Journal of Multidisciplinary Engineering Science Studies (JMESS)
ISSN: 2458-925X
Vol. 5 Issue 12, December - 2019

Lateral Stability of Active Suspension System for a Saloon Car

Uwayzor, Jimmy Moses
Department of Mechanical/Marine Engineering
Niger Delta University
Wilberforce Island
Bayelsa State
Email: uwayzorjimmy@gmail.com

Olali, Olala Michael
Department of Mechanical/Marine Engineering
Niger Delta University
Wilberforce Island
Bayelsa State
Email: mikolali@hotmail.com

***Abstract*— Vehicle suspension system provide good road handling and improve passenger comfort. Dynamic problem in suspension system are associated with vertical and lateral acceleration. Acceleration, vertical or lateral are unwanted phenomena that are always present in vehicles in motion and are some of the challenging problems in automotive engineering. They cannot be eliminated, but can be controlled. Vertical acceleration arises from the unevenness (bumps, potholes) of the road. Lateral acceleration largely arises when the vehicle is negotiating a curve (bend) at high speeds or moving on inclined terrain surface. The objective of this study is to use the braking systems to control lateral acceleration of vehicles at curves, bumps or on inclined surfaces. Also obtain a model for the control manifold system and the wheel speed sensor systems that will send a signal current to the control valve system. Automobile suspension system use passive components; spring and damper; its coefficient is fixed. Active suspension system has the ability to introduce energy and to distribute energy to the system with the force actuators. An analysis of the forces acting on the suspension system were carried out. Mathematical modelling of passive and active suspension system were carried out. Analysis of forces acting on the vehicle at curves, mathematical modelling of electronic stability control and the use of the braking system to control both vertical and lateral acceleration was achieved. It is recommended to add more block and more sensor to the control valve system in order to brake individual wheel of the vehicle**

Keywords—component; ACTIVE SUSPENSION SYSTEM; BRAKING SYSTEM; MODELING; CONTROLLER; VERTICAL ACCELERATION AND LATERAL ACCELERATION

I. INTRODUCTION

Traditionally, the automobile suspension design, is compromised between the three different criteria, namely road handling, load carrying, and passenger relief. The suspension system has to support the vehicle, give directional control using handling movement and give effective comfort to the passengers and reduce load disturbance. Good ride relief requires a gentle suspension. Whereas the ability to respond to abrupt loads demand stiff suspension. Good control demands a suspension setting, most between it [1]. Due to these different demands. Suspension designe has to be something that can be compromised between these two problems. Passive suspenation component have the ability to store energy, but it cannot distribute energy to entire suspension system. It also make up,of spring and shock absorbers system. It's parameters are generally fixed. Being select to obtain a certain level of compromised between the road control, load carrying and ride relief.An active suspension system has the ability to store energy, distribute and to introduce power to the entire suspension system. It may vary its parameters depending on the operating conditions.

Suspension comports of a system of springs, shock absorbers and linkages that connects a machinery to it wheels. In other content, suspension system is a part that physically respective the car body from the car wheel. The main work, of machinery suspension system is to make it small as possible. The vertical acceleration conducts to the passenger which directly provides road comfort. There are three description of suspension component, these are; inactive, semi-active and functional suspension component. Traditional suspended consists springs and shock absorber are referred to inactive suspended component, then if the suspension is on the surface controlled. It is known as a semi active or functional suspension compounded [3].

Dynamic problem in suspension systems are associated with upright and side acceleration. Acceleration, vertical or lateral are unwanted phenomena that are always present in vehicles in motion and are some of the challenging problems in automotive engineering [4]. They cannot be eliminated, but can be controlled. Vertical acceleration arises from unevenness (bumps, potholes) of the road. Lateral acceleration largely arises when the vehicle is negotiating a curve (bend) at high velocity or moving in inclined terrain surface [5]. Other challenges associated with the design and control of suspension systems are; leakages, fatigue, buckling etc.

This paper is aimed at reducing both vertical and lateral acceleration of the machinery at a curve, bumps or in an inclined surface.

This template, modified in MS Word 2007 and saved as a “Word 97-2003 Document” for the PC, provides authors with most of the formatting specifications needed for preparing electronic versions of their papers. All standard paper components have been specified for three reasons: (1) ease of use when formatting individual papers, (2) automatic compliance to electronic requirements that facilitate the concurrent or later production of electronic products, and (3) conformity of style throughout a conference proceedings. Margins, column widths, line spacing, and type styles are built-in; examples of the type styles are provided throughout this document and are identified in italic type, within parentheses, following the example. Some components, such as multi-leveled equations, graphics, and tables are not prescribed, although the various table text styles are provided. The formatter will need to create these components, incorporating the applicable criteria that follow.

