Modeling, Simulation, and Control of Half Car Suspension System Using Matlab/Simulink

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Abstract: *The modeling, simulation, and control of linear half car suspension system with different control algorithms are studied using Matlab programming package. The model has four degrees of freedom; comprising of heave movements of the front and rear axle, pitch and heave motions of the unsprung mass of the vehicle. Different controllers developed and implemented in this study such as PID, Fuzzy and Fuzzy-PID. Each controller was widely simulated for linear half car models hydraulically actuated for active suspension system. The aim of each controller was to minimize the deflection and the acceleration of the suspension system in the presence of road disturbances, modeled by step input excitation wheels. Comparisons between passive and active, linear simulation models have been carried out with different control schemes. The result of these comparisons was that performance of the linear model was attuned better than the linear model, and the Fuzzy-PID controller suggest in this work was the best among other controllers used in analysis. Shows the superior performance of response amplitude, shorter settling time, small overshot, high steady precision, and good dynamic performance.*

Keywords: PID, Fuzzy Logic Controller, Suspension System, Half Vehicle, Road Uncertainty

1. Introduction

Generally, Vehicle suspension system consist of spring and shock absorbers, used to an accommodated vehicle osculation, also connecting the associate vehicle will its wheels. The suspension system performance recently has been developed due to increasing vehicle efficiency. Several suspension system design proposals have been introduced to increase the performance and sophistication of the vehicle suspension system by redefine the boundaries of the elements. Because of the advantage of suspension, systems participate to the car's road holding and braking for driving pleasure and good safety device, and maintain vehicle well isolated from road disturbance, bumps and within an acceptable limit of deflection. Road and load disturbance consider the main two factors points of disturbances on a vehicle comfort. Such as road roughness, consider small Value in high frequency and such as hill consider bigger value in low frequency of road discomfort. Load disturbances include the variables loads such as accelerating, braking and cornering. These objectives are to find the proper compromise by directly and indirectly control the suspension force to achieve required performance characteristics. Suspension system assist to keep the wheel in touch with the road surface, because of the force acting on the vehicle do so through the contact spot of the tires. Automotive researchers studied many designs of suspension system for passive suspension design, semi-active suspension design and active suspension design thought both analysis by using Maltlab/Sumlink and experimental research. The purpose of this studies is to design best suspension system to give maximum ride comfort and rode handling by maintain vehicle well isolated from road disturbance, bumps and within an acceptable limit of deflection by controlling the suspension force to observing or dissipating the energy accordantly [1]. Suspension system is playing big role which targeting to isolating vehicle body from road profile to achieve better ride comfort and detained continuous wheel contact to the road to provide fantastic stability and passenger comfort. Subsequently a tradeoff between inconsistent criteria of quality of vehicle handling, vehicle ride comfort, and road holding within the limitation of suspension journey [2]. Three type of suspension system, categorized as passive suspension system, semi-active suspension system and active suspension system.
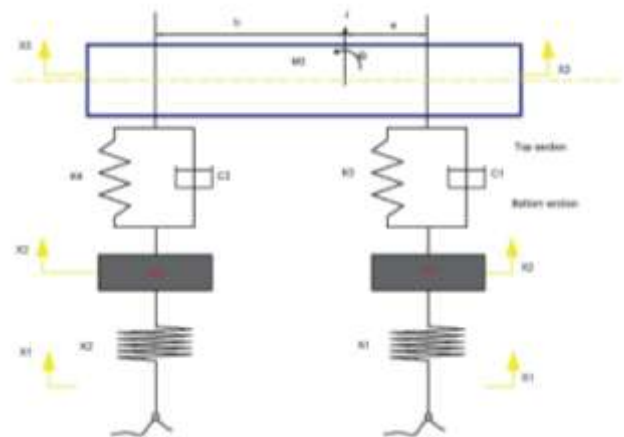

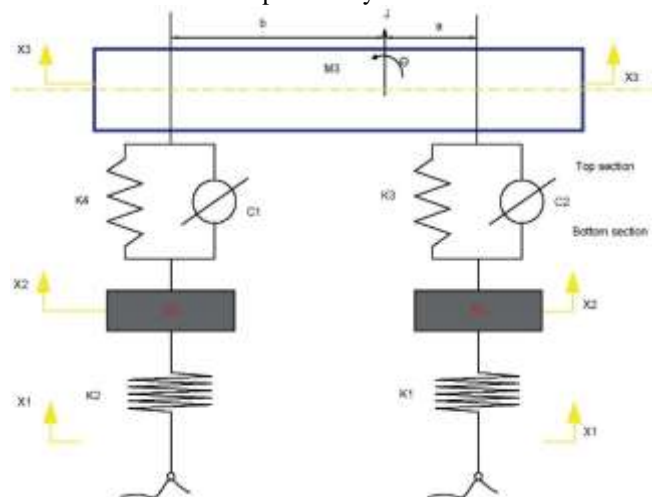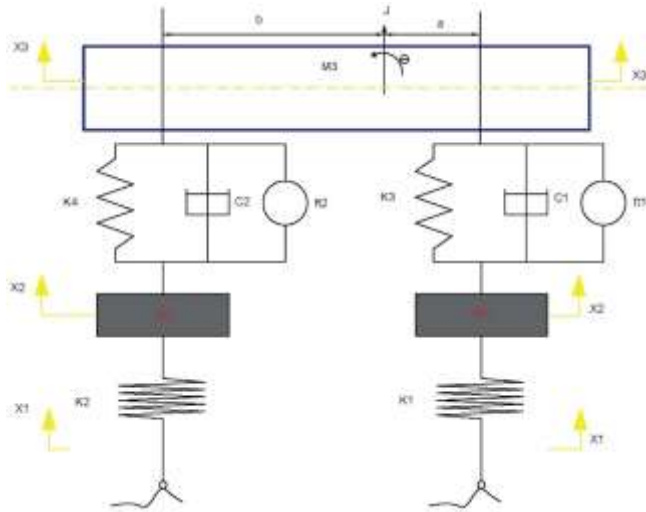**Figure 1.1:** Shows the diagram of half car passive suspension system.

Figure 1.2: Shows the diagram of half car semi-active suspension system.

Figure 1.3: Shows the diagram of half car active suspension system

2. Derivation of linear Suspension for half Car Suspension Model

$$M_1 \ddot{X}_1 - C_1 \left[\dot{X}_3 - \dot{X}_1 + a\dot{\theta}\right] - K_3 \left[X_3 - X_1 + a\theta\right] + K_1 \left[X_1 - U_1\right] = 0$$

$$M_2 \ddot{X}_2 - C_2 \left[\dot{X}_3 - \dot{X}_2 - b\dot{\theta}\right] - K_4\left[X_3 - X_2 - b\theta\right] + K_2\left[X_2 - U_2\right] = 0$$

$$M_3 \ddot{X}_3 + C_1 \left[\dot{X}_3 - \dot{X}_1 + a\dot{\theta}\right] + K_3 \left[X_3 - X_1 + a\theta\right] + C_2 \left[\dot{X}_3 - \dot{X}_2 - b\dot{\theta}\right] + K_4 \left[X_3 - X_2 - b\theta\right] = 0$$

$$J \ddot{\theta} + C_1 a \left[\dot{X}_3 - \dot{X}_1 + a\dot{\theta}\right] + K_3 a \left[X_3 - X_1 + a\theta\right] - C_2 b \left[\dot{X}_3 - \dot{X}_2 - b\dot{\theta}\right] - K_4 b \left[X_3 - X_2 - b\theta\right] = 0$$

Whereas, derived the equations of motion of the half car active suspension system are as follows [7]:

$$M_1 \ddot{X}_1 - C_1 \left[\dot{X}_3 - \dot{X}_1 + a\dot{\theta}\right] - K_3 \left[X_3 - X_1 + a\theta\right] + K_1 \left[X_1 - U_1\right] - Fa1 = 0$$

$$M_2 \ddot{X}_2 - C_2 \left[\dot{X}_3 - \dot{X}_2 - b\dot{\theta}\right] - K_4 \left[X_3 - X_2 - b\theta\right] + K_2 \left[X_2 - U_2\right] - Fa2 = 0$$

$$M_3 \ddot{X}_3 + C_1 \left[\dot{X}_3 - \dot{X}_1 + a\dot{\theta}\right] + K_3 \left[X_3 - X_1 + a\theta\right] + C_2 \left[\dot{X}_3 - \dot{X}_2 - b\dot{\theta}\right] + K_4\left[X_3 - X_2 - b\theta\right] - Fa1 - Fa2 = 0$$

$$J \ddot{\theta} + C_1 a \left[\dot{X}_3 - \dot{X}_1 + a\dot{\theta}\right] + K_3 a\left[X_3 - X_1 + a\theta\right] - C_2 b \left[\dot{X}_3 - \dot{X}_2 - b\dot{\theta}\right] - K_4 b\left[X_3 - X_2 - b\theta\right] - aFa1 + bFa2 = 0$$

