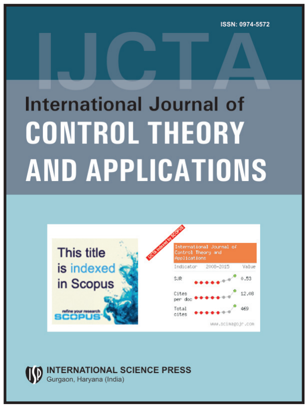

International Journal of Control Theory and Applications

ISSN : 0974-5572

Volume 9 • Number 43 • 2016

Active Suspension System Based on Fuzzy Logic Controller for Quarter Car Model

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Abstract: Active suspension is an independent type of suspension system that controls the vertical displacement of the wheel with reference of the car body, rather than in passive suspensions where the displacement is being decided entirely by the road profile. For enhancing handling and comfort performance, semi-active and active suspension systems are being developed instead of a conventional static suspension system. A quarter car model is considered and a fuzzy logic controller is developed for the active suspension system which decreases the time required for stability of chassis compared to other suspension systems.

Keyword: Fuzzy logic controller, Active suspension.

1. INTRODUCTION

In recent years of post-liberalization the Indian roads seem to be flooded with more and more number of international cars. Before liberalization the Indian car industry was not offering any special safety features to Indian customers though these were compulsory in countries like the U.S.A, U.K, etc. But soon after the liberalization as the world giants of car industries began to Indian market, the Indian consumer is offered with latest luxurious and safety features like active suspension system, seat belts, side-impact bars, air bags, collapsible steering and etc.

Vehicle Suspension is the system of tyres, spring, tyre air, linkages and shock absorbers that connect a vehicle to its wheels and allow relative motion between them. In design of Active Suspension (AS) system road irregularities are generally considered as dominant source of excitation of a vehicle. In design of Active Suspension (AS) system road irregularities are generally considered as dominant source of excitation of a vehicle. It is also assumed that vehicle is moving with constant velocity. Active suspension system consists of an actuator with the spring and damper in the suspension system. The force of the actuator is controlled by the fuzzy logic controller which keeps the chassis stable.

2. LITERATURE REVIEW

Wei Wang in 2014 discussed that active suspension system is complex in nature so fuzzy logic is used to gain control over the system Fuzzy logic does not require accurate model as that done by mathematical model so to get the membership values and rules they have used cultural algorithm [1]. Performance requirement for vehicle active suspension system were explained by Weichao Sun (2013). A problem was formulated using quarter car model and dynamic equations of sprung mass and unsprung mass were derived after this state space equation was derived to decide the boundary of problem [2]. Dependency of development of problem statement on vehicle ride comfort along with the vehicle speed is well explained by M. Soleymani(2012). Eight degrees of freedom were selected and full vehicle system was considered. Fuzzy logic controller design along with the simulation for different road conditions were also explained [3]. A integrated control algorithm for both antilock braking system and active suspension system was studied by Wei-Yen Wang(2012) [4]. A quarter car model for nonlinear dynamic behavior of suspension system was designed by Guido Koch (2010) and experimentally validated the controllers for active suspension system [5]. A fuzzy sliding mode controller was proposed by Jeen Lin (2009) to control the active suspension system and study its control performance. It was compared with the traditional fuzzy controller and then validated on a quarter car hydraulic suspension system [6]. The constraints on the achievable response of quarter car active suspension systems were derived by Semiha Turkay (2007) for a wide range of suspension parameters. The influence of tyre damping on an active suspension was also considered [7]. A quarter car model with sliding control was developed by T. Yoshimura (2000) which was constructed by the switching function whose amplitude is denoted by the absolute value of the equivalent control [8]. An adaptive fuzzy logic based controller for an active suspension system was developed by Nizar Al-Holou. The main controller network integrates inference into a feed-forward network [9].

