Fuzzy Logic Control for Half Car Suspension System Using Matlab

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Abstract- **To improve ride comfort of vehicle a suspension system is designed to stimulate the actions of an active vehicle suspension. To make the ride comfort and to support vehicle body such a suspension system can be used. The aim of the work is to focus on the application of fuzzy logic technique to control the damping of the suspension system of the vehicle. In this paper, the approach is to design a half car system by using the details of quarter car model and also the results of fuzzy logic and PID controller system is analysed.**

Keywords- **Fuzzy logic, half-car, suspension, PID, MATLAB.**

I. INTRODUCTION

It is the necessity to prevent road disturbances and passenger discomfort; it can be achieved by improving control of suspension system. While the purpose of the suspension system is to give smooth ride and help to maintain control of the vehicle over rough terrain or in case of severe vibrations. Increase in ride comfort may leads to large suspension stroke and small damping. To overcome such problems many control methods have been proposed. The implementations of the control system play important role to prevent these problem. Fuzzy logic control is widely accepted now a day and implemented very fast. Fuzzy control system is used for reducing discomfort of operator and to reduce vibrations. Also to check the best suited control system, comparison between PID and fuzzy control system for quarter car model is proposed in [3]. The results of PID and Fuzzy logic will show which is having higher performance. The ride comfort is improved by means of the reduction of the body acceleration caused by the car body. In [8] it is described also about the model and controller used in the suspension system and discusses the vehicle response results obtained from a range of road input simulations. In the conclusion, a comparison of active suspension fuzzy control and Proportional Integration Derivative (PID) control is shown. Simulations are shown by using genetic algorithm. In mentioned paper simulations based are on quarter car model which shows body deflection variations with respect to time. And gives a scope for the half car suspension system. Also paper [6] illustrates the results for quarter, half as well as full car model based on Bond graph model.

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In this paper the main objective is to propose a design for half car suspension system. It must be noted that all the results of quarter car model is studied using fuzzy control and PID as well as Un- controlled suspension system The vibration of vehicle can be controlled by proper designing of the controller. The output is shown using MATLAB software. For fuzzy logic rule view and surface view is shown for input and output. For PID and Uncontrolled suspension system, the simulation of body displacement is shown using MATLAB. The also illustrated about the comparison of PID and fuzzy. The approach to design a half car is shown as further scope.

II. HALF CAR MODEL:

The mathematical model in this research is derived based on the approach as presented in [2] which include mathematical modulations of half-car suspension system. Figure 1 shows half-car suspension system model [2].

The equivalent forces in both wheels are given by as follows equation:

$$F_{f} = -K_f\,(x_{bf} - x_{wf}) - B_f\,(\dot{x}_{bf} - \dot{x}_{wf}) \qquad (1)$$

$$F_{r} = -K_r\,(x_{br} - x_{wr}) - B_f\,(\dot{x}_{br} - \dot{x}_{wr}) \qquad (2)$$

By applying Newton's second law and using the static equilibrium position as the origin for both the displacement of the centre of gravity and angular displacement of the vehicle body, the equations of motion for the system can be formulated. The equation of motion is:

$$m_b\,\ddot{x}_{bf} = -K_f\,(x_{bf} - x_{wf}) - B_f\,(\dot{x}_{bf} - \dot{x}_{wf}) - K_r\,(x_{br} - x_{wr}) - B_f\,(\dot{x}_{br} - \dot{x}_{wr}) + f_f + f_r - a m_b \ddot{\theta}$$

(3)

$$m_b \ddot{x}_{br} = -K_f (x_{bf} - x_{wf}) - B_f (\dot{x}_{bf} - \dot{x}_{wf}) -K_r (x_{br} - x_{wr}) - B_f (\dot{x}_{br} - \dot{x}_{wr}) + f_f + f_r + bm_b \ddot{\theta}$$

(4)

$$J_y \ddot{\theta} = - F_f a + F_r b$$

$$= a (-K_f (x_{bf} - x_{wf}) - B_f (\dot{x}_{bf} - \dot{x}_{wf})$$

$$+ b (-K_r (x_{br} - x_{wr}) - B_f (\dot{x}_{br} - \dot{x}_{wr}))$$

(5)

Using $Jy = m_b r_y^2$

$$\ddot{\theta} = (1/ m_b r_y^2) \{a (-K_f (x_{bf} - x_{wf}) - B_f (\dot{x}_{bf} - \dot{x}_{wf}) + b (-K_r (x_{br} - x_{wr}) - B_f (\dot{x}_{br} - \dot{x}_{wr}))\}$$

(6)

With applying Newton's second law again on the front and rear wheel masses.