Where:
$M1$ = unsprung mass (front wheel)
$M2$ = unsprung mass (rear wheel)
$M3$ = sprung mass (body mass)
$K1$ = tire stiffness (front wheel)
$K2$ = tire stiffness (rear wheel)
$K3$ = sprung stiffness (front wheel)
$K4$ = sprung stiffness (rear wheel)
$C1$ = sprung damping (front wheel)
$C2$ = sprung damping (rear wheel)
$X1$ = road profile displacement
$X2$ = unsprung mass displacement (wheel displacement)
$X3$ = sprung mass displacement (body displacement)
$Fa1$ = front actuator force
$Fa2$ = rear actuator force

Due to stiffness of the front tire and stiffness of rear tire and when the front tire or the rear tire or both of front and rears tires hits a certain road profile that will create an upright force transmit to the wheels lead to vertical acceleration of the wheel. The suspension elements will damp part of the vertical force, and the rest is transmitted to the car body via the suspension system. Due to vertical force of the

In this section, a complete mathematical model of the passive system for a half car model as shown in Figure 3.1 are derived base on the approach as present in Sam [12]. The passive suspension system parameter components are used in the study is as presented in Abdullahi [1] and is tabulated in table 3.1. It is assumed that all spring and damper are linear. The assumptions for modeling half car linear suspension system are:
1) The front and rear tires are act as spring with no damping.
2) Wheels rotational motion are not considering
3) There is rotational motion in the body.
4) Assumed that all springs are linear
5) Assumed that all dampers are linear.
6) The tires and road surface are always in contact.
7) Effect of friction between road surface and tires are neglected.

By applying Newton's Second Law of motion, the linear differential equations describing the dynamics of the passive half car suspension model of Figure 3.1a can be written as follows:

suspension system, the car body will oscillation vertically up and down. The suspension system performance criteria can be investigating through parameters such as vehicle body displacement, body acceleration, wheel displacement, and suspension working space.

3. PID Control (Proportional-Integral-Derivative)

The PID controller block diagram as shown in Figure 3.4, it is the most common controller in industry applications [34].
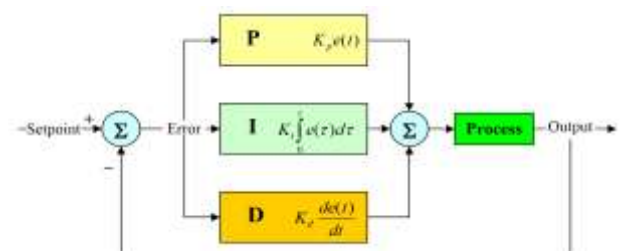
Figure 3.4: Block diagram of PID controller [34].

The mathematic form of PID controller can be expressed as follows:

$$u(t) = K_P \, e(t) + K_i \int_0^t e(t) \, dt + K_d \, \frac{de(t)}{dt}$$

Where,

e(t) = set-point - plant output

K_P = proportional gain

K_i = integral gain

K_d = derivative gain

The PID controller model exemplified in its state-space format is serially connected. Displacements of the axles considered as outputs are feed back to the input to form double close-loops and smooth road surface considered as the reference inputs are zeros, which together with the disturbance form the input to the plant. The amplifier is placed to boost the effect of the PID.

1) Based on the present error is generated the proportional control action.
2) Based on the past error is generated integral control action.
3) Based on the anticipated future error is generated the derivative control action.

1. Present, past and anticipated error all are processed by PID controller.
The controller performance relies on the typical and correct parameter of the controller gains; K_P, K_i and K_d .

4. Tuning of PID Parameters

There are several methods for tuning of PID controller parameters, that is, methods for finding proper valves of K_P, K_i and K_d. By tuning various parameters of the controller to improve values of the required response. The stability, desired rise time, peak time and overshoot are the basic objectives of the output of the control. Different PID parameters could be obtained if the system can be taken offline. In the industrial implementation, the suspension system must be study online, by manually carried out the tuning processes, which experienced personal required achieve that, and in the same time human error needs to be considered. Ziegler-Nichols method one of the good online calculation methods of tuning [15], which is not very preferable because it involves some trial and error. Tuning of PID parameters are given in [34] by the rules from the below table 3.1:

Table 3.1: PID controller characteristic in closed loop system

Response	Rise Time	Overshoot	Settling Time	S-S Error
K_P	Decrease	Increase	NT	Decrease
K_I	Decrease	Increase	Increase	Eliminate
K_D	NT	Decrease	Decrease	NT

5. Fuzzy Logic Controller

The FLC has three inputs used in the active suspension with fuzzy logic controller that are body acceleration, body velocity, body deflection velocity, and one output represents actuator spool valve signal which is desired actuator force. The fuzzy logic comprised of three principal components: first stage fuzzification interface, second stage fuzzy inference machine and third stage represent defuzzification interface, as shown in Figure 3.4 [32].

FLC used to apply crisp number to be converted to a number between (0, The fuzzification stage converts real-number (crisp) input values into fuzzy values; this is done by based on fuzzy rule table depending on physical system's prosperities, this process called fuzzy inference. While the fuzzy inference machine processes the input data and computes the controller outputs in cope with the rule base and database. These outputs, which are fuzzy values, are converted into real numbers by the defuzzification stage. After fuzzy rule gives the decision, FLC gives an output; crisp value will be given by defuzzification process to the system as from FLC [32]. As shown in figure 1.5 below a half car active suspension system described with FLC and speed of sprung mass as an error feedback.
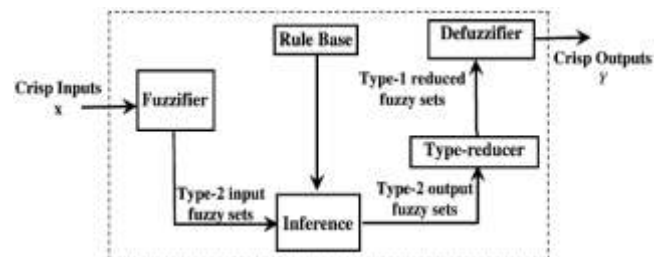

Figure 3.4: Fuzzy and plant block diagram [32].

1) Fuzzification
Initially, inputs signals and outputs signals of the controller are specified. Inputs are vehicle acceleration, vehicle velocity and vehicle deflection, vehicle velocity, and one output signal that is the control actuator force. The difference measurement between actual and desired input is call the error which it is considered as input signal. Membership function (MF) should be chosen. Different membership functions used has been study and find out that the best output performance for suspension system is the triangular MF shape [37].
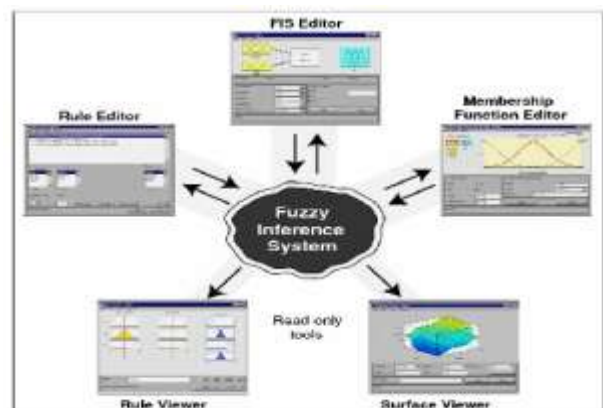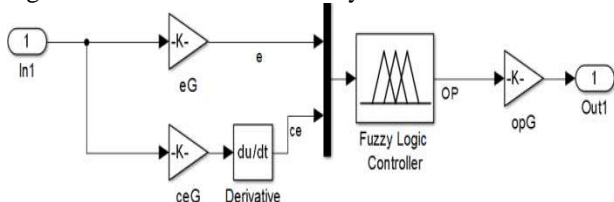

Figure 3.5: Fuzzy inference system.
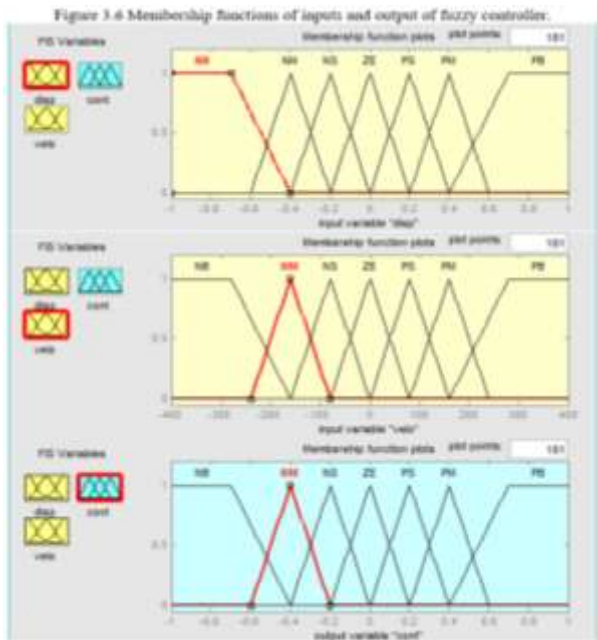
In Figure 3.6, a fuzzy rule described by using linguistic variables as expressed below:
- Negative Big (NB)
- Negative Medium (NM)
- Negative Small (Ns)
- Zero (ZE)
- Positive Small (PS)
- Positive Medium (PM)
- Positive Big (PB).

