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Design & Implementation of Fuzzy Inference System For Automatic Braking System

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ABSTRACT

The significant application of fuzzy set theory and fuzzy logic are investigated. Attempt is made to simulate Fuzzy Logic Controller (FLC) for an Automatic Braking System. Keeping this idea in mind, an initiative is taken to design and simulate a Fuzzy Inference System (FIS) to perform Antiskid braking in a quasi - virtual environment. In this paper, the implementation of a Mamdani Fuzzy Inference System has been demonstrated with the application of an automatic braking system. The system consists of fuzzy logic controller that analyzes possible accident situation based on the inter-vehicle distance and their relative speed. The controller determines the sufficient brake pressure required to prevent collision while providing a smooth ride for the passengers in vehicle. This paper illustrates the simulation and design concepts of fuzzy logic controller for automatic braking system.

Keywords: Centroid, Defuzzification, Fuzzification, Fuzzy Inference System, Mamdani.

I. INTRODUCTION

Driver Assistance Systems (DAS) have been attempted as early as in 1950s.The fundamental components of DAS include Parking Assistance System, Adoptive front lighting system(AFS), Blind spot detection, Emergency braking system, Collision warning system, Driver drowsiness alert, Adoptive cruise control and Electronic stability control (ESC). The emergency braking could be achieved through Automatic brake system (ABS). The ABS is a nonlinear system can not easily be controlled by classical control methods. Several approaches of system modeling are identified [1]. In present work Fuzzy system modeling (model based approach) has been used for our research purpose. The uniqueness of a fuzzy modeling approach is its ability to utilize both qualitative and quantitative information. Qualitative information is human modeling expertise and knowledge, which are utilized in the form of fuzzy sets, fuzzy logic and fuzzy rules. The theory and design concepts of Fuzzy Logic Controller presented in [2] facilitate better understanding of the object, which is essentially that of a control problem in our case. Here we have designed a fuzzy logic controller using fuzzy logic tool box in MATLAB (Version 7.0.0.499 R2010a 32 bit) software and simulate the designed model using the Simulink. The main function of the fuzzy logic controller used here is to provide automatic braking without any manual involvement. Within the several inference strategies, Mamdani's technique is the most frequently used in the existing fuzzy control applications due to its simplicity [3]. Experiments and theoretical investigations in the referred Literature confirm that Mamdani's technique give better performance than that of other methods in fuzzy control applications [4]. The Mamdani Fuzzy Inference System is developed with two inputs, one output and forty nine rules. Two inputs to the fuzzy logic controller are vehicle speed (km/h) and

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inter-collision distance (m/s) & output is the brake shoe pressure (lbs per unit time). Each input function is defined with seven membership functions (five triangular & two trapezoidal) and *Centroid* defuzzification method is used for extracting the crisp output. The fuzzy controller takes the decision with reference to the speed and collision distance between the vehicles. The hardware implementation of fuzzy controller for specific application [5] is presented in simple way in order to realize the proposed model. In order to detect collision distance of the vehicle, suitable non-contact type sensors and wheel speed sensors can be utilized. Once the detection is done, these systems either can provide an alert to the driver or take action automatically without any driver input. Collision avoidance through braking is possible at low vehicle speeds (e.g. below 50 km/h), but it becomes very difficult at higher vehicle speeds.

This paper has two main contributions. Firstly, a DC motor plant has been designed by solving some physical equations [6] for second order system and its performance has been observed. Secondly, for the same system a fuzzy logic controller has been proposed with simple approach and suitable number of rules (Forty nine rules) as it gives the good performance for larger rule set [7]. The model of the both Fuzzy logic Controller and Automatic Braking System (plant model) are represented in figure 1. Simulation results for a second order system have been demonstrated. The main aim of the work presented in this paper is to create, analyze the model and carry out the simulation of fuzzy logic controller for non linear dynamic system implemented for Automatic Braking System.

