DESIGN OF SKYHOOK SURFACE SLIDING MODE CONTROL ON SEMI-ACTIVE VEHICLE SUSPENSION SYSTEM

[1]Mable Alex, [2]Anish M Jose,

[1]Assistant Professor Department of Electronics and Instrumentation Engineering SJCET Palai,

,[2]Assitant Professor Department of Electronics and Communication Engineering VJCET Vazhakulam.

Abstract : Skyhook surface sliding mode control (SkyhookSMC), fuzzy logic control (FLC) and fuzzy sliding mode control are designed to control a semi-active suspension system for its ride comfort enhancement. A two degree dynamic model of a vehicle semi-active suspension (SA) system was used, focusing on the quality of passenger's ride comfort. Sliding mode control is a robust and efficient control method because it is low sensitivity to a system's parameter changing under various uncertainty conditions. In fuzzy logic control, mathematical modeling knowledge as used in the conventional control design method is not required. Optimal parameters of the sliding mode controller and fuzzy logic controller are determined using the Genetic algorithm (GA) and Covariance matrix adapted evolutionary strategy (CMAES). For evaluating the performance of the given system, Integral Absolute Error (IAE) is used as an objective function. Fuzzy sliding mode control gives better results compared to sliding mode control and fuzzy logic control.

***IndexTerms* - fuzzy logic control , Integral absolute error ,Semi-active, Sliding mode control.**

I. INTRODUCTION

The vehicle suspension system's function is to support and isolate the vehicle body and payload from road disturbances, retain the traction force between tires and road surface. It offers ride comfort as it reduces vibration transmission and maintains adequate tire contacts. The active and semi-active suspension is designed and developed to achieve better ride comfort performance than a passive suspension system. The active suspension is intended to use separate actuators that can exert an independent force on the suspension, in order to enhance the efficiency of the suspension ride comfort, but it is hardware complicated and costly. The semi-active(SA) suspension system was introduced in the early 1970s as a good option between active and passive suspension system.. In SA suspension system, active force actuators are substituted by continuously adjustable components that can differ or change the rate of the energy dissipation in response to the instantaneous condition of motion.SA suspension system can change the shock absorber's viscous damping coefficient and does not add additional energy to the suspension system. The SA suspension system is also less expensive and energy cost than the active suspension system in operation. The majority of the performance characteristics of the active suspension system can be achieved by the SA suspension system, resulting in a wide class of practical applications.

Sliding Mode Control (SMC) has been recognized as a robust and efficient control method for high order nonlinear dynamical systems. The main objective of the sliding mode control technique is to force a system state to a specified manifold, known as the sliding surface. When the manifold is reached, the system is subsequently compelled to stay on it.. When in the sliding mode, the system is equivalent to an unforced system of a reduced order, which is insensitive to both parametric uncertainty and unknown disturbances that satisfy the matching condition. The primary drawback of the sliding mode control is the need for of a discontinuous control throughout the sliding manifold. This contributes to a phenomenon called chattering in practical systems. A skyhook surface sliding mode control(SkyhookSMC) method will be developed and applied to the semi-active vehicle suspension system for the ride comfort enhancement in this work.

In order to compare and validate the control effects from the Skyhook SMC, a Fuzzy Logic Controller(FLC) is also designed in this work. In fuzzy logic control, mathematical modeling knowledge as used in the conventional control design method is not required. The FLC's rule base comes from a human's practical experience, however, the linguistic expression of the FLC rule base makes it difficult to make guarantee the stability of the control system.

The parameters of Skyhook sliding mode control and Fuzzy logic control are optimized using evolutionary algorithms such as the Genetic algorithm(GA) and Covariance matrix adapted evolutionary strategy(CMAES). The aim of this work is to improve the ride comfort of passengers using a semi-active suspension system. Thus, Skyhook sliding mode control, Fuzzy logic control, and Fuzzy-sliding mode control scheme are presented. In Fuzzy-sliding mode control, the sliding surface of the nonchattering sliding-mode controller is controlled by the fuzzy logic unit.

II. LITERATURE REVIEW

N.Jalili[2], in their work, used a semi-active suspension system for providing ride comfort by reducing the vibration transmission and keeping proper tire contacts. The semi-active suspension system has been considered a good alternative between active and passive suspension systems. In the active suspension system, separate actuators are used for exerting independent force on the suspension, this cause to increase the complexity and cost of the hardware. But in a semi-active suspension system, active force actuator is replaced with continually adjustable elements. So the SA suspension system is less expensive and energy cost.