In figure 1.6 shown the block fuzzy controller

Figure 1.6: Contents of fuzzy controller [37].

Figure 1.6 contain three gains, error and change of error as input lines and third one as output line. These gains state as scaling factors.

2) Fuzzy Rule Base
Fuzzy rule is coming from accumulated experience from related field of applications. The law to create a set of fuzzy rules is depended on actual application and based on a human experience is required to tuning the controllers to get the typical performance.

A fuzzy rule is represented by a sequence and using linguistic variables, fuzzy rule provide base between input signal and output signal by using linguistic variables, which describes the relationship between the fuzzy input and the fuzzy output. It is difficult to derive relationship between the input and the output. For those cases, fuzzy logic rules base is a good solution. Each rule is consisting of two parts. The first part contains an inequality and need to be satisfied and that part called as antecedent. The second part could

conclude if antecedent output is satisfied that has called consequent [37]. As shown in Table 3.2.

Table 3.2: The fuzzy rule base [19]

| K_D ΔE / E	NB	NM	NS	ZO	PS	PM	PB
NB	PS	NS	NB	NB	NB	NM	PS
NM	PS	NS	NB	NM	NM	NS	ZO
NS	ZO	NS	NM	NM	NS	NS	ZO
ZO	ZO	NS	NS	NS	NS	NS	ZO
PS	ZO	ZO	ZO	ZO	ZO	ZO	ZO
PM	PB	PS	PS	PS	PS	PS	PB
PB	PB	PM	PM	PM	PS	PS	PB

3) Defuzzification
The fuzzy inference is conclusion or control output derived from the combination of input, output membership functions and fuzzy rules is still a vague or fuzzy element.

A defuzzification process is needed to make that conclusion or fuzzy output available to real implementations. A defuzzification is convert or change fuzzy output set to crisp output value. There are three types of defuzzification techniques, which are center of gravity technique (COG), mean if maximum technique and the height technique. The center of gravity technique has been introduced in the literature. The center of gravity method is widely used in actual applications. In the Center of Gravity principle, crisp output is calculated as shown in reference [32]. Figure 3.7 shown fuzzy controller block diagram.

6. Fuzzy-PID Controller

In recent years, classical PID controller well known is common used in practice and industrial processes because of it is simplicity structure, and performance over wide range of operation conditions for linear suspension system. PID controllers has been modified to fuzzy logic control techniques and best method of controlling to the complex model system associated with simplicity, effectiveness, good dynamic response, rising time and overstrike for both linear systems. An analytic study of the FLC-PID is carried out to allow us to explain the influence of each tuning parameter and establish an equivalence between the FLC-PID and a conventional PID to obtain general results. The objective of the controller is to maintain a process in specific state by monitoring a set of variables and selecting the adequate control actions. Figure 3.8 is shown the structure of the Fuzzy-PID controller [22].
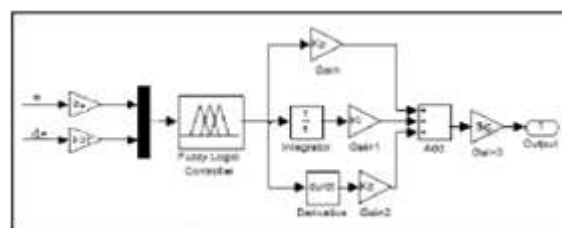

Figure 3.8: Block diagram of the Fuzzy-PID controller.

Simulation with Matlab/Simulink has been performed to verify the effectiveness of half car passive suspension system. Half car suspension system defined in the mathematical model as per the Equations 3.1, and parameters of half car has been defined as per the list in Table 4.1. Figure 4.1 shown the block diagram of the simulation.

Table 4.1: System parameters of the model

| Parameter	Symbol	Values	Unit
Constants			
Sprung mass of the vehicle Chassis	M2	1795	Kg
Moment of inertia of the vehicle	J	3443.05	Khm2
Unsprung mass of the front axle	M1	87.15	Kg
Unsprung mass of the rear axle	M2	140.4	Kg
Stiffness of the rear tire material	K1	190	KN/m
Stiffness of the rear tire material	K4	190	KN/m
Spring constant of the front axle	K2	36350	N/m
Spring constant of the rear axle	K3	26530	N/m
Damping coefficient of the front axle	C1	1200	Ns/m
Damping coefficient of the rear axle	C2	1100	Ns/m
Front body length from the CG	a	1.32	m
Rear body length from the CG	b	1.46	m
State Variables			
Vehicle vertical displacement	X3	------	m
Vehicle rotational movement	Ѳ	------	rad
Front axle vertical displacement	X1	------	m
Rear axle vertical displacement	X2	------	m
Inputs (road excitation)			
Road Excitation at the front axle	u(t)	------	m
Road excitation of the rear axle	u(t+td)	------	m

Amplitude of step function has been entered 10 mm and for road profile one second of step-time has been entered in the matlab simulation and in Figure 4.2 and 4.6, respectively shown the result of the linear passive half model.
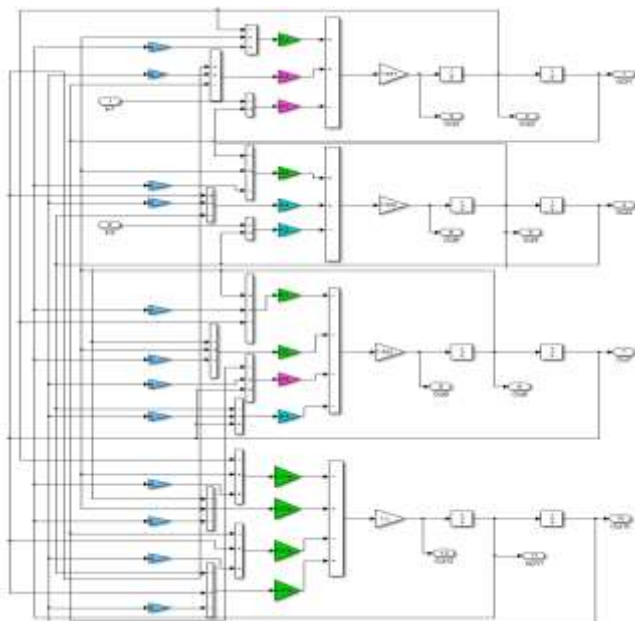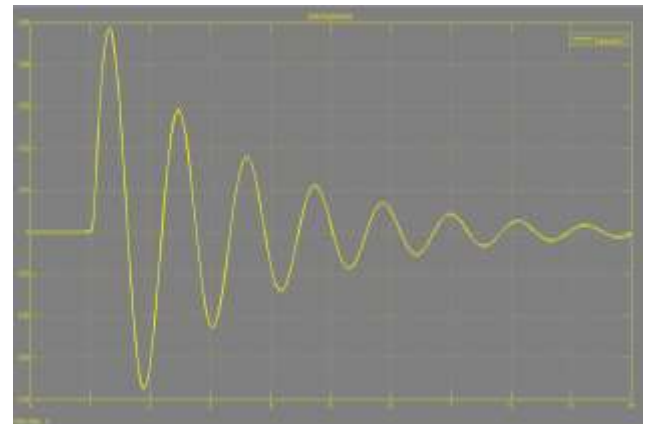

