PID CONTROLLER OF ACTIVE SUSPENSION SYSTEM FOR A QUARTER CAR MODEL

Abd El-Nasser S. Ahmed[1], Ahmed S. Ali[2], Nouby M. Ghazaly[1], G. T. Abd el- Jaber[1]
[1]Department of Mechanical Engineering, South Valley University, Qena, Egypt.
[2]Department of Mechanical Engineering, Assuit University, Assuit, Egypt.

ABSTRACT

The objectives of this study are to obtain a mathematical model for the passive and active suspensions systems for quarter car model and to construct an active suspension control for a quarter car model subject to excitation from a road profile using PID controller. Current automobile suspension systems using passive components only by utilizing spring and damping coefficient with fixed rates. Vehicle suspensions systems typically rated by its ability to provide good road handling and improve Passenger comfort. Passive suspensions only offer compromise between these two conflicting criteria. Active suspension poses the ability to reduce the traditional design as a compromise between handling and comfort by directly controlling the suspensions force actuators. In this study, the active suspension system is synthesized based on PID control for a quarter car model. Comparison between passive and active suspensions system are performed using road profile. The performance of the controller is compared with PID controller, and the passive suspension system. The performance of this controller is determined by performing computer simulations using SIMULINK toolbox.

KEYWORDS: *Quarter Car Model, Passive and Active Suspension System, PID controller, Road Profile.*

I. INTRODUCTION

A car suspension system is the mechanism that physically separates the car body from the wheels of the car. The purpose of suspension system is to improve the ride comfort, road handling and stability of vehicles. Apple yard and Well stead have proposed several performance characteristics to be considered in order to achieve a good suspension system. Suspension consists of the system of springs, shock absorbers and linkages that connects a vehicle to its wheels. In other meaning, suspension system is a mechanism that physically separates the car body from the car wheel. The main function of vehicle suspension system is to minimize the vertical acceleration transmitted to the passenger which directly provides road comfort [1].
Current automobile suspension systems using passive components can only offer a compromise between these two conflicting criteria by providing spring and damping coefficients with fixed rates. A good suspension system should provide good vibration isolation, i.e. small acceleration of the body mass, and a small “rattle space”, which is the maximal allowable relative displacement between the vehicle body and various suspension components. A passive suspension has the ability to store energy via a spring and to dissipate it via a damper. Its parameters are generally fixed, being chosen to achieve a certain level of compromise between road handling, load carrying and ride comfort. An active suspension system has the ability to store, dissipate and to introduce energy to the system. It may vary its parameters depending upon operating conditions. Generally, traditional suspension consists springs and dampers are referred to as passive suspension, then if the suspension is externally controlled it is known as a semi active or active suspension [2].
The passive suspension system is an open loop control system. It only designs to achieve certain condition only. The characteristic of passive suspension fix and cannot be adjusted by any mechanical part. The problem of passive suspension is if it designs heavily damped or too hard

suspension it will transfer a lot of road input or throwing the car on unevenness of the road. Then, if it lightly damped or soft suspension it will give reduce the stability of vehicle in turns or change lane or it will swing the car. Therefore, the performance of the passive suspension depends on the road profile. In other way, active suspension can gave better performance of suspension by having force actuator, which is a close loop control system. The force actuator is a mechanical part that added inside the system that control by the controller. Controller will calculate either add or dissipate energy from the system, from the help of sensors as an input. Sensors will give the data of road profile to the controller. Therefore, an active suspension system shown is Figure1 is needed where there is an active element inside the system to give both conditions so that it can improve the performance of the suspension system[3:6].

Recently, in order to improve the stability and ride handling performance of the vehicle, active suspension systems have been studied by many researchers. There are many control approaches such as Linear Quadratic Regulator [7], Adaptive sliding control [8], H∞ control [9], sliding mode control [10], fuzzy logic [11], preview control [12], optimal control [13:14] and neural network methods [15] have been used in the area of active suspensions systems. The performance of the active suspension system can be improved through control methods. However, these methods need refined mechanisms or a specific performance decision table and a certain difficulties in applications.

In this study, a mathematical model for the passive and active suspensions systems for quarter car model that subject to excitation from a road profile using PID controller is conducted. Comparison between passive and active suspensions system are performed considering road profile. The performance of the controller is compared with PID controller and the passive suspension system by performing computer simulations through the MATLAB and SIMULINK toolbox.