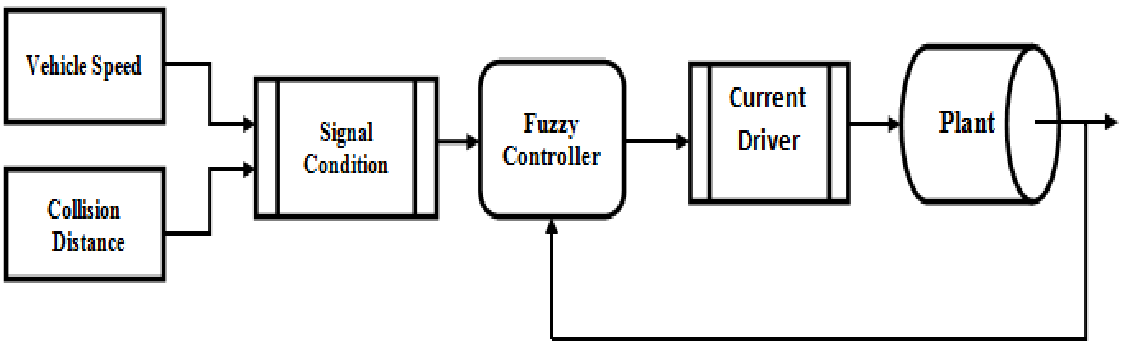

Figure 1. Auto Braking System Controller

II . ARMATURE CONTROLLED DC MOTOR MODEL

The two input variables (e.g. speed and distance) are taken into consideration to control vehicle speed through the brake pressure using DC motor linear (actuator) position control. Hence it is necessary to prepare the mathematical model of DC motor. The equivalent circuit of a DC motor is depicted in Figure.2, with the armature resistance Ra and winding leakage inductance La.

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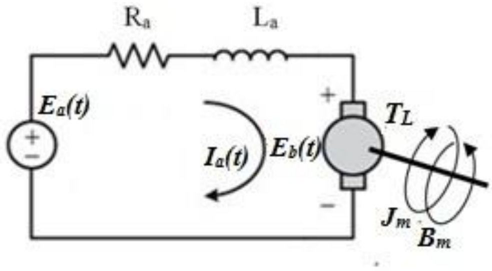

Fig. 2 Electrical equivalent of DC Motor

According to the Kirchhoff's voltage law in armature loop, the electrical equation of motor is described as

$$e_a(t) = R_a i_a(t) + L_a \frac{di_a(t)}{dt} + e_b(t) \tag{2.1}$$

where $I_a(t)$ the armature is current, $e_b(t)$ is the back emf voltage and $e_a(t)$ is the armature emf voltage. The back emf voltage $e_b(t)$ is proportional to the angular velocity ω_m(t) of the rotor in the motor [8] [9]; its electromechanical equation is expressed as

$$e_b(t) = K_e \omega_m(t) \tag{2.2}$$

Where K_e is the back emf constant. In addition, the motor generates a torque $T(t)$ proportional to the armature current, given as

$$T(t) = k_T i_a(t) \tag{2.3}$$

Where k_T is the torque constant.

Mechanical dynamics of DC motor is found to be

$$T(t) = J_m \frac{d\omega_m(t)}{dt} + B_m \omega_m(t) \tag{2.4}$$

Take Laplace transform of eq. (1)

$$E_a(s) = L_a s I_a(s) + R_a I_a(s) + E_b(s)$$

$$E_a(s) = (L_a s + R_a) I_a(s) + E_b(s)$$

$$E_a(s) - E_b(s) = (L_a s + R_a) I_a(s)$$

$$I_a(s) = \frac{1}{(L_a s + R_a)} E_a(s) - E_b(s) \tag{2.5}$$

Taking Laplace transform of electromechanical equation (2.2) and (2.3), we have

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$$E_b(s) = K_E\Omega_m(s) \tag{2.6}$$

$$T(s) = K_T I_a(s) \tag{2.7}$$

Laplace transforms of mechanical system dynamic eqn. (2.4)

$$T(s) = J_m\, s\, \Omega_m(s) + B_m\Omega_m(s)$$

$$T(s) = (J_m\, s + B_m)\Omega_m(s)$$

$$\Omega_m(s) = \frac{1}{(J_m\, s + B_m)}\, T(s) \tag{2.8}$$

If the input voltage $e_a(t) = E_a$ is constant, the resulted Armature current $i_a(t) = I_a$, Angular velocity $\omega_m(t) = \Omega_m$ and torque $T(t)) = T$ are also constant in the steady state.

From equations (2.5) (2.7) (2.8) and (2.6), we can draw the block diagram of armature controlled DC motor as shown below.

