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Study on fuzzy systems and concepts: review papers

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K E Y W O R D S: Fuzzy Logic, Fuzzy Controller, Fuzzy Logic Overview

ABSTRACT: The application of fuzzy is wide, ranging from control, computer and mechanical engineering to chemistry and even psychology. Nowadays, scientists would like to develop their systems more intelligent and as a result, intelligent air conditioners, intelligent traffic light, smart TV, etc. has been developed which the base of their intelligent is fuzzy logic. In this paper, we will cover the basics of fuzzy logic and fuzzy control systems, and we will review one journal paper published in this field.

Introduction

The literal meaning of word Fuzzy means vague or blurred. The real world is too complex to describe an exact model for a system. It means that the disturbances entered to a system are too much that scientists eliminate the least important of them or use approximation (Fuzzy) for that system. There are also some concepts which mathematically cannot be introduced. For example the concept of remoteness for a distance is based on one's mind and a far distance for one person may seem a short distance for another. Therefore we cannot identify a mathematical formula to say whether a distance is far or near. Such problems are being called fuzzy problems and could be solved by human experience. In another word, the mathematical equations describing for them are based on human experience and not a previous theorem. Fuzzy systems are those systems which use a rule base or knowledge base (mostly IF THEN rules) identified and designed by an expert of that system. These systems are mostly used to control other systems. [Wang,1997]

Fuzzy systems use fuzzy logic introduced by Professor Lotfi Askarzadeh in 1965 at University of Berkeley California. The early applications of fuzzy systems were in Japan where the most modern underground train system controlled by Fuzzy Logic Controller (FLC) or an earthquake prediction system which developed using this technique [Kosko,1993]. Nowadays, the FLC is being used widely in applications ranging from control, signal processing, communications, integrated circuit manufacturing to medicine, business and even psychology [Wang,1997].

In this survey, we will shortly cover the basics of fuzzy systems and their components. In the other stage, we will introduce a few scholarly publications and discuss about their results. Our focus will also be on application of fuzzy systems in control engineering which have made it possible to develop intelligent systems such as Smart TV or intelligent condition airs.

History of fuzzy theory

` The idea of Fuzzy theory was introduced by Professor Lotfi Askarzadeh [lotfi,1968], a well-known control scholar in 1965. After that, he also proposed the concept of fuzzy algorithms [lotfi,1968] fuzzy decision making [lotfi,1970] and fuzzy ordering [lotfi,1971]. Since fuzzy theory's birth, many scientists endorsed and worked on this new idea. The first application of fuzzy on a real system was developed by Mamdani and Assilian who used a fuzzy logic controller to control a steam engine [mamdani,1974]. Since then, the control engineers trusted and started working on development of fuzzy logic controller for their systems. The application of fuzzy on a large scale systems happened after 1980s where Japanese scientist Sugeno, used fuzzy logic controller to control a water purification plant. He also made the first self-parking car in 1983 using fuzzy logic controller [Sugeno and M. Nishida,1985]. Yasunobu and Miyamoto also started a project in Hitachi company on 1980 about development of the world's most modern subway system which they used fuzzy logic controller to control it. Because of those huge innovations, the year 1990 was named "Fuzzy year" in Japan [1]. Since then, the application of fuzzy Logic on various fields has been very wide. Today almost all smart applications are using fuzzy logic to perform.

Fuzzy Sets

Crisp set

In mathematics, a set is defined as a collection of things which can be anything; numbers, people, letters, other sets and so on [Stoll,1979]. By this definition, an item either belongs to a set or does not belong to it. This definition is being called "Crisp Set".in another word, the membership function for an item in Crisp set rule is either 0 (for not being the member) or 1 (for being a member). Let's look at an example. A set includes people taller than or equal to 6 feet. Using Crisp set, this set can be represented as figure 1.

