Temperature Control Using Fuzzy Controller for Variable Speed Vapor Compression Refrigerator System

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Abstract

Keeping the cold chain vaccine is crucial to a stable immunisation programme; however, faulty processes may occur more frequently than are often thought in developing nations. This paper discusses the quick and accurate control process for designing fuzzy controllers for variable speed vapor compression refrigerator system. The suggested controller is based on the fuzzy logic intended to improve performance while keeping the cooler's constant internal temperature and increasing the refrigerator efficiency. Despite the external changes such as the outside temperature change or the volume change in the refrigerator vaccine, the fuzzy logic controller is utilised to maintain the interior temperature. However, a variable speed compressor (VSC) must be used to control the thermophysical characteristics, which dramatically alter the temperature with a small pressure change. In this case, fuzzy rules of the sort developed by Mamdani are used to build up the system. The programming platforms utilised to implement the model include MATLAB, SIMULINK, and Fuzzy Logic Toolbox (FLT). The efficiency of fuzzy logic controller design membership will be compared to ensure that the refrigerator temperature is more accurate and until it achieves the best performance, maintains a temperature of 5°C, and adapts to its surroundings. From the research done, the membership 2 with load shows the near accurate temperature of 5°C with steady-state error ±1.97°C.

Keywords: Fuzzy controller, membership, variable speed compressor, temperature control, control effort

1 INTRODUCTION

Refrigerators work by converting the liquid refrigerant that circulates through them into a gas phase. This process, known as evaporation, cools the environment surrounding it and resulting in the intended outcome[1]. There are many different types of a refrigerator in the refrigerator industry, such as vapour compression refrigerators,air and gas expansion refrigerators, vapor absorption refrigerators, and others. Refrigerators systems are widespread in the natural gas processing sector, petroleum refining operations, petrochemical industries and chemical processes in the synthetic rubber manufacture, textile, plastic, etc.[2].

Fuzzy logic is a primary control system based on the degrees of input and output depending on the input and changing rates. In other words, the idea of assigning a particular output relies on the probability of the input condition. Fuzzy logic focuses on output definition according to assumptions[3]. It operates based on sets. Each set has specific linguistic characteristics that define the state of the prospective output. Depending on the outcome, each possible input state and state degree of change is part of the set. It operates on if-the-mind. These fuzzy sets are represented graphically using membership functions, and the output may be decided according to the membership level of each function. IF-ELSE logic determines the membership settings[4]. Three parts are essential in the fuzzy controller: the fuzzification process, rule extraction, and defuzzification process. The decomposition of a system's input or output into one or more fuzzy sets is known as fuzzification. The fuzzification technique allows system inputs and outputs to be represented in language terms, allowing simple rules to define a complex system[5].

This research needs to study a controller that can control temperature precision and analyse the membership of fuzzy controllers. To reach the desired temperature of 5°C, the refrigerator's input current must be appropriately regulated. The conventional circuit is updated in this segment with a resistance temperature controller known as an RTD. It also contains a newly updated circuit and a controller based on the Arduino MEGA microcontroller.

2 METHODOLOGY

In this project, a mini-refrigerator has been selected to carry on. The mini refrigerator had been modified with an RTD sensor, Arduino Mega and controller. The modification was made to improve the refrigeration system's temperature output precision. The refrigerator is adjusted until it achieves the best performance, maintains a temperature of 5°C, and adapts to its surroundings.

2.1. Experimental Setup of Refrigerator System

During this research, a minibar-sized Vapour Compression Refrigeration System-type refrigerator with dimensions of 51 cm x 48.9 cm x 48.8 cm, the storage capacity of 60 L, and a weight of 13.5 kg were used. The Hitachi CL 1588- DA variable speed compressors were used. The refrigeration system will function because of the pressure generated by the compressor. When the pressure of the refrigerant R600a changes, the characteristics of the refrigerant change as well. However, for the purpose of control, the system's input is represented by current, and the temperature response of the system represents its output. The refrigerator original control circuit was replaced with a custom build system. As input, the system makes use of a Resistive Temperature Detector (RTD)- sensor, and as a controller, and it makes use of an Arduino control unit that serves as a pass-through to Matlab. The system makes use of an output unit that consists of a single-phase diode rectifier, a three-phase inverter, a small DC-link film capacitor, and a permanent magnet synchronous motor as well as other components to perform.When design a fuzzy controller, the parameter of each output and input can set from the calculated frequency. Maximum frequency of this system is 350Hz and the minimum frequency is 0. When the frequency is high the speed of compressor is increase.