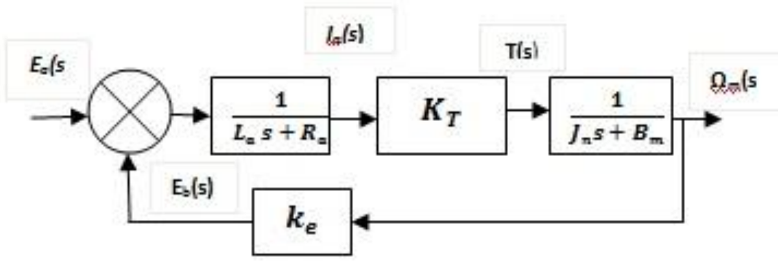

Fig. 3. Plant model of DC motor

The feedback formulae to reduce the block diagram

$$\frac{\Omega_m(s)}{E_a(s)} = \frac{G(s)}{1 + G(s)H(s)} \tag{2.9}$$

$$\therefore H(s) = K_e$$

G(s) is the product of the entire block in forward path

$$G(s) = K_T\left(\frac{1}{L_a s + R_a}\right)\left(\frac{1}{J_m s + B_m}\right)$$

$$= \frac{K_T}{(L_a s + R_a)(J_m s + B_m)}$$

Put $G(s)$ and $H(s)$ in (2.9)

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$$\frac{\Omega_m(s)}{E_a(s)} = \frac{\frac{K_T}{(L_a s + R_a)(J_m s + B_m)}}{1 + \left(\frac{K_T}{(L_a s + R_a)(J_m s + B_m)}\right) K_e}$$

$$= \frac{K_T}{(L_a s + R_a)(J_m s + B_m) + K_T K_e}$$

$$\frac{\Omega_m(s)}{E_a(s)} = \frac{\frac{K_T}{(L_a s + R_a)(J_m s + B_m)}}{1 + \left(\frac{K_T}{(L_a s + R_a)(J_m s + B_m)}\right) K_e}$$

$$\frac{\Omega_m(s)}{E_a(s)} = \frac{K_T}{L_a J_m s^2 + (R_a J_m + B_m L_a)s + (K_T K_e + R_a B_m)}$$

Clearly, the motor will encounter two external sources [10], the input voltage $E_a(s)t$ to drive the motor and the torque $T_L\ (t)$ reacted from the motor speed $\Omega_m(s)$.

TABLE I

Parameters used in DC motor

Sr. No.	Parameter	Value
1	Max. Speed (ω_m)	500 rad/sec
2	Max. Armature Current (I_a)	2.0 A
3	Back emf constant (K_e)	0.060 V s/rad
4	Torque constant (K_T)	0.06 N-m/A
5	Friction constant (T_f)	0.012 N-m
6	Armature resistance (R_a)	1.2 Ω
7	Armature Inductance (L_a)	0.020 H
8	Armature inertia (J_m)	$6.2\times^{10-4}$ N-m-s^2/rad
9	Armature viscous friction (B_m)	1×10^{-4} N-m-s/rad

According to the parameters mentioned in table **I,** the transfer function of armature controlled DC motor (plant) is derived as follows:

$$\frac{\Omega_m(s)}{E_a(s)} = \frac{0.06}{1.24\times10^{-5}s^2 + 7.46\times10^{-4}s + 0.00372}$$

III. FUZZY SET THEORY AND FUZZY LOGIC

The concept of Fuzzy Logic (FL) was conceived in 1965 by Prof. Lotfi A. Zadeh of the University of California at Berkeley [11]. He elaborated his ideas in his paper that introduced the concept of "linguistic variables", which in this article equates to a variable defined as a fuzzy set [12]. He presented not only a control methodology, but also a way of processing data by allowing partial set membership rather than crisp set membership or non-membership[13]. It deals with information arising from computational perception [14] and cognition, that is,

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uncertain, imprecise or without sharp boundaries. The FL poses the ability to mimic the human mind to effectively employ modes of reasoning that are approximate rather than exact [15]. He also reasoned that humans do not require precise, numerical information input, and yet they are capable of highly adaptive control. He suggested that, if feedback controllers could be programmed to accept noisy, imprecise input, they would be much more effective and perhaps easier to implement. Fuzzy Logic provides a simple way to arrive at an accurate conclusion based upon vague, ambiguous, imprecise, noisy, or missing input information.