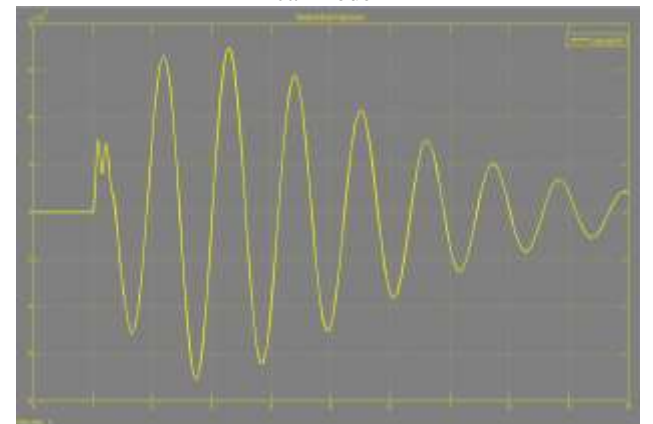**Figure 4.1:** Block diagram of linear passive half car model.
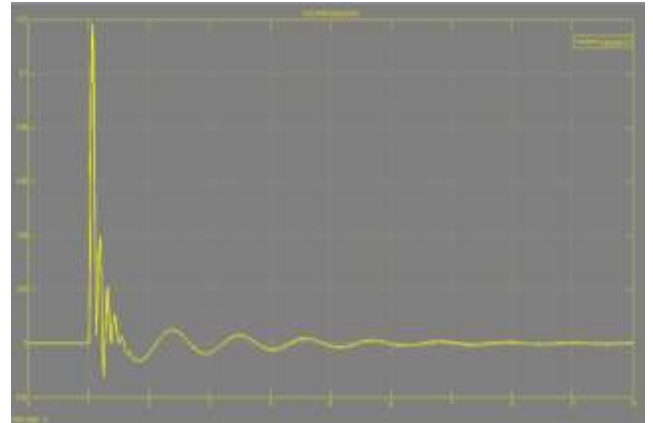
Figure 4.2: Front axle vertical displacement of linear passive half car model
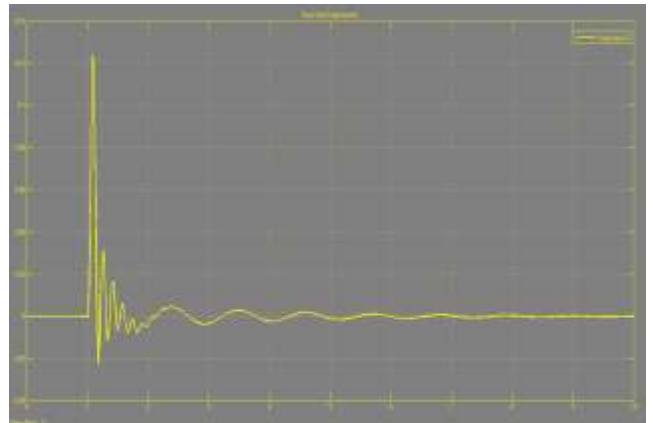
Figure 4.3: Rear axle vertical displacement of linear passive half car model.

Figure 4.4: Vertical body displacement of linear passive half car model

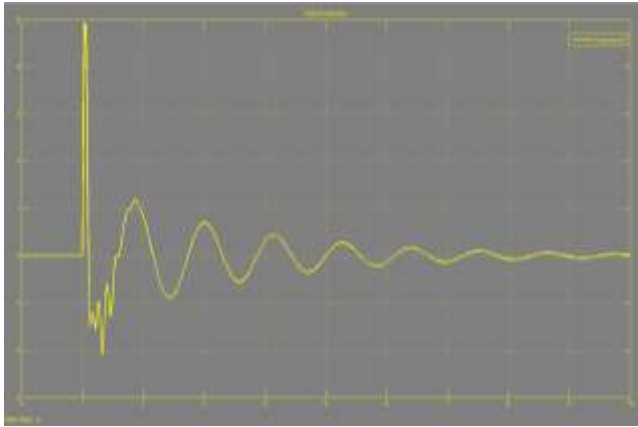**Figure 4.5:** Rotational body displacement of linear passive half car model

Figure 4.6: Body acceleration of linear passive half car model.

Active suspension system with PID controller

The different between active suspensions system and conventional passive suspensions system is in their capability to inject energy into the system, as well as store energy and disperse energy. Outer- loop controller focus on the in computation of the desired control force between of the vehicle body and road disturbance. As shown in Figure 4.7 outer-loop controller, is used to compute the typical target force to minimize the effects of road disturbances by using the hydraulic actuator to generate an ideal force to be able to carry out the commanded forced accurately [19]. The mathematical model given in equations 3.2 used to simulation of active suspension system with PID outer loop controller.
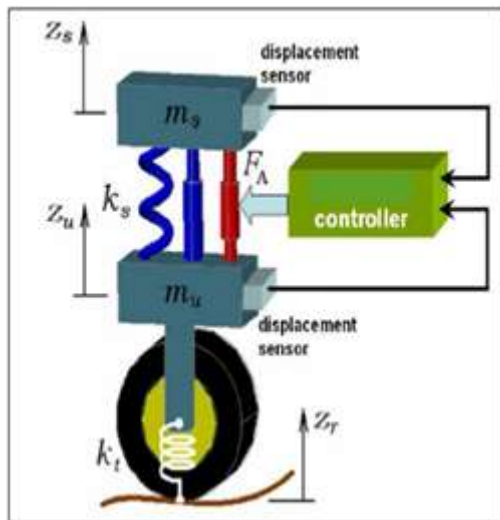

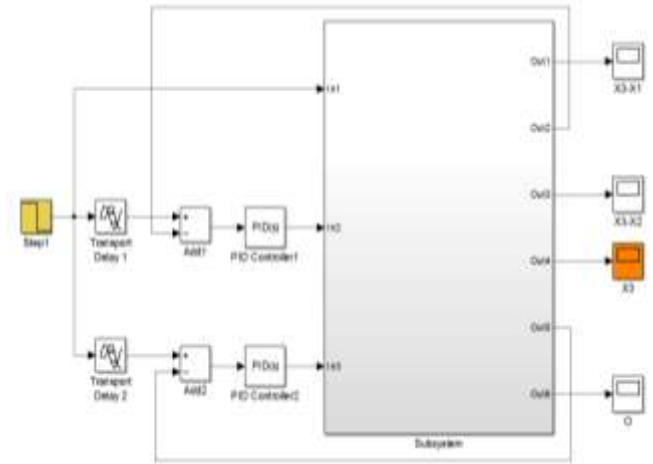**Figure 4.7:** The Outer-loop controller for active suspension of half car model.

Figure 4.8: Block diagram of linear active half car model with PID controller.

Matlab/Sumlink is used to carry out the simulation. A linear vehicle velocity is assumed of 100km/hr. At the moment of the vehicle pass over the triangular bump of 1o mm amplitude. Time delay between the front wheel and rear wheel can be computed by using below equation by, td can have computed as 0.02 second using below equation:

$$td = (a + b)/v$$

Response of the active suspension system with PID control and passive suspension system are analyzed simultaneously to compare the performance of the active suspension system over passive suspension system. The effectiveness of the model established by computing maximum over shoot and the settling time of the vehicle. Response of front wheel vertical displacement is described as shown in Figure 4.9, at the maximum heights of the road disturbance the maximum suspension travels occurred for both models.
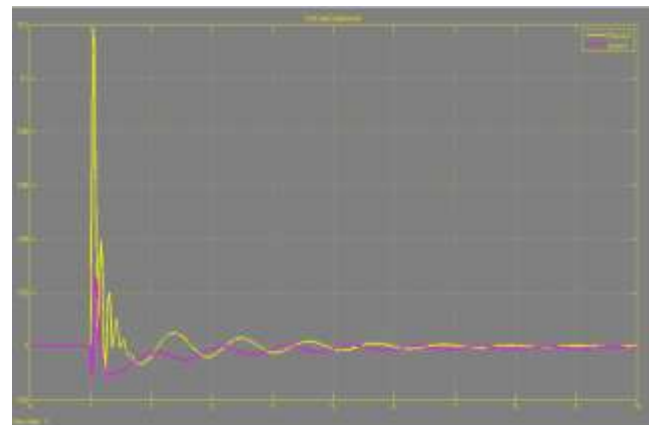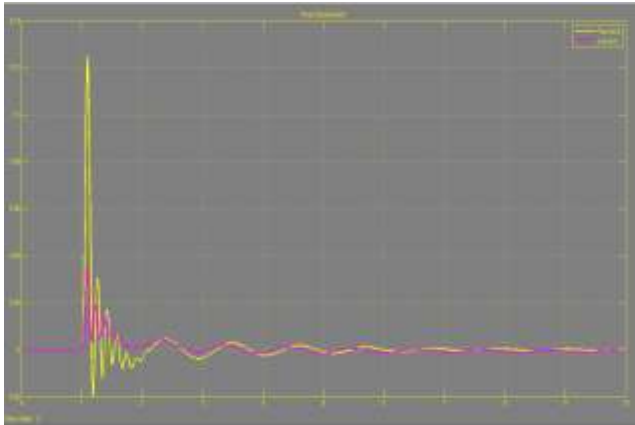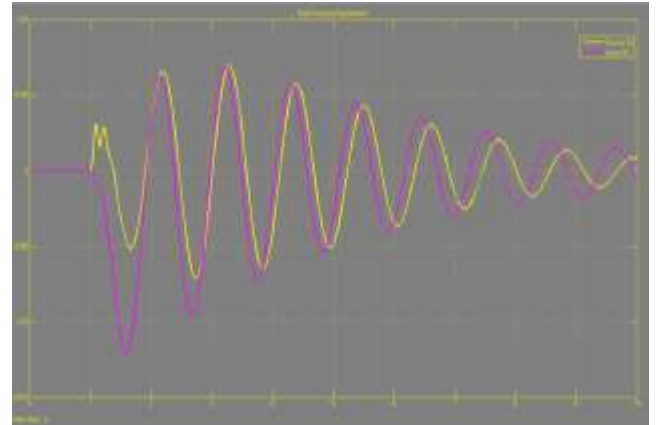