2.2. The Design of Frequency Logic Controller

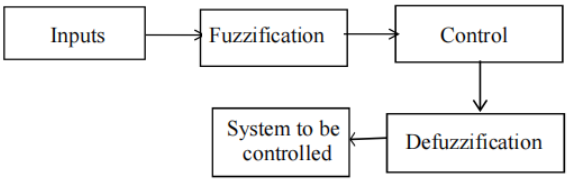


Fig. 1. Block Diagram of the Fuzzy Control System

A fuzzy logic controller was designed by using Matlab software. It is necessary to do three phases to build up a fuzzy logic controller: fuzzification, Inference, and finally defuzzification[6].

2.2.1 Fuzzification

The decomposition of a system's input or output into one or more fuzzy sets is known as fuzzification. It uses the membership contained in the fuzzy knowledge base to convert the crisp input to a linguistic variable. When it comes to systems, fuzzification is the process of identifying their input, output, and membership function[7]. Before designing the membership, the minimum range for temperature is 0°C, and the maximum is 35°C. The temperature needs to maintain at 5°C. For the speed, the minimum range is 0 Hz, and the maximum is 350 Hz. The function of the frequency is to control the speed of the refrigerator.

2.2.2 Inference

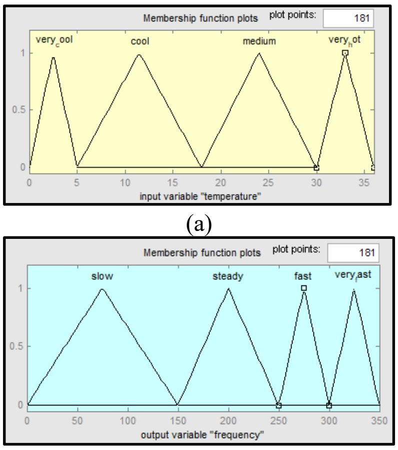
By extracting IF-THEN rules from a decision tree, a rule extraction classifier is created. When extracting a rule from a decision tree, one rule is constructed for each path from the root to the leaf node. Each splitting criterion is logically ANDed to generate a rule antecedent[8][9]. The class prediction is stored in theleaf node, which forms the rule consequent. So, for the fuzzy refrigerator, it had four phases: very cool, cool, medium, and very hot. The temperature needs to maintain at medium temperature. So, if the temperature is hot, then the speed will be faster. And if the temperature is cold, then the speed will be slower to maintain the medium temperature set.

2.2.3 Deffuzification

Defuzzification is the method through which a fugitive set with a crisp number is represented. Internal data displays in a fuzzy system are generally fuzzy sets. Fuzzy sets are commonly used as internal data representations in fuzzy systems[10]. On the other hand, the output is usually required to be a precise number that may be utilised to conduct a function. The centre of area approach (COA), also known as the centroid approach, is the most often used defuzzification method. This function returns the crisp value corresponding to the fuzzy set's centre of the area[11][12]. After the range had been confirmed, need to try the suitable membership and the size of membership to get the best output to reach the desired temperature of 5°C. The crisp output is the combination output that will analyse using Matlab.

2.2.4 Input-Output Membership of Fuzzy Controller

The membership function for the input temperature of the fuzzy logic controller is shown in Figure 2 (a). It was imperative to provide four different membership functions for the input temperature: very cool, cool, medium, and very hot. The membership function for the output frequency of the fuzzy logic controller is shown in Figure 2 (b). It was imperative to provide four different membership functions for the input temperature: slow, steady, fast and very fast. Trapezoidal and triangular geometric also had been used in this research with another data for membership. The parameter had been set for each of membership function based on the stability of the refrigerator.



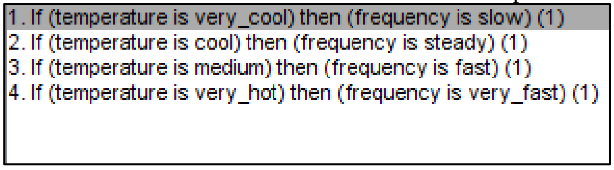
(a)

(b)

Fig. 2 The Relation of Input-Ouput Membership of Fuzzy Controller

2.2.5 Mamdani Law

The Mamdani law is shown in Figure 3 and is used in the decision-making process of the fuzzy logic controller. If the Fuzzy Inference System is of the Mamdani type, then both the input and output variables will include a collection of fuzzy sets[13]. The Mamdani law is a collection of principles that describe the connection between the temperature of the input and the output speed.[14] First rule objectsrepresent fuzzy if-then rules that relate input membership function conditions to corresponding output membership function conditions in a declarative method. The antecedent of a fuzzy rule is the part of the rule that describes the membership function for each of the variables in the rule's input [15].