The equations of motion can also be formulated as follows [2]:

$$m_b \ddot{x}_{bf} = -K_f (x_{bf} - x_{wf}) - B_f (\dot{x}_{bf} - \dot{x}_{wf}) -K_{rf} (x_{bf} - z_f) - f_f \quad (7)$$

$$m_b \ddot{x}_{br} = -K_r (x_{br} - x_{wr}) - B_r (\dot{x}_{br} - \dot{x}_{wr}) -K_{tr} (x_{br} - z_r) - f_r \quad (8)$$

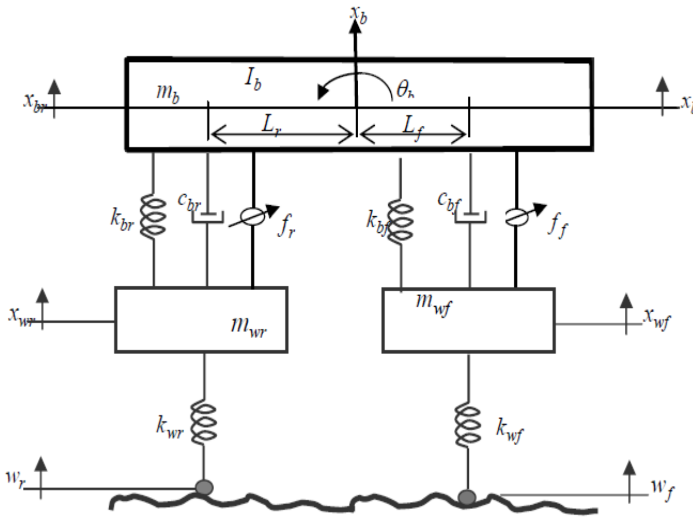

Figure 1. Half vehicle car model [2]

Following research paper of Suaib et al [2], the forces f_f and f_r that are applied between the sprung and unsprung masses are generated by means of the hydraulic actuator placed between the two masses.

Table 1. Parameter values for half car suspension

Car body	575 Kg
Centroidal moment of inertia for the car body	769 Kg/m^2
Front wheel mass, m_{wf}	60 Kg
Rear Wheel mass, m_{wr}	60 Kg
Front spring coefficient, K_f	16812 N/m
Rear spring coefficient, K_r	16812 N/m
Front tyre spring coefficient, K_{tf}	190000 N/m
Rear tyre spring coefficient, K_{tr}	190000 N/m
Front damping coefficient, B_f	1000 N- s/m
Rear damping coefficient, B_r	100 N-s/m

Space state model:

Here quarter car model is considered to make space state model which is represented in following Figure.

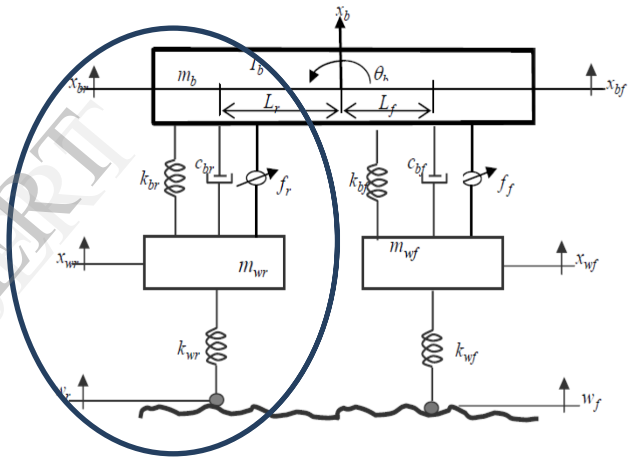

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Figure 2. Quarter car section in half car model [3]

The motion equation of quarter car body and wheel are as follows:

$$m_b \ddot{x}_{bf} = f_a - K_b (x_b - x_w) - B_b (\dot{x}_b - \dot{x}_w)$$

$$m_w \ddot{x}_{wf} = - f_a + K_w (x_b - x_w) - K_w (x_b - x_r)$$

(9)