In traditional hard computing, decisions or actions are based on precision, certainty, and vigor. Whereas in soft computing, tolerance and impression are explored in decision making. With FL, we can specify mapping rules in terms of words rather than numbers. Computing with the words explores imprecision and tolerance. According to the authors [16] claimed that Fuzzy logic can easily be implemented on a standard computer.

3.1 Fuzzy Sets nd Membership Function

A fuzzy set is an extension of a crisp set. Crisp sets allow only full membership or no membership at all, whereas fuzzy sets allow partial membership. A fuzzy set ***A*** on a universe of discourse ***U*** is characterized by a membership function $\mu_A(A)$ that takes values in the interval [0, 1]. Various types of membership functions [17] were used, including triangular, trapezoidal, generalized bell shaped, Gaussian curves, polynomial curves, and sigmoid functions. Figure 3.3 shows input (vehicle speed and collision distance) membership functions. Triangular curves depend on three parameters *a, b,* and *c* are given by

$$f(x{:}a,b,c) = \begin{cases} 0 & for\ x < a \\ \dfrac{x-a}{b-a} & for\ a \le x \le b \\ \dfrac{c-x}{c-b} & for\ b \le x \le c \\ 0 & for\ x > a \end{cases} \tag{3.1}$$

In Equation (3.1), ***a, b***, and ***c*** are the parameters that are adjusted to fit the desired membership data. The parameter ***b*** is the half width of the curve at the crossover point.

3.2. Logical operations and if-then rules

Fuzzy set operations are analogous to crisp set operations. The most elementary crisp set operations are union, intersection, and complement, which essentially correspond to *OR*, *AND*, and *NOT* operators, respectively. Let *A* and *B* be two subsets of *U*. The union of *A* and *B*, denoted as $A \cup B$, contains all elements in either *A* or *B*; that is , $\mu_{A\cup B}(x) = 1\ if\ x \in A\ or\ x \in B$. The intersection of *A* and *B*, denoted as A∩B, contains all the elements that are simultaneously in *A* and *B*; that is $\mu_{A\cap B}(x) = 1\ if\ x \in A\ and\ x \in B$,. The complement of *A* is denoted by $\bar{A}$, and it contains all elements that are not in A; that is $\mu_A(x) = 1\ if\ x \notin A$ **, and** $\mu_A(x) = 0\ if\ x \in A$ **.**

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In FL, the truth of any statement is a matter of degree. In order to define FL operators, we have to find the corresponding operators that preserve the results of using *AND, OR,* and *NOT* operators. The answer is *min, max,* and *complement* operations. These operators are defined, respectively, as

$$\mu_{A\cup B}(x) = max[\,\mu_A(x), \mu_B(x)] \tag{3.2}$$

$$\mu_{A\cap B}(x) = min[\,\mu_A(x), \mu_B(x)] \tag{3.3}$$

$$\mu_{\bar{A}} = 1 - \mu_A(x) \tag{3.4}$$

Most applications use ***min*** for fuzzy intersection, ***max*** for fuzzy union, and $1 - \mu_A(x)$ for complementation.

Fuzzy inference systems consist of if–then rules that specify a relationship between the input and output fuzzy sets. Fuzzy relations present a degree of presence or absence of association or interaction between the elements of two or more sets. Let *U* and *V* be two universes of discourse.

A singleton fuzzy rule assumes the form "**if *x* is *A*, then *y* is *B*,**" where $x \in U$ *and* $y \in V$, and has a membership function, where $\mu_{A\to B}(x, y) \in [0,1]$. The 'if' part of the rule, "**x is A,**" is called the *antecedent* or *premise*, while the 'then' part of the rule, "**y is B**," is called the *consequent* or *conclusion*. In designing a fuzzy inference system, membership functions are associated with term sets that appear in the antecedent or consequent of rules.It was *Mamdani* (1977) who first proposed the minimum implication, and later *Larsen* (1980) proposed the product implication.