Yi Chen[1], in their work, has applied Skyhook sliding mode control to the semi-active vehicle suspension system for the ride comfort enhancement. The principal goal of the sliding mode control technique is to force a system state to a certain prescribed manifold, known as the sliding surface. When the manifold is reached, the system is subsequently compelled to stay on it thereafter. The system is equivalent to an unforced system of a lower order when in sliding mode, which is insensitive to both parametric uncertainty and unknown disturbances that meet the matching condition. The main drawback of the sliding mode control is the requirement of a discontinuous control across the sliding manifold.This leads to a phenomenon termed chattering in practical systems. By using Skyhook control, it can reduce the resonant peak of the sprung mass quite significantly and thus can achieve a good ride quality. So Skyhook SMC reduces the sliding chattering phenomenon.

L.Zheng[3], et al, in their work, have applied integrated fuzzy logic control and sliding mode control on a semi-active suspension system with MR dampers. This proposed controller can effectively suppress the vibration of vehicles and improve ride comfort. Furthermore, the chattering of the sliding mode controller is smoothed.

Y. Chen, in their work, designed fuzzy logic control and Skyhook sliding mode control on a semi-active vehicle suspension system for ride comfort enhancement. The parameters of FLC and Skyhook SMC are obtained from manual parameter selection which based on passive suspension system simulation results.

The proposed work is to optimize the parameters of fuzzy logic control and Skyhook sliding mode control on a semi-active vehicle suspension system using the Genetic algorithm(GA) and Covariance matrix adapted evolutionary strategy(CMAES)for ride comfort enhancement. For evaluating the performance of the given system, Integral Absolute Error (IAE) is used as an objective function. Further optimized FLC and SMC are integrated and applied to the system.

III. PROBLEM DESCRIPTION

This Work presents the application of Genetic Algorithm (GA) and Covariance matrix adapted evolutionary strategy(CMAES) techniques to find optimized parameters of fuzzy logic control and Skyhook sliding mode control on semi-active vehicle suspension system to achieve maximum ride comfort. Integral Absolute Error(IAE) is used as an objective function for analyzing system performance. The parameters optimized in Skyhook SMC and FLC are

a. The slope of the sliding surface(λ)
b. Skyhook SMC damping coefficient(c_0)
c. The thickness of the sliding mode boundary layer(δ)
d. FLC scaling gains for error(k_e)
e. FLC scaling gains for change in error(k_{ec})
f. FLC scaling gains for output(u)

Optimized FLC and SMC are combined and applied them to the system. Simulations are performed on a semi-active suspension system and the results are obtained.

.

IV. PROBLEM FORMULATION

The SA suspension system can deliver both the reliability and versatility including passenger ride comfort with less power demand. A two degree of freedom model which concentrated on the passenger ride comfort performance [13] is introduced for SA suspension system in Fig 1 The model of this system can be defined by the equation(1) and (2)

$$m_1\ddot{z_1} + k_2(z_2 - z_1) + (c_2 + c_e)(\dot{z_2} - \dot{z_1}) - k_1(z_1 - q) + m_1 g = 0 \qquad (1)$$

$$m_2\ddot{z_2} - k_2(z_2 - z_1) - (c_2 + c_e)(\dot{z_2} - \dot{z_1}) + m_2 g = 0 \qquad (2)$$

Where

m_1 unsprung mass

m_2 sprung mass

k_1 tire deflection stiffness

k_2 suspension stiffness

c_2 damping coefficients

q road disturbance

Damping force f_d is given by equation (3)

$$f_d = c_e(\dot{z}_2 - \dot{z}_1) \qquad (3)$$

Where

c_e semi-active damping coefficient

z_1 displacement for unsprung mass

z_2 displacement for sprung mass

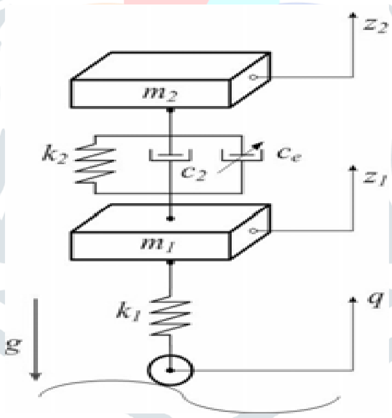

Fig. 1. Two degrees of freedom semi-active suspension system

A road profile (q) is a series of random data in the actual surroundings. That is the reason to describe the road profile by statistical techniques. The description of road roughness in power spectral density (PSD) is a practical statistical way to produce road input.