Table 2. Parameter values for quarter car suspension

Body mass, m_b	250 Kg
Wheel mass, m_w	50 Kg
Stiffness of the body, K_b	16 KN/m
Stiffness of the wheel, K_w	160 KN/m
Stiffness of the damper, Cs	1.5 KNs/m

The following state variables are considered:

$$X=[x_1, x_2, x_3, x_4]^T$$

$$X_1= X_4-X_2,\ X_2= X_2-d,\ X_3= \dot{x}_4,\ X_4= \dot{x}_2 \tag{10}$$

Where, X_1 = is the body displacement. X_2 = is the wheel displacement, X_3 = is the absolute velocity of the body, and X_4= is the absolute velocity of the wheel. Then the motion equations of the quarter car model for the active suspension can be written in state space form as follows:

$$\dot{x}= AX\,(t) +B\,u\,(t) + f\,(x, t) \tag{11}$$

With,

$$A=\begin{bmatrix} 0 & 0 & 1 & -1 \\ 0 & 0 & 0 & 1 \\ -\frac{Ks}{m_s} & 0 & -\frac{C_s}{m_s} & \frac{C_s}{m_s} \\ \frac{Ks}{m_u} & -\frac{Kt}{m_u} & \frac{C_s}{m_u} & -\frac{C_s}{m_u} \end{bmatrix},\quad B=\begin{bmatrix} 0 \\ 0 \\ \frac{1}{m_s} \\ \frac{1}{m_u} \end{bmatrix},\quad F=\begin{bmatrix} 0 \\ -1 \\ 0 \\ 0 \end{bmatrix} \tag{12}$$

The fuzzy logic controller used in the active suspension has three inputs: body acceleration, body velocity, body deflection velocity and one output: desired actuator force. The control system itself consists of three stages: fuzzification, fuzzy interference machine and Defuzification. The fuzzification stage converts real-number (crisp) input values into fuzzy values while the fuzzy inference machine processes the input data and computes the controller outputs in cope with the rule base and data base. These outputs, which are fuzzy values, are converted into real-numbers by the defuzzification stage. A possible choice of the membership functions for the four mentioned variables of the active suspension system represented by a fuzzy set is as follows:

Table 3: Rule base

Body deflection velocity	Body velocity	Body acceleration	Actuator force
PM	PM	ZE	ZE
NM	PS	ZE	NM
PS	NS	ZE	PM
PS	NM	ZE	PM

Above Linguistic rule can be used as Follows:

If (Body deflection velocity = PM) AND (Body velocity = PM) AND If (Body acceleration = ZE) THEN (Actuator force = ZE)

The abbreviations used correspond to:

NV is Negative Very Big, **NB** is Negative Big, **NM** is Negative Medium, **NS** is Negative Small, **ZE** is Zero, **PS** is Positive Small, **PM** is Positive Medium, **PB** is Positive Big and **PV** is Positive Very Big.

The rule base used in the active suspension system showed in Table 2. With fuzzy terms derived by the designer's knowledge and experience. Here zero body acceleration is considered so that control action was chosen to minimize the relative and the absolute body velocities only.

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The output of the fuzzy controller is a fuzzy set of control. As a process usually requires a non-fuzzy value of control, a method of defuzzification called "Centre of gravity method" (COG), is used here [8].

$$f_a = \frac{\int_{F_a} f * \mu_D(f).df}{\int_{F_a} \mu_D(f).df} \tag{13}$$

Where, µD (f) is corresponding membership function [3].

The Fuzzy Logic operations in MATLAB are done as follows:

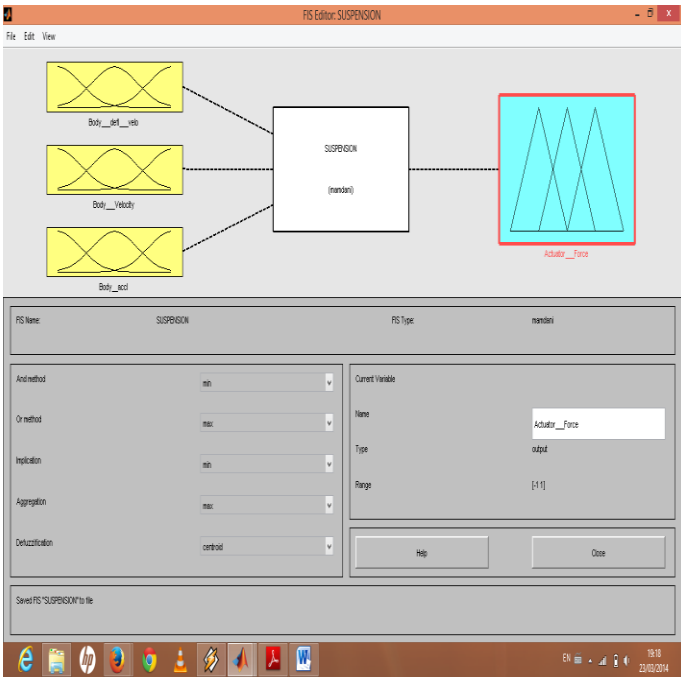

Figure 3. Representation of input and output using MATLAB

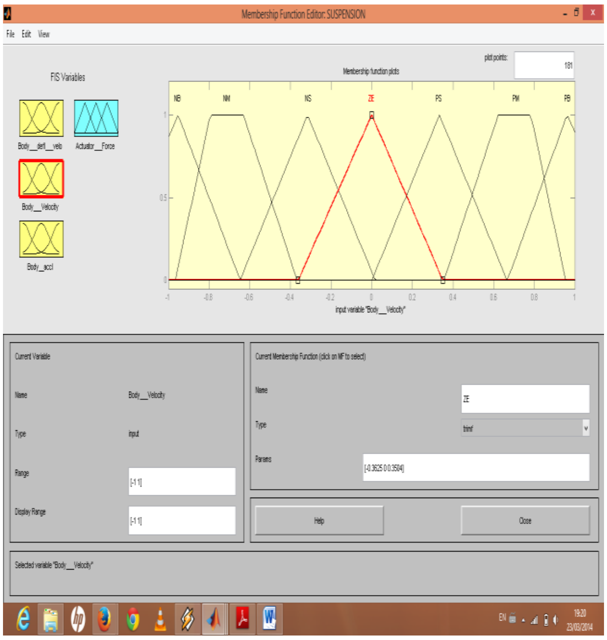

Figure 5. Membership function for body velocity

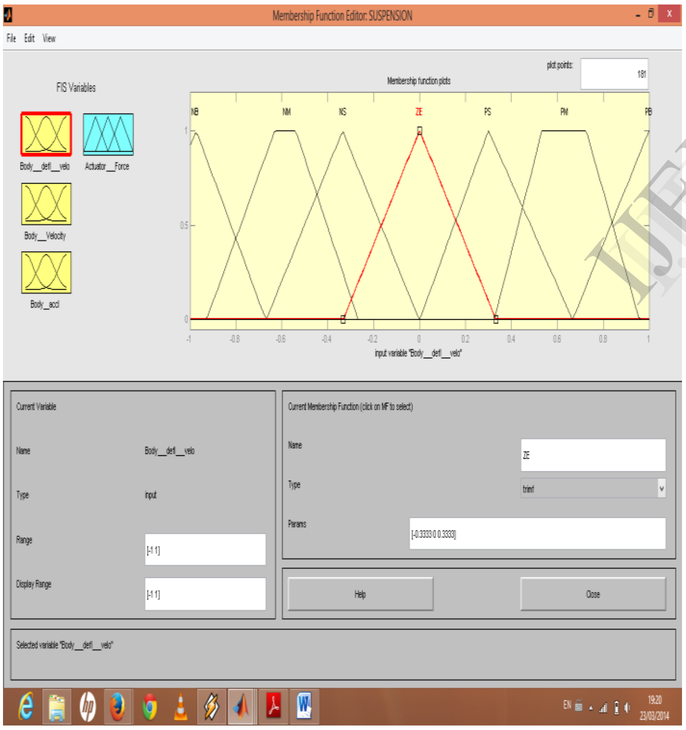

Figure 4. Membership function for body deflection velocity

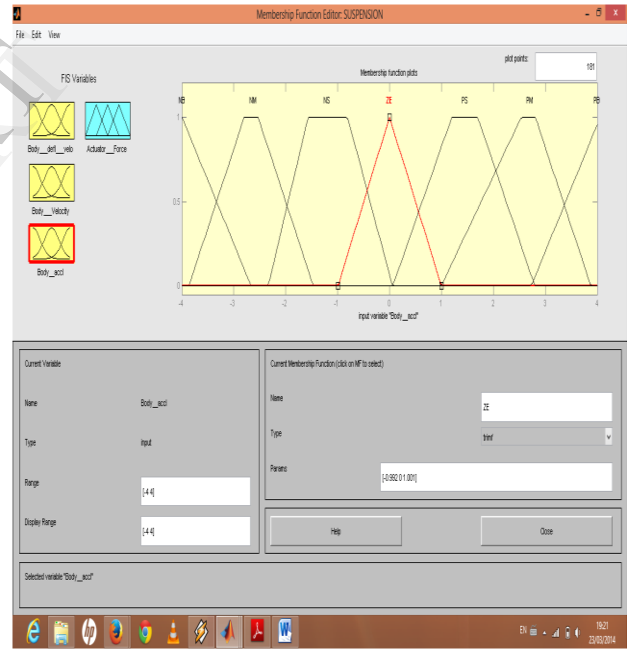

Figure 6. Membership function for body acceleration

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IV.SIMULATION RESULTS

The Rule Viewer displays a roadmap of the whole fuzzy inference process. The four plots across the top of the Figure represent the antecedent and consequent of the first rule. Each rule is a row of plots, and each column is a variable. The rule numbers are displayed on the left of each row.

The first two columns of plots (the six yellow plots) show the membership functions referenced by the antecedent, or the if-part of each rule. The third column of plots (the three blue plots) shows the membership functions referenced by the consequent, or the then-part of each rule. The fifth plot in the third column of plots represents the aggregate weighted decision for the given inference system.