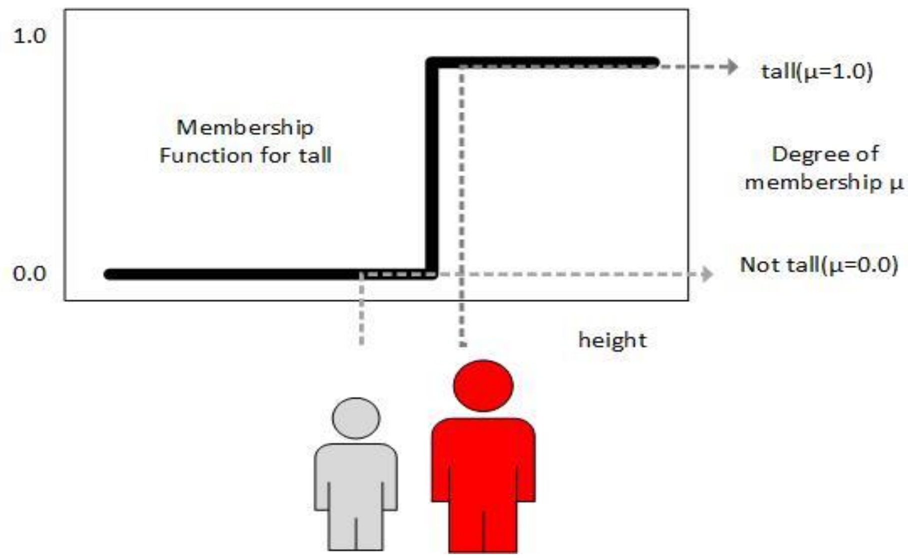

Figure 1. Set of people taller or equal to 6 feet in Crisp Set Definition

Using this technique, a person who is 5.9 feet, is 100% short or a 6 feet person is 100% tall. This technique however is exact and could be proven and defined by mathematical expressions, but it has huge inequality in it. Let's assume we want to develop a controller for an air conditioner based on this system. We say when the weather is 30 degrees or higher, then the fan should start to work. Using this, the system believes that the degree 29.9 is not warm enough to start the fan; however there is only 0.1 degree difference.

Fuzzy Sets

In comparison with Crisp Set, Fuzzy set represents a better and equal representation to the Sets. For the example of people's tallness, the membership function can be represented as below:

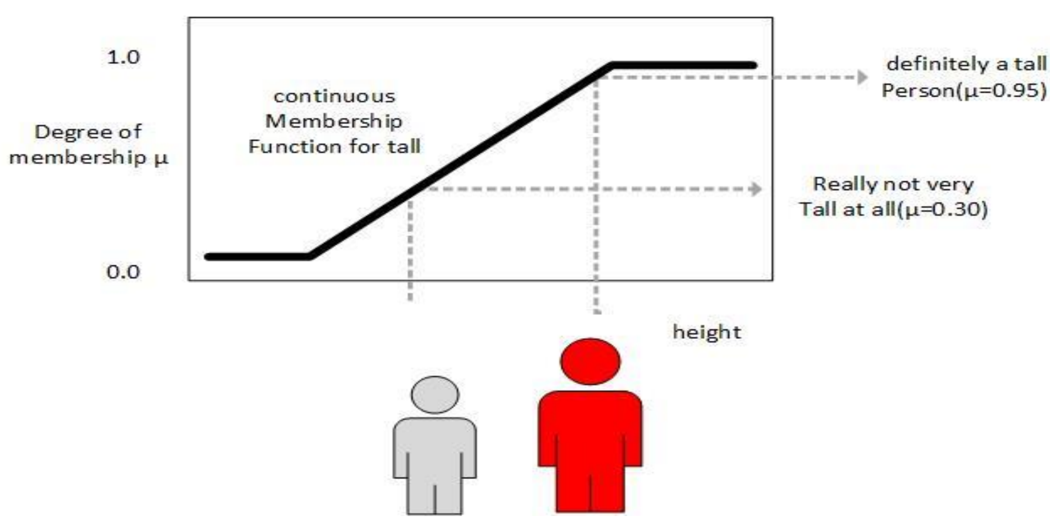

Figure 2. Set of people taller or equal to 6 feet in fuzzy set definition

In this case, an object to some extent can be member of a set. As for the above graph, the taller person is 95% tall but the shorter person is only 30% tall. As it can be seen, the membership of an object in fuzzy set can be expressed as a decimal number between 0 and 1 [3].