4.1 Sliding Mode Control with Skyhook Surface Design

s(e,t) is the sliding surface of the hyper-plane which contains the system information[1]. s(e,t) is given in equation (4) and also shown in Fig 2

$$s(e,t) = \left(\frac{d}{dt} + \lambda\right)^{n-1} e \qquad (4)$$

Where

λ slope of the sliding surface

In the 2-DOF SA suspension system, Sliding surface of the hyper-plane is given by equation (5)

$$s = \dot{e} + \lambda e \qquad (5)$$

Where

$\dot{e}$ velocity error

e position error

λ slope of the sliding surface

From equation (4) and (5), the second order tracking problem is now being replaced by a first-order stabilization problem in which the scalar s is kept at zero by means of using the Lyapunov stability theorem [8]. It states that the origin is a globally asymptotically stable equilibrium point for the control system.

$$V(s) = \frac{1}{2}s^2 \qquad (6)$$

$$\dot{V}(s) = s\dot{s} < 0 \qquad (7)$$

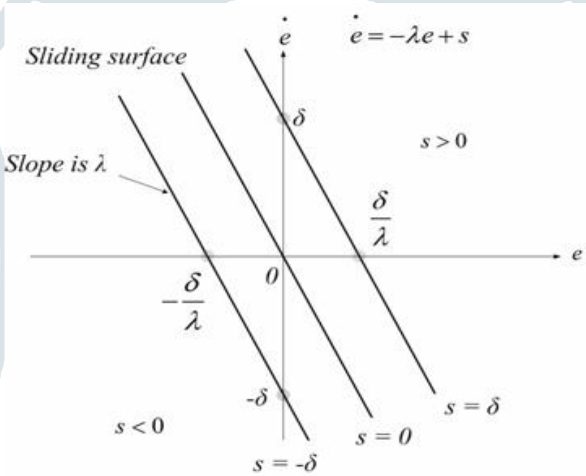

Fig. 2. Sliding surface design

Karnopp et al.[9] introduced the ideal skyhook control strategy in 1974, which is one of the successful control algorithms.

Fig.3 shows the ideal skyhook control scheme, which connects the vehicle body sprung mass to the stationary sky by a controllable 'skyhook' damper [12], it can generate the controllable force of $f_{skyhook}$ and reduce the vertical vibrations by the road disturbance of all kinds [10-11]. The skyhook control will reduce the resonant peak of the sprung mass and therefore can achieve a good ride quality. This idea is also to scale down the sliding chattering phenomenon. A soft switching control law is introduced for the major sliding surface switching activity in equation (8) which is to attain good switch quality for the Skyhook SMC [1]. The variable of s contains the system data which may be taken as a part of the Skyhook SMC control law in equation (8).

Skyhook SMC control law is given by equation (8)

$$U_{SkyhookSMC} = \begin{cases} -c_0 \tanh\left(\frac{s}{\delta}\right) & s\dot{s} > 0 \\ 0 & s\dot{s} \le 0 \end{cases} \qquad (8)$$

Where

c_o Skyhook SMC damping coefficient

δ thickness of the sliding mode boundary layer

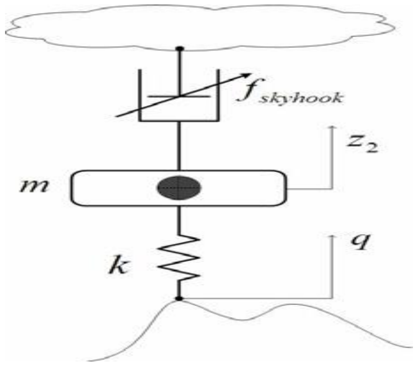

Fig. 3 The ideal skyhook control scheme

V. SIMULATIONS

5.1 Skyhook Sliding Mode Control on Semi-Active Suspension System

In the simulation for the control on a 2-DOF SA suspension system, it is excited by a random road disturbance loading that is represented by the road profile with the parameters of reference space frequency n_0(0.1 m^{-1}) and road roughness coefficient $P(n_0)$ (m^3/cycle). The Skyhook SMC damping coefficient c_0 is used to expand the normalized controller output force into a practical range. The parameters in the Skyhook SMC are Skyhook damping coefficient c_0, the thickness of the sliding mode boundary layer δ and the slope of the sliding surface λ. These parameters are optimized using the Genetic algorithm (GA) and Covariance matrix adapted evolutionary strategy(CMAES) to achieve better system performance. Skyhook SMC Simulink block for SA suspension system is given in Fig. 4

