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Controlling Thermal Comfort Of Passenger Vehicle Using Fuzzy Controller

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ABSTRACT

The automobile car cabin is complex man –machine interface. Two main goals of Heating Ventilation and Air conditioning System is providing thermal comfort and save energy. Comfort is a subjective feeling and hard to model mathematically. This is because thermal comfort is influenced by many variables such as temperature, relative humidity, air velocity and radiation. Aim of this paper is to design the mathematical model for car cabin and to show feasibility with fuzzy logics. Fuzzy controller is designed for cabin to control the cabin temperature.

Keywords - Thermal comfort, Fuzzy controller

I. INTRODUCTION

Car is a medium of fulfilling vital part of society need of transport. Many people in modern society utilize a car in one way or other. Temperature is an important factor in occurrence of traffic accident. Better climate control system in car cabin improves thermal comfort which results in increased driver as well as passenger caution and thus improves driving performance and safety in different driving conditions. Since an automobile is operated in various weather Conditions, such as scorching heat and downpours, passenger thermal comfort is constantly affected by environmental changes [7]. An air conditioning system must maintain an acceptable thermal comfort inside the cabin despite these changes. However, an air conditioning system inevitably uses energy, which increases automobile fuel consumption. This energy must be minimized. Therefore, an effective control procedure is needed to resolve the contradictions of low energy consumption and a pleasant driving climate for passenger as well as driver [2].

Fuzzy logic provides an alternative control because it is closer to real world. Fuzzy logic is handled by rules, membership functions and inference process, which results in improved performance, simpler implementation and reduced design costs [1, 2]. Most control applications have multiple inputs and require modeling and tuning of a large number of parameters, which makes implementation very tedious and time consuming. Fuzzy rules can simplify the implementation by combining multiple inputs into single if-then statements while still handling non-linearity [7].

NOMENCLATURE

bp	Blower Power (kW)
Cp	Specific Heat (kJ/kg _C)
E	Rate of Change of Energy (kW)
e	Temperature Error
Δe	Rate of Change of Temperature Error
Δz	Blower Input
m ·	Mass Flow Rate (kg/s)
pf	Percent of Fresh Air
T	Temperature (_C)
V	Velocity (m/s)
W	Power (kW)
ε	Heat Exchanger Effectiveness

SUBSCRIPTS

a	Air
amb	Ambient
b	Blower
cabin	Automobile Cabin
cooler	Cooler Compartment
e	Evaporator
eR	Evaporator refrigerant
fa	Fresh Air
gen	Generation
i	In
min	Minimum
o	Out
R	Refrigerant
ra	Re-circulation Air

II. THERMAL MODELING OF AUTOMOBILE CABIN

Initially mathematical model of thermal environment for an automobile cabin is derived. Specific parameters for Maruti alto automobile are used. This model includes blower, evaporator, as well as the impact of important thermal loads such as sun radiation, outside air temperature and passengers on climate control of cabin. Mathematical modeling should be performed in a manner to clearly show the effect of control parameters on occupant thermal comfort [5]. The main control point is blower power, which regulates the blower speed for cold air.

III. ASSUMPTIONS

1.1 The following assumptions were made to derive the mathematical model:

- Dry air.
- Ideal gas behavior.
- Perfect air mixing.
- Neglect potential energy in all parts.
- Neglect thermal losses between components.
- Negligible infiltration and exfiltration effects.
- Neglect transient effect in components and channels.
- Negligible energy storage in air conditioning components.
- Zero mechanical work in the cabin ðW=0
- Air parameters at standard conditions of 20°C, 50% rh, sea level.
- Air parameter exiting the cabin has the same properties as inside the cabin.

Above assumptions help to simplify the equations while produce negligible error in modeling.