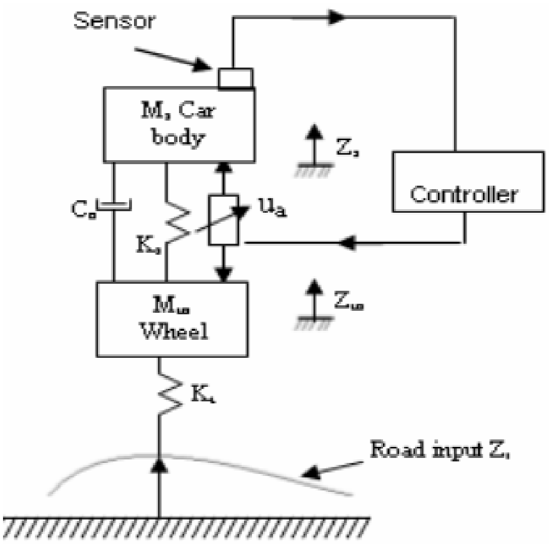

Fig.1. Active suspension system of quartet car.

II. MATHEMATICAL MODELLING OF ACTIVE SUSPENSION SYSTEM

Active suspension systems add hydraulic actuators to the passive components of suspension system as shown in Figure 1. The advantage of such a system is that even if the active hydraulic actuator or the control system fails, the passive components come into action. The equations of motion are written as,

$$M_s\ \ddot{z}_s + k_s\,(z_s - z_{us}) + C_a(\dot{z}_s - \dot{z}_{us}) - u_a = 0.0 \qquad (1)$$

$$M_{us}\ddot{z}_{us} + k_s(z_{us} - z_s) + C_a(\dot{z}_{us} - \dot{z}_s) + K_t(z_{us} - z_r) + u_a = 0.0 \qquad (2)$$

Where u_a is the control force from the hydraulic actuator. It can be noted that if the control force u_a= 0, then Equations (1, 2) become the equation of passive suspension system [16, 17].

Considering u_a as the control input, the state-space representation of Equations (1, 2) become,

$\dot{z}_1 = z_2$ (3)

$\dot{z}_2 = -\frac{1}{M_s}[K_s(z_1 - z_3) + C_a(z_2 - z_4)]$ (4)

$\dot{z}_3 = z_4$ (5)

$\dot{z}_4 = \frac{1}{M_{us}}[K_s(z_1 - z_3) + C_a(z_2 - z_4) + K_t(z_3 - z_r)]$ (6)

Where $z_1 = z_s, z_2 = \dot{z}_s, z_3 = z_{us}$ and $z_4 = \dot{z}_{us}$

III. System Modeling

Block diagram of control system used to develop active suspension system is shown in Figure 2 [18]. In order to develop an active suspension system, the following hydraulic components are used,

- Pressurized hydraulic fluid source
- Pressure relief valve to control the pressure of hydraulic fluid
- Direction control valve
- Hydraulic cylinder (active actuator) to convert the hydraulic pressure into force to be transmitted between the sprung and the unsprung mass.

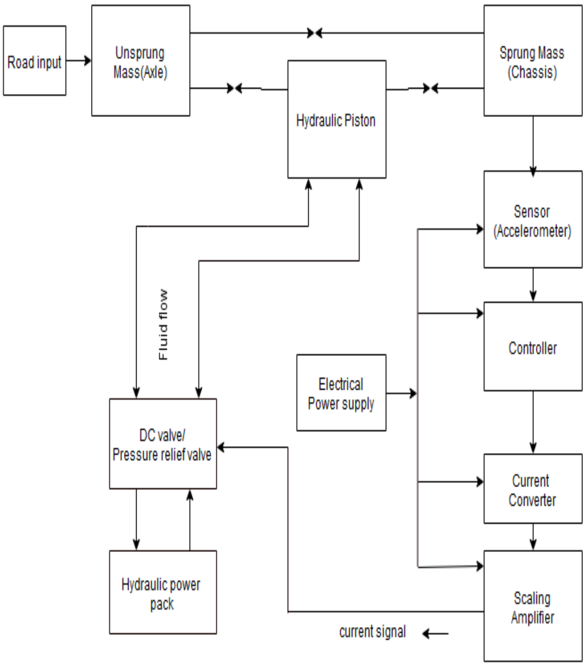

Fig.2.Block diagram of control system

Figure 3 shows the hydraulic actuator installed in between sprung mass and unsprung mass, including a valve and a cylinder, where U_h is the actuator force generated by the hydraulic piston and x_{act}(= x1-x3) is the actuator displacement. U_h (equal to Ua) is applied dynamically in order to improve ride comfort as and when the road and load input vary [18].