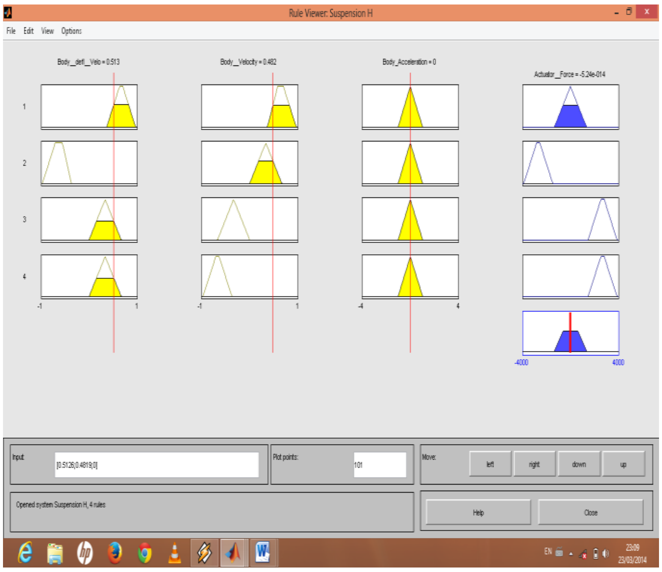

Figure 7. Rule Viewer

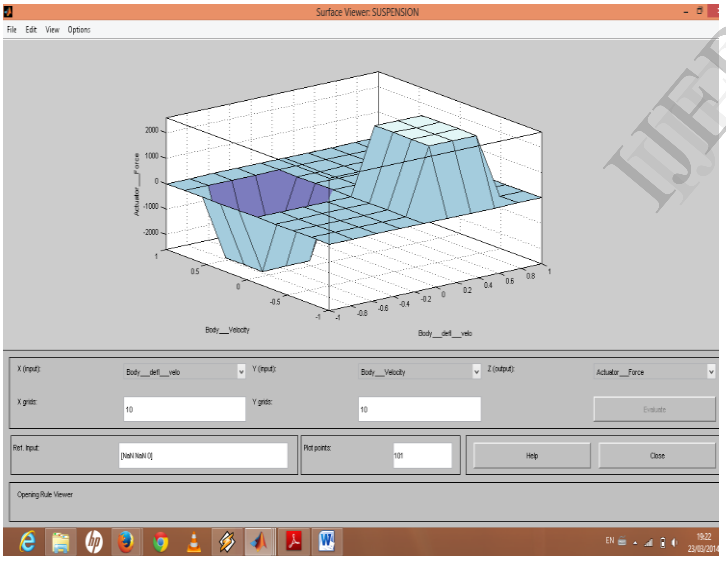

Figure 8. Surface viewer

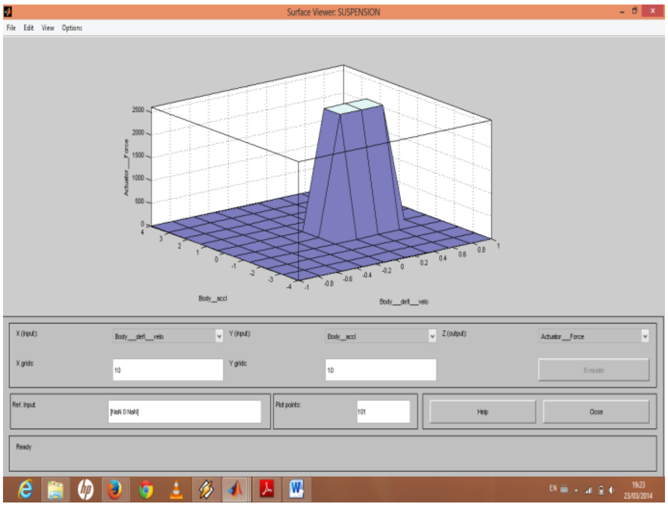

Figure 9. Surface viewer results

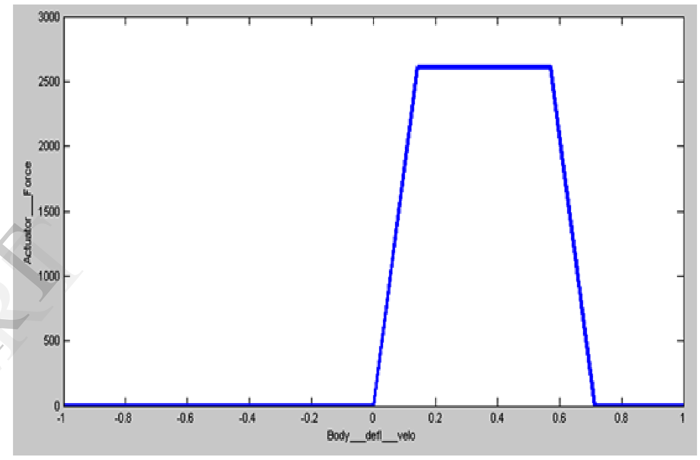

