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Performance Evaluation of Mamdani-type and Sugeno-type Fuzzy Inference System Based Controllers for Computer Fan

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Abstract— Nowadays, there are several models of computer systems finding their ways into various offices, houses, organizations as well as remote locations. Any slight malfunction of the computer system's components could lead to loss of vital data and information. One of the sources of computer system malfunction is overheating of the electronic components. A common method of cooling a computer system is the use of cooling fan(s). Therefore, it is essential to have an appropriate control mechanism for the operation of computer system's cooling fan in order to save energy, and prevent overheating. Failure to adopt a well designed and efficient performance controller could lead to the malfunction of a computer system. Presently, most controllers in computer systems are pulse width modulation based. That is, they make use of pulses in form of digits, 0 and 1. It was observed that inherent noise is still prevalent in the operation of computer system. Also, eventual breakdown of components is common. A new approach is therefore investigated through the use of fuzzy logic to serve as a base or platform to build an intelligent controller using a set of well defined rules to guide its operational performance. Mamdani-type fuzzy inference system and Sugeno-type fuzzy inference system were used with two input sets each and a single output function each. Simulation was carried out in MATLAB R2007a platform and operational performances of the two approaches were compared. Simulated results of the performances of the Mamdani-type fuzzy inference system based controller and the Sugeno-type fuzzy inference system based controller are presented accordingly.

Index Terms— Fuzzy Logic, Inference System, Controller, Rule-Based Operation, Computer Fan

I. Introduction

A computer is a necessity in all areas of human endeavours as it has helped in getting results quicker with high efficiency. Meanwhile, before results could be obtained from a computer, series of actions or works have to be done by the computer on the raw-data (input) electronically[1]. For every machine that works, heat, noise, and undue power consumption result. In early computers, before 1975, computers were large and resident in rooms with cooling system as big as the room itself[2]. With the advent of smaller size computers, a means of cooling the computer system has to be developed as mobility and compatibility of computer system is highly desired. The central processing unit's processing power increases making the heat generated to be enormous. So, computer components such as Central Processing Units(CPUs), graphics card, and hard disk drives could malfunction temporarily or failed permanently if overheated[2]. Also, the need to conserve energy is now an issue of great importance to everyone worldwide.

Moreover, before the 'green campaign', most computer fans run at full load speed wasting energy in the process. Though fan cooling system is widely used to provide good ventilation for computer while it works but it is more important to be able to control and manage the rotational speed of the electric fan[2,3] in order to conserve energy and reduce operational noise.

In further sections of this paper, analysis of various methods of fan control, each resulting from innovative improvements on the existing methods were carried out [3]. New computer fan control approaches were also considered, namely;

1) Mamdani fuzzy inference system method; (2) Sugeno fuzzy inference system method. Comparison of the two approaches were done in order to determine the approach that is more robust.

The input quantities of the resulting controller are the operating temperature of the computer in ^{0}C and the computer load in percentage while the output quantity is the speed in revolution per minute(r.p.m). A well thought-out rules were developed to serve as the working base for the controller. Fuzzy inference systems were developed which comprise of four membership functions each for the quantities involved. The ranges of these quantities were defined as appropriate and the algorithm for performing the task was developed.

This work, therefore, focuses on the control of the speed of the computer fan using fuzzy logic controller.

The main content of this paper has five sections, namely; computer fan concept, fuzzy logic overview/experiment, results and discussion, and conclusion.

II. Computer Fan Concept

A computer fan according to Wikipedia(2012), is any fan inside, or attached to a computer case that is used for active cooling, and may be referred to as fans that draw cooler air into the case of the computer system from the outside, expel warm air inside the computer system, or move air across a heat-sink to cool a particular component.

It should be noted that the purpose of a computer fan is to create a cool working condition for the computer in order to prolong its lifespan and improve its operational capabilities. A cool working condition would reduce breakdown that normally result from overheat and maintenance issues would be minimized to the barest minimum.

2.1 Types of Computer Fan

According to an article titled “computer fan” on wikipedia(2012), computer fans come in various designates such as:

i. Case- mount-type which is used to aerate the case of the computer. This is necessary to provide a cool surrounding for the components.

ii. Power supply fan which is used to cool the power supply unit thereby preventing overheating of the components.

iii. Central processing unit (CPU) fan which is usually used to cool the CPU heatsink thereby cooling the CPU.

iv. Graphic card fan which is used to cool the memory of the graphic cards.

v. Chipset fan which is used to cool the heat sink of the northbridge of a motherboards’s chipset [1].

2.2 Existing Fan Control Methods

Computer fan can be controlled using these methods:

1) No Control

Under this method, once a computer is set up and swicthed on, the fan continues to work. This method of control increases power consumption and noise but provides very cool operation environment.

2) Thermostarts

A range of temperature is set, such as the upper limit and the lower limit. The thermistor is used to sense temperature in the computer and switches the fan on or off. Power is therefore managed as per usage. The draw-back is when the computer is under usage for a long period, power consumption increases.