3. COMPONENTS OF ACTIVE SUSPENSION SYSTEM

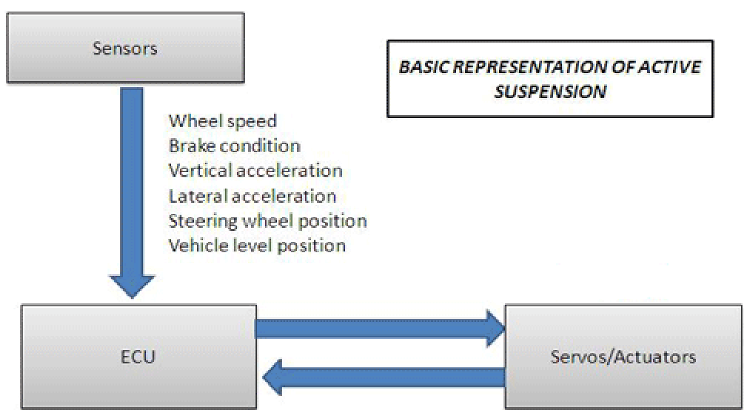

Figure 1: Basic representation of active suspension system.[10]

Figure 1 above represents a basic view of active suspension system and the components required are listed as below.

1. Adjustable shocks and springs
2. Electronic control unit (ECU).
3. Sensors are required at every wheel of car

   (Acceleration sensors, displacement sensors, steering wheel position sensor)
4. Actuator with each shock absorber

Active suspension uses sensors to measure changes occurring constantly in the road profile and providing the feedback information by means of control unit to other components. These components bring changes in the system to adjust shock, stiffness of spring, rate of spring to improve ride quality and response etc.

4. TYPES OF ACTIVE SUSPENSION SYSTEM

There are following two types of active suspension system High bandwidth system and Low bandwidth system which are explained in detail below.

A. High Bandwidth Systems

High band width system is also known as fully active suspension system. In this system the chassis and wheel of the vehicle are connected by an actuator between them i.e. in high band width system components are linked in parallel. The system is designed such that it controls both body and axle motions. This system controls the suspension over high frequency range of system. A fully active system has significant power consumption and requires actuators with a wide bandwidth.

B. Low Bandwidth Systems

Low bandwidth systems are also known as slow active systems. In this type of systems actuator is attached in series with shock absorber. This suspension system controls the suspension over lower bandwidth and specifically near rattle space frequency. The actuator gets locked at higher frequencies and the wheel motion is controlled passively.

5. CONSIDERATIONS IN CAR SUSPENSION SYSTEM DESIGN

The following considerations must be taken into account for designing a cars suspension system.

A. Human Response to Frequency

The purpose of active suspension system is to enhance ride comfort along with road handling for which three parameters must be considered. These parameters are wheel deflection, car body acceleration and dynamic load. Humans are most sensitive to vibrations for some frequencies. Hence there are limits for chassis acceleration. According to report of ISO 2631 – 1974 for vertical acceleration, endurance limit for frequency is 4 ~ 8Hz. [15]

B. Conflict Diagram

Vehicle suspension system consists of two main components spring and damper. Person sitting in a vehicle will not feel disturbance due to lower frequencies because of high damping. But, high damping proves to be poor for absorbing larger frequencies. Contrarily, For low damping it is observed that even higher frequencies are absorbed by the damper.[13] Figure 2 below shows the conflict diagram that must be considered for selecting the damping coefficient and spring stiffness to isolate the sprung mass from disturbances due to road profile.

(a) To isolate the sprung mass from the disturbances due to road profile soft damping can be used with larger suspension displacement.

(b) Improved road contact will be gained by use of a hard damping which will remove unnecessary suspension displacement.

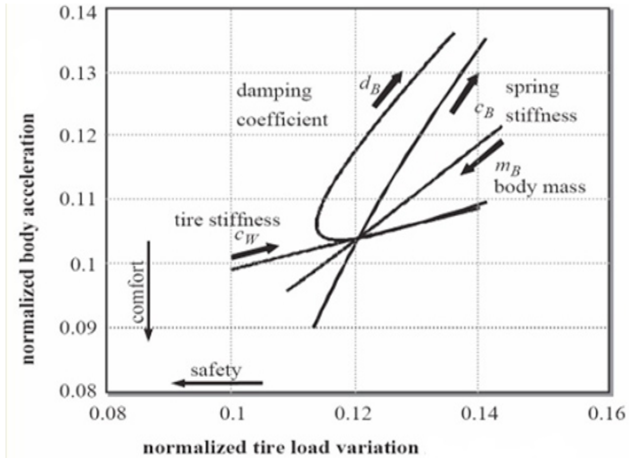

Figure 2: Conflict diagram [13]

(c) It can be seen from the diagram that for a given input road condition the passive suspension system always has a compromise between safety and comfort. Hence active suspensions are used.