1. If (temperature is very_cool) then (frequency is slow) (1)
2. If (temperature is cool) then (frequency is steady) (1)
3. If (temperature is medium) then (frequency is fast) (1)
4. If (temperature is very_hot) then (frequency is very_fast) (1)

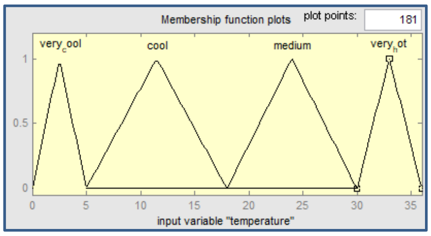
Fig. 3. Mamdani Laws of the Fuzzy Logic

3 RESULT & DISCUSSION

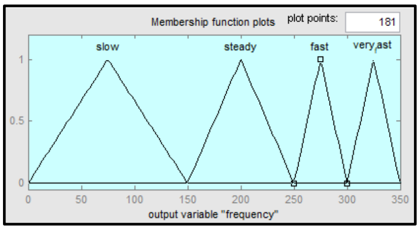
A few memberships had been tested to find the most accurate temperature for the fuzzy controller refrigerator.

3.1. The Performance of Control Effort and Temperature Response for Membership 1

Figure 4 shows that the fuzzy controller of membership 1. All the four membership functions for temperature and speed use a triangular geometric shape. For temperature input, very cool has the parameter of [0 2.5 5], cool has a parameter [5 11.5 18], the medium has a parameter of [18 24 and 30] and lastly, very hot has the parameter of [30 33 36]. For output speed, slow has a parameter [0 75 150], steady has a parameter of [150 200 250], fast has a parameter [250 275 300] and lastly, very fast has a parameter of [300 325 350].



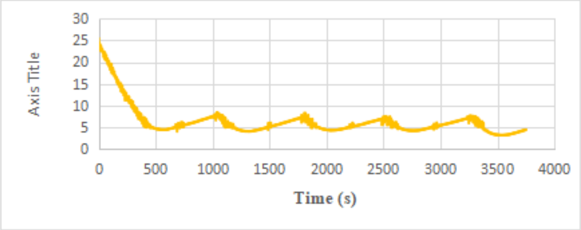
(a) Input variable (Temperature)



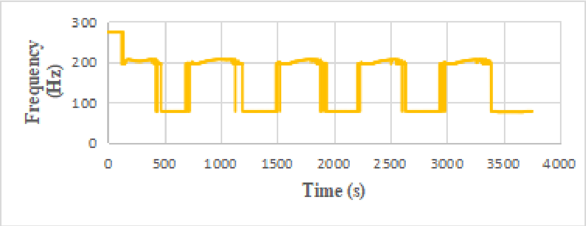
(b) Output variable (Speed)

Fig. 4. Membership 1 of Fuzzy Controller

Figure 5 shows the relationship between the control effort of the controller and its measured temperature for a Fuzzy-Logic Controller without load. The peak overshoot temperature for data 1 (a) is 8.24°C to achieve the desired temperature with a still respectable steady-state error of ±1.30°C. From Figure 5 (b), it can be seen that the control effort of the Fuzzy-Logic controller initially run at 272Hz before throttling down to 194Hz and then alternating between 78Hz and 194Hz. The alternating of the frequency follows the Mamdani law established before, where when the input temperature is medium, the output speed is fast while the temperature is very cool, the output speed will slow.



(a)

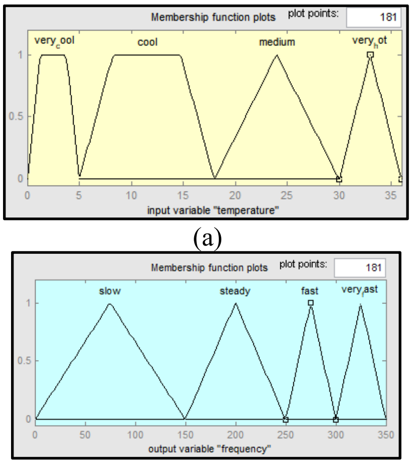


(b)

Fig 5. The Fuzzy-Logic controller performance (a) control effort, (b) temperature response for membership 1

3.2. The Performance of Control Effort and Temperature Response for Membership 2

Figure 6 shows the fuzzy controller of membership 2. For the input variable membership, trapezoid and triangular membership were used, and for the output variable speed, all four members used triangular membership. For temperature input, very cool has the parameter of [0 1.25 3.75 5], cool has a parameter [5 8.25 14.8 18], the medium has a parameter of [18 24 and 30] and lastly, very hot has the parameter of [30 33 36]. For output speed, the parameters use the same parameters as previous for membership 1.