3) Linear Voltage Regulator

This is another cooling fan that uses bladed dc motor. The voltage across the motor could be varied within the acceptable range for the fan, making the speed increases when voltage is added or reduces when voltage is reduced. This is given mathematically as;

$$Fan\ voltage \propto Speed \tag{1}$$

4) Resistors

Though resistors reduces the noise of the fan, they add to the heat of the computer. Care should be taken to have resistors whose values match the corresponding fans in order to have a desirable performance.

5) Diodes

Diodes are also used as a means of control.

6) Volt Modding

This is another method of controlling the speed of a computer fan. The voltage to the fan could be controlled by interchanging of connector leads to ground thereby altering the overall voltage delivered across the fan connector.

7) Pulse Width Modulation

This is a common method of controlling fans. The speed of rotation is monitored by sense pin. The mathematical relationship between the control signal and the speed control is given as follows:

$$Control\ signal \propto Speed\ control \tag{2}$$

$$Speed\ control = k \times Control\ signal \tag{3}$$

Where k is constant.

Or we can say that:

$$Control\ signal = k \times Speed\ control \tag{4}$$

In equations (2), (3) and (4), the control signal is a square wave operating at a frequency of 25kHz and the resulting duty cycle determines the fan speed.

The range of speed control is 30% and 100% of maximum computer load. When the computer is maximally loaded, a control signal of up to 100% duty cycle could be used.

However, the shortcomings of pulse width modulation control are noise and eventual breakdown of computer fan system due to persistent vibrations.

8) Software Control

Software are now being used in Microsoft Windows platform to control fan speed on the motherboard as the motherboard has a temperature sensor. This will help in reducing the CPU noise. Other independent software developers are also making frantic efforts to promote their fan control software products but cautions have to be taken by the intended user.

2.3 Speed Behaviour of Computer Fan

There are three types of speed behaviour of computer fan such as:

i. Linear

ii. Off until a threshold value

iii. Minimum speed until a threshold.

At low control levels the speed behaviour is determined by the manufacturer.

III. Overview of Fuzzy Logic/Experiment

Fuzzy logic is a type of mathematical logic whose truth value is not exactly 0 or 1 but increases or decreases continuously from 0 to 1. It was developed from the theory of fuzzy sets by Lofti Zadeh (1965)[3]. Fuzzy logic could be viewed from a broad and a narrow angle. Broad angle in the sense that its application could be older, better known, heavily applied but not asking deep logical questions. This broad view approach is the apparatus for fuzzy control, analysis of vagueness in natural language and several other applications. This is one of soft-computing techniques making it to be "suboptimality" tolerant, vague, quick, simple and sufficiently good solutions.

On the other hand, fuzzy logic in the narrow sense is symbolic logic with a comparative notion of truth developed fully in the spirit of classical logic. It is a branch of many valued logic based on the paradigm of inference under vagueness. In other words, fuzzy logic deals with the reasoning that is approximate rather than fixed and exact[4].

Fuzzy logic is fast gaining popularity with the manufacturers as many consumer electronic products like washing machine, air-conditioning unit, water heater, rice cooker and so on are now fuzzy logic controller based.

3.1 Block Diagram of Fuzzy Logic Controller

The fuzzy logic controller is set up as shown in figure 1. Two input quantities(load in percentage and temperature in ^{0}C) were applied to the comparator where the value of output is compared with the set point or input quantities. Fuzzificationn is carried out and fuzzy rule is applied for proper control actions. Inferences were drawn and defuzzification done in order to get the output which is fed back to the comparator for comparison. The cycle is repeated until a satisfactory result emerges.

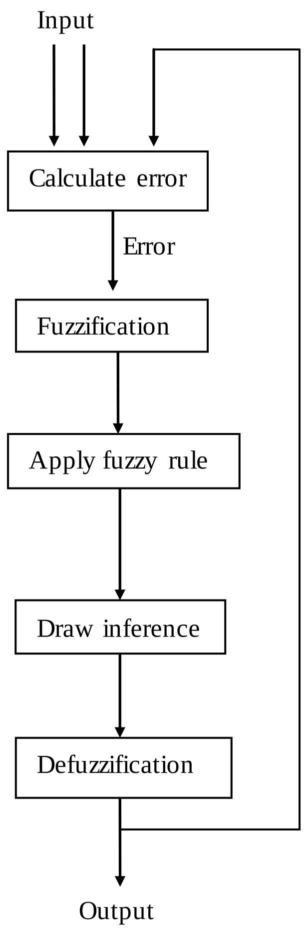

Fig. 1: Fuzzy logic controller

3.2 Algorithm for the Fuzzy Logic Controller

Application of fuzzy logic to computer fan control is aimed at utilizing the precise solutions provided by fuzzy logic from certain or approximate information[5,6]. As most computer fan controls are based on the pulse width modulation(PWM) method, in an overdamped or underdamped situation, undesired control response is experienced by the fan. Therefore, fuzzy logic based algorithm is developed for the computer fan controller as explained below:

Mamdani type fuzzy inference system and Sugeno type fuzzy inference system approaches were considered.