Figure 4.9: Front axle vertical displacement of active half car model with PID controller.

The active suspension system is not only lessening maximum overshoot of the maximum suspension travel, but also accelerate the settling time. Due to the time delay between the front wheel and rear wheel when pass over the bump, the maximum overshoot of the rear wheel occurred after 0.02 second from the front wheel as shown in Figure 4.10 below.

Figure 4.10: Rear axle vertical displacement of active half car model with PID controller.

Similarly, the active suspension system has reduced the maximum suspension travels compared with the passive suspension system. The system stability has been speed up and the system reached to steady state earlier compare with the passive suspension system. The vehicle's road holding performance has been described as shown in the Figures 4.11 and 4.12. Skidding and ineffective braking happened when the wheels failed to settle faster. In sport car usually have stiff and harsh suspension just to improve road holding, however with poor passenger comfort. Effectiveness of the active suspension system against passive suspension system in settling the translational displacement of the unsprung mass of the vehicle has been shown in Figure 4.11. This model is more applicable to luxury cars that are more concern with passengers' comfort [21].
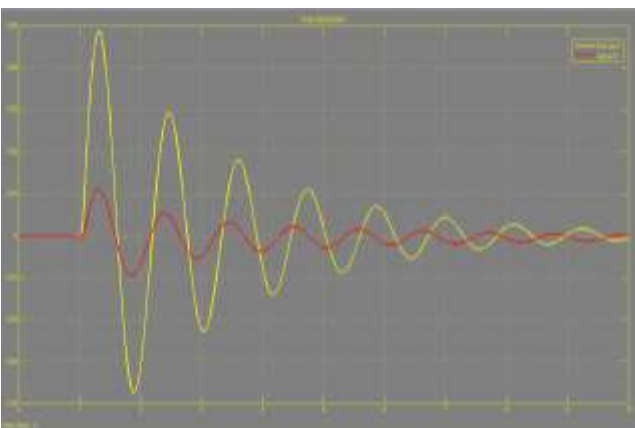
**Figure 4.11:** Vehicle body displacement of active half car model with PID controller.

In Figure 4.12 shown response of unsprung mass of the vehicle of the rotational displacement and in Figure 4.13 shown the vehicle acceleration for both active and passive suspension system. The PID controller aims to restore the system to its steady state faster and with less overshoot. From result of the simulation, proved that the active suspension system is more effective in controlling the vehicle oscillation and more robust in restoring the system to its steady state as compared to the passive suspension system.

Figure 4.12: Rotational body displacement of active half car model with PID controller.
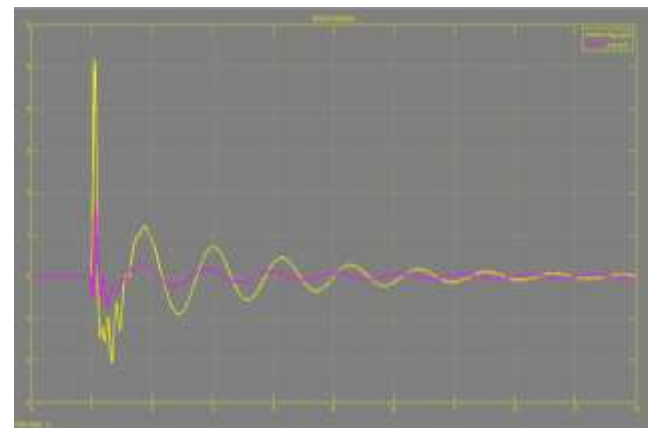
Figure 4.13: Body acceleration of active half car model with PID controller

7. Active Suspension System with Fuzzy controller

Fuzzy logic controller system is successfully implement, to reduce a cost function to prevent an excessive growth of parameters of the consequent part. The idea is who to generate the conclusion parts of the rules automatically by using to an optimization technique. Fuzzy logic control is provided conventional method for linear controls using heuristic information. This might come from an operator who acts as a human-in loop controller and from whom experiential data is obtained. In Figure 4.14 shown the design of the FLC for the half car suspension system. The FLC rule base is characterized by a set of linguistic variables rules based, which is required experienced person to achieve that. The two-inputs as shown in table 3.2, in this study used one output rule base table. A membership function (MF) defines as a curve that how each point in the input space is mapped to a membership valve. The membership function used in this study shown in Figure 3.6. Triangular and fixed in order membership shape function has been used to extract and represent the knowledge from the final results easily and input variables for the main operator of the composition used to reduce the truth value
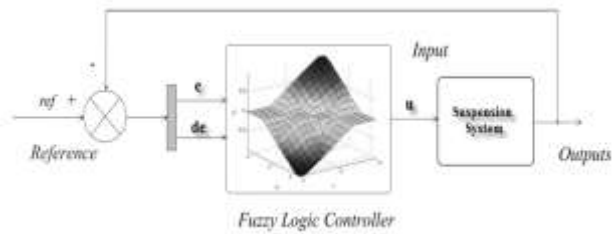
Figure 4.14: the structure of the Fuzzy Logic Controller (FLC).

In Figure 4.15 below, shown the block diagram of the linear half car model with FLC.
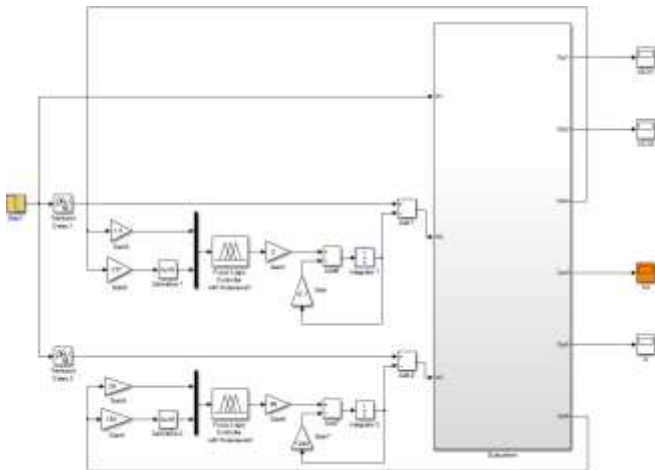
**Figure 4.15:** Block diagram of the active half car model with FLC.