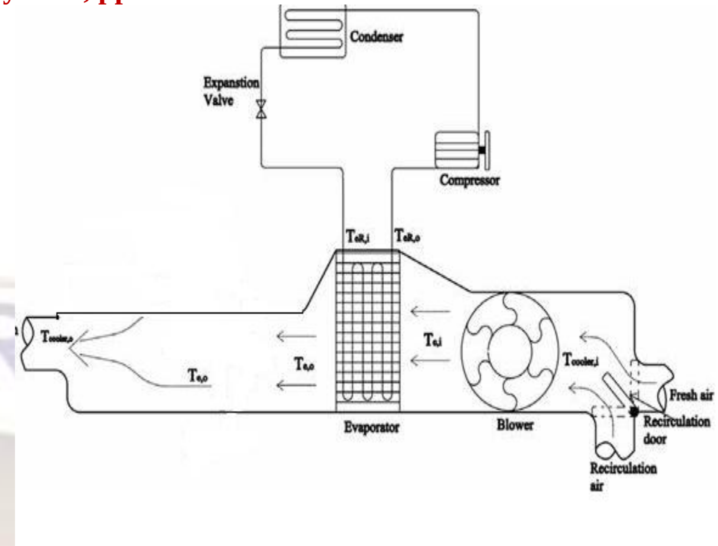

Figure 1.Automobile cabin air conditioning system

Mathematical model of system is obtained as [1]

$$E_{gen} = 0.118\,(T_{amb} - T_{cabin}) + 0.0022\,(T_{amb} - T_{cabin}) + 0.2618 \qquad (1)$$

The principle of energy and mass conservation are used to derived the equation for mathematical model [6].

$$\frac{dE_{cabin}}{dt} = E_{gen} - W_{cabin} + \sum E_{cabin,i} - \sum E_{cabin,o} \quad (2)$$

$$\frac{dm_{cabin}}{dt} = \sum m_{min} - \sum m_{out} = 0 = m_{cabin} = \text{constant} \quad (3)$$

on simplification equation are as follows

$$\frac{dE_{cabin}}{dt} = \frac{d(m_{cabin}\ h_{cabin})}{dt}$$

$$= \frac{d[(\rho_{air} V_{cabin})(CpT_{cabin})]}{dt}$$

$$= \frac{\rho_{air} V_{cabin}\, Cp\, dT_{cabin}}{dt} \qquad (4)$$

$$\sum E_{cabin,i} = E_{cooler,o} = m_{air}\, CpT_{cooler,o} \qquad (5)$$

$$\sum E_{cabin,o} = E_{cooler,i} = m_{air}\, CpT_{cabin,i} \quad (6)$$

Putting the values on eq. (2) which leads to

$K_1.T_{cabin} + K_2.T_{cabin} = (K_3 .T_{amb} + K_4.T_{eRi} + K_5 + k_6.T_{wi})$ (7)

$K_1 = \rho_{air} V_{cabin} .m_{air} Cp_a^2$

$K_2 = m_{air} Cpa [m_{air} Cpa -(1- \varepsilon_e) \{ m_{air} Cp_a \} + 0.1202]$

$K_3 = 0.1202 m_{air} CP_a$

$K_4 = m^2air C^2Pa \varepsilon_e$

$K_5 = 0.2618 m_{air} Cp_a$

$K_6 = 0$

$V_{air} = 0.0245 \exp (4.0329*bp)$

The governing equation (7) is first order differential equation with time dependent coefficients. So it has a complex behavior.

IV. FUZZY CONTROLLER

Fuzzy logic was born in 1965 by Zadeh [1]. Nowadays, it is widely used in industrial applications. Fuzzy logic can model the nonlinear relationship between inputs and outputs. It can simulate the operator's behavior without use of mathematical model. It is a method that transfers human knowledge into mathematics, with the aid of if–then rules [3]. Each rule explains a nonlinear relationship between inputs and outputs. All rules together define a linguistic model. For more information about fuzzy logic see Zimmerman.

Fuzzy control is the most practical branch of fuzzy logic. Fuzzy control is inherently vague and nonlinear, thus it is suitable for systems with this behavior. Automobile air conditioning system is also nonlinear and complex therefore, it is difficult for conventional methods to for controlling this system.