Mamdani membership function method is first used for the controller design. Two input variables whose values are defined represent the fuzzy sets. These variables have range definitions. The output variables is also defined by a fuzzy set. Four membership functions and truth values were defined over these ranges. The operational rules were applied to generate a result for each rule before a combined operational rules were applied which then combines the results of the rules[7,8,9]. The inputs variables were loads and temperature derivable from sensors. The output of the controller is the quantity that controls the speed of the fan. The load quantity for the computer ranges from 0% to 66.7%. The temperature quantity ranges from 39°C to 56°C. The output quantity which is the speed ranges from 644 revolutions per minute(r.p.m) to 745 revolutions per minute(rpm).

It should be noted that 'load' being used here refers to the 'heaviness of task' that the computer does and is rated in percentage.

By using the fuzzy logic graphical user interface, the fuzzy inference system(FIS) for the Mamdani type based controller is shown in figure 1 below:

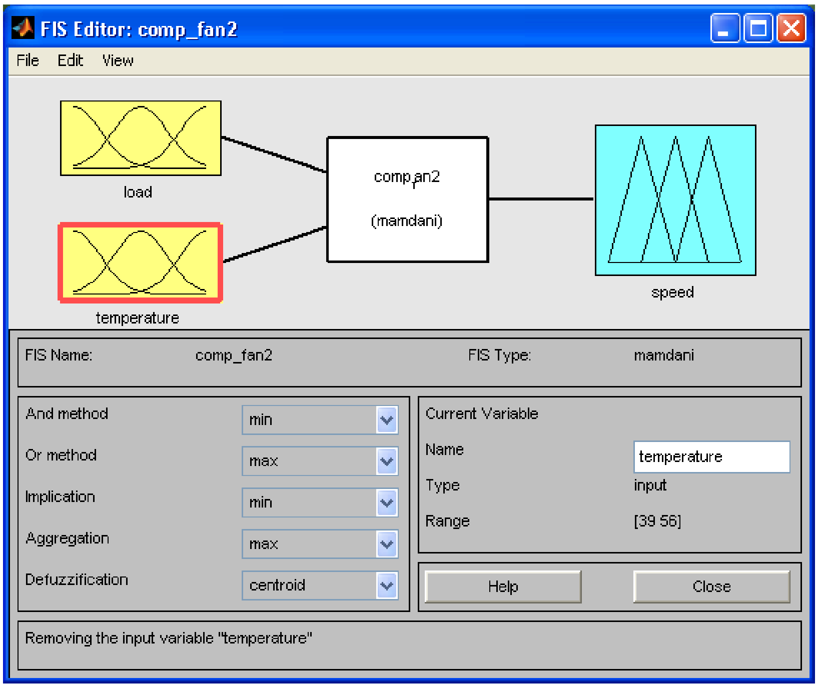

Fig. 2: Mamdani - Type FIS fan controller

Each input variable has four membership functions as shown in figure 3 and figure 4 respectively.

The load membership functions are; minimum, light, moderate, and maximum while the temperature membership functions are; very low, low, high, and very high.