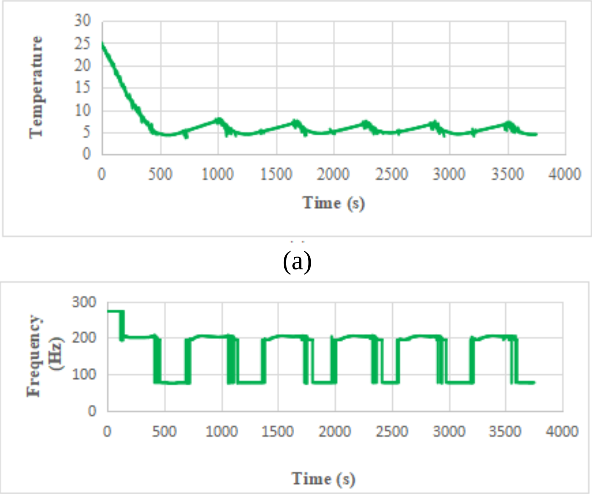


(b)

Fig 6. Membership 2 of Fuzzy Controller

Figure 7 shows the measured temperature for a Fuzzy-Logic Controller. The peak overshoot temperature for data 1 (a) is 7.54°C to achieve the desired temperature with a still respectable steady-state error of ±1.5°C. From Figure 7 (b), it can be seen that the control effort of the Fuzzy-Logic controller initially run at 272Hz before throttling down to 204Hz and then alternating between

77Hz and 194Hz. The compressor will stop entirely at 77Hz then will work again when the temperature gets higher.



(a)

(b)

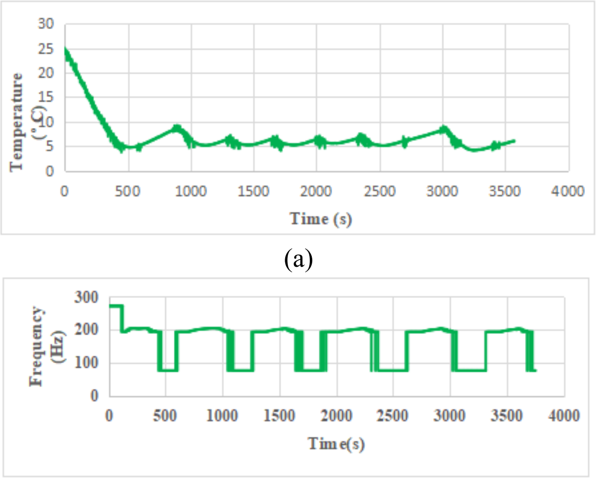
Fig. 7. The Fuzzy-Logic controller performance (a) control effort, (b) temperature response for membership 2

3.3. The Performance of Control Effort and Temperature Response for Membership 2 with load

Two fuzzy controllers had been tested to find the most precise temperature control for this refrigerator, with the desired temperature with the acceptable steady-state error of ±1°C. From the fuzzy membership without load, membership 1 is most precise from membership 2 with the average ±1.3°C. The water of 500ml also had been tested with the refrigerator to find out the refrigerator's performance. The result shows that with the load, data 2 is more precise than the fuzzy membership controller of data 1.

Table 1. Steady State Error of Two Membership

Figure 8 shows the relationship between the control effort of the controller and its measured temperature for a Fuzzy-Logic Controller with the load. The peak overshoot temperature for data 2 (a) is 8°C with a still respectable steady-state error of ±1.97°C. After the peak overshoot, the temperature has a steady temperature until 3000sec. Figure 5 (b) shows that the control effort of Fuzzy-Logic controller initially runs at 200Hz before throttling down to200Hz and then alternating between 194Hz and 205Hz. The graph frequency of data 2(b) with load almost constantly working.



(a)

(b)

Fig 8. The Fuzzy-Logic controller performance (a) control effort, (b) temperature response for membership with load.

4. CONCLUSION

In conclusion, the two fuzzy controllers could be designed, studied and compared the performance of each type of controller. The first fuzzy controller designed was able to achieve a steady-state error of ±2.02°C with a load while the second fuzzy controller was able to achieve a steady-state error of ±1.97°C. Even though the first fuzzy controller has lower steady-state error at ±1.30°C compared to the second fuzzy controller with ±1.52°C. The system also tested based on load is to know the performance of the refrigerator with the load. By comparing the temperature response between each fuzzy controller, it can be concluded that the fuzzy controller for membership 2 with load has the fastest settling time and a low steady-state error.

	Membership 1	Membership 2
Without Load	1.300610739	1.518598611
With Load	2.0234474	1.966741478

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