The equation of the active suspension system, including the hydraulic dynamics is rewritten as Equations (7, 8, 9, 10, and 11)

$\dot{x}_1 = x_2$ (7)

$\dot{x}_2 = \frac{K_s}{M_s}x_1 + \frac{C_a}{M_s}x_2 + \frac{K_s}{M_s}x_3 + \frac{C_a}{M_s}x_4 + \frac{A_1}{M_s}x_5$ (8)

$\dot{x}_3 = x_4$ (9)

$\dot{x}_4 = \frac{K_s}{M_{us}}x_1 + \frac{C_a}{M_{us}}x_2 + \frac{K_s+K_t}{M_{us}}x_3 + \frac{C_a}{M_{us}}x_4 + \frac{A_1}{M_s}x_5$ (10)

$\dot{x}_5 = \beta x_5 + A(x_2 - x_4) + x_6\omega_3$ (11)

$\dot{x}_6 = \frac{x_6}{\tau} + U_c$ (12)

Where, $\omega_3 = sgn[P_s - sgn(x_6)x_5]\sqrt{|P_s - sgn(x_6)x_5|}$

Thus Equations 7,8,9,10,11 become state feedback model of active suspension system including hydraulic dynamics [18].

To ensure that our controller design achieves the desired objective, the open loop passive and closed loop active suspension system are simulated with the following values.

Table 1 Parameter Values of suspension system

M_b	250 kg
M_{us}	50 kg
K_a	16812 N/m
C_a	1000 N.sec/m
K_t	190000 N/m
β	1 sec^{-1}

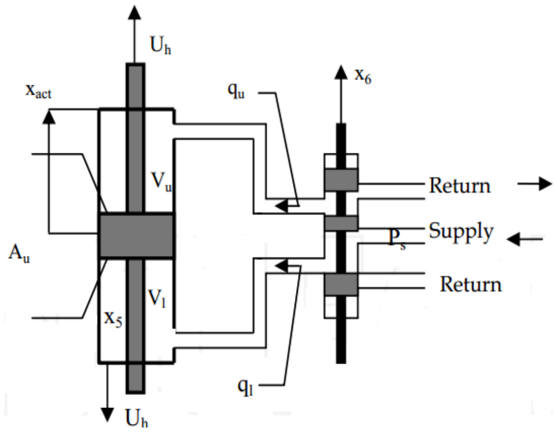

Fig.3. Hydraulic valve and cylinder

IV. Passive Suspension System

Figures 4 represent the Simulink model of passive suspension system as following.

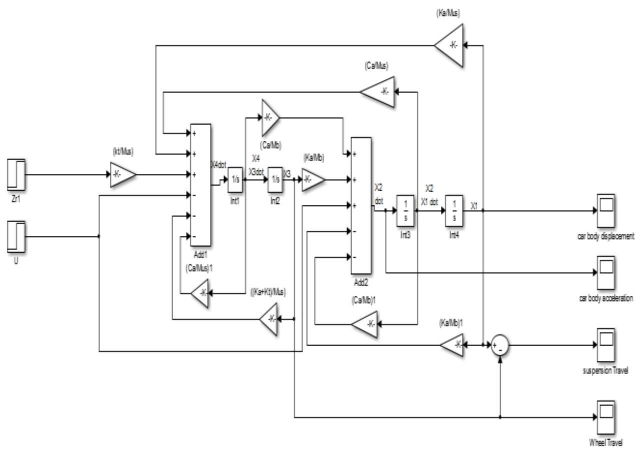

Fig.4. Simulink Model of passive Suspension system.

V. Controller Design

The PID controller is the most-used feedback control design. PID is a short form for Proportional-Integral-Derivative, show the three terms operating on the error signal to produce a control signal. If u(t) is the control signal which sent to the system, y(t) is the actual output and r(t) is the desired output, and tracking error e(t) = r(t) − y(t), a PID controller has the next form.

$$u(t) = k_p\, e(t) + k_i \int e(t)\, dt + k_d \frac{d}{dt} e(t) \quad (13)$$

The desired closed loop dynamics can be obtained by adjusting the three parameters KP, KI and KD, often iteratively with "tuning" and without specific knowledge of a plant model. Stability can often be obtained using only the proportional term. The integral term permits the rejection of a step disturbance. The derivative term provides damping or shaping of the response. PID controllers are the most well established class of control systems: however, they cannot be used in several more complicated cases, almost in the MIMO systems. Figures 5 represents the Simulink model of active suspension system using PID controller.