II. LITERATURE REVIEW

Passive suspended system can be found in controlling the dynamics of vertical motion of a vehicle. There is no energy supplied by the suspension element to the vehicle [6]. Even though it does not supply energy to the vehicle , it checks the relative motion of the body to the wheel by using different types of damper or power dissipating elements. Passive suspension has significant limitation in structural applications [7].

The characteristics are determined by the designer according to the intended goals and the intended operation. The disadvantage of inactive suspension system is that it has fixed characteristic, for example if the designer designs the suspension cracking damped it will only contribute good vehicle handling only at the same time it transfers road input (disturbance) for the vehicle body [8].

The effect of this action is if the vehicle travel at the low speed on a rough road or at the high speed in a straight line, it will be perceived as a harsh road. Then, if the suspension is design lightly damped, it will give more comfortable ride [3]. Unfortunately, this design will diminish the stability of the vehicle in make rotate and lane changing. Figure 1 shows traditional passive suspension components system that consists of damper and spring.

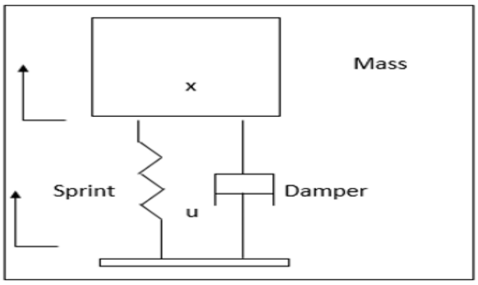

Fig.1. Passive Suspension Component

Semi-active suspension system was first proposed by [9]. It gives a rapid change in rate of springs damper coefficients. It does not provide any energy into suspension system but the damper is replaced by controllable damper. The controllers determine the position of damper based on control strategy and automatically adjust the damper to the desired position [10]. This description of suspension system use external power to operate. Sensors and actuator are added to detect the road profile as control Intake. The most frequently semi-active suspension system is called skyhook damper. Schematic diagram for semi-active suspension is shown in Figure 2.

Active suspension system has the ability to respond to the vertical changes in the road intake. The damper or spring is intervening by the force actuator. This force actuator as its own duty which is to add or remove power from the system [11].

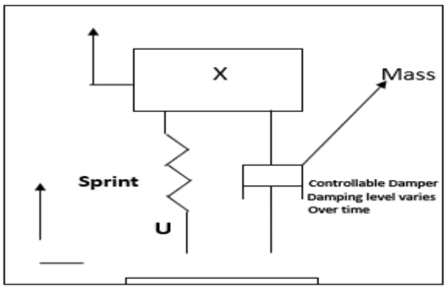

Fig. 2. Semi Active Suspension Component

The force actuator is controlled by various descriptions of controller determined by the designer. The rectify control strategy will provide better compromise between comfort and vehicle stability [12]. Therefore, active suspension system offers better riding relief and vehicle handling for the passengers. Figure 3 shows simple plain diagram to clarify how the active suspension can attain better performance. Figure 4 describe essential component of active suspension. In this type of suspension, the controller can qualify the system dynamics by activating the actuators [13]. All these three descriptions of suspension systems have its own advantages and disadvantages. However, researchers are focus on the active car suspension and it is because the performance obtained is better than the other two types of suspension systems as mentioned before [14].

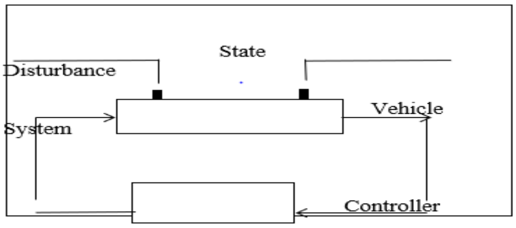

Fig. 3. Active Suspension Control System

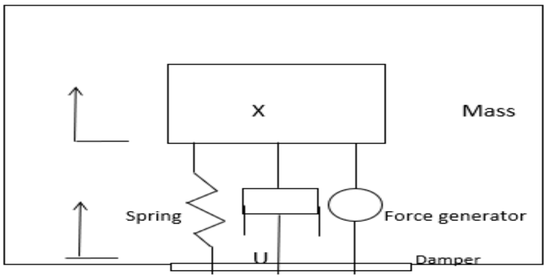

Fig. 4. Active Suspension Component.