IV. FUZZY INFERENCE SYSTEM

A fuzzy inference system (FIS) essentially defines a nonlinear mapping of the input data vector into a scalar output, using fuzzy rules. General model of FIS is shown in Figure 1. It can be seen from the figure that the FIS contains four components:

A. Fuzzification
B. Rule base
C. Inference engine
D. Defuzzification

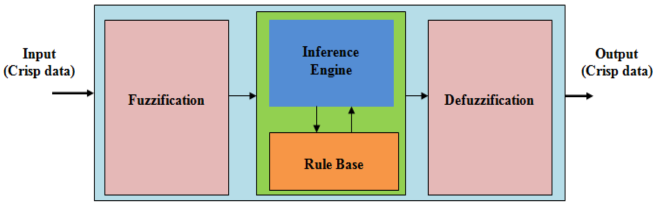

Fig. 4. Block diagram of Fuzzy Logic Controller

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The fuzzifier maps input numbers into corresponding fuzzy memberships. This is required in order to activate rules that are in terms of linguistic variables. The fuzzifier takes input crisp values and determines the degree to which they belong to each of the fuzzy sets via membership functions. For a two input fuzzy controller 3,5,7,9 or 11 membership functions for each input are mostly used [18] [19]. The fuzzy set of collision distance was fuzzified using trapezoid and triangular membership function within the universe of discourse with 7 linguistic values, as shown in Fig.5, the linguistic values are ECL (Extremely Close, VCL (Very Closed), CL (Closed), MD (medium), FAR (Far), VFAR (Very Far), and EFAR (Extremely Far).

Table 2.

Fuzzy variables for Vehicle Speed

Sr.No.	Crisp Input Range (km/hrs)	Fuzzy Set
1	0-40	DSL
2	20-60	VSL
3	40-80	SL
4	60-100	MSL
5	80-120	FST
6	100-140	VFS
7	120-160	EFS

Similarly the linguistic terms for vehicle speed are DSL (Dead Slow), VSL, SL, MSL, FST, VFS and EFS (Extremely Fast).

Table 3.

Fuzzy variables for Collision Distance

Sr.No.	Crisp Input Range (feet)	Fuzzy Set
1	0-30	ECL
2	20-40	VCL
3	30-50	CL
4	40-60	MD
5	50-70	FAR
6	60-80	VFAR
7	70-100	EFAR

The required fuzzy membership function for vehicle speed, collision distance and applied brake pressure (RELEASE, VLP, LP, MP, HP, VHP and EHP) are shown in fig. 4, 5 and 6 as follows.

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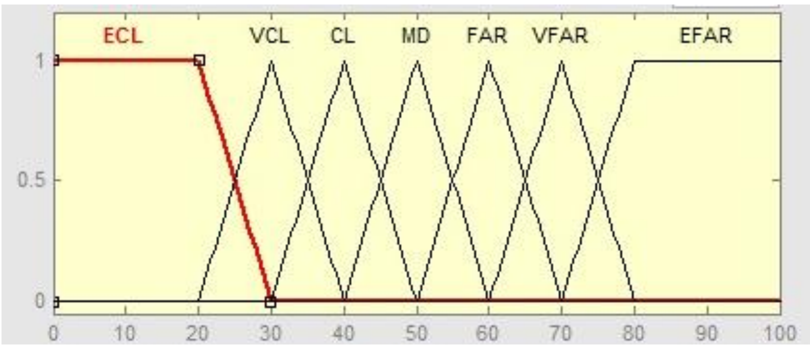

Fig. 5. Input membership function for collision distance

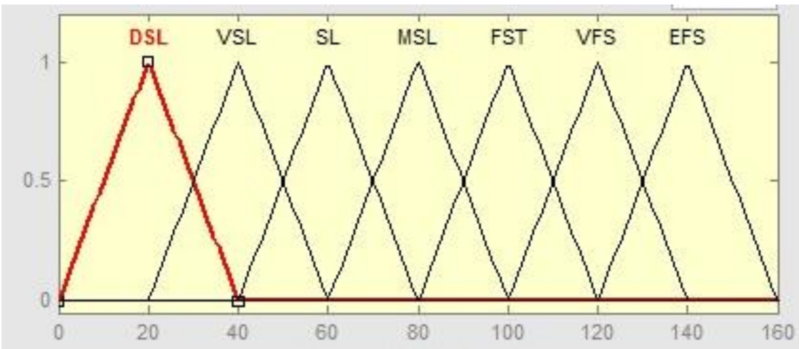

Fig. 6. Input membership function for vehicle speed

The inference engine stage consists of fuzzy rules which decide what action to be taken. This is the main block of the fuzzy controller and constructed from the expert knowledge and experience [20].

