Design of fuzzy logic controller for temperature control of small-scale food storage

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Abstract. A Fuzzy Logic Controller (FLC) is developed to control the temperature of small-scale food storage. The FLC has two components such as the algorithm part and the hardware part. For the algorithm part, The FLC takes two input parameter such as the temperature and the humidity of the storage and takes one output parameter such as the speed of the fan. The membership function is designed as following hot, fair, cold, and too cold as for the membership functions of the temperature parameter. For the humidity membership functions are dry, dry enough, normal, less moist, and moist. As for the fan speed, the membership functions are fast, less fast, fair, slow, and too slow. On the other hand, for the hardware, the DHT11 senses the temperature and the humidity. For the cooling process, thermoelectric is used to decrease the temperature. The results show that the FLC can be used to control the temperature of the storage to achieve as the minimum temperature as 12.5°C.

1. Introduction

Fuzzy Logic Controller (FLC) is one of the method to control the engineering process or system that has been studied by researcher [1-3] and is applied in many engineering field such as fan rotation speed controller [4], controller of HVAC of electric vehicle [5], and robust controller in wireless sensor network [6]. Also, the FLC can be used to control temperature [7, 8]. Moreover, temperature regulation or control is very important to gain some advantages such as maintaining room conditions for comfort [5] and maintaining the temperature of cold thermal storage [9, 10]. To get good conditions and high performances of temperature control need some cost and some complex constructions, especially, for large-scale cold thermal energy applications [8, 9, and 11].

However, for a small-scale cold thermal storage, the cost and the complex constructions need to be reduced. For example, the cold thermal energy source of the large-scale storage that uses compressor and coolant liquid should be replaced by low-cost technology such as thermoelectric cooling [12]. Thermoelectric cooling has some advantages such as no CFC and a small-shape material size. This technology can replace from the vapor compression refrigerator to the thermoelectric cooling refrigerator.

Therefore, by combining the abilities of FLC and the thermoelectric cooling, this paper aims to design the FLC for temperature control of small-scale cold thermal storage with the thermoelectric cooling as the actuator of the cooling source.
2. Research Method
This section describes the algorithm of FLC, the hardware of FLC and as well as the design of the small-scale cold thermal food storage.

2.1. Algorithm of FLC
Given Figure 1, it is well known that FLC has three steps in processing the input parameter these are:

- **Fuzzification.** It is a process to change the input from the form of crisp becomes a fuzzy form is usually presented in the form of a set of fuzzy-set with a function of their membership function. Fuzzification input has two variables which are the temperature and humidity of the storage and fuzzification output has one variable which is the speed of the fan. For temperature, it is set about four kinds of membership function, i.e., hot, fair, cold, and very cold. For humidity, the membership functions are dry, dry enough, normal, less moist, and moist. Then, for the speed of the fan, the membership function is fast, less fast, fair, slow, and too slow. The membership function of temperature, humidity, and fan speed can be seen in Figure 2, Figure 3, and Figure 4 respectively.

![Figure 1. The architecture of FLC [3]](image)

![Figure 2. The membership function of temperature](image)
2.1.2. Inference system. It is a reference to describe the relationship between input and output variables which are processed and generated fuzzy shape. To explain the relationship between the input and output are usually using "IF-THEN." To generate this IF-THEN rules is by combining the variables of input and output. This can be summarized in Table 1. It results in about 20 rules. One of the rules, for example, is if the temperature is hot and the humidity is dry then the speed of the fan is fast. In an implementation, the FLC uses the Mamdani method with the mean of the maximum for deciding the output of the rules.

| Temperature Humidity | Hot   | Fair | Cold | Too cold |
|----------------------|-------|------|------|----------|
| Dry                  | Fast  | Less fast | Slow | Too slow |
| Less dry             | Less fast | Fair | Slow | Slow     |
| Normal               | Fair  | Fair  | Fair | Fair     |
| Less Moist           | Less fast | Less fast | Fair | Slow     |
| Moist                | Fast  | Less fast | Slow | Too slow |

2.1.3. Defuzzification. It is the process of modifying the variable shape of fuzzy to be crisp data which can be sent to another process such as computing in the microcontroller.

2.2. Hardware of FLC
On the designed system, see Fig. 6, there is a DHT11 that is used as a sensor for measuring the temperature and humidity of the room. The data obtained are then processed by a microcontroller that is the temperature, and the humidity is to be created fuzzy rules. Then the result is the decision of
fuzzy logic in the form of a PWM signal to be sent to the fan through a motor driver. So that the fan speed is regulated based on PWM value that is obtained by FLC. The speed of fan causes air flow hit thermoelectric cooling device such that the air to be cold. Therefore, the room will be cold.