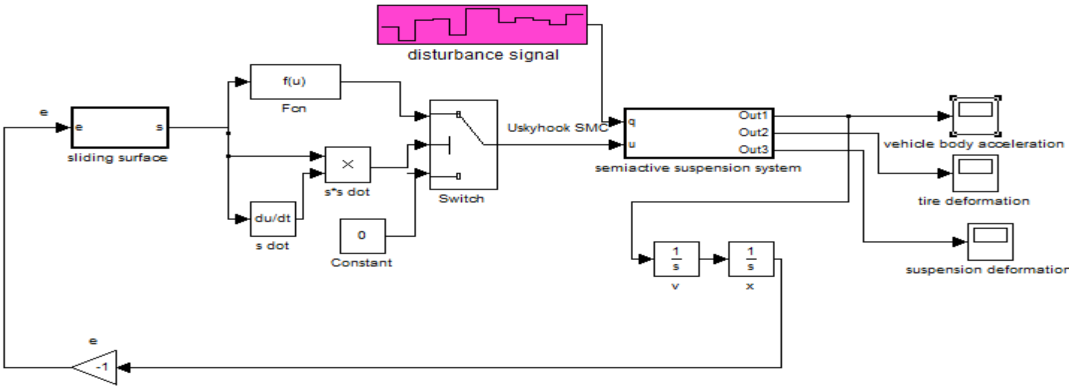

Fig.4 Simulink block for semi-active suspension system using Skyhook SMC

5.2 Fuzzy Logic Control on Semi-Active Suspension System

Fuzzy logic control is a practical alternative for a range of difficult control applications, as a result of it provides a convenient technique for constructing nonlinear controllers via the utilization of heuristic information. The fuzzy logic control's rule-base comes from an operator's expertise that has acted as a human in the loop controller. It actually provides a human experience based on representing and implementing the concepts that human has regarding the way to achieve high performance control. The Simulink block of the fuzzy logic controller on the 2-DOF SA suspension system is shown in Fig.5.

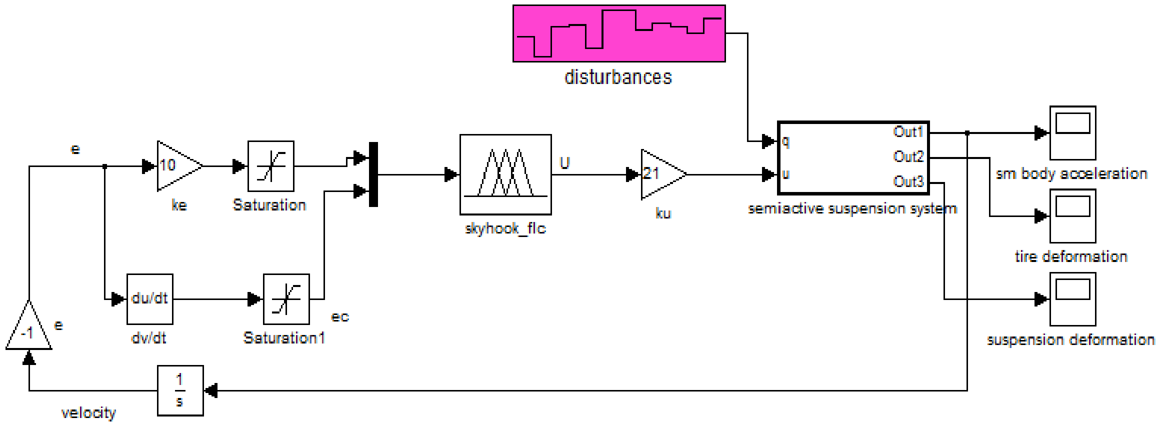

Fig.5 Simulink block for semi-active suspension system using FLC

Velocity and acceleration of the vehicle body are chosen as an error(e) and change in error(ec) feedback signals for the 2-DOF SA suspension system control. The 2-in-1-out FLC rule base for the ride comfort of the system is based on two main linguistic control rules. These are:1) when the body acceleration increases, the SA damping force increases;2)when the body acceleration decrease, the SA damping force decreases. The full 2-in-1-out FLC rule base is given in Table 1, which can map the FLC rule-base supported the inputs information of semi-active suspension body acceleration to the output control force.