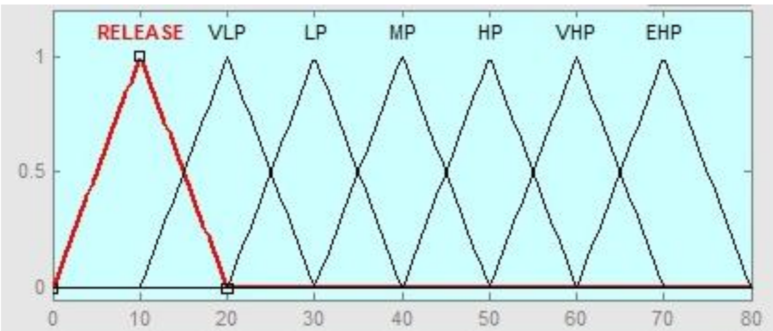

Fig. 7. Output membership function for applied brake pressure

The inference engine defines mapping from input fuzzy sets to output fuzzy sets. It determines the degree to which the antecedent is satisfied for each rule. If the antecedent of a given rule has more than one clause, fuzzy operators are applied to obtain one number that represents the result of the antecedent for that rule. It is possible that one or more rules may execute at the same time.

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5.1 Defuzzification

The input for the defuzzification process is a fuzzy set (the aggregated output fuzzy set), and the output of the defuzzification process is a crisp value obtained by using some defuzzification method such as the Centroid, height or maximum. A fuzzy inference system maps an input vector to a crisp output value. The defuzzifier maps output fuzzy sets into a crisp number [21]. Given a fuzzy set that encompasses a range of output values, the defuzzifier returns one number, thereby moving from a fuzzy set to a crisp number. The most popular defuzzification method is the Centroid, which calculates and returns the center of gravity of the aggregated fuzzy set.

5.2 Centroid defuzzification method

In this method, the defuzzifier determines the center of gravity (Centroid) y' of B and uses that value as the output of the FLS. For a continuous aggregated fuzzy set, the Centroid is given by

$$y' = \frac{\sum_{i=1}^{n} y_i \mu_B(y_i)}{\sum_{i=1}^{n} \mu_B(y_i)} \tag{4.1}$$

The Centroid defuzzification method finds the “balance” point of the solution fuzzy region by calculating the weighted mean of the output fuzzy region. It is the most widely used technique because, when it is used, the defuzzified values tend to move smoothly around the output fuzzy region.

If the universes are discrete, it is always possible to calculate all thinkable combinations of inputs before putting the controller into operation. In a ***table based controller*** the relation between all input combinations and their corresponding outputs are arranged in a table. Such array implementation improves execution speed [22]. The formulated table helps to develop ‘If–Then’ rules connecting the 3 variables (***if*** vehicle speed is x ***and*** collision distance is y ***then*** brake pressure is z). The rules are entered using the Rule editor window. By taking the rule viewer we can see the effect of each rule on the different values of the variable.

1. If (vehicle-speed is DSL) and (collision-distance is EFAR) then (break-pressure is RELEASE) (1)
2. If (vehicle-speed is VSL) and (collision-distance is VFAR) then (break-pressure is VLP) (1)
3. If (vehicle-speed is SL) and (collision-distance is FAR) then (break-pressure is LP) (1)
4. If (vehicle-speed is MSL) and (collision-distance is MD) then (break-pressure is MP) (1)
5. If (vehicle-speed is VFS) and (collision-distance is VCL) then (break-pressure is VHP) (1)
6. If (vehicle-speed is EFS) and (collision-distance is ECL) then (break-pressure is EHP) (1)
7. If (vehicle-speed is FST) and (collision-distance is FAR) then (break-pressure is HP) (1)

Fig. 8. Mapping between input and output fuzzy variables

V. RESULTS AND DISCUSSION

The rule-based feature of fuzzy models allows for a model considered in a way that is similar to the one that humans use. Conventional methods for computer automation based on numerical data can be complemented by the human expertise that often involves heuristic knowledge and intuition. Fuzzy models can be used for various

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aims: analysis, design, control, monitoring, supervision, etc. Rather than as a fully automation technique, fuzzy modeling should be seen as an interactive method, facilitating the active participation of the user in a computer-assisted modeling