In a fuzzy set, each member may be part of several sets. Let's take a look at another example:

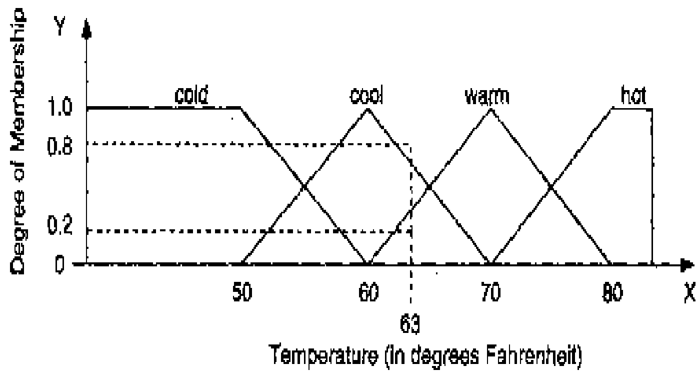

Figure 3. Fuzzy Sets for temperature

Figure 3 shows an example of fuzzy sets for temperature. As it could be seen 63 degrees Fahrenheit is both belongs to set warm and cool however the degree of membership for coldness is higher (0.8) than coolness (0.2). it means that 63 degrees rather than being warm, is a cool temperature But fuzzy system must consider both sides so fuzzy system uses algorithms and equations which helps to make a decision based on equality and fairness.

Fuzzy Set Membership Function

The membership function of a fuzzy set is the degree of truth of its objects. As mentioned before, for the set X, a membership function on X is any function from X to real unit intervals [0 1]. The value 0 means an object does not belong to a fuzzy set but value 1 means the object is fully a member of the fuzzy set or in another word; it is on the pick of the grades. Also a member could be considered as partial member of a set [1]. In figure 3, 63 degrees Fahrenheit is partially member of both cool temperature (0.8) and warm temperature (0.2). The Fuzzy set membership function is opposite to the idea of crisp set. To compare, both graphs could be illustrated as figure 4:

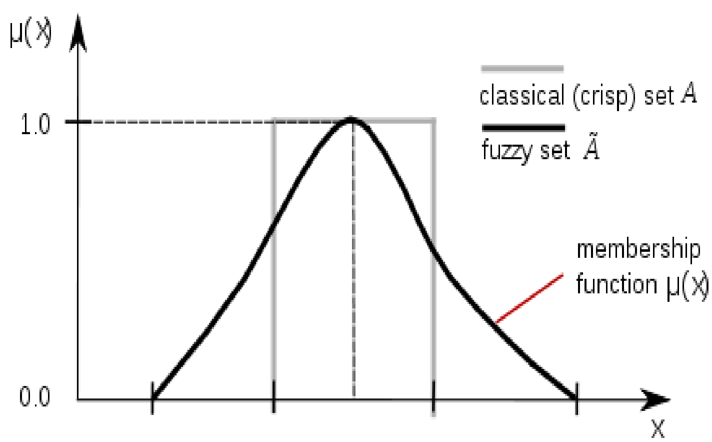

Figure 4. Comparison between Fuzzy membership function and Crisp set

In the Crisp set an object is 100% member of a set or it is 0% a member. On the other hand, objects' membership in Fuzzy set definition ranges from 0 to 1 and also it can contain more members than Crisp set members.

Ways to express membership function

Based on the characteristics of objects, the will of system designer or value of the membership of objects, a fuzzy set membership function can be shown as figure 5 [1]:

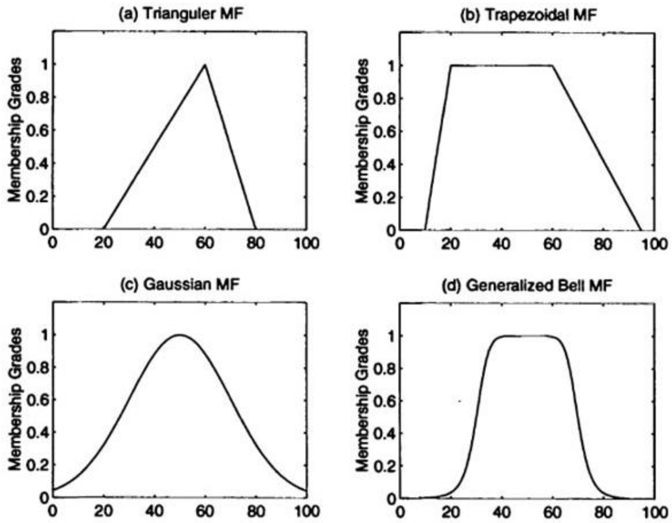

Figure 5. The ways to represent membership function of sets in fuzzy

As shown above, each membership function is being used in different conditions. For example, in a set which the numbers of objects which have the membership of 1 are high, the trapezoidal or Bell membership function is being used.