![Figure 5. Block Diagram of FLC’s Hardware](image)

2.3 The small-scale cold thermal storage

Figure 7 shows the designed storage as the small-scale cold thermal storage. The storage has dimensions about 60 cm x 60 cm x 40 cm. There are four thermoelectric cooling devices with an attached fan for flowing air in the chamber.

![Figure 6. The designed storage](image)

3. Results and analysis

In this section, the results of the research are divided into two kinds of implementation of the FLC. The first implementation is using Matlab Simulation which is conducted by the programming of the FLC. The results are shown in Figure 8, Figure 9, and Table 2.

The second implementation of the FLC is conducting by translating and installing the fuzzy inference system in C programming into the microcontroller. The microcontroller reads the input variables such as temperature and humidity of the storage from sensor DT11 and gives the output variable such as the speed of the fan to the motor driver. The result can be seen in Table 2.

As shown in Table 2, it can be compared between the Matlab simulation and the microcontroller implementation in term of the duty cycle of PWM. The duty cycle of both implementation shows that the difference is small. It is about 4.67% on average.
In general result, from Table 2, the time that takes the storage to achieve the storage temperature to the minimum temperature of 12.4°C is about 3 hours from the initial condition of 28.4°C. Even though the temperature of the lowest one is not equal but close to the target minimum temperature of thermoelectric cooling device that is 10°C. This shows thermoelectric cooling device has disadvantage of the amount of heat flux that can be dissipated is limited [12]. However, the
thermoelectric cooling device has some advantages such as non-CFC, no need compression system and small-scale storage.

| No | $T(\text{°C})$ | Hmd (%) | Time (second) | PWM Microcontroller (%) | PWM Matlab (%) | PWM Difference (%) |
|----|----------------|---------|---------------|-------------------------|----------------|------------------|
| 1  | 28.4           | 95      | 0             | 94.12                   | 94.51          | 0.42             |
| 2  | 24.6           | 95      | 540           | 91.37                   | 93.73          | 2.38             |
| 3  | 23.8           | 95      | 1080          | 90.20                   | 93.73          | 3.91             |
| 4  | 22.2           | 95      | 1620          | 88.24                   | 93.33          | 5.78             |
| 5  | 21.4           | 95      | 2160          | 87.06                   | 92.94          | 6.76             |
| 6  | 20.0           | 95      | 2700          | 87.06                   | 83.92          | 3.14             |
| 7  | 20.4           | 95      | 3240          | 87.06                   | 86.27          | 0.92             |
| 8  | 19.2           | 95      | 3780          | 85.88                   | 80.78          | 5.94             |
| 9  | 18.4           | 95      | 4320          | 83.92                   | 80.39          | 4.21             |
| 10 | 17.0           | 95      | 4860          | 80.39                   | 80.39          | 0.00             |
| 11 | 17.2           | 95      | 5400          | 80.78                   | 80.39          | 0.49             |
| 12 | 16.8           | 95      | 5940          | 80.78                   | 80.39          | 0.49             |
| 13 | 15.4           | 95      | 6480          | 84.31                   | 80.39          | 4.65             |
| 14 | 14.2           | 95      | 7020          | 76.47                   | 69.02          | 7.45             |
| 15 | 13.0           | 95      | 7560          | 57.65                   | 52.94          | 4.71             |
| 16 | 12.4           | 95      | 8100          | 56.47                   | 52.94          | 3.53             |
| 17 | 13.2           | 95      | 8640          | 61.57                   | 56.47          | 5.10             |
| 18 | 12.8           | 95      | 9180          | 56.86                   | 52.94          | 3.92             |
| 19 | 13.0           | 95      | 9720          | 57.65                   | 52.94          | 4.71             |
| 20 | 12.5           | 95      | 10260         | 56.47                   | 52.94          | 3.53             |

Average of PWM Difference 4.67

Note: PWM Difference $= \frac{|PWM_{\text{matlab}}-PWM_{\text{micro}}|}{PWM_{\text{matlab}}} \times 100\%$

4. Conclusion
The FLC for temperature control of small-scale cold thermal storage has been proposed. The FLC was first is implemented in Matlab simulation, and then it was implemented in a microcontroller. The result shows that both implementations are close to the resulted PWM. The FLC also can conduct the output of the research in term of the minimum temperature of storage about 12.4° C.

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