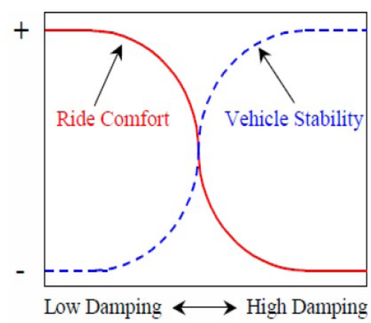

Figure 3: Suspension compromise [13]

Conventional suspension systems consist of a spring and a damper. The energy storage function is done by the spring and the energy dissipation is done by the damper. The spring and damper are decided during the design phase. Due to this reason, conventional suspension system has to make a classic suspension compromise [13]. Figure 3 shows the relation for compromising Ride comfort with vehicle stability and the compromise between the two criteria's of conflict cannot be achieved if the suspension is developed by using conventional spring and damper system. The answer to this problem can only be found by developing an active suspension system.

6. MATHEMATICAL MODEL

Figure 4 represents a 2D freedom system of quarter-car model for active suspension system. It imitates the system of single wheel for an automobile vehicle which means the movement of the axle and of the car body at any single wheel among the four wheels of the automobile vehicle [16]. Quarter car model is used because of the symmetry of the vehicle and it is simple as well the basic parameters for the active suspension system which are sprung and unsprung mass, tyre deflection and suspension deflection is also observed in the Figure 4.

where,

k_s = Stiffness of spring

b_s = Coefficient of damping

f_a = Actuator force

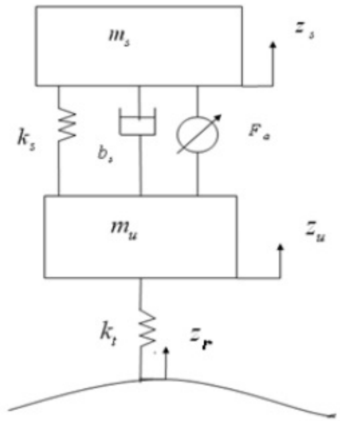

Figure 4: Mathematical model [16]

m_s = Sprung mass

m_u = Unsprung mass

k_t = Tyre stiffness

z_s, z_u, z_r = Vertical displacement of sprung and unsprung mass and road

Equations of motion of the 2D freedom system of quarter car model is given by

$$m_s \ddot{Z}_s = F_a - k_s(Z_s - Z_u) - b_s(\dot{Z}_s - \dot{Z}_u) \tag{1}$$

$$m_u \ddot{Z}_u = k_s(Z_s - Z_u) + b_s(\dot{Z}_s - \dot{Z}_u) + k_t(Z_r - Z_u) - F_a \tag{2}$$

It is considered that the stiffness of spring and stiffness of tyre is within the operating limits. It is also assumed that the tyre is constantly in contact with the road surface.

7. FUZZY LOGIC CONTROLLER

Fuzzy logic is a propositional form of logic that is controlled by a knowledge base. It does not require highly accurate mathematical model for the system. The fuzzy control rules are defined considering the experience of the system.

These rules are morphological in nature. They use simple relationship to link fuzzification and de-fuzzyfication process

It can be proven that complex systems can be defined easily with the help of fuzzy logic theory.

Linguistic variables like small, big, very big represents the knowledge base, by assigning membership value to each variable within range of 0 to 1. A fuzzy logic controller consists of following components.

(a) The fuzzification process reads and converts the input variables in to relevant linguistic variables.

(b) The knowledge base made of linguistic variables which is called rule base.