For example, the passive suspension system the design is fix depend on the goal for the suspension. The passive suspension is an open loop control system. It doesn't have any feedback signal to correct the error. The passive suspension system will not give optimal ride comfort. Alternatively, the active suspension, has the ability to give ride comfort. This is happening by having force actuator control by the controller [15]. The active suspension system is a closed loop control system. It will correct the error and gave the output to the desired position [16]. By application the right control strategy the ride quality and control performance can be optimize [17]. Therefore, in this arrangement there will be

Quarter-car model in Figure 5 is very constantly used for suspension analysis; because it simple and can capture significant characteristics for full mode [18]. The equation for the model moves is found by adding vertical forces on the spring and unspring masses. Most of the quarter-car model suspension will represent the M as the spring mass, while tire and axles are illustrated through the unspring mass m [19]. The spring, shock absorber and a variable force-generating element position between the spring and unspring masses constitutes suspension. From the quarter car model, the design can be expended into full car model through adding the link between the spring mass to the four unspring masses (body – front left and right, rear left and right) [20]. Generally, the link between spring and unspring masses will give roll and pitch angle the basic modeling is still the same but there is additional [21].

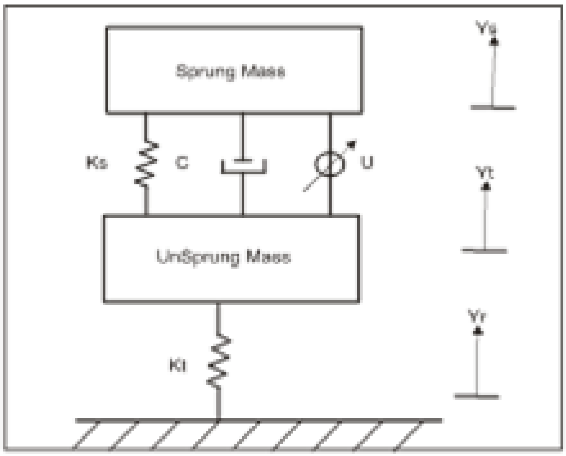

Fig. 5. Quarter Car Model

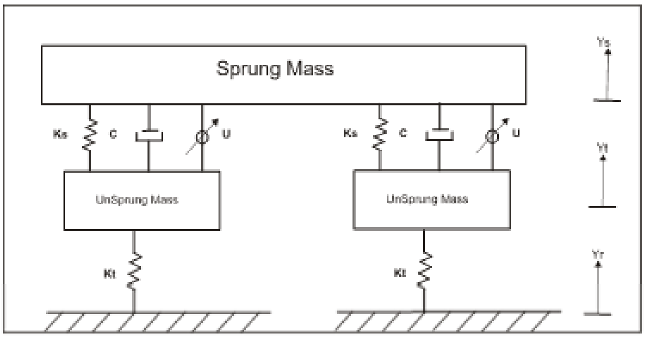

Fig.6. Half Car Model

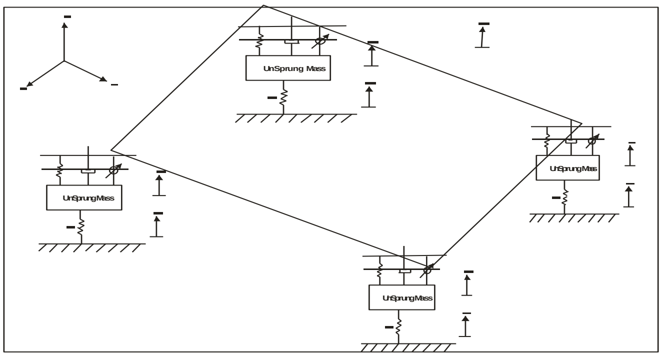

Fig. 7. Full Car Model

The suspension system is modeled when a linear suspension system [22]. The state variable can be defined as a vertical movement of the car body and a upright movement of the rotation. In order to capture linear model, roll and pitch angles are accept to be small [23].

III. MATERIALS AND METHOD

The strength to stand without being moved of the condition of being stable or in equilibrium and thus resistant to change [24]. Lateral stability can be outlined as the property of an object to develop force imposed upon it that restore to is original position.

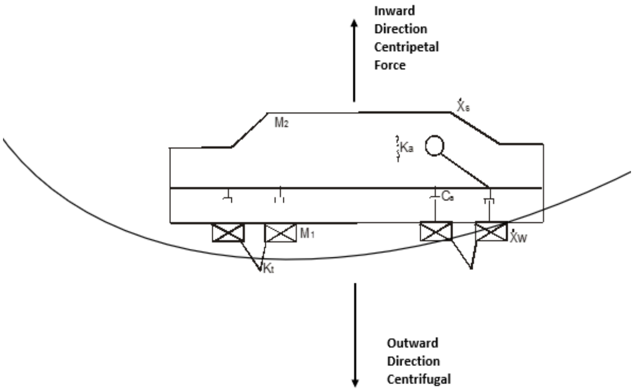

Fig. 8. The diagram of a car rounding a curve.

$$F= Ma \tag{1}$$

Where F is the various forces that act on the system, M is the masses of the various body act on the vehicle and is the side acceleration of the vehicle [25].