VI. Result And Discussion

Simulation based on the mathematical model for quarter car by using MATLAB/SIMULINK software will be performed. Performances of the suspension system in term of ride quality and car handling will be observed, where road disturbance is assumed as the input for the system. Parameters that will be observed are the suspension travel, wheel travel, the car body acceleration and displacement for quarter car. The aim is to achieve small amplitude value for suspension travel, wheel deflection and the car body acceleration. The steady state for each part also should be fast. Suspension travel, wheel travel, the car body acceleration and displacement for quarter car are obtained as shown in the following Figures [6:6] for three different inputs namely; Step input Zr = 0.1, Sinusoidal input (bumpy road) and Random road input.

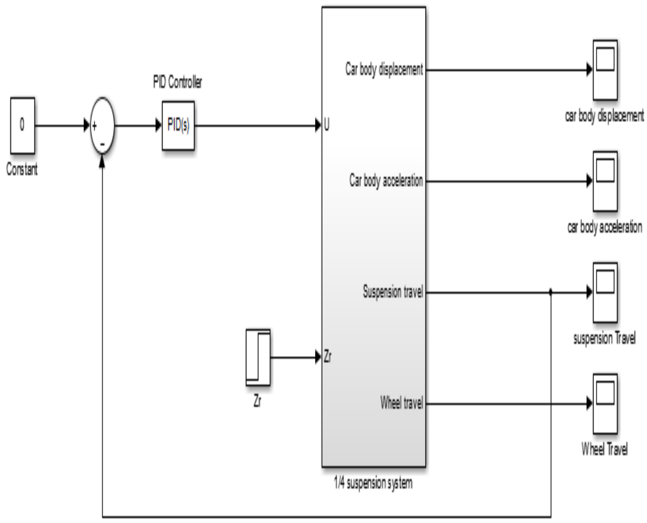

Fig.5. Simulink Model of active Suspension system using PID Controller.