(c) Logic for deciding the action of fuzzy logic control on the basis of input variables, which are very difficult for humans for taking decicissions.

(d) A defuzzification process to read and convert the action of linguistic variables into a non-fuzzy control input for the system being controlled.

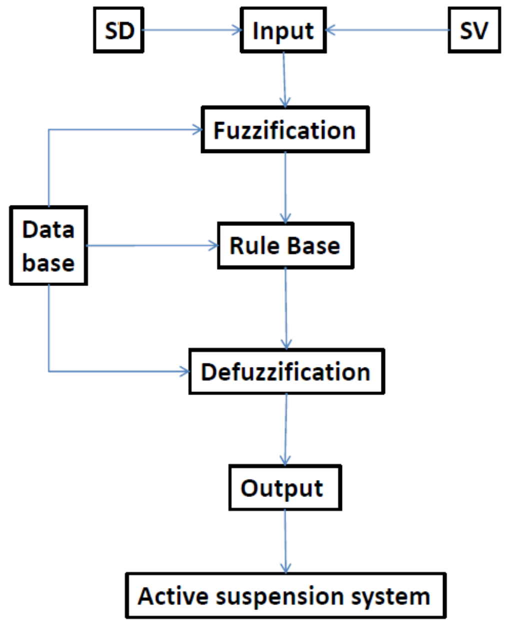

Figure 5: Graphical representation of fuzzy logic

The Figure 5 shows the graphical representation of fuzzy logic. The two inputs are given such as suspension displacement and suspension velocity. These inputs are given to fuzzification and rule defuzzification with data base as feedback loop. The output of defuzzification is actuator force which is given to active suspension system.

A. Fuzzy Logic Controller (FLC) Design

A Mamdani fuzzy logic controller is designed. It has two inputs and single output. The inputs for fuzzy logic controller are Suspension Displacement (SD) and Suspension Velocity (SV). SD and SV here represent the body and wheel relative displacement and velocity, respectively. The output of the fuzzy logic controller is the actuator force.

Each input has seven Membership Functions (MFs), and the output has seven MFs. Therefore, the rule base contains 49 rules. Moreover, it is assumed that input MFs are identical in shape. Triangular shape membership function has been chosen. The initial output and input MFs are NL, NM, NS, Z, PS, PM, and PB are linguistic variables, which represent negative large, negative medium, negative small, zero, positive small, positive medium, and positive large respectively[3].

B. Fuzzy Rule Base

The fuzzy rule base converts the control strategy into the control rules described by verbose statements[3]. The main objective of the FLC design in this work is to get the required ride comfort as well as enhance it. Therefore, the rule base is devised, such that the transmission of forces to the body is minimized. Hence, immediate understanding of the suspension system and logical proofs has been employed.

Let us consider some cases:

1. Where both SD and SV are negative large, implying that the spring is largely compressed and has a tendency to be intensively compressed, even further. In this case, in order to attenuate the resultant force exerted to the body, the actuator extends the spring and damper with a big force.

2. SD is positive small and SV is negative small. In this case, the spring is extended a little, but it is likely to be closed, and, therefore, it is wise to cancel the actuator force in order to save energy.

Table 1
Fuzzy rule base

SD	*NL*	*NM*	*NS*	*Z*	*PS*	*PM*	*PL*
SV							
NL	PL	PL	PM	PM	PS	PS	Z
NM	PL	PM	PM	PS	NS	Z	NS
NS	PM	PM	PS	Z	Z	NS	NM
Z	PM	PS	NS	Z	Z	NS	NM
PS	PS	NS	Z	Z	NS	NS	NM
PM	NS	Z	NS	Z	NS	NM	NL
PL	Z	NS	NS	NS	NM	NL	NL

C. Membership Function

Fuzzy logic toolbox from MATLAB is used to design the active suspension system. Mamdani system is used to design rule base. Triangular membership functions are used to describe input and output parameters.

Figure 6 below shows two input functions on left named suspension displacement and suspension velocity which are provide as an input to the controller and one output named actuator force on right which is provided by the controller to the actuator in the system.