M_1= mass of the wheel (kg)
M_2= mass of the car body (kg)
r = road disturbance
Xw = wheel deportation (m)
Xs = car body deportation (m)
$\dot{X}$w = wheel velocity (m/s)
$\dot{X}$s = car body velocity (m/s)
ka = Stiffness of auto body (N/m)
kt = Stiffness of tire (Ns/m)
Ca = damper (Ns/m)
$\ddot{X}$w = Acceleration for the wheel
$\ddot{X}$s = Acceleration of the auto body
Kt (Xw - r) - Ka (xw - Xs) - Ca (Xw -Xs) = M1 $\ddot{X}$w

Therefore

$$\ddot{X}w = \frac{Kt(xw-r)- ka(xw - xs) - Ca\,(xw -Xs)}{M_1} \qquad 2$$

i.e

$$\ddot{X}s = \frac{Ka(Xw-Xs) - Ca\,(\dot{X}w - \dot{X}s)}{M_2} \qquad 3$$

For a car moving along a curved path, conflict between the tire and the road provide the centripetal force needed by the car to make the turn. If the friction force is not great enough (as on a wet road) sufficient force cannot be supply and the car will laterally accelerate out of a circular path. Banking of curves on roads can decrease the chance of lateral acceleration because the normal force of the road will have a component toward the centre of the circle. Figure 9 is resolved into horizontal and vertical component as shown in figure 10

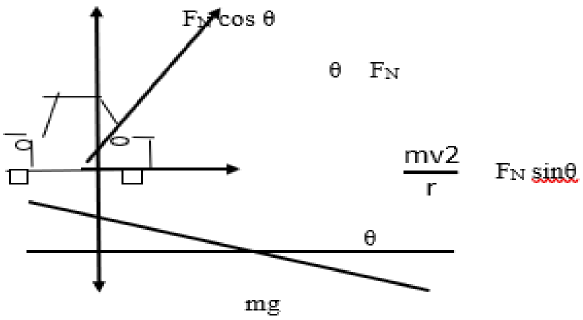

Fig. 9. Normal force on a car rounding a curve.

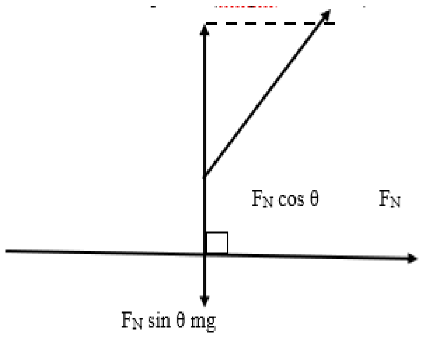

Fig. 10. Horizontal and Vertical component of rounding curve

An essential instrument is Electronic Stability Control (ESC). It improves drivers to avoid crashes by break the danger of losing control as a result of overtaking become active when a driver loses control of the car. It uses computer-controlled technology to apply individual brake and help bring the car safely back for the road. ESC works by the use of electronic device called sensors that detect any loss of control. The system will apply the brake to the relevant wheel