Matlab/Simulink has been used to simulate the above model, in Figure 4.16 shown the control surface describes the relations between the input parameters and the output and in Figure 4.17 and 4.21, respectively shown the behavior of memberships for each rule base. The Rule viewer displays a roadmap of the completely 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 [22].
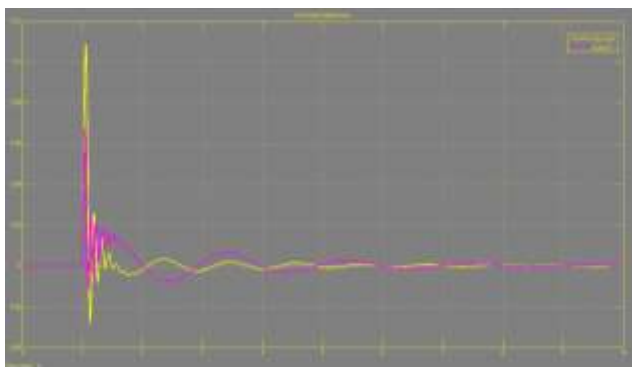
Figure 4.22: Front axle vertical displacement of active half car model with FLC controller
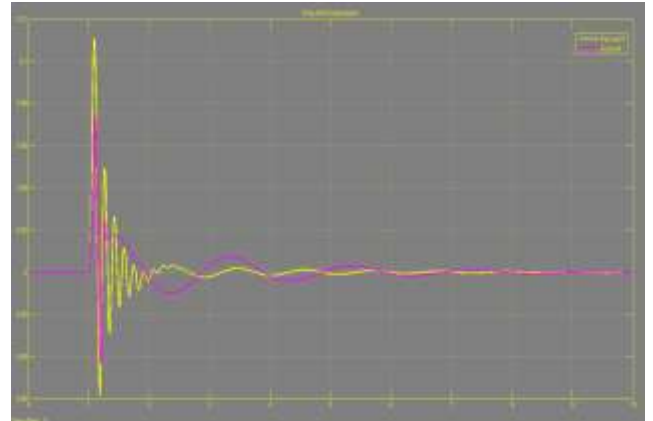
Figure 4.23: Rear axle vertical displacement of active half car model with FLC controller.
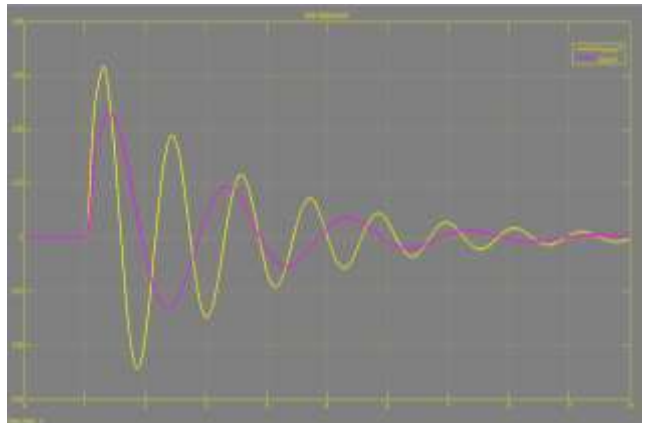
Figure 4.24: Vertical body displacement of active half car model with FLC controller.

Figure 4.25: Rotational body displacement of active half car model with FLC controller.
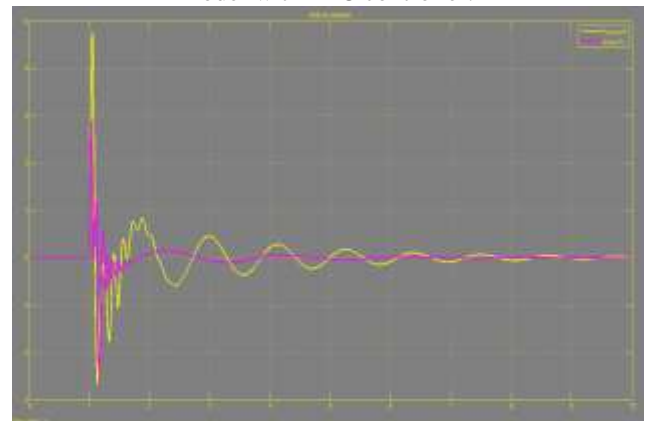
Figure 4.26: Body acceleration of active half car model with FLC controller.

The Result obtained by using fuzzy logic control as shown in Figure 4.22 to Figure 4.26, respectively 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 minimize the relative and absolute body velocities only. The rule viewer Figure 4.17. Illustrates that the vertical line if moved to right or left then simultaneously we can see the change in actuator force. Figure 4.16 shows the surface viewer in matlab, the actuator force can be easily analyzed using grid representation according to change in body deflection velocity and body velocity. In addition, body acceleration is kept zero represented by horizontal surface. In Figures 4.24 and 4.25, the graph of body deflection velocity versus actuator force is shown which illustrates the actuator force. The Simulink block diagram using matlab is shown in Figure 4.15, which considers only half car part of full car suspension system, gives the simulation graph as shown in Figure 4.22. Giving variation of body displacement with respect to time. With applying fuzzy logic control system in the design, we have performance that is more efficient. 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 got from half car model, which is clearly illustrated. Considering all the above result, we can have better scope to design 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 [22].

Active suspension with Fuzzy-PID controller

The Fuzzy-PID controller suggested to be used to control the linear half car model of this study. In Figure 4.27 shown the block diagram for linear model.

Matlab program used to development of the controllers in simulation to view the suspension system performance by simulation responses. To make the comparison easier between the active and passive response plot in varying work environment. The developed Simulink basically, consists of two main subsystems with the road disturbance being injected to simulate the actual vehicle performance. The controllers need to be carefully tuned to get the best response. The time response plot is obtained during simulation while considering passive and active system.

Figure 4.27: Block diagram of the linear half car model with Fuzzy- PID controller.

Figures 4.28 to 4.32, respectively shown the simulation results of the linear half car model with Fuzzy-PID controller.
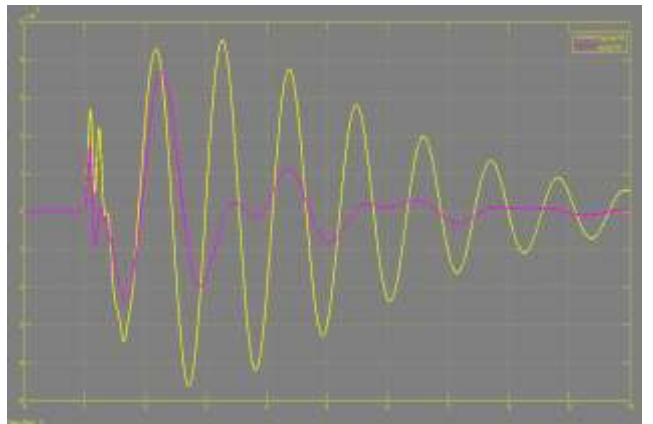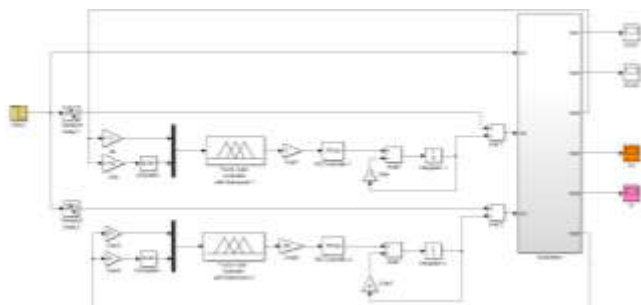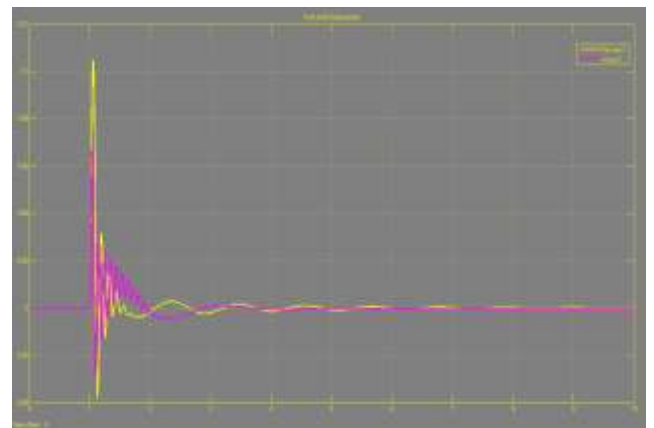

Figure 4.28: Front axle vertical displacement of active half car model with FLC-PID controller.
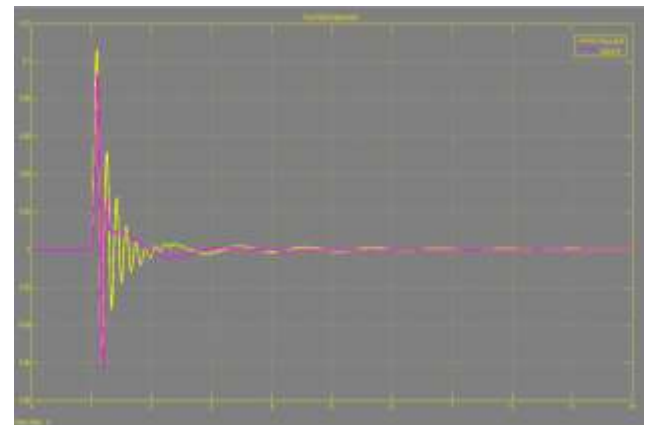
Figure 4.29: Rear axle vertical displacement of active half car model with FLC-PID controller

Figure 4.30: Vertical body displacement of active half car model with FLC-PID controller.