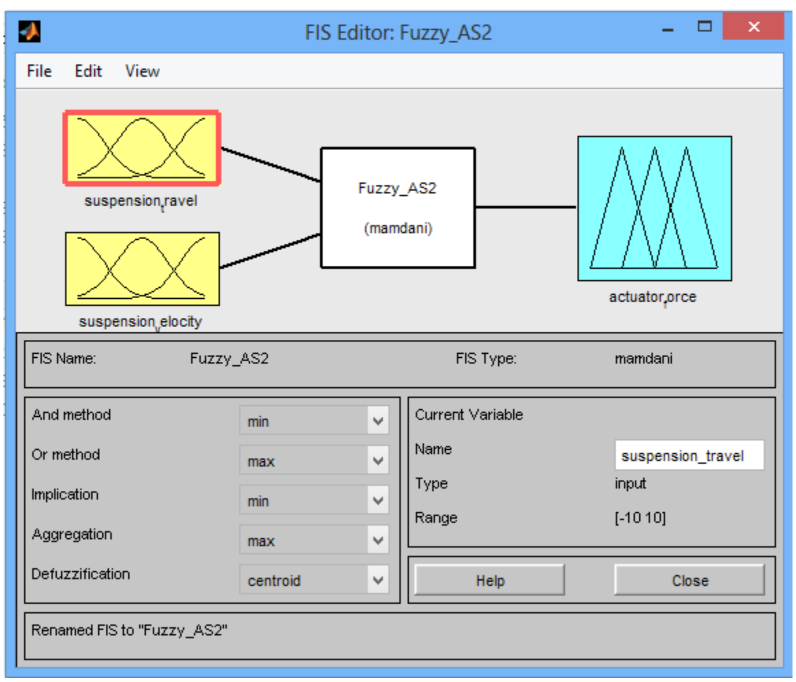

Figure 6: Input output parameters

Figure 7 below shows the rule viewer of the fuzzy logic controller where the 1st column indicates the suspension travel, the 2nd column indicates the suspension velocity and third coloumn indicates the actuator force.

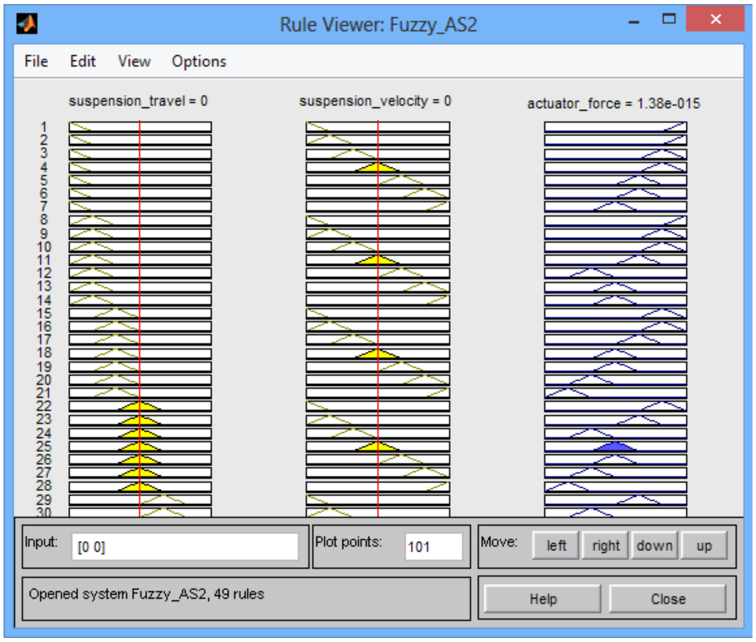

Figure 7: Rule viewer

D. Case Discussion

After defining both input parameters and output parameter along with rules we can calculate easily the actuator force required at different locations. Let us consider following cases:

1. When the inputs are given as Suspension displacement (column 1) = 2.2 and suspension velocity (column 2) = 1.2 then actuator force (column 3) required is -210. This means that when suspension moves by 2.2 mm with velocity of 1.2 m/s then the actuator must provide a force of -210 N to keep the system stable. Figure 8 below shows the representation of case 1.