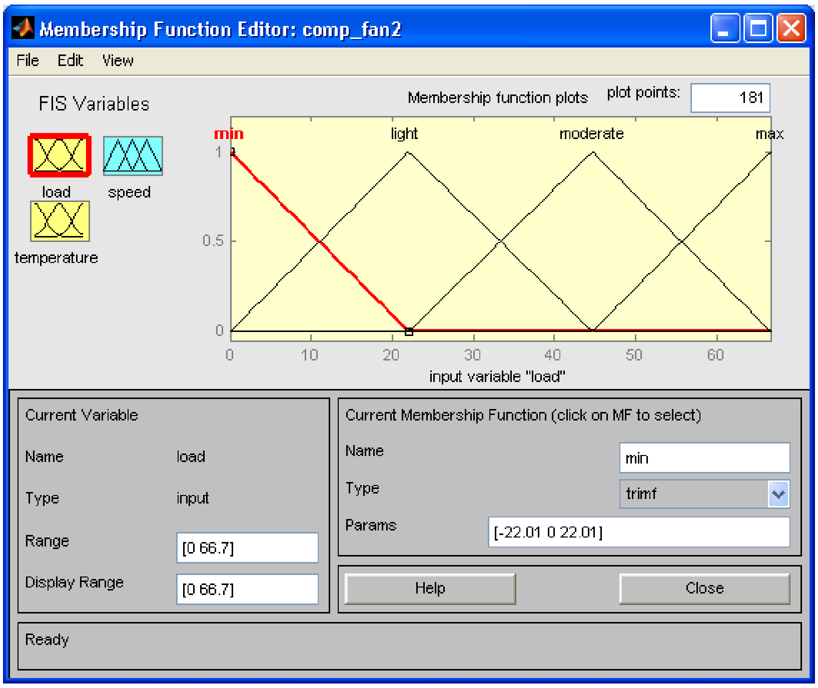

Fig. 3: Membership function for load input variable

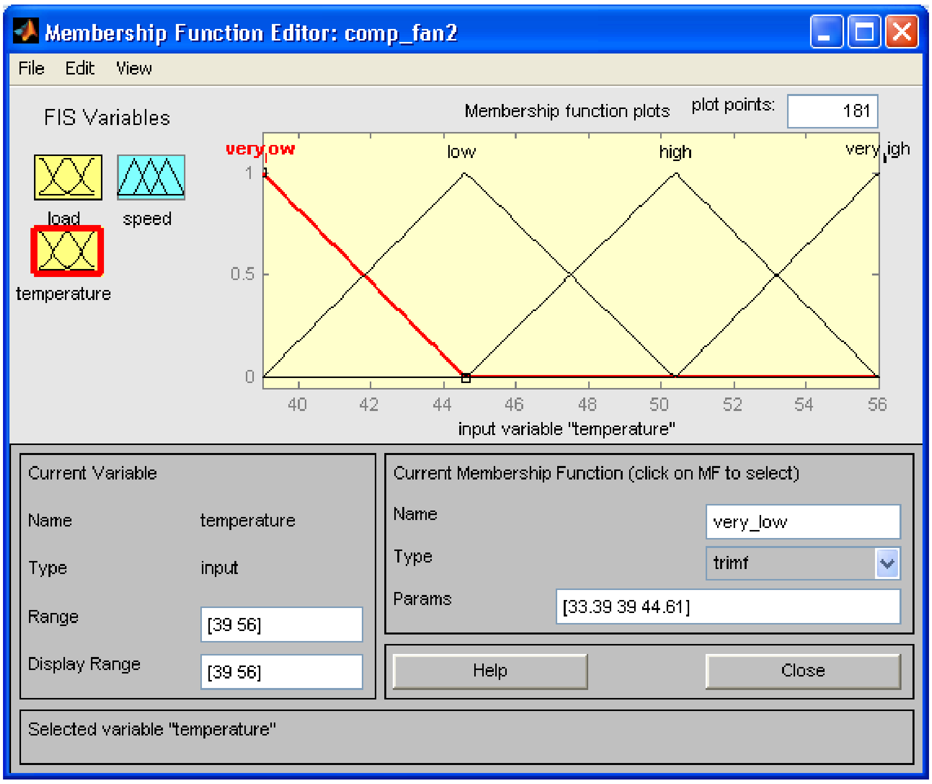

Fig. 4: Membership function for temperature input variable

The output variable also has four membership functions namely; very low, low, moderate, and high as shown in figure 5 below:

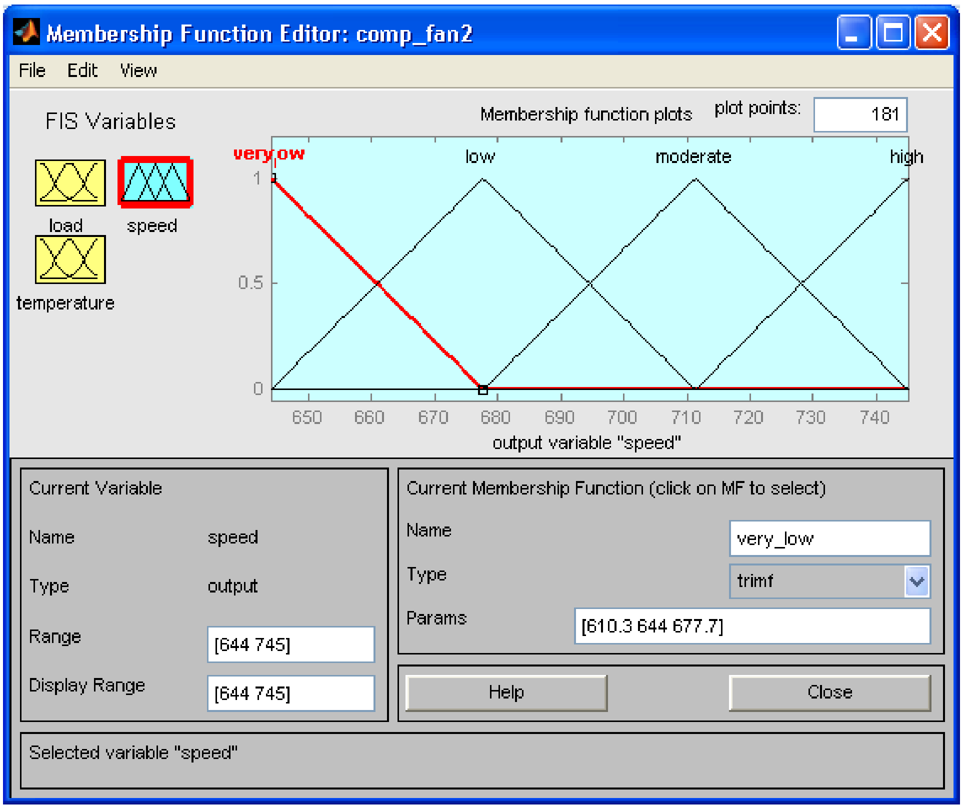

Fig. 5: Membership function for the output variable

3.3 Fuzzy Controller Rules

The rules governing the operation of the fuzzy logic controller is given in table 1 below:

Table 1: Computer fan Fuzzy inference rules

Rules	Load (Input 1)	Temperature (Input 2)	Fan-Speed (Output)
1	Maximum	Very low	Very low
2	Maximum	Low	Low
3	Maximum	High	Moderate
4	Maximum	Very high	High
5	Moderate	Very low	Very low
6	Moderate	Low	Low
7	Moderate	High	Moderate
8	Moderate	Very high	High
9	Light	Very low	Very low
10	Light	Low	Low
11	Light	High	Moderate
12	Light	Very high	High
13	Minimum	Very low	Very low
14	Minimum	Low	Low
15	Minimum	High	Moderate
16	Minimum	Very high	High

These rules in table 1 were applied to the inputs and the output of the Mamdani-type fuzzy inference system based controller and Sugeno-type fuzzy inference system based controller and displayed during simulations as follows:

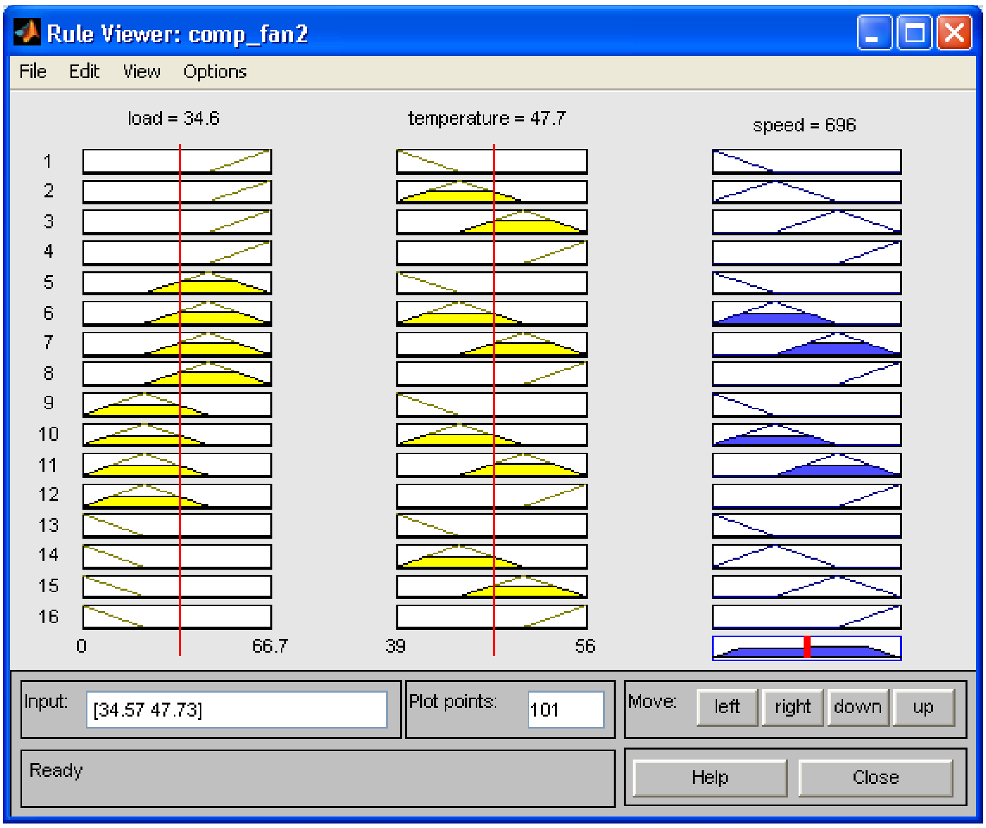

Fig. 6: Mamdani based rule viewer for the controller

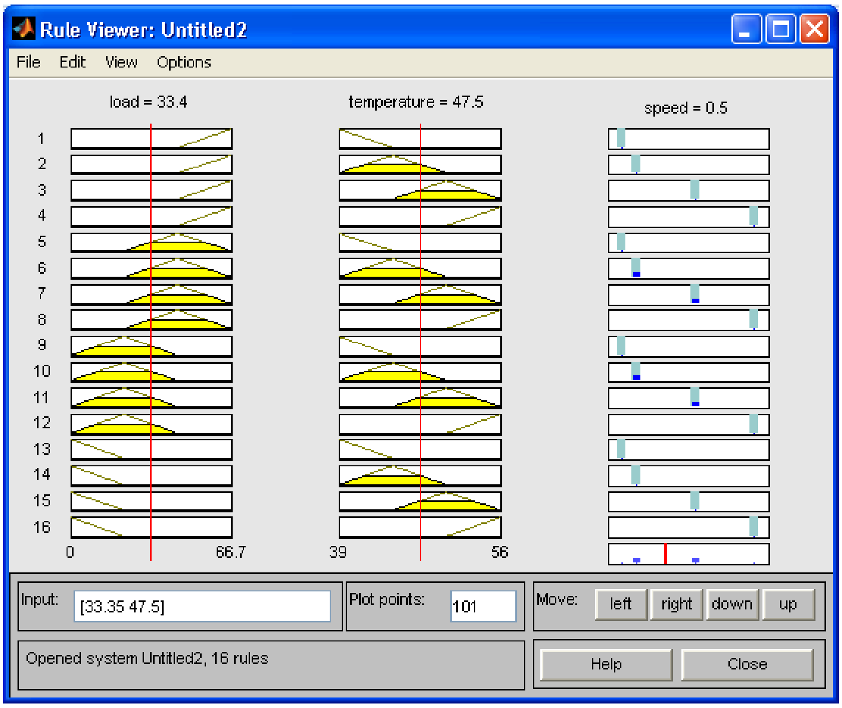

Fig. 7: Sugeno based rule viewer for the controller

IV. Results and Discussions

4.1 Mamdani-type FIS Based Simulation Results

The following results were obtained during the simulation of the Mamdani-type fuzzy inference system based controller:

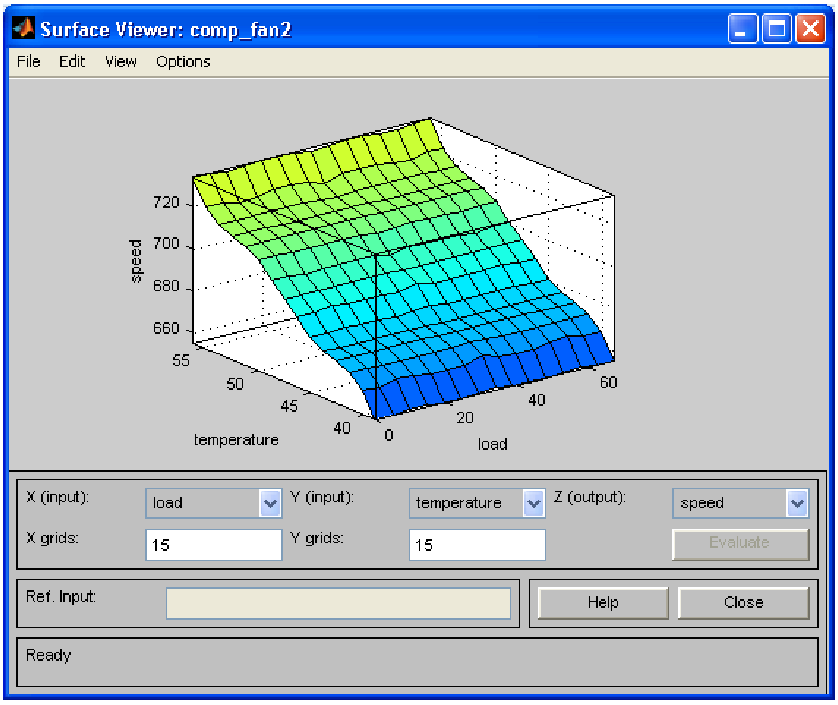

Fig. 8: Surface view of the output and the inputs

The surface view shows the three-dimensional view of the relationship between the load in percentage, the temperature in degree Celsius and the speed in revolutions per minute (rpm).

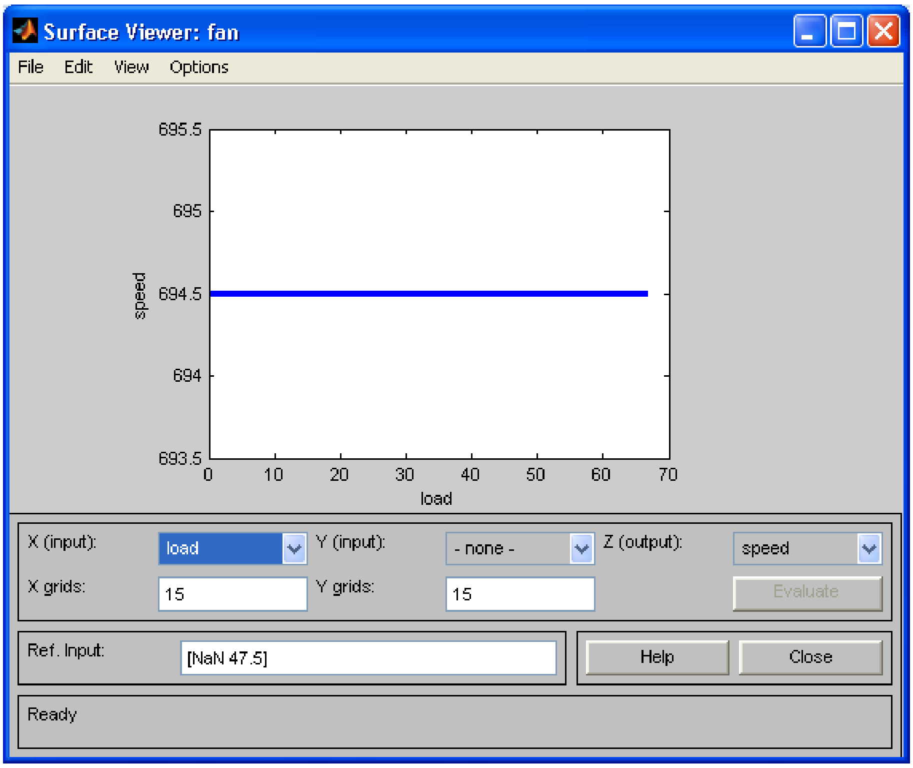

Fig. 9: Relationship between the fan speed and load

The surface view of the two dimensional view of the relationship between the output(speed) in revolutions per minute(rpm) and the percentage of load.