Table 1 2-in-1-out FLC rule table for the 2-DOF SA suspension system

	Change in error(EC)							
	U	**NL**	**NM**	**NS**	**ZE**	**PS**	**PM**	**PL**
Error (E)	**NL**	PL	PL	PM	PS	PS	PS	ZE
	NM	PL	PM	PS	PS	PS	ZE	NS
	NS	PM	PS	ZE	ZE	ZE	NS	NM
	ZE	PM	PS	ZE	ZE	ZE	NS	NM
	PS	PM	PS	ZE	ZE	ZE	NS	NM
	PM	PS	ZE	ZE	ZE	ZE	NM	NL
	PL	ZE	NS	NS	NS	NM	NL	NL

The membership functions for each input and output are triangular shaped membership functions. The FLC parameters are scaling gains of $\{k_e,k_{ec}\}$ for fuzzification and the scaling gain of $\{k_u\}$ for defuzzification, in which the $\{k_u\}$ is employed to map the control force from the fuzzy space range to practical space range that actuators can work practically. For getting performance, these parameters are optimized using a genetic algorithm and covariance matrix adapted evolutionary algorithm.

5.3 Fuzzy-Sliding Mode Control on Semi-Active Suspension System

In the combined fuzzy-sliding mode controller, the sliding surface of the non-chattering sliding-mode controller is controlled by the fuzzy logic unit. The rules of the fuzzy-sliding mode controller can be described as follows:

Rule1: If s is NB, then f_d is PB

Rule2: If s is NM, then f_d is PM

Rule3: If s is ZE, then f_d is ZE

Rule4: If s is PM, then f_d is NM

Rule5: If s is PB, then f_d is NB

Where NB, NM, ZE, PM, PB are linguistic terms of antecedent fuzzy set, they mean negative big, negative medium, zero, positive medium and positive big. Simulink block of fuzzy-sliding mode control on the semi-active suspension system is shown in Fig. 6

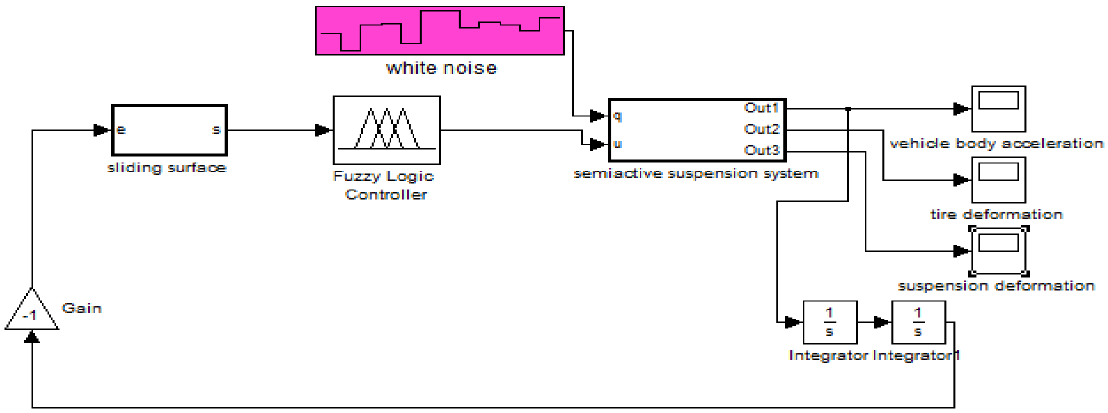

Fig.6 Simulink block for semi-active suspension system using fuzzy-sliding mode control

VI. RESULT AND DISCUSSION

In a semi-active vehicle suspension system, three outputs are considered which are vehicle body acceleration, tire deformation, and suspension deformation. Skyhook surface sliding mode control, fuzzy logic control, and fuzzy sliding mode control are designed to control on semi-active suspension system for its ride comfort enhancement.IAE value of vehicle body acceleration is minimized using the Genetic algorithm and Covariance matrix adapted evolutionary strategy so that ride comfort is improved. System performances are analyzed for various disturbances and output obtained after optimization for skyhook sliding mode control, fuzzy logic control and fuzzy-sliding mode control on SA suspension system is shown in Table2.