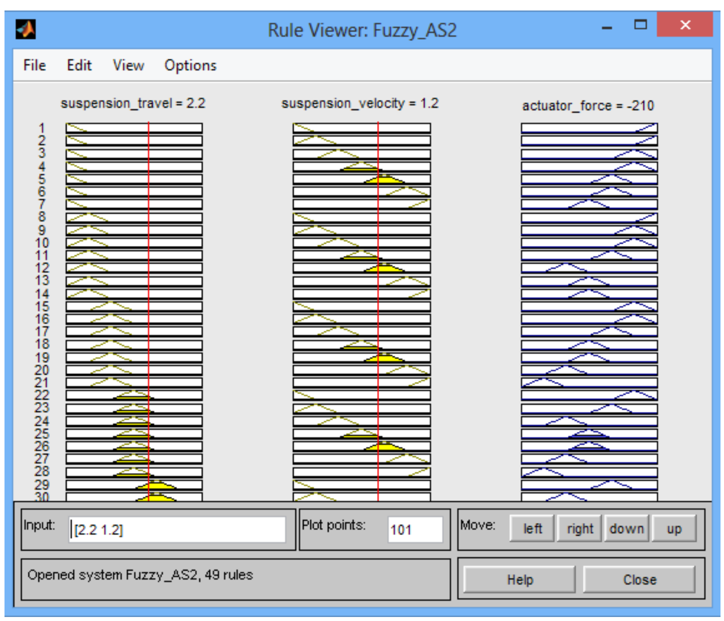

Figure 8: Case 1 representation in Matlab

2. When suspension displacement (column 1) is –4.5 and suspension velocity (column 2) is 1.2 then required actuator force (column 3) is –18.3. This means that when suspension moves by –4.5 mm with velocity of 1.2 m/s then the actuator must provide a force of –18.3 N to keep the system stable. Figure 9 below shows the representation of case 2.

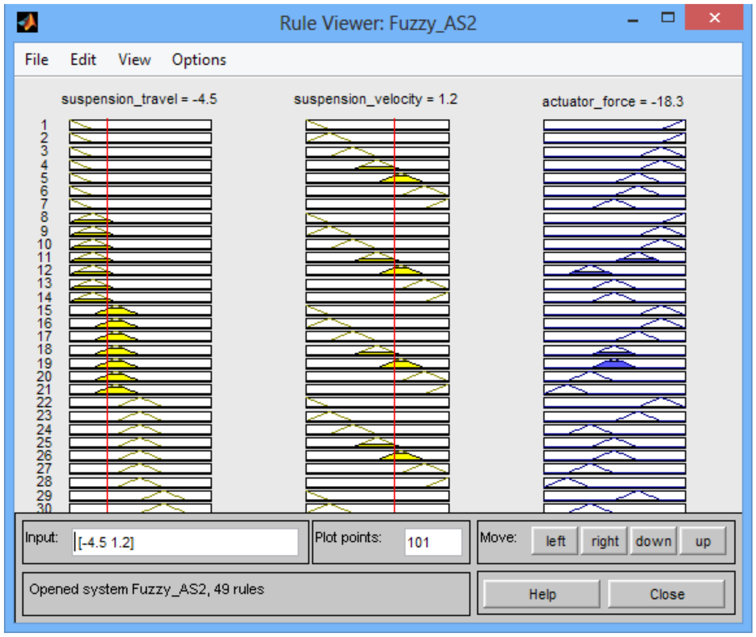

Figure 9: Case 2 representation in Matlab

8. SIMULINK MODEL

The Simulink model for active suspension system is developed in MATLAB. The upper half portion of the Simulink model represents the car body suspension and the lower half represents the vehicle wheel. The Fuzzy logic controller is implemented in the Simulink model. The velocity and displacement of car body is provided as an input to the fuzzy logic controller in the Simulink model. The Simulink model was tested for two types of inputs one is the step input and other is the random road input. The random road input was also developed in the MATLAB model. Figure 10 shows the Simulink model.