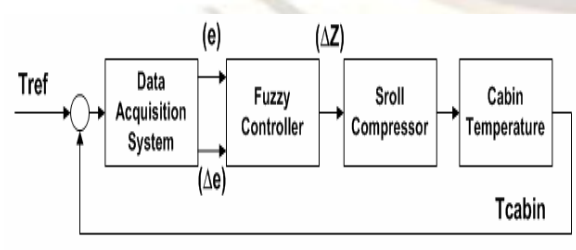

Figure2. Climate control system using fuzzy logic

V. DEVELOPMENT OF FUZZY LOGIC CONTROLLER

The major components of fuzzy logic controller (FLC) are the input and output variables, fuzzification, inference mechanism, fuzzy rule base and deffuzification. FLC involves receiving input signal and converting the signal into fuzzy variable (fuzzifier). In most air conditioning controllers, temperature is used as feedback and a fix temperature is the controller goal. Block diagram of this controller for automobile cabin is given in figure 3. Inputs to fuzzy controller are the error and the changes of error. Output is blower power for regulating the necessary blend of cold air. Error is defined by the following equation [6]:

Error = T d - T cabin

Desired temperature is adjusted in the automobile, which in warm months is about 22°C. Formation of suitable fuzzy sets is important in designing of fuzzy controller. Triangular fuzzy sets are chosen for this controller and are equally divided. The min–max limits are adjusted based on the dynamics of the system and the control goal. For this system, the min–max limits are manually selected. Maximum number of rules is equal to multiplication of the number of input membership functions. It is clear that a large number of rules are more difficult to define [3, 4]. Therefore, to simplify the problem three membership functions are selected for each input and output variables. This results into nine rules for each output. The state evaluation fuzzy control rule is applied for controlling this system [2].

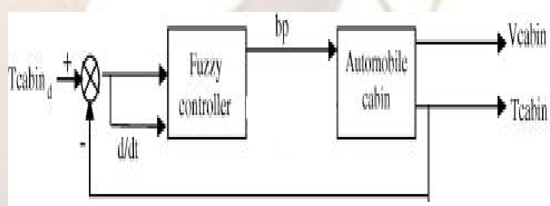

Figure 3. Temperature feedback system

The fuzzy control rules relate the input fuzzy variables to an output fuzzy variable which is called fuzzy associative memory (FAM), and defuzzifying to obtain crisp values to operate the system (defuzzifier).

A linguistic variable in the antecedent of a fuzzy control rule forms a fuzzy input space with respect to a certain universe of discourse, while that in the consequent of the rule forms a fuzzy output space. In this work the FLC will have two inputs and one output. The two inputs are the temperature error (e) and temperature rate of change of error (Δe), and the output is the blower speed change (ΔZ).

The membership functions for fuzzy sets can have many different shapes, depending on definition [4,5]. Popular fuzzy membership functions used in many applications include triangular, trapezoidal, bell-shaped and sigmoidal membership function. The membership function used in this study is the triangular type. This type is simple and gives good controller performance as well as easy to handle. The universe of discourse of e, Δe and ΔZ is -6 ^{o}C to +6 ^{o}C, –1 ^{o}C to +1 ^{o}C, and 0 to 5 V_{dc}.

Table1. Input and output fuzzy variables

Fuzzy variable		Linguistic	Labels
Input	e	Hot	H
		Normal	N
		Cool	C
	Δe	Negative	NE
		Normal	NO
		Positive	PO
Output	Δz	Slow	SL
		Normal	NM
		Fast	FT

A fuzzy logic rule is called a fuzzy association. A fuzzy associative memory (FAM) is formed by partitioning the universe of discourse of each condition variable according to the level of fuzzy resolution chosen for these antecedents, thereby a grid of FAM elements. The entry at each grid element in the FAM corresponds to fuzzy action. The FAM table must be written in order to write the fuzzy rules for the motor speed. The FAM table for the motor speed has two inputs (temperature error and temperature rate-of-change-of-error) and one output (the blower speed change).