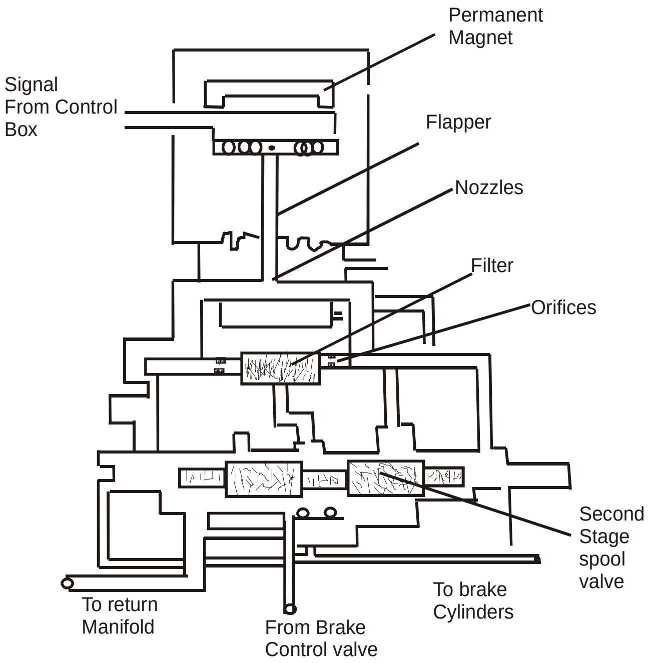

Fig. 11. The control manifold system

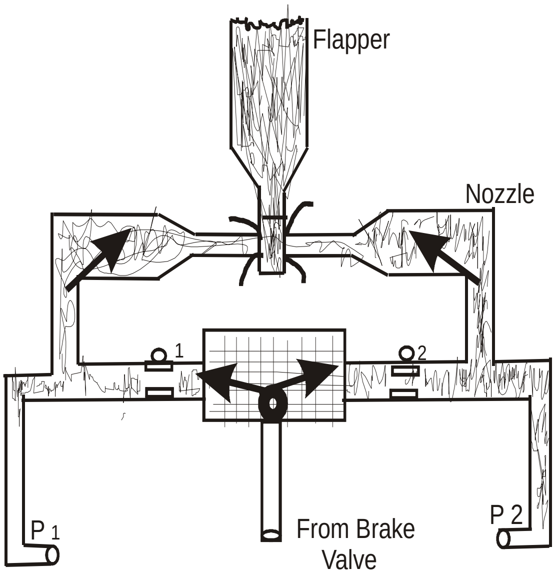

Fig.12. The enlargement of the control manifold system

A system which is called the control manifold system is an important aspect too. A direct conventional signal from the control box, supply energy to the coil on the armature of the flapper valve, and motion of the flapper changes the pressure drop across the final orifices. This valve works fast enough to maintain an output pressure that is directly proportion to the quantity of signal current fore the control box. The DC signal from the control box runs through a coil around the armature of the flapper valve. This armature is independent, to pivot and is central between two permanent magnets.

When the flapper is central between the nozzles, the tension drop across the two orifices is the same, and P1 is equal to P2. When the signal for the control box indicates that no Lateral Acceleration is remaining, and the braking action should be normal, the magnetic field of the coil reacts with the field of the permanent magnets and hold the flapper centered between the nozzles. Fluid from the brake valve flows through the filter and discharges equally for each nozzle. Since the quantity of flows is the same through each orifice the pressure drop across the orifices will be the same and the second stage spool valve will assume a position that allow free avenue between the brake valve and the brake

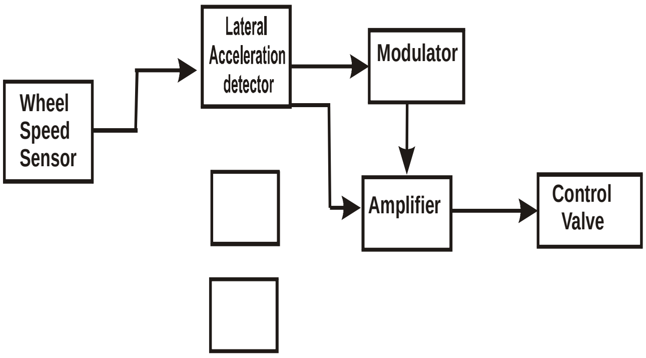

Fig 13. The wheel speed sensor system.

The main functions for the control box are to produce electrifying signals usable by the control valve to control the brake stress to help, a High Lateral Acceleration and to prevent excessive brake pressure being applied. Prior to negotiate a curve that send a signal into the amplifier, which courses the control valve to unclosed the passage between the brakes and the system reciprocate manifold. A lateral acceleration of 0.3m/s^2 is designed into the Lateral Acceleration detector as reference. Any time the vehicle laterally accelerates at a rate greater than this threshold value of 0.3m/s^2, a signal is sent to the amplifier and then to the control valve to increase the brake pressure. At this time the lateral Acceleration detector sends a signal to the modulator which by measuring width of the lateral accelerator detector signal automatically established the quantity of current that will continue to flow through the valve after the vehicle has recovered from the lateral accelerator when the amplifier receives its signal from the modulator, it maintains this current, which is competent enough to hold the flapper over to prevent the excessive pressure. A timer circuit in the modulator then allows this pressure to increase slowly until another lateral acceleration starts to occur and the cycle repeats itself when the vehicle begins to operate on a wet or ice road and the lateral stability control system will hold the wheel, on a slip area. But if one-wheel controls valves begin to hydroplane or hit the pasture of eye and slow down Lateral Acceleration

IV. RESULTS AND DISCUSSION

Using the braking system to control both vertical and lateral acceleration have been achieved. Performances for the suspension system in term of ride rate and car handling has been analysed, disturbance is assumed as the input for the system [27]. Parameters that were observed are the suspension travel, wheel deflection and the auto body acceleration as quarter car model. The aim is to reduce lateral acceleration for the vehicle at a curves or bumps [28].