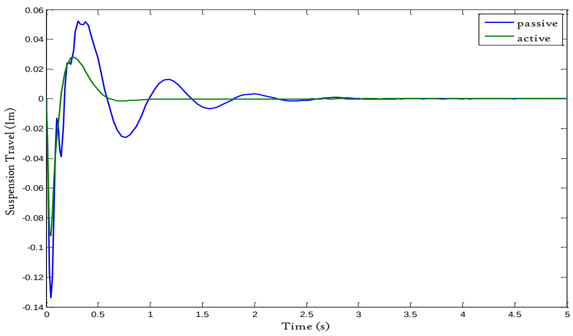

Fig. (6-a) Car body displacement for step input Zr = 0.1

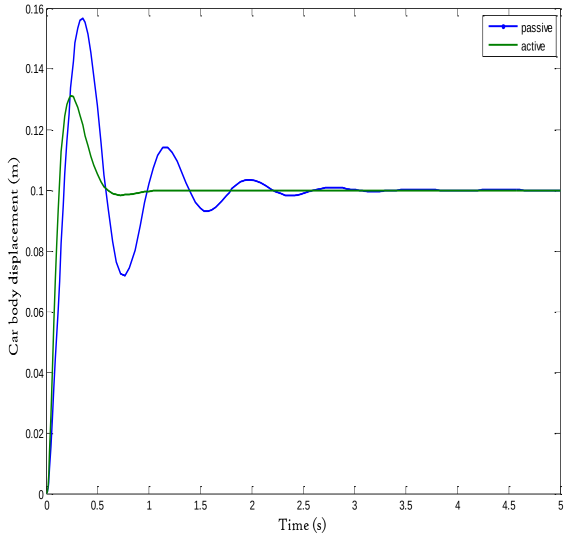

Fig. (6-b) Car body acceleration for step input Zr = 0.1

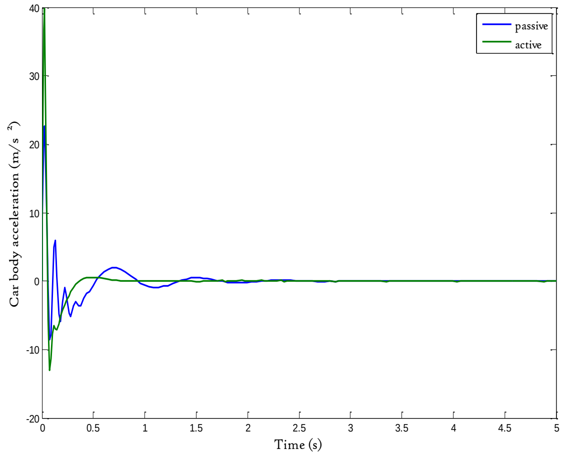

Fig. (6-c) Suspension deflection for step input Zr = 0.1

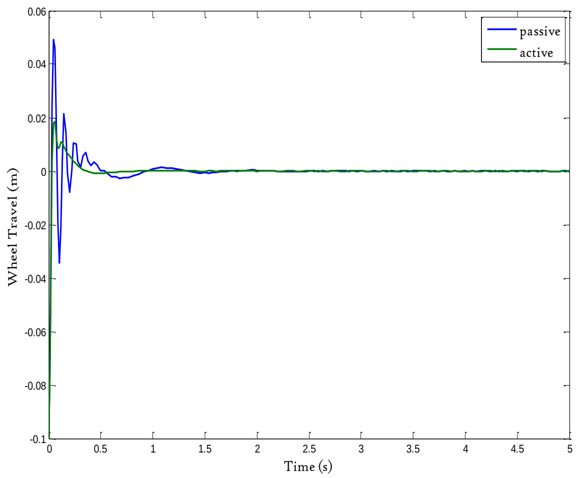

Fig. (6-d) Wheel Travel for step input Zr = 0.1

Fig.6 illustrates that both peak or overshoot values and settling time have been reduced by the active suspension system compared to the passive system for all the parameters of sprung mass acceleration (passenger comfort), suspension deflection (road holding) and tyre deflection. In additions, Table-2 shows the percentage reduction in peak values of the various parameters for the step road input.

Table: 2. Reduction in overshoot values for step road input

No	Parameters	Passive	Active	Reduction $(\frac{passive-active}{passive})$ **100**
2	Car body acceleration	2 m/s^2	0.55m/s^2	72.5 %
3	Suspension travel	0.052 m	0.0281 m	46 **%**
4	Wheel travel	0.0491m	0.0186 m	62.11 **%**

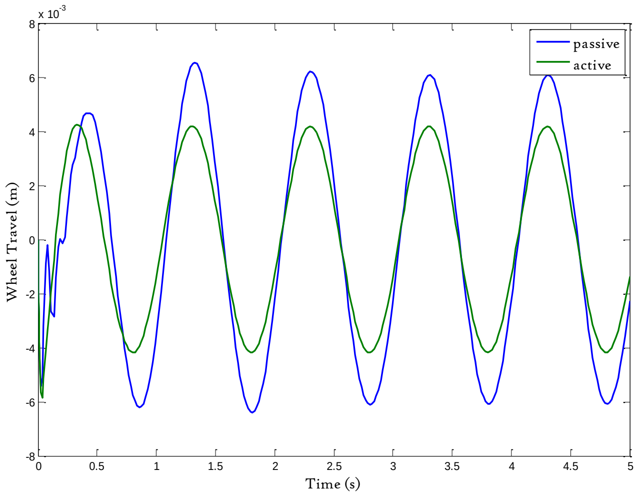

Fig. (7-a) Car body acceleration bumpy road

Active suspension system using any control has better performance than passive suspension system because controller using feedback to improve system response.