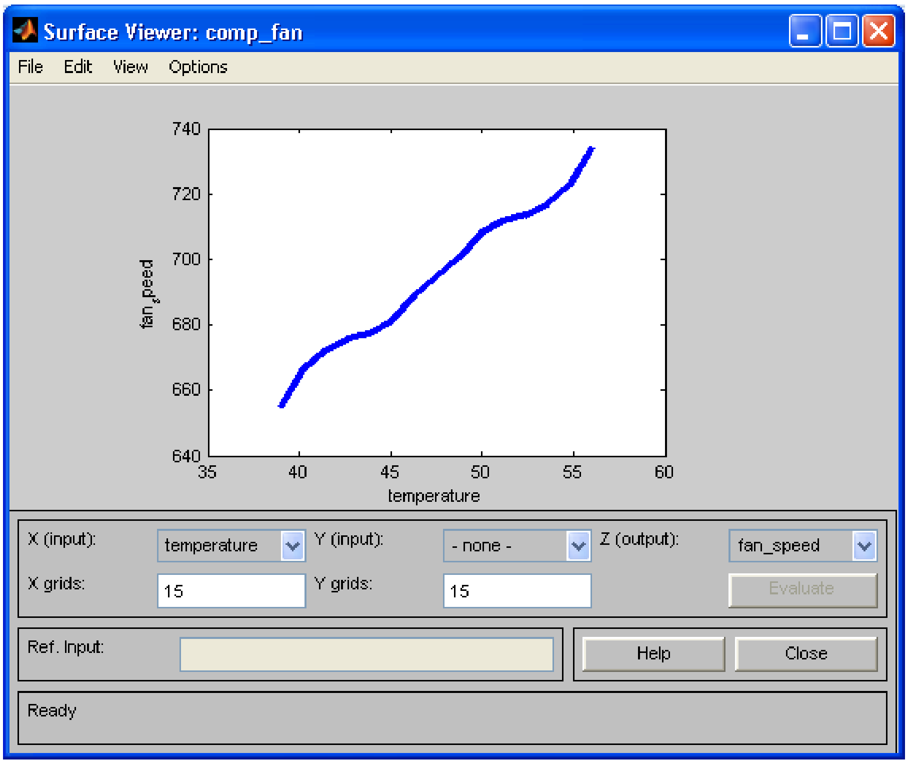

Fig. 10: Fan speed versus temperature

Figure 10 is the two dimensional view of the relationship between the speed(output) in revolutions per minute(rpm) and the temperature in degree Celsius(^{0}C).

4.2 Sugeno-type FIS Simulation Results

The same rules were applied to the inputs of the Sugeno-type fuzzy inference system controller. Membership functions were four for each input quantity as in the case of Mamdani-type fuzzy inference system. Unlike the output value range of the Mamdani-type fuzzy inference system, the range of Sugeno-type output is between 0 and 1 making it to be fit for automatic optimization by the algorithm. This set of rules that were applied to the output is given in table 2 below using constant fit function of the matlab's version R2007a graphical user interface:

Table 2: Fan speed Ranges

Computer fan speed	Constant value
Very low	0
Low	0.33
Moderate	0.66
High	1

The following results were obtained during the simulation of the Sugeno-type fuzzy inference system based controller for the computer fan system having its output (speed) function as shown in table 2.

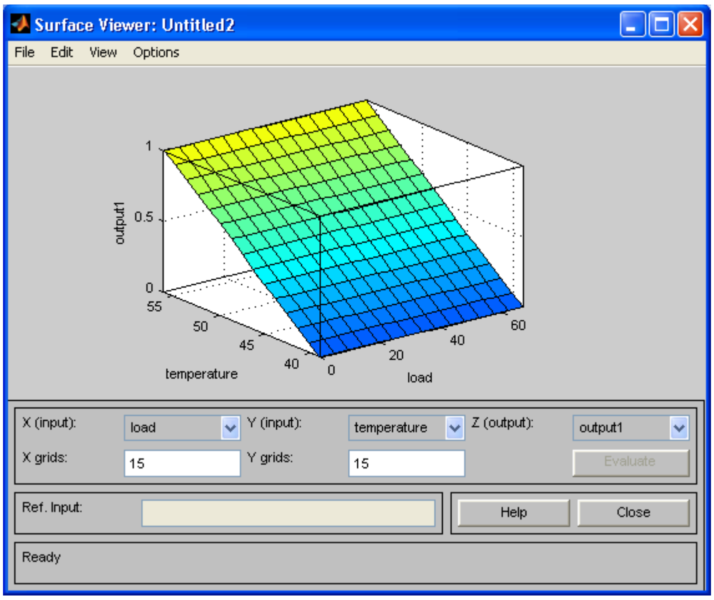

Fig. 11: Relationship between the output and the inputs

Figure 11 shows the three-dimensional relationship between the speed(output) in revolutions per minute(rpm), the temperature in degree Celsius (^{0}C), and the percentage of load.