Figure 4.31: Rotational body displacement of active half car model with FLC-PID controller.

Figure 4.32: Body acceleration of active half car model with FLC-PID controller

8. Comparison of Different Controllers

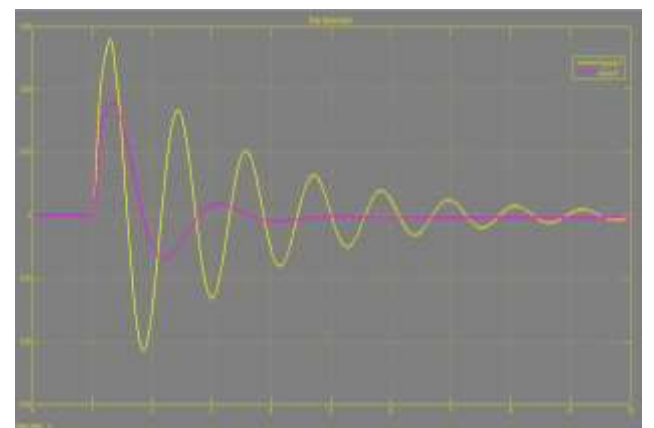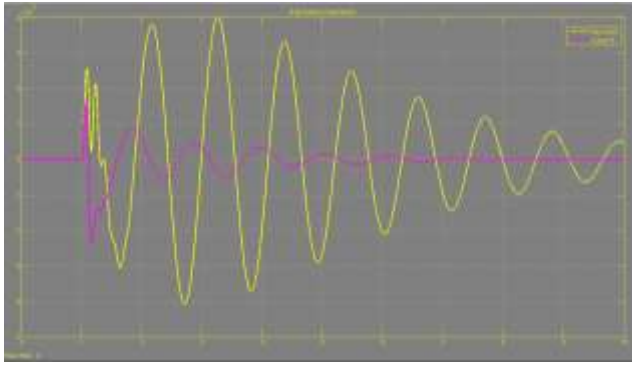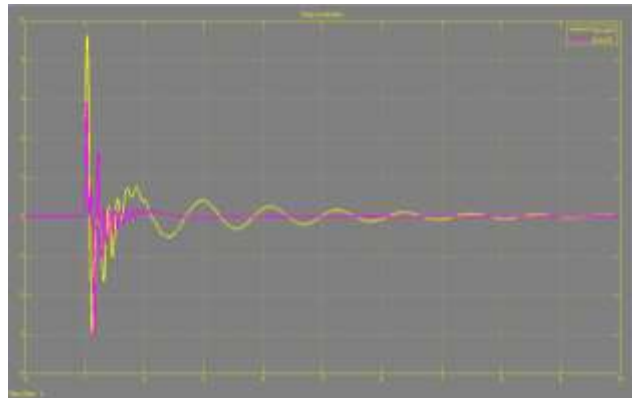To find the best controller to use with linear half car model, comparisons will be made between the deferent control schemes proposed in this study for both linear models, using the suspension deflection as criterion for comparison. Figure 5.11, shows the suspension deflection of the half car model for the different control methods used. It is clear from this Figure that the Fuzzy controller proposed in this work, gives the best suspension deflection considering all thee comfort parameters such as amplitude, rise time, overshot, and settling time of the system. For the linear model Figure 5.12, illustrated that Fuzzy and Fuzzy-PID controllers have similar behavior in controlling the model, taking into the account all the above comfort parameters.
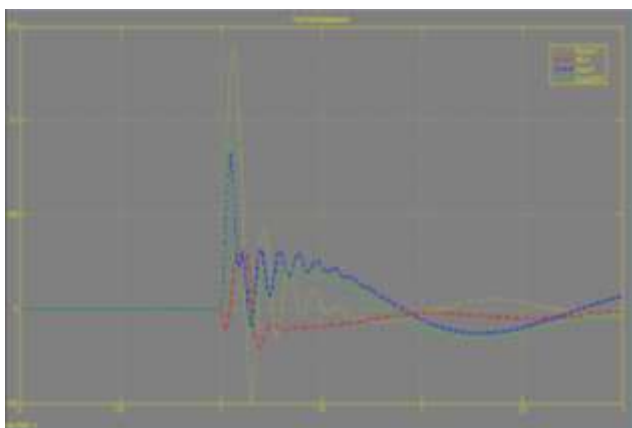
Figure 5.13: Comparison of different controllers for front axle

9. Conclusions

The project is considered as important since the suspension system is one of the most important parts of the vehicle, the successful design of the active suspension system, which gives more comfort and better handling. The half car model implemented in simulation using Matlab/Simulink. The half car suspension model has been investigated and can be summarized as follows:

1) Simulations of Mathematical models for active suspension systems have been developed for half car model and Newton's second law of motion is used to develop the modeling.
2) PID controller has been successfully implemented and different control algorithms such as Fuzzy and Fuzzy-PID has been implemented and investigation of the linear suspension system. The results show good performance of the Fuzzy-PID control algorithm for linear models.
3) The Performance between active and passive, suspension system with different control schemes have been evaluated and looked that the active model gives good resolution.
4) From the result of these study, the performance of fuzzy logic controller better than PID controller by minimizing the vehicle body's deflection and acceleration.
5) The simulation results revealed that, Fuzzy-PID controller has a better response amplitude, shorter settling time, small overshot, high steady precision, and good dynamic performance.

The simulation results revealed that, compared with other controllers, Fuzzy-PID controller has a better response amplitude, shorter settling time, small overshot, high steady precision, and good dynamic performance.

The analysis of these study shown and proven that the simulation result can be improved by achieving better simulation and the controller need to by be tuned carefully and experience is required to have better result.

References

[1] Abdullahi, B.; Atef, A., "Half car suspension system integrated with PID controller" Proceedings 29th European Conference on Modelling and Simulation ©ECMS Valeri M. Mladenov, Petia Georgieva, Grisha Spasov, Galidiya Petrova (Editors) ISBN: 978-0-9932440-0-1 / ISBN: 978-0-9932440-1-8 (CD).
[2] Cheng, W., "Design and synthesis of active and passive vehicle suspension" IEEE Transactions on Control Systems Technology, Vol. 10, No. 1, (2001).
[3] Williams, R.A., "Electronically Controlled Automotive Suspensions". Computing & Control Engineering Journal. 5(3): 143-148., (1994).
[4] Fialho, I.; Balas, G.J., " Road adaptive active suspension design using linear parameter-varying gain-scheduling", IEEE Transactions on Control Systems Technology, Vol. 10, No. 1, (2002).
[5] Alleyne, A.; Hedrick, J.K., "Nonlinear control of a quarter car active suspension", Proceedings of the American Control Conference, Chicago IL, pp. 21–25, (1992).

[6] Lin J.S.; Kanellakopoulos, I., "Nonlinear design of active suspensions", Control System Magazine, Vol. 17, pp. 45–59, (1997).

[7] Lin, J.S.; Huang, C.J., "Nonlinear backstepping active suspension design applied to a half-car model", Vehicle System Dynamics, Vol. 42, No. 6, pp.373-393, (2004).

[8] Emir, L.; Rahmi, G., "Fuzzy logic control of vehicle suspension with dry friction nonlinearity" S¯adhan¯a Vol. 30, Part 5, October 2005, pp. 649–659. © Printed in India.

[9] Gursel N., Altas I.H., Gumusel L., "Fuzzy Control of a Bus Suspension System", Proc. of 5th International Symposium on Intelligent Manufacturing Systems, Sakarya University, Department of Industrial Engineering, May 29-31, (2006).

[10] Sam, Y.; Osman, J.H.S., "Sliding mode control of a hydraulically actuated active suspension" Jurnal Teknologi, No. 44(D), pp. 37-48, UTM, (2006).

[11] Gao, W.; Zhang, N., "A half car model for dynamic analysis of vehicles with random parameters" 5th Australasian Congress on Applied Mechanics, ACAM 2007 10-12 December 2007, Brisbane, Australia.

[12] Sam, Y.; Suaib, N.M; Osman, J.H.S., "Proportional integral sliding mode control for half-car active suspension system with hydraulic actuator", 8th WSEAS Conf. (ROCOM), pp. 52-57, China, (2008).

[13] Zulfatman and Rahmat M.F., "Application of Self-Tuning Fuzzy PID Controller on Industrial Hydraulic Actuator using System Identification Approach", International Journal on Smart Sensing and Intelligent Systems, Vol. 2, No.2, (2009).