When the road profile is taken to be a single bump, the disturbance input represented is shown below where *a* denotes the bump amplitude.

$$0.5 \geq t \leq 0.75$$

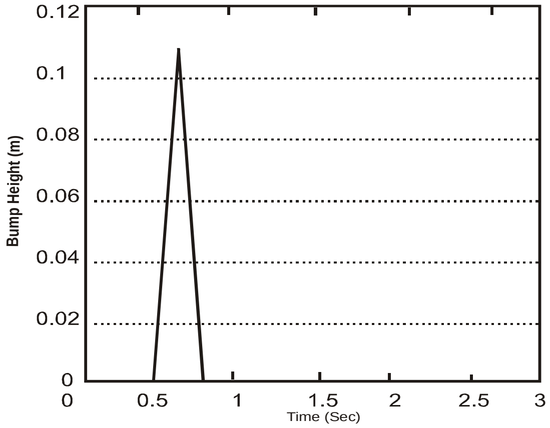

Fig. 14. shows the road profile 1

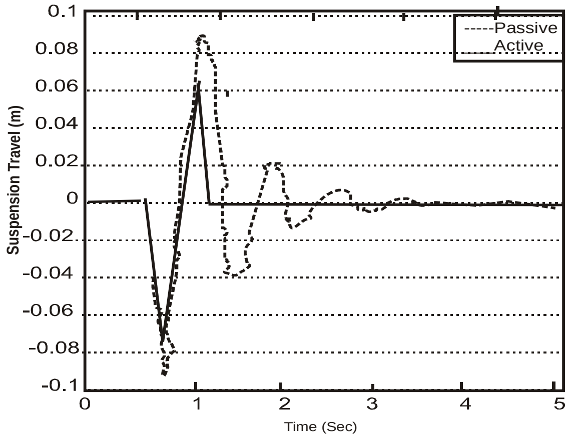

Fig. 15. Road Profile 2

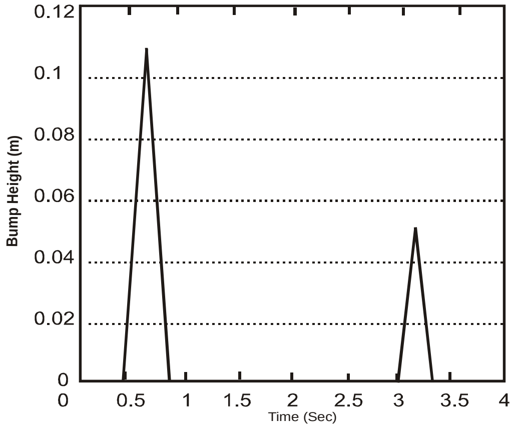

Fig. 16. Car Body Displacement through Road Profile 1

In figure 15, the road profile is assumed to have 2 bumps: 0.5≤ t ≤ 0.75 and 3.00 ≤ t ≤ 3.25
For disturbance inputs as shown in the two ranges,

$$0.5s \leq t \leq 0.75s$$
$$3.0s \leq t \leq 3.25s$$

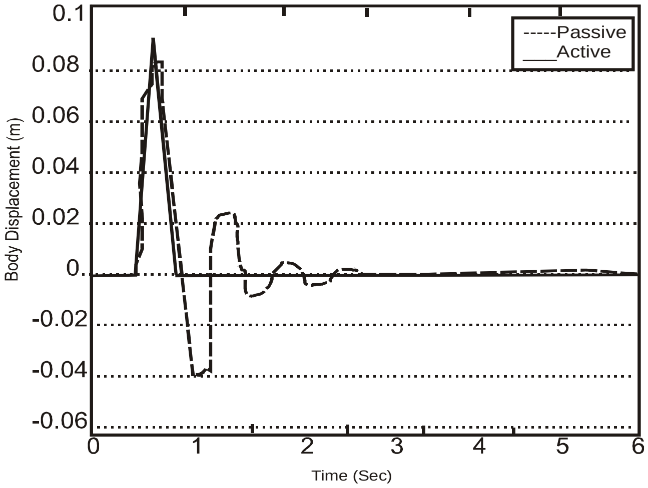

Fig. 17. Suspension Travel through Road Profile 1

$0.5s \leq t \leq 0.75s$ is an input distance for front right and left wheel and $3.0s \leq t \leq 3.25s$ is an input disturbance for rear right and left wheel. There is an assumption which has to be made which is accepted that front wheel for right and left reach the bump at the same time. This order also refers to the rear wheel