As the input and the output have three fuzzy variables, the FAM will be three by three, containing nine rules. A FAM of a fuzzy logic controller for the motor speed is shown in the FAM diagram in Table2.

The rules base from Table 2 are as follows :

- If e is H and Δe is NE Then ΔZ is SL
- If e is N and Δe is NE Then ΔZ is SL
- If e is C and Δe is NE Then ΔZ is SL
- If e is H and Δe is NO Then ΔZ is SL
- If e is N and Δe is NO Then ΔZ is SL
- If e is C and Δe is NO Then ΔZ is SL
- If e is H and Δe is PO Then ΔZ is FT
- If e is N and Δe is PO Then ΔZ is NM
- If e is C and Δe is PO Then ΔZ is SL

Δe↓ \ e→	H	N	C
NE	SL	SL	SL
NO	SL	SL	SL
PO	FT	NM	SL

Table 2. FAM

The output decision of a fuzzy logic controller is a fuzzy value and is represented by a membership function, to precise or crisp quantity.

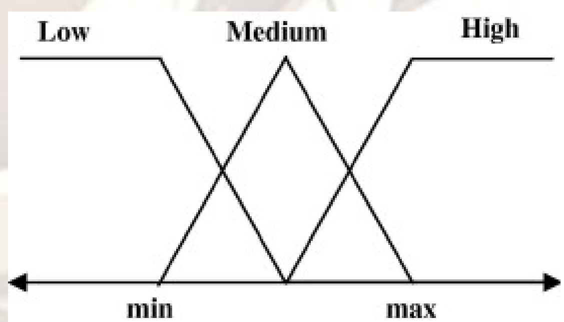

Figure4. Fuzzy sets

A defuzzification strategy is aimed at producing a non-fuzzy control action that best represents the possibility distribution of an inferred fuzzy control action. As to defuzzify the fuzzy control output into crisp values, the centroid defuzzification method is used. For practical purposes, the centroid method gives stable steady state result, yield superior results and less computational complexity and the method should work in any situation.

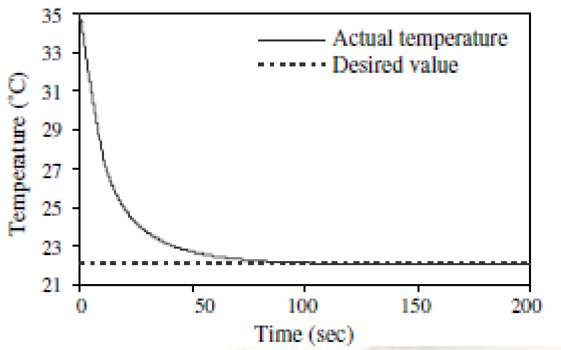

Figure 5. Temperature variation in automobile cabin

CONCLUSIONS

Through this paper, many simulations have been carried out to study the implementation of fuzzy logic control in automobile cabin climate control. Poor interior condition of automobile contributes to traffic accidents as well as discomfort in long distance drives. Thermal comfort is one of the most important comfort factors. Automobile cabin thermal environment is complex, continually varies during time and cannot be described with temperature alone. Important parameters that affect thermal comfort are cabin air temperature, relative humidity, air velocity, environment radiation, activity level of passengers and clothing insulation. In this paper thermal comfort for Maruti Alto automobile is studied. A simplified mathematical model is introduced where cabin air temperature and the air velocity are the only two variables. This simplification is made without introducing significant error. The temperature is used as the feedback in fuzzy controller.

Providing thermal comfort while minimizing energy consumption was the goal of the controller. Evaporator cooling capacity was selected as criterion for energy consumption. These two goals result in a two-objective optimization problem, this minimizing both the comfort error and energy consumption. The multi-objective goal is converted into a single objective problem. To improve the performance of fuzzy controller, It is observed that after optimization controller reaches thermal comfort quicker while minimizing energy consumption.

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