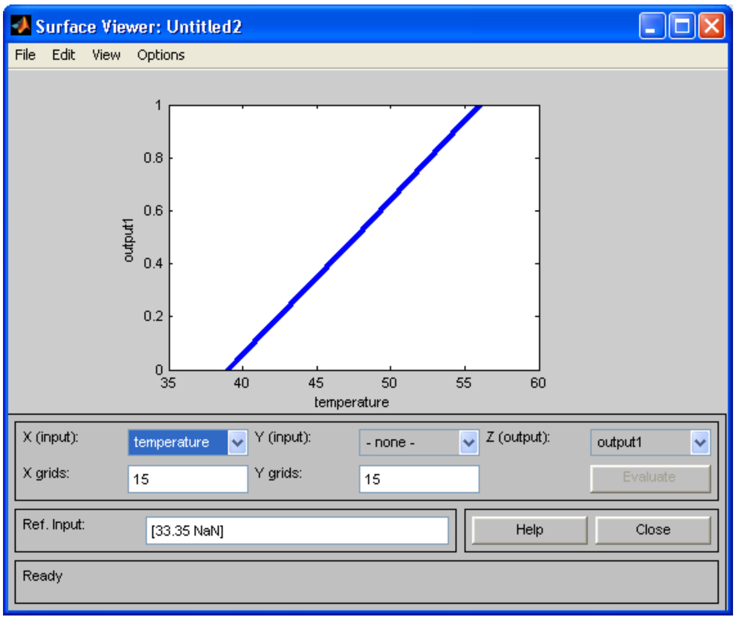

Fig. 12: Fan speed versus temperature

Figure 12 shows the two dimensional relationship between the speed(output) in revolutions per minute(rpm) and the temperature in ^{0}C.

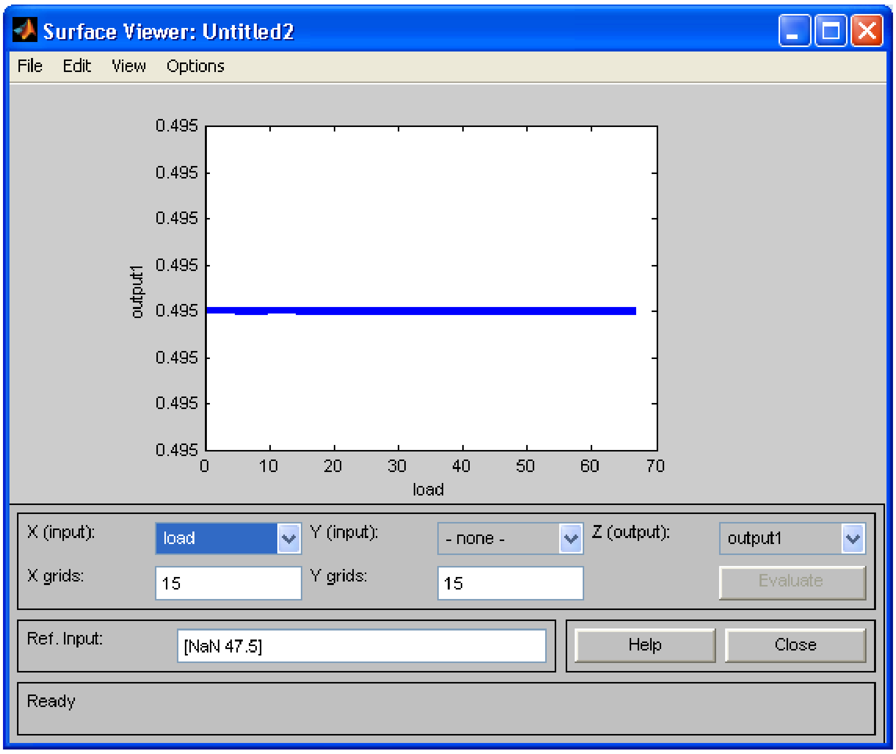

Fig. 13: Fan speed versus load

Figure 13 shows the two dimensional relationship between the speed(output) in revolutions per minute(rpm) and the percentage of load.

4.3 Discussions

Results obtained shows that the sugeno-type fuzzy inference based controller has a smooth operational performance than that of the mamdani-type fuzzy inference based controller. Also, the the sugeno-type fuzzy inference system based controller works to full capacity unlike that of mamdani based fan controller.

It is also noted that the Sugeno-type fuzzy inference system based controller, respond to inputs values changes quite efficiently more than the Mamdani type.

The two inference systems (Mamdani-type and Sugeno-type) responded to operational changes as determined by the input quantities' working variations.

V. Conclusion

The development of Mamdani-type fuzzy inference system based computer fan controller and Sugeno-type fuzzy inference system based computer fan controller could be used to control the computer fan operations. Sugeno-type fuzzy inference system based computer fan controller gives better result in terms of performance and adaptability to other user defined environment making it highly flexible. Thus, optimization of fuzzy inference system could be done by a well defined set of algorithms.

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