintaining the nutrient water temperature in the Lollo Verde lettuce system, with an average of 26.57±0.5 °C. This temperature was in the recommended temperature range for Lollo Verde lettuce, i.e. 25-27 °C [19].

Table 5: The weight comparison between the conventional NFT and NFT with FLC systems

Pot no.	NFT (g)	NFT+FLC (g)	Pot no.	NFT (g)	NFT+FLC (g)	Pot no.	NFT (g)	NFT+FLC (g)
1	187	193	11	189	199	21	197	193
2	183	192	12	192	199	22	189	193
3	184	198	13	193	196	23	198	188
4	188	185	14	200	184	24	183	195
5	187	200	15	193	196	25	184	182
6	197	184	16	198	189	26	200	183
7	192	198	17	190	193	27	184	199
8	184	198	18	194	182	28	196	184
9	196	201	19	201	198	29	185	200
10	183	200	20	181	185	30	196	189

The weight comparison between the conventional NFT and NFT with FLC systems was performed on Lollo Verde lettuce, 10 d after seeding and transferred to the NFT system. The harvest on the 35th day after planting on the NFT system. The weight of the Lollo Verde lettuce of the conventional NFT and NFT with FLC systems was 190.8±0.4 g and 192.5±0.2 g, respectively (table 5). These results indicate that the NFT with FLC system was 0.9% better than the conventional NFT system. The inlet filters and suitable fan were needed for bigger hydroponic scales. This was aimed to reach the ideal temperature, which far from the ambient temperature. The ideal temperature can be maintained by other heat replacement techniques, such as a peltier or refrigerator and other input parameters, models, and methods. The test place with a different air environment temperature from this study was recommended to change the membership of the input, output, and rules in the program by considering other factors, such as plant type, location, hydroponic system, etc.

CONCLUSION

The yield of NFT FLM system was better compared to the conventional NFT system.

FUNDING

AUTHORS CONTRIBUTIONS

All the authors contributed equally.

CONFLICT OF INTERESTS

Declared none

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