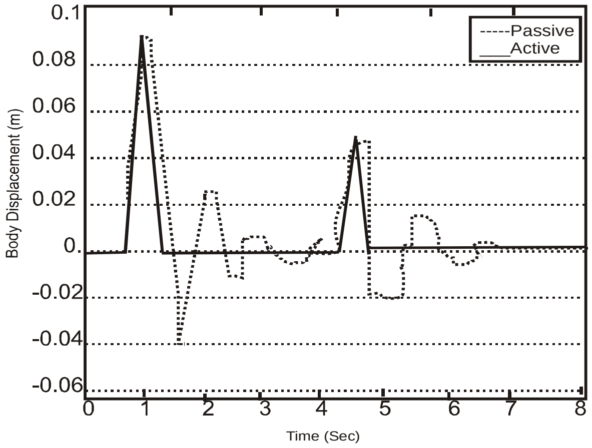

Fig.18. Body Displacement through Road Profile 2

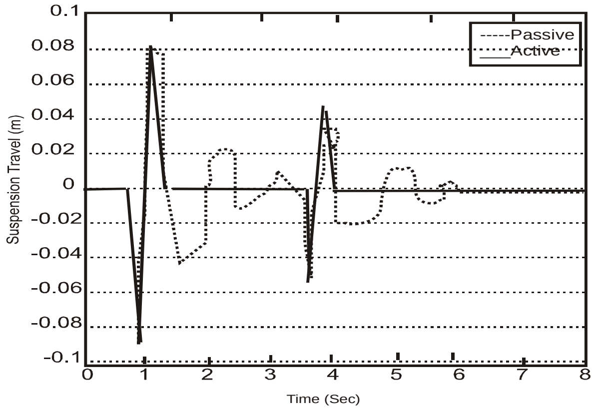

Fig. 19. Suspension Travel through Road Profile 2

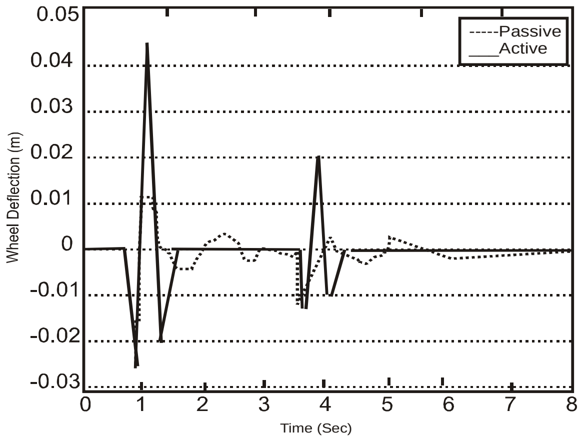

Fig. 20. Wheel Displacement through Road Profile 2

Through comparing the interpretation of the passive and active suspension system control approach it is clearly display that active suspension can give lower amplitude and quick settling time. Suspension Travel for both descriptions of Road Profile can reduce the amplitude and settling time compare fore passive suspension system. Body Displacement also better, even the amplitude is weak higher compare with passive suspension system, yet the settling time is very fast. Body Displacement is used to describe ride quality. Wheel Displacement also gives weak higher amplitude, yet assure fast settling time. The main purpose to observe Wheel Displacement it represents car handling performance.

V. CONCLUSION

The dynamic model as the control manifold system and the wheel velocity sensor system have been achieved. Using the braking method to control the upright accelerating at bumps or pots holes and the lateral acceleration at curves, bends, corners or in an inclined surface have been achieved.

REFERENCES

[1] Y. M. Sam, M.R.A. Ghani & N. Ahmad. LQR Controller for Active Car Suspension. IEEE Control System. 2000, I441-I444

[2] D. Hrovat, Surey of advanced suspension development and related optimal control application, Automatic, 30(10), 1997, 1781-1817.

[3] P.C. Chen & A. C. Huang. Adaptive sliding control of non-autonomous active suspension systems with time-varying loadings. Journal Sound Vibration. 282(3–5), 2005, 1119–35.

[4] A. Aldair & W. J. Wang. Allow an Intelligent Controller for Full Vehicle Nonlinear Active Suspension Systems, International Journal on Smart Sensing and Intelligent Systems, 4(2), 2011, 224-243.