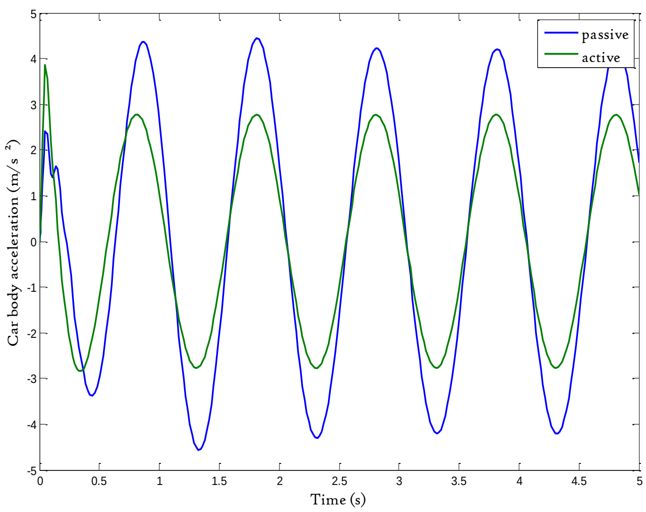

Fig. (7-b) Suspension Travel bumpy road

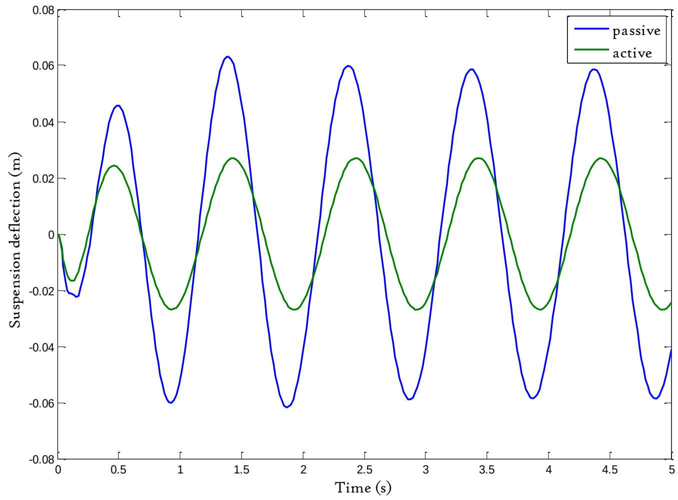

Fig. (7-c) Wheel Travel for bumpy road

Fig.7 illustrates that overshoot values and settling time have been reduced by the active system compared to the passive system for all the parameters of sprung mass acceleration (passenger comfort), suspension deflection (road holding) and tyre deflection. Table-3 gives the percentage reduction in peak values of the various parameters for the sinusoidal input (bumpy road).

Table: 3. Reduction in overshoot values for bumpy road

No	Parameters	Passive	Active	Reduction
1	Car body acceleration	4.5628 m/s^2	2.772 m/s^2	39.24 %
2	Suspension travel	0.0632 m	0.027 m	57.3 %
3	Wheel travel	0.00654 m	0.004176 m	36.15%