Linguistic Variables

For talking about Linguistic variables it is better to use an example. In our daily life, we are using words to describe variables. For example, to answer to the questions, how is the temperature, the person might say, it's COLD, or it's WARM. Clearly this question also can be answered by numerical values such as 18 degrees or 39 degrees but most of the time this coldness or warmness is based on the experience of human and it has vague value which cannot be expressed in mathematical way. That means a person is feeling hot but he is not sure about the exact temperature. In the same manner, a fuzzy set is a way to express the real world and experience-based problems.

A fuzzy is using daily-life expressions such as; "cold", "warm", "expensive", "very expensive",etc. for its membership values which are being called Linguistic Variables. Each Linguistic Variable has a range, which objects are member of it from 0% to 100%. In figure 7, speed of the car between 0 to 35 mph is 100% slow. But in higher speed, its membership to slow set is decreasing but in medium set is increasing. The medium set contains the speed between 35 to 75 mph, however for example the speed 37 mph is more the member of slow, rather than medium speed. In the same manner, the speed 70 mph and more can also be the member of fast speed. The membership function for medium is a triangular one which means only 55 mph is 100% belongs to the set medium. 49.9 or 55.1 are not 100% member. The speed 75 or higher is 100% fast.

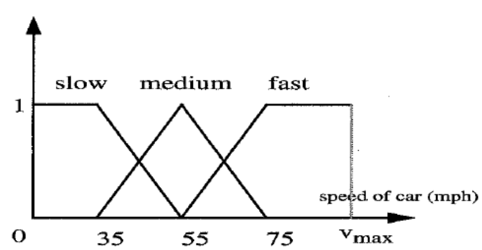

Figure 6. Linguistic Variables

If- Then Rules

The rules in fuzzy logic, follow IF-THEN rules. With using linguistic variables, the rules in fuzzy logic looks like a daily-life conditions. A basic IF-THEN rule is like below:

If x is A then y is B

For example, as a daily-life condition we know if a distance is far, then we should take a taxi, or if the distance is short, then we can walk to our destination.

If distance is Far then to get there is taking taxi

Let’s assume that you are visiting a restaurant. Then if you liked the service then you will pay high tip to the waiter. If the food was so so, then you pay average money and if you didn’t like the service you will not pay anything as a tip.
If food is good then tip is high
If food is so so then tip is average
If food is Bad then tip is Zero

In some cases, you have to check other conditions for the rules you are making too. For example, you liked the food but service was not bad, then you will pay average amount of money or let’s assume that the service was good but food was bad, then you will pay a little amount as a tip.
If food is good and service is bad then tip is low
Also instead of “AND” you can use “OR”, when you want to reach to a decision based on any 2, 3 or more conditions.

Fuzzy inference engine

Fuzzy inference engine is a place to formulate a given input to an output using fuzzy logic. The Basic schematic of the job which Fuzzy inference engine is doing can be shown as below:

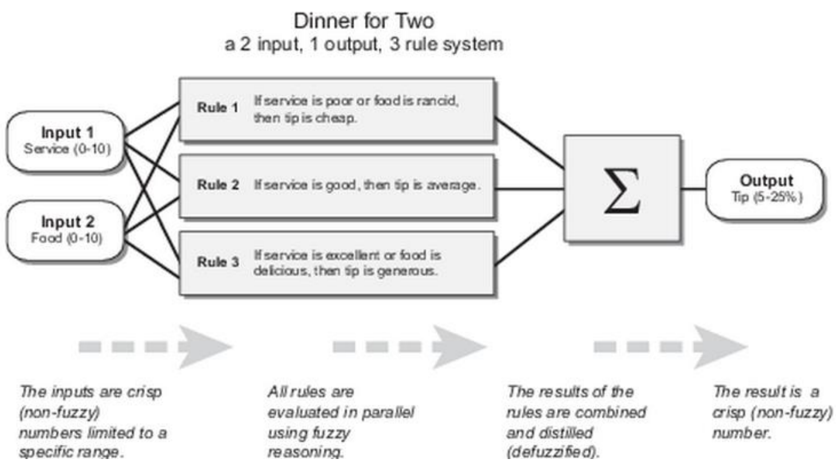

Figure 7. Fuzzy inference engine overview

In figure 8, there are 2 conditions as inputs. A limited numerical value (crisp value) will express the quality of food and service, and then based on the knowledge base, rules will be made.