Figure 10. Graph of Actuator Force Vs. Body deflection velocity

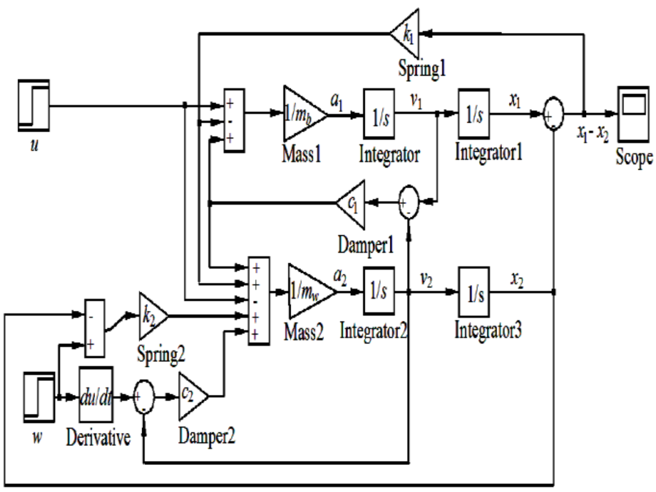

Figure 11. Simulink Model belonging to car suspension system [6].

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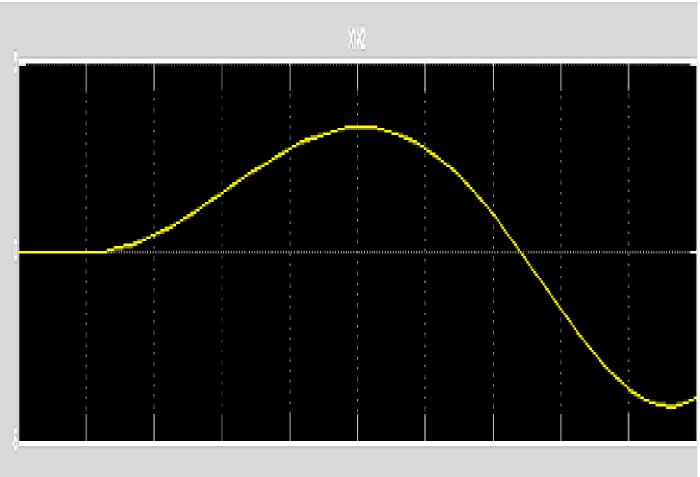