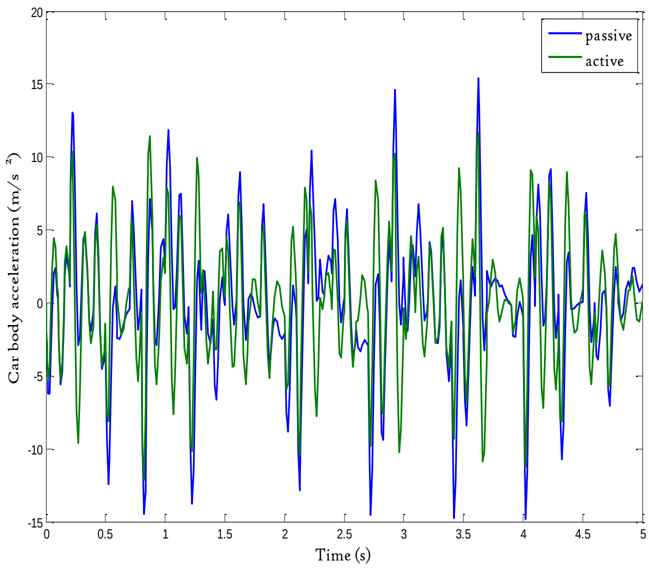

Fig. (8-a) Car body acceleration for random road

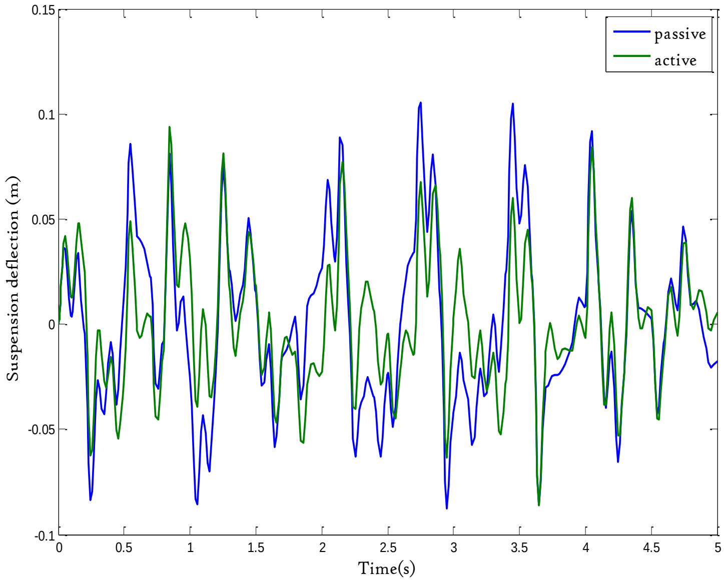

Fig. (8-b) Suspension Travel for random road

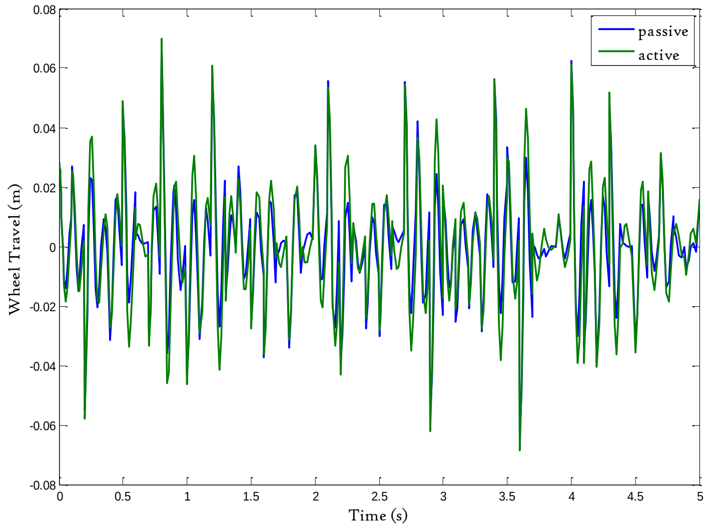

Fig. (8-c) Wheel Travel for random road

Fig.8 illustrates that overshoot values and settling time have been reduced by the active system compared to the passive system for all the parameters of sprung mass acceleration (passenger comfort), suspension deflection (road holding) and tyre deflection. Table-4 gives the percentage reduction in peak values of the various parameters for the random input (random road).

Table: 4. Reduction in overshoot values for random road

No	Parameters	Passive	Active	Reduction
1	Car body acceleration	15.4569 m/s^2	11.68 m/s^2	24.44 %
2	Suspension travel	0.1052 m	0.0676 m	35.74 %
3	Wheel travel	0.0625 m	0.061 m	2.4 %

VII. CONCLUSION

The methodology was developed to design an active suspension for a passenger car by designing a controller, which improves performance of the system with respect to design goals compared to passive suspension system. Mathematical modeling has been performed using a two degree-of-freedom model of the quarter car model for passive and active suspension system considering only bounce motion to evaluate the performance of suspension with respect to various contradicting design goals. PID controller design approach has been examined for the active system. Suspension travel in active case has been found reduced. By including an active element in the suspension, it is possible to reach a better compromise than is possible using purely passive elements. The potential for improved ride comfort and better road handling using PID controller design is examined. The objectives of this project have been achieved. Dynamic model for linear quarter car suspensions systems has been formulated and derived only one type of controller is used to test the systems performance which is PID.

VIII. SCOPE OF FUTURE WORK

Future work must focus on other types of control methods and compare between them to select the best one. In addition, the mathematical model using Matlab can further improved and validated using experimental results. Additional efforts are needed to improve the mathematical model of suspension systems include more details of full car.

REFERENCES

[1]. Hrovat, D. (1997). Survey of advanced suspension development and related optimal control application, Automatica, Vol. 30, No. 10, pp. 1781-1817, ISSN 0005-1098.
[2]. Chen H.Y. , Huang S.J.,(2005) "Adaptive Control for Active Suspension System" International Conference on Control and Automatic. June. Budapest, Hungary.
[3]. Aldair, A , Wang, W. J. (2011). Design an Intelligent Controller for Full Vehicle Nonlinear Active Suspension Systems, International Journal on Smart Sensing and Intelligent Systems,vol. 4, no. 2, 224-243.
[4]. M. A. Aref Soliman, Nouby M. Ghazaly, Fatma S. Kadry (2014) "Parameters Affecting Truck Ride Comfort" SAE Technical Paper 2014-01-0147, DOI:10.4271/2014-01-0147.
[5]. Nouby M. Ghazaly, Ahmad O. Moaaz "The Future Development and Analysis of Vehicle Active Suspension System" IOSR Journal of Mechanical and Civil Engineering, Volume 11, Issue 5 Ver. V (Sep- Oct. 2014), PP 19-25.
[6]. Fatemeh Jamshidi. , Afshin Shaabany. (2011). Robust Control of an Active Suspension System Using H2 & H∞ Control Methods, Journal of American Science, 7(5), pp.1-5.
[7]. M. S. Yahaya, and M. R. A. Ghani, (2000) "LQR Controller for Active Car Suspension," Proc. On TENCON, Malaysia.
[8]. PC Chen, Huang AC. (2005) .Adaptive sliding control of non-autonomous active suspension systems with time-varying loadings. J Sound Vib; 282(3–5):1119–35.
[9]. Du H, Zhang N. "H∞ control of active vehicle suspensions with actuator time delay. J Sound Vib 2007; 301(1–2):236–52.
[10]. Elnaz Akbari, Morteza Farsadi, Intan Z.Mat Darus ,Ramin Ghelichi (2010) "Observer Design for Active Suspension System U sing Sliding Mode Control "Proceedings of 2010 IEEE Student Conference on Research and Development, 13 - 14 Dec 2010, Putrajaya, Malaysia.
[11]. H., Elbab, Allam, E., Hady, M., and Abouel-Seoud, S., (2009) "Performance of Active Suspension with Fuzzy Control," SAE Technical Paper 2009-01-1614.
[12]. W. A. H. Oraby, M. A. Aly, S.M. El-Demerdash, A. M. Selim (2007) .Influence of Active Suspension Preview Control on the Vehicle Lateral Dynamics " SAE 2007-01-2347.
[13]. J. Marzbanrad, Y. Hojjat, H. Zohoor, S.K. Nikravesh, (2003) Optimal previewcontrol design of an active suspension based on a full car model, Scientia Iranica 10, 23–36.
[14]. J. Marzbanrad, G. Ahmadi, Y. Hojjat, H. Zohoor, (2002) Optimal active control of vehicle suspension systems including time delay and previewfor rough roads, Journal of Vibration and Control 8, 967–991.