The experimental results of the controller will be presented in this section. Figure 9 shows the effect of input and output fuzzy variable observed in rule viewer in fuzzy logic toolbox. The designed FLC model is simulated with different numbers of membership function and it was found that, Performance accuracy is better with seven membership functions. So it is more appropriate for proposed system, which has 49 possible control signal (rule based)[23].The Graphical representation of both the simulation are presented in figure 10 and figure 11 through Surface mapping, which is a three dimensional plot. It is obtained in the MATLAB fuzzy logic environment, shows the relation between the input and the output values. Figures 14 and 15 shows the user defined control signals (collision distance and vehicle speed) required for the forty nine rules. These two inputs are then applied to fuzzy inference engine. The figure 12 shows abrupt changes in applied brake pressure (Defuzzified output) whereas these fast transitions are slow down by suitable transfer function of plant as shown in figure 13..

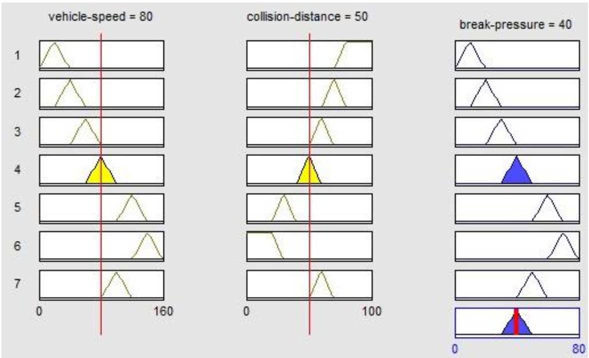

Fig. 9. Input and output Fuzzy variables in Rule viewer

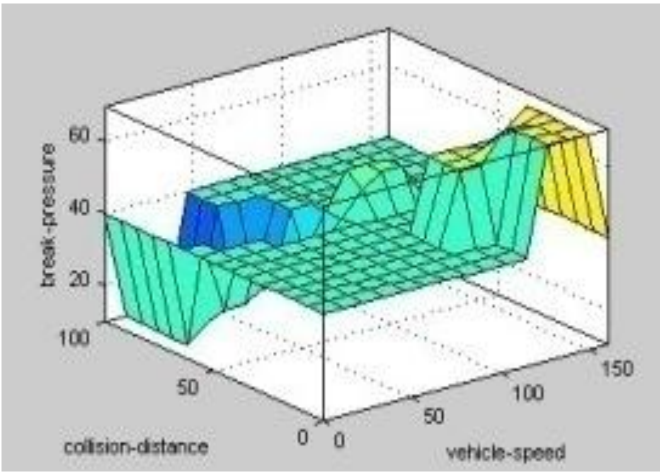

Fig. 10. Surface mapping with 49 rules

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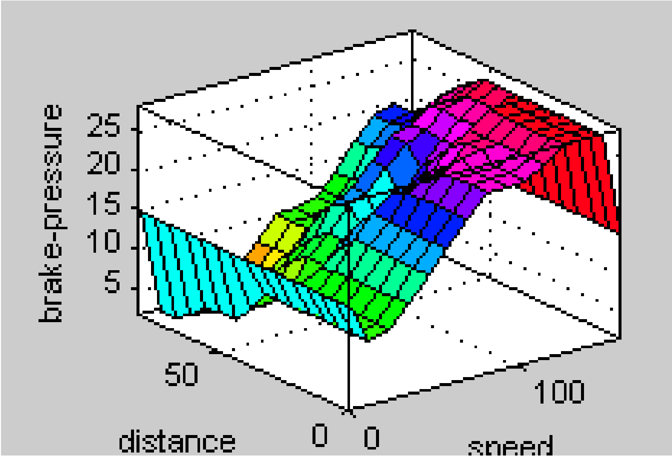