[14] Patel, C.B.; Cohil, P.P; Borhade, B., "Modelling and vibration analysis of a road profile measuring system" International Journal of Automotive and Mechanical Engineering (IJAME) ISSN: 1985-9325(Print); ISSN: 2180-1606 (Online); Volume 1, pp. 13-28, January-June 2010 ©Universiti Malaysia Pahang.

[15] Ekoru, J.E.D.; Dahunsi, O.A.; Pedro, J. O., "PID control of a nonlinear half- car suspension system via force feedback", IEEE Africon, Zambia, (2011).

[16] Sawant S.H., "Analysis and Comparison of Vehicle Dynamic System with Nonlinear Parameters Subjected to Actual Random Road Excitations", International Journal of Mechanical Engineering and Technology, Vol. 3, Issue 2, (2012).

[17] Filippo, G., "Modelling, simulation and control for a skyhook suspension" Trabalho apresentado com requisito parcial à conclusão do curso de Engenharia de Controle e Automação na Pontifícia Universidade Católica do Rio de Janeiro, Rio de Janeiro, Brasil.

[18] Mohd, A.; Rajeev, S., "Performance improvement of light vehicle suspension system using PID and Fuzzy logic controllers" MIT International Journal of Mechanical Eng neering, Vol. 4, No. 2, August 2014, pp. 90-93 90 ISSN 2230- 7680 © MIT Publications.

[19] Nasser, S.; Ahmed, A.; Nouby, M.; Jaber, G., "PID controller of active suspension system for a quarter car model" International Journal of Advances in Enginee ing & Technology, Dec., 2015. ©IJAET.

[20] Shafie, A.; Bello, M.M.; Khan, R.M., "Active vehicle suspension control using electro hydraulic actuator on rough road terrain" Journal of Advanced Research in Applied Mechanics ISSN (online): 2289-7895 | Vol. 9, No. 1. Pages 15-30, 2015.

[21] Manzhen, W., "Semi-Active suspension comprehensive control" 3rd International Conference on Management, Education, Information and Control (MEICI 2015).

[22] Narinder S.; Bhangal, K., "Fuzzy control of vehicle active suspension system" International Journal of Mechanical Engineering and Robotics Research Vol. 5, No. 2, April 2016.

[23] Mujde, T.; Nurkan, Y., "Sliding mode control of a bus suspension system" World Academy of Science, Engineering and Technology International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering Vol:10, No:8, 2016.

[24] Ankita, R.; Rutuja, G.; Yerrawar, R., "Comparison between passive and semi-active suspension system using matlab/simulink" IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN: 2278-1684, p-ISSN: 2320-334X, Volume 13, Issue 4 Ver. I (Jul. - Aug. 2016), PP 01-06.

[25] Mohammed, H.; Mahir, B., "Fuzzy Control strategy for the low bandwidth active suspension system" International Journal of Mechanical Engineering and Robotics Research Vol. 5, No. 2, April 2012.

[26] Beno, J.H.; Weeks, D.A.; Bresie, D.A; Guenin, A.M., "Comparison between active and pssive suspension in coast-dwon tests" Fourht International AECV Conference, Noordwijkerhourt, The Netherlands, September 23-26, 2001.

[27] Williams, R.A.; Best, A., "Control of a low frequency active suspension", IEE Control Conf., No. 389, (1994).

[28] Rahmdel S., Bairami M., Manssorzadeh M., and Fahham H.R., "Design Chattering-Free Performance-Based Fuzzy Sliding Mode Controller for Bus Suspension", International Journal of Engineering Sciences Research, Vol. 03, Issue 5, (2012).

[29] Pankj, S.; Nittin, S.; Dimple, S.; Parveen, S., "Analysis of automotive passive suspension system with matlab program generation" International Journal of A vancements in Technology, ISSN 0976-4860, Vol. 4 No. 2(July 2013) ©IJoAT.

[30] Shuttlewood, D.W.; Crolla, D.A.; Sharp, R.S., "Theoretical results of an electrically actuated hydro-pneumatic slow-active suspension", International Symposium on Theory of Machines and Mechanisms, Nagoya, Japan, (1992).

[31] Mehrad, N.; Vahid, A., "Comparison between optimized passive vehicle suspension system and semi-active fuzzy logic controlled suspension system regarding ride and handling" World Academy of Science, Engineering and Technology International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering Vol:1, No:1, 2007.

[32] Sivanandam, S.N.; Deepa, S.N.; Sumathi, S., "Introduction to fuzzy logic using matlab" Library of Congress Control Number:200693009, ISBN-10 3-540-35780-7 Springer Berlin Heidelberg New York, © Springer-Verlag Berlin Heidelberg 2007.

[33] Ziegler J.G. and Nichols N.B., "Optimum setting for automatic controllers", Trans. ASME, Vol. 64, (1942).

[34] Desborough, L.; Miller, R., "Tuning PID controll" Feedback Systems by Astrom and Murray, v2.11b http://www.cds.caltech.edu/~murray/FBSwiki.

[35] Mirji, S.; Arockia, S., "Fuzzy logic control for half car suspension system using matlab" International Journal of Engineering Research & Technology (IJERT), ISSN: 2278-0181, Vol. 3 Issue 3, March - 2014.

[36] Aminreza, R.; Saeed, B., "Control design of a semi active suspension using optimal, PID and sliding mode theory" ©2012- Mediamira science publisher. All right reserved, volume 53, number2, 2012, Manuscript received april 13, 2012.

[37] Ying, B.; Dali, W., "Fundamentals of fuzzy logic control – fuzzy sets, fuzzy rules and defuzzifications" IEEE Trans. On Sys., Man, and Cybernetics, Vol.25, No.3, March 1995, pp. 505-512.

[38] Ram, T.; Venkata, R.; Sreenivasa, R., "Analysis of passive and semi active controlled suspension system for ride comfort in an omnibus passing over a speed bump" Rao & al. Analysis of Passive & Semi Active Controlled Suspension Systems, IJRRAS 5 (1), October 2010.

[39] Wissam, H.; Turki, Y., "Quarter car active suspension system control using fuzzy controller turned by PSO", International Journal of Computer Applications (0975 – 8887), Volume 127 – No.2, October 2015.

[40] Leegwater, M.S.P., "An active suspension system capable of economically a car during cornering" Eindhoven university of technology (TU/e), The Netherlands, S010527 (TU/e), DST 2007.087.

[41] Richard, E.; Niema, M.P., "Modeling passive suspension system for a sedan car, a truck, or an SUV" International Journal of Computer Applications (0975 – 8887), Volume 127 – No.2, AM 610, Fall 2005.

[42] John, E.; Jimoh, O., "Proportional-integral-derivative control of nonlinear half-car electro-hydraulic suspension systems", Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering), ISSN 1673-565X (Print); ISSN 1862-1775 (Online), Ekoru et al. / J Zhejing Univ-Sci A (Appl Phys & Eng) 2013 14(6):401-416.

[43] Mohd, A.; Rajeev, S., "Modeling simulation and control of active suspension system in matlab Simulink environment", 978-1-4673-0455-9/12/$31.00 ©2012 IEEE.

[44] Merek, S.; Jaroslaw, K.; Janusz, K.; Waldemar, R., "Optimal control of slow active vehicle suspension results of experimental data", Journal of low frequency noise, vibration and active control, AGH university of Science and Tec nology, 30 Mickiewicza Av., 30-059 Krakow, Poland 1sibielak@agh.edu.pl, 2koniejar@agh.edu.pl, 3jkowal@agh.edu.pl, 4waldemar.raczka@agh.edu.pl, 5dorota.marszalik@agh.edu.pl.

[45] Rosmazi, R.; Musa, M.; Gigih, R., "Active suspension system for passenger vehicle using active force control with iterative learning algorithm", Department of Applied Mechanics and Design Faculty of Mechanical Engineering Universiti Teknologi Malaysia 81310 Skudai, Johor M., 1Faculty of mechanical engineering, universiti Malaysia Pahang, 26600 Pekan, Pahang.

[46] Alexandru, C.; Petre, A., "A comparative analysis between the vehicles passive and active suspensions", International Journal of mechanics with the transilvania university of Brasov, BV 500036 Romania (e-mail: alex.p@unitbv.ro).

[47] Abdolvahab, A.; Ghobad, S.; Armin, B., "Simulation and analysis of passive and active suspension system using quarter car model for different road profile", International Journal of Engineering Trends and Technology- Volume3Issue5- 2012.