[15]. N. Al-Holou, T. Lahdhiri, D. Joo, J. Weaver, and F. Al-Abbas, (2002) "Sliding mode neural network inference fuzzy logic control for active suspension systems," IEEE Trans. Fuzzy Syst., vol. 10, no. 2, Apr. 2002, pp. 234–246.
[16]. Robert L.W., Kent L.L., (1997) "Modeling and Simulation of Dynamic System", Second Edition, Prentice-Hall.
[17]. Hung V.V. , Esfandiari S.R., (1997) .Dynamic Systems: Modeling and Analysis", Second Edition, McGraw-Hill.
[18]. Mouleeswaran S. (2008) .Development of Active Suspension System for Automobiles using PID Controller, Proceedings of the World Congress on Engineering, Vol II WCE, July 2-4, London, U.K.

BIOGRAPHIES

G. T. Abd el- Jaber is the Dean of Qena Faculty of Engineering, South Valley University, Egypt and has also been an Associate Professor in Mechanical Engineering Department of the same university since 2011. He obtained his BSc in Mechanical Engineering from Mechanical Design and Production Dept., Faculty of Engineering, Minia University., Minia, Egypt in 1992, his MSc from the same university in 1998. He obtained his PhD from Minia University and Machine elements, Engineering Construction, and Tribology Institute, Hanover University, Hanover, Germany in 2004 in Machine Design and Tribology. He has many international and national journal and conference papers to his credit. His current research interests are Tribology, Vibrations, and Material Science. He is an Editorial Board Member and a Reviewer of several journals and conferences.

Nouby Mahdy Ghazaly is an assistant Professor in Department of Mechanical Engineering, South Valley University, Egypt. He received his BSc and MSc from Department of Automotive and Tractor Engineering, Minia University, Egypt in 1999 and 2003, respectively. He obtained his PhD from AU-FRG Institute for CAD/CAM, Faculty of Mechanical engineering, Anna University, India in 2011. He has to his credit a book and more than 55 research papers in refereed journals and international conferences in the areas of vehicle dynamics, noise and vibrations and Computer Aided Design. He is a member of Editorial Board and a Reviewer of several international journals and conferences.

Abd El-Nasser S. Ahmed is a Demonstrator in Department of Mechanical Engineering, South Valley University, Egypt. He received his B.Sc. degree from Department of Mechatronic Engineering, South Valley University, Egypt in 2013. His current research interests are mechatronics, control, sensors and vehicle dynamic.

Ahmed Saad received his B. Sc. and M. Sc. Degrees in mechatronics section from Mechanical Engineering Department, Faculty of Engineering, Assiut University, Assiut, Egypt, in 2001, 2007 respectively. He received his PhD Mechatronics Engineering, Southern Federal University, Russia in 2012. Now He is currently a Lecturer (assistant professor) at Mechanical Engineering Department, Faculty of Engineering, Assiut University. He is also Research and Development Manager at Integrated technology transfer unit, Assiut University. His research interests include mechatronics system, Automatic control, Mobile robot and Electro-Hydraulic System.