Fuzzy System Components

The fuzzy system, consists of Fuzzy Inference Engine, Fuzzifier, Knowledge Base, decision making unit and defuzzification unit [1].

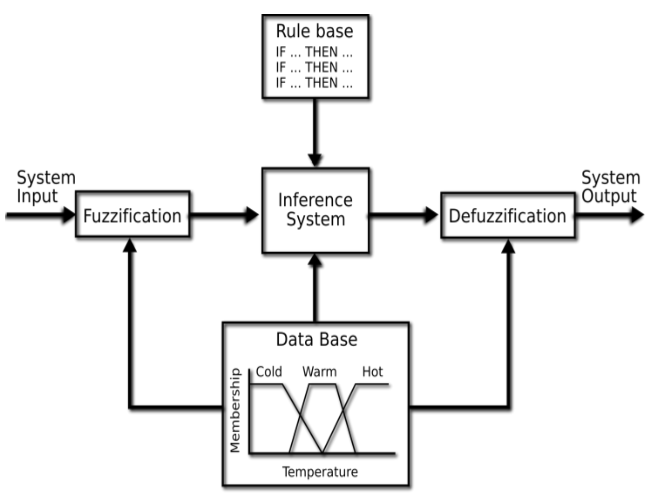

Figure 8. Fuzzy System Components

The steps inside fuzzy system are as follow [1]:
System input: values which are a numeric value (Crisp set) are collected by sensors and will be sent to the system as input.
Fuzzification: values are numeric which means they are in Crisp form. In order to become understandable by inference system, they need to be changed to fuzzy values. In fuzzification unit, the value is being changed to a linguistic variable and based on database which includes membership functions, the rate of membership of each value will be found.
The inference system checks the rule base and retrieves the best rule and decision which is applicable based on the fuzzy value.
The controlled systems such as air conditioner or mechanical devices only understand crisp values so the chosen fuzzy rule by inference system must be defuzzified into a numeric value. Defuzzification unit based on the membership function in data base, converts the fuzzy values into crisp set.
In next sections we will discuss about the application of fuzzy on systems.

Control of Automobile Air Conditioner Based on Fuzzy Logic Controller

In this section the Paper [Zhao,2009] will be discussed. In this paper a vehicle's air conditioner has been simulated and tries to control the temperature inside the car in summer using Fuzzy Logic Controller. The simulated system's diagram can be expressed as below:

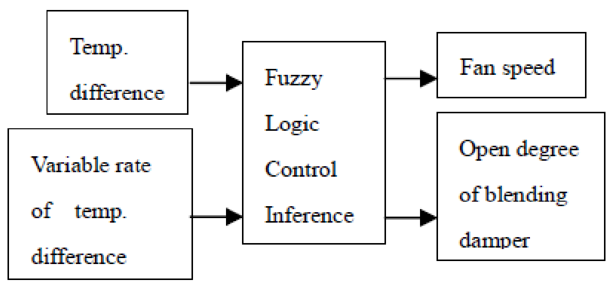

Figure 9. FLC System Diagram of Automobile Air-Conditioner

The input to the system is Temperature difference and Variable rate of temperature difference. Temperature difference is subtraction between desired temperature and current temperature. In other words it is the error which FLC should try to decrease it to zero. The variable rate of temperature difference is a variable which indicated the rate of force which FLC should give to system to obey the orders. If a high grade is chosen, the system may consume more energy. Also a lower grade may not have effect on the system so finding that variable is very important and it's based on human experience or computational intelligence techniques such as genetic algorithm which measures the output and system energy consumption and based on that the better variable will be chosen. The output of the system also as it could be seen is the damper's degree and fan speed.
The designer of the system has defined the inputs and outputs to be categorized as below:
Error={-5,-4,-3,-2,-1,0,1,2,3,4,5}
variable rate of temp. difference={-3,-2,-1,0,1,2,3}
Fan speed: {0,1,2,3,4,5}
Damper angle={0,1,2,3,4,5}
And by making it to linguistic variable it will be a set like below:
Error, Var Rate Diff{NB,NS,Z,PS,PB} Fan Speed, Damper {ZE,PZ,PS,PM,PB}
Where NB means Negative Big, NS is negative small, Z is Zero, PS is positive small and PB is positive Big and PZ means Positive Zero. The membership function of the inputs and outputs are also being represented as below:

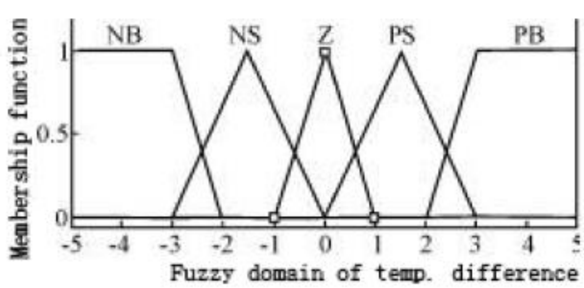

Figure 10. Membership function curve of temp. difference

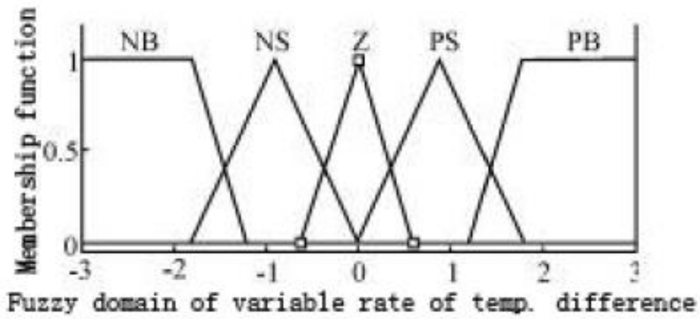

Figure 11. Membership function curve of variable rate of temp. difference

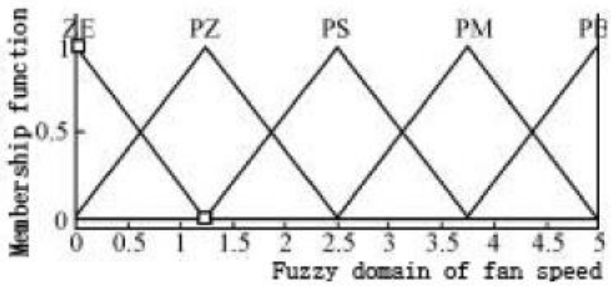

Figure 12. Membership function curve of fan speed

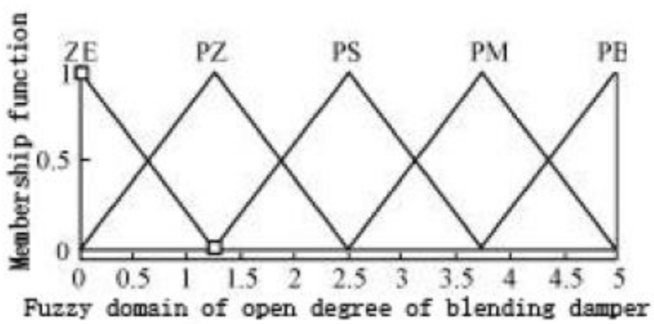

Figure 13. Membership function curve of blend damper

The rule base figure 14 for fan speed is also defined as below:

		EC				
		PB	PS	Z	NS	NB
	PB	PB	PB	PM	PM	PM
	PS	PM	PM	PM	PS	PS
E	Z	PZ	PZ	ZE	PZ	PZ
	NS	PS	PS	PM	PM	PM
	NB	PM	PM	PM	PB	PB

Figure 14. FLC rule list of fan(U)

As an example two rules could be written as below:
If E is PB and EC is Z then Fan Speed Scale is PM
If E is NS and EC is NB then Fan Speed Scale is PM
The rule base for the blending damper also is defined as below:

		EC				
		PB	PS	Z	NS	NB
	PB	PB	PB	PB	PB	PB
	PS	PB	PB	PB	PM	PM
E	Z	PM	PM	PS	PZ	PZ
	NS	PZ	PZ	PZ	ZE	ZE
	NB	ZE	ZE	ZE	ZE	ZE

Figure 15. FLC rule list of bkending damper(U)

The simulated Fuzzy Logic Controller in computer is as below:

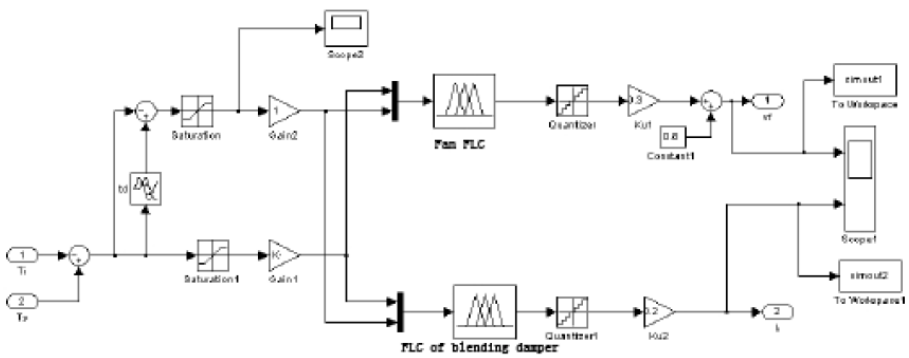

Figure 16. Simulated Fuzzy Logic controller

The result of developed system has been shown as below figure:

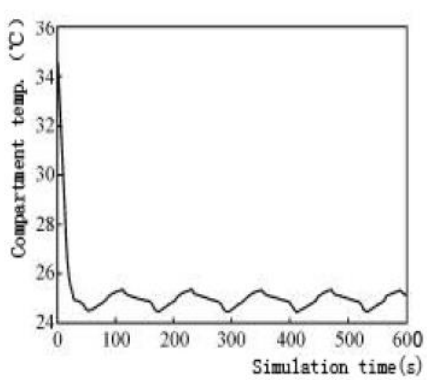

Figure 17. Changing curve of compartment temp. in summer

In above figure, the temperature inside the car is about 35 degrees. The input to the system is 25 degrees so the controller controls the fan speed and the damper in order to reach to that point.

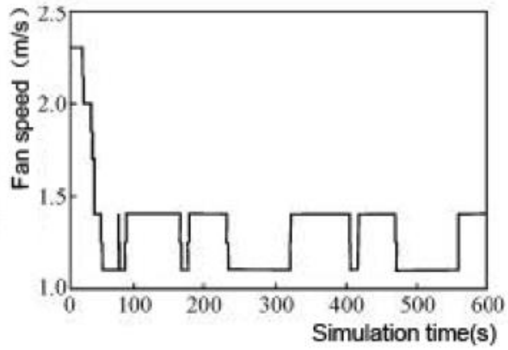

Figure 18. Changing curve of fan speed

This figure shows the change in the fan speed during the time. By change in the temperature, the controller controls the fan's speed to keep the temperature to the desired point.

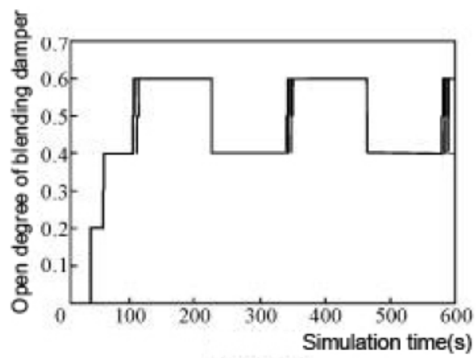

Figure 19. Changing curve of blend damper

Conclusion

As discussed in previous sections, Fuzzy is widely being used on intelligent systems. The overview of this technique proves that Fuzzy is simple and is based on experience of expert of system. Also, with discussing about fuzzy rule base, it was proved that fuzzy is performance based and has no relation to the mathematical model of system's dynamics. The application of fuzzy on several intelligent systems throughout history has proven the fuzzy logic controller's stability and robustness. In this paper we also reviewed one journal paper and discussed about the results to prove the efficiency of fuzzy logic controller on mechanical systems.

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