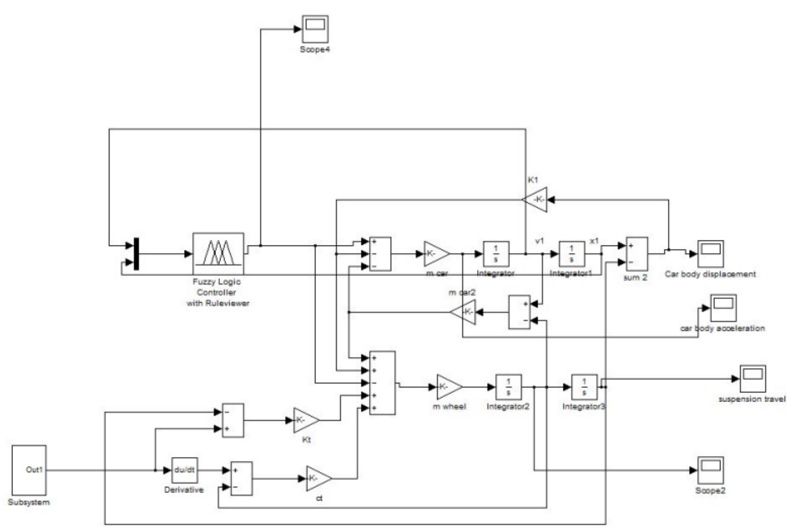

Figure 10: Simulink model

The output of Simulink model is considered based on the road inputs and the amount of bump provided to the wheel. Therefore the car body displacement in the output is compared with the input bump provided. The Figure 11 below shows the output of the step input provided to the suspension system.

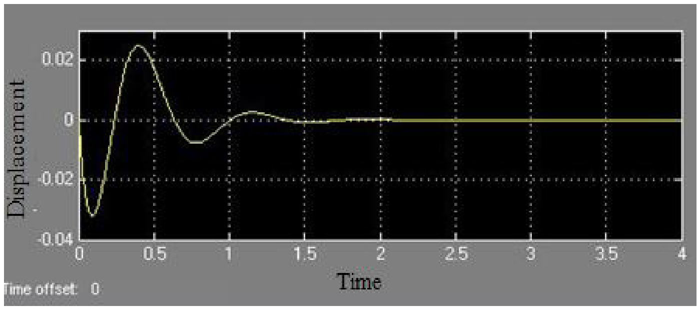

Figure 11: Car body displacement for step input

The input bump provided was 0.1m and it was damped upto 0.023m. and it can be seen in the Figure that damping occurs in 2 seconds which is very less compared to other systems. Similarly the output of car body displacement for rough road input is shown in Figure 12 below.

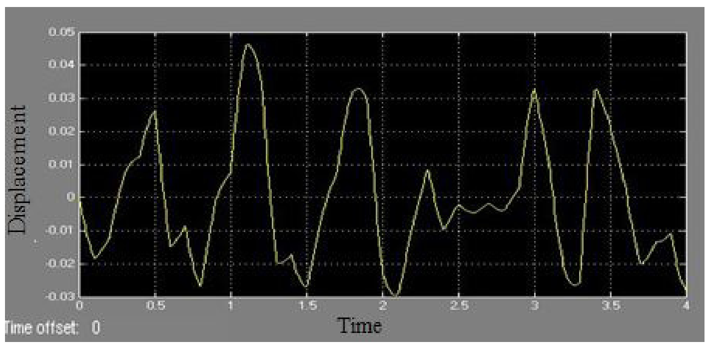

Figure 12: Car body displacement for rough road

9. CONCLUSION

In this paper, a fuzzy logic controller for active suspension system is designed considering two inputs suspension displacement and suspension velocity. The actuator force was obtained as an output. It can be seen from the cases discussed above that when the input parameters changes the required actuator force changes. This actuator force obtained is the force required to be given as an input to the actuator in the actual system.

It can be also seen from the outputs that the active suspension systems damps out the road bumps to a very low value and this damping is achieved in less time compared to the other suspension systems.

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