Fig. 11. Surface mapping with seven inference rules

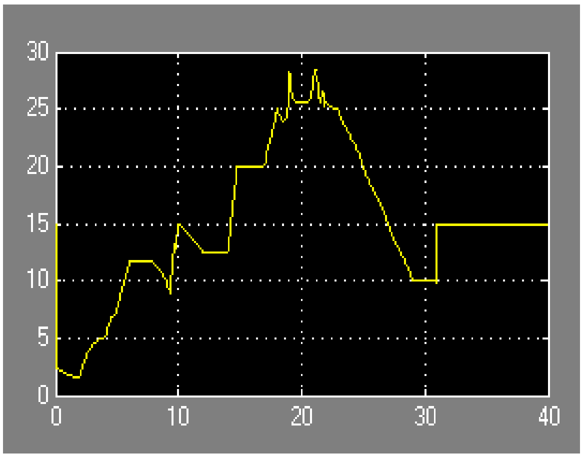

Fig. 12 defuzzified output brake pressure (lbs/sec)

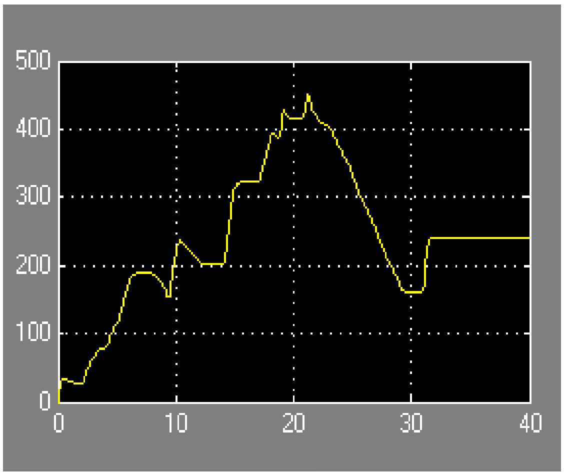

Fig. 13. Output brake pressure

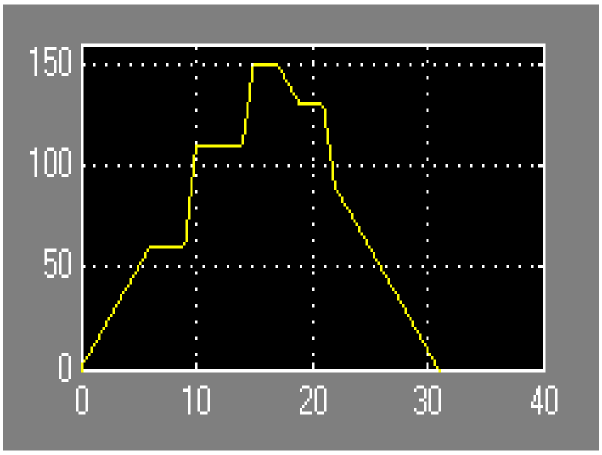

Figure 14. Vehicle speed

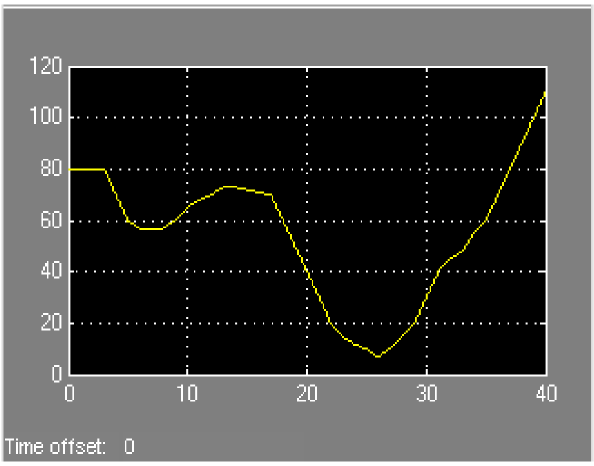

Figure 15. Inter vehicle collision distance

VI. CONCLUSION

The presented experimental results show that it is possible to build an Automatic Braking System with low-price hardware and inaccurate sensors. The design, implementation and simulation results of Fuzzy Inference System and Simulink model were presented. The whole work attempted to develop an ABS simulation system

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integrated with Simulink software and Fuzzy Logic Toolbox. Because of the great enhancement in Simulink block performance, improvement of FIS interfaces, and reinforcement of software functions have become very efficient and turned into reality. By implementing the proposed control strategy for a multi- purpose microprocessor, custom hardware can be developed with ABS application Authors believe that using advanced electronics hardware if combined with software, ABS model along with the test vehicle will be capable to tackle the accidental situation.. We expect that auto braking features provide the biggest benefits to collision-avoidance system that would brake of its own, if the driver is not able to avoid a forward collision.

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