Table 2 Output obtained for various disturbances

	q=256*10^-7(m^3/cycle)			q=256*10^-6(m^3/cycle)			q=256*10^-5(m^3/cycle)		
	Skyhook sliding mode control	Fuzzy logic control	Fuzzy sliding mode control	Skyhook sliding mode control	Fuzzy logic control	Fuzzy sliding mode control	Skyhoo k sliding mode control	Fuzzy logic contro l	Fuzzy sliding mode control
IAE(a)	238.295	289.6480	76.585	459.7369	557.81	192.44	1217	904.7	610.86
IAE(out 2)	16.2698	16.5370	3.0793	15.4212	16.892	4.7321	14.671	16.96	10.601
IAE(out 3)	160.927	162.2330	80.894	157.0479	164.11	88.275	152.40	164.0	111.67

VII.CONCLUSIONS

In this work, the Skyhook sliding mode controller, fuzzy logic controller and fuzzy sliding mode controller on a semi-active vehicle suspension system are designed. For optimizing the parameters of the sliding mode controller and fuzzy logic controller, the Genetic algorithm and Covariance matrix adapted evolutionary strategy were used.IAE value of the semi-active vehicle suspension system's first output is minimized using evolutionary algorithms, whereas the IAE values of second and third outputs remain constant for various disturbances. For various disturbances, the fuzzy sliding mode controller gives better results compared to a sliding mode controller and fuzzy logic controller.

REFERENCES

[1] Yi Chen, "Skyhook Surface Sliding Mode Control on Semi-Active Suspension System for Ride comfort Enhancement",Engineering,2009,1,1-54

[2] N.Jalili, "A comparative study and analysis of semi-active vibration-control system",Journal of Vibration and Acoustics,Vol.124,No.4,pp.593-605,2002

[3] L.Zheng, Y.N.Li and J.shao, "The Design of a Fuzzy-sliding Mode Controller of Semi-Active Suspension Systems with MR Dampers", Fourth International Conference on Fuzzy Systems and Knowledge Discovery(FSKD 2007)

[4] Dragan Antic, Marko Milojkovic, Sasa Nikolic and stanisa Peric, "Optimal Fuzzy Sliding Mode Control with a Time-Varying Sliding Surface", IEEE International Joint Conference on Computational Cybernetics and Technical Informatics(ICCC-CONTI 2010) May 27-29,2010,Timisora,Romania

[5] S.V.Emelyanov, "Variable structure control systems(in Russian)," Moscow: Nauka,1967

[6] Y.Chen and M.P.Cartmell, "Multiobjective optimization on motorized momentum Exchange tether for pay-load orbital transfer," IEEE congress on Evolutionary Computation,pp.987-993,September 25-28,2007

[7] Nurkan Yagiz, Yuksel Hacioglu, and Yener Taskin, "Fuzzy Sliding Mode Control of Active Suspensions", IEEE transactions on Industrial Electronics,Vol.55,No.11,2008

[8] J. J. E. Slotine and W. P. Li, "Applied nonlinear control," Prentice-Hall International,1991

[9] D. C. Karnopp, M. J. Crosby, and R. A. Harwood, "Vibration control using semi-active force generators," Journals of Engineering for Industry, Transactions of the ASME, Vol.94, pp. 619-626, 1974.

[10] H.-S. Kima and P. N. Roschke, "Design of fuzzy logic controller for smart base isolation system using a genetic algorithm," Engineering Structures, Vol. 28, No. 1, pp. 84-96,2006.

[11] S. M. Savaresi, E. Silani, and S. Bittanti, "Acceleration-Driven-Damper (ADD): An Optimal control algorithm for comfort-oriented semiactive suspensions," ASME Transactions: Journal of Dynamic Systems, Measurement and Control, Vol. 127, No. 2, pp. 218-229, 2005

[12] Saad Kashem, Romesh Nagarajah, Mehran Ektesabi. "Vehicle Suspension Systems and Electromagnetic Dampers", Springer Nature, 2018

[13] Yi Chen. "Fuzzy Skyhook Surface Control Using Micro-Genetic Algorithm for Vehicle Suspension Ride Comfort", Studies in Computational Intelligence, 2011.