[5] H.Y. Chen & S.J. Huang. Adaptive Control for Active Suspension System. Retrieved from http://vsdia.bme.hu/wp-content/uploads/2018/03/VSDIA2016_united.pdf, 2005

[6] K.J. Astrom & B. Wittenmark. Adaptive Control (2nd Ed.). Addison-Wesley Publication, 1995

[7] K. M. Ardeshir. Vehicle Active Suspension Control, Using a Variable Structure Model Reference Adaptive Controller. Proceedings of the ACSE 05 Conference, CICC, Cairo, Egypt, 19(21), 2005, 616.

[8] S. Chandrasekharan. Development of a Tractor Semi-trailer Roll Stability Control Model (Master's Thesis), the Ohio State University, Ohio, 2007.

[9] M.J.C. Karnopp & R.A .Harwood. Vibration Control Using Semi-Active Force Generators. Journal of Engineering for Industry, 96(2), 2010, 619-626.

[10] S. Chandrasekharan, D. A. Guenther, G.J. Heydinger, M. K. Salaani, , S. Zagorski & P. A. Grygrier.. Development of a Roll Stability Control Model for a Tractor Trailer Vehicle, SAE Paper, 1, 2008, 601.

[11] D.L. William & W.M. Hadad. Active Suspension Control to Improve Vehicle Ride and Handling, Vehicle System Dynamic. 28(1), 1997, 2470.

[12] V. Cherian, R.Shenoy, A. Stothert, J. Shriver, J. Ghidella & T. D. Gillespie. Model Based allow of a SUV Anti-rollover Control System, SAE Paper, 1, 2008, 579.

[13] Y.M. Sam. Proportional Integral Sliding Mode Control in an Active Suspension System. Malaysia University of Technology (Doctoral Dissertation). University of Technology, Malaysia, 2004

[14] D.C. Karnopp, M. J. Crossby, & R. A. Harvod. Vibration control using semi-active force generator for industry, Trans ASME, Journal of engineering, 96, 1970, 619-626.

[15] X. Dong. Human simulated brainy control of automobile magnetorheological semi-active suspension (Doctoral Dissertation), Chongqing University, Chongqing, China, 2006.

[16] H. Du & N. Zhang. H∞ control of active vehicle suspensions through actuator time delay. Journal of Sound Vibration, 301(1), 2007, 236–52.

[17] A. Elnaz, F. Morteza, Z. Intan, D. Mat & G. Ramin, Observer Design for Active Suspension System Using Sliding Mode Control. Proceedings of IEEE Student Conference on Research and Development, Putrajaya, Malaysia, 2010.

[18] N. Al-Holou, D. S. Joo & A. Shaout. The Development of Fuzzy Logic Based Controller for Semi Active Suspension System. Proceedings of Midwest Symposium on Circuits and Systems, IEEE, 37, 1996, 1373-1376.

[19] D. B. Emmanuel. For the Control Aspects of Semi-active Suspensions for Automobile Applications (Master's Thesis), Blacksburg, Virginia, USA, Virginia Polytechnic Institute and State University, 2003

[20] J. Fatemeh & S. Afshin. Robust Control in an Active Suspension System Using H2 & H∞ Control Methods, Journal of American Science, 7(5), 2011, 1-5.

[21] J.P. Hyvarinen. The Improvement for Full Vehicle Semi-Active Suspension through Kenimatical Model (Master's Thesis), Oulu University, Findland, 2004

[22] G.J. Forkenbrock & P.L. Boyd. Light Vehicle ESC Performance test development, ESV Paper, 7, 2007, 456.

[23] T. Yoshimura, A. Kume, M. Kurimoto & J. Hino. Construction of an Active Suspension System of a Quarter-Car Model Use the Concept of Sliding Mode Control. Journal of Sound and Vibration, 239, 2000, 187-199.

[24] S. Mouleeswaran. Development of Active Suspension System for Automobiles use PID Controller, action of the World Congress on Engineering. London, U.K., 2008.

[25] N. Al-Holou, T. Lahdhiri, R. D. Joo, J. Weaver & F. Al-Abbas. Sliding mode neural network inference fuzzy logic control for active suspension systems, IEEE Trans. Fuzzy Syst., 10(2), 2002, 234–246.

[26] N. Yagiz, & L. E. Sakman. Fuzzy Logic Control on a Full Vehicle without Suspension Gap Degeneration.International Journal of Vehicle Design,42(12), 2006, 198-212.

[27] S. Xubin. Cost-Effective Skyhook Control on Semi-active Vehicle Suspension Applications. The Open Mechanical Engineering Journal, 3, 2009, 17.