Figure 12. Graph of Body displacement Vs. Time(s) using MATLAB

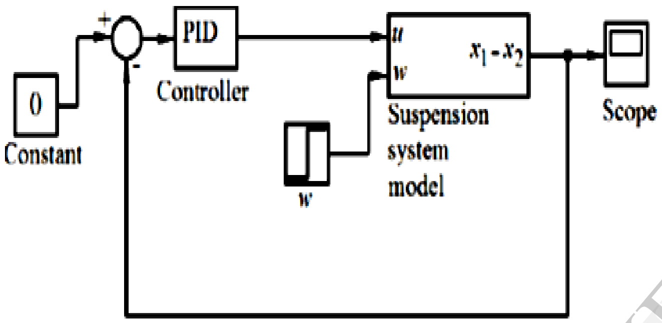

Figure 13 PID Controller Simulink Model belonging to car suspension system [6].

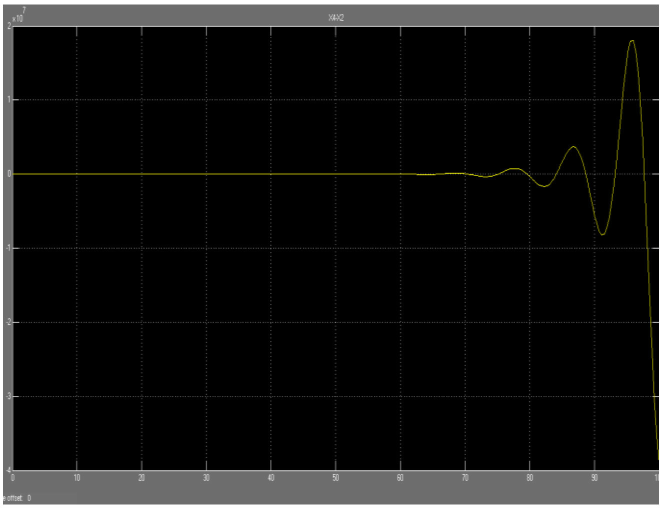

Figure 14. Graph of Body displacement Vs. Time(s) using MATLAB (PID controller system)

The Result obtained by using fuzzy logic control as shown in Figure 7 to Figure 10, explains variation of actuator force according to change in body deflection velocity and body velocity, where body acceleration is kept at zero so that control action was chosen to minimise the relative and absolute body velocities only. The rule viewer Figure 7. Illustrates that the vertical line if moved to right or left then simultaneously we can see the change in actuator force. Figure 8 shows the surface viewer in MATLAB, the actuator force can be easily analysed using grid representation according to change in body deflection velocity and body velocity. And body acceleration is kept zero represented by horizontal surface. In Figures 9 and 10, the graph of body deflection velocity versus actuator force is shown which illustrates that from range 0.1 to 0.7 the actuator force is high around 2.5 KN. The Simulink block diagram using MATLAB is shown in Figure 11 which considers only quarter car part of half car suspension system gives the simulation graph as shown in Figure 12. Giving variation of body displacement with respect to time. Further, PID controller system is applied and shown in Figure 13. The signal amplitude can be reduced for better performance, as shown in Figure 14. But further if we apply fuzzy logic control system in the design then we can have more efficient performance. Because fuzzy logic gives range of values, the actuator force can be adjusted according to rule base given .Many rule bases we can provide and according to which the actuator force can be controlled. All the above result basically got from quarter car model which is clearly illustrated in Figure 2. Considering all the above result we can have better scope to design half car as well as full car model in more precise way of design. According to above result the fuzzy logic controller design is more precise and can be comfortably used for the design.

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IV. CONCLUSION

Fuzzy logic control for half car suspension system is done by using MATLAB. The result shows by using Fuzzy control is very effective and can be used in vehicles that will be manufactured in future. In this paper, the new active suspension control system for half car system design is proposed according to basis of quarter car model for achieving ride comfort and good handling. The results of the active suspension system based on the fuzzy logic controller shows the improved stability. Here in this paper the fuzzy logic suspension system and PID control system is studied as well as Simulink model without any control system also analysed.

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