Hybrid Fuzzy-PID Control of a Semi-Active Quarter Car System

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Abstract: *In this paper, performance evaluation of nonlinear quarter car model having three degrees of freedom is considered for uncontrolled and fully controlled suspension system in terms of passenger ride comfort issues.Magneto-rheological (MR) damper in combination with Hybrid Fuzzy-PID controller (HFPID) is used in primary and secondary suspension system of semi-active vehicle for vibration control purpose. Simulation results for uncontrolled and fully controlled cases are calculated in time domain while the vehicle travels over the sinusoidal roadprofile. The calculated simulation results show that the proposed semi-active quarter car model provides better performance in achieving desired ride comfort and safety of traveling passengers compared to uncontrolled one.*

Keywords: *Quarter car model, Hybrid Fuzzy-PID controller, MR damper, passenger ride comfort*

I. INTRODUCTION

Vehicle performance in terms of passenger ride comfort and handling issues is dependent on the type of suspension system assembled in it. Depending on the response delivered, suspension systems can be categorized in passive, semi-active and active types. Passive suspension system can provide limited ability in vibration suppression due to uncontrollable parts such as passive damper and spring. Active suspension systems are most effective in achieving best ride comfort and vehicle handling tasks. But high cost and complicated mechatronics based technology are main hindrance for its application in automotive sector. On the other hand, semi-active suspension system can fulfill the desired objectives related to ride comfort and vehicle handling issues at low cost and simple technology. Thus, semi-active suspension systems are reasonable and favorable choice in suspension system compared to passive and active types.

In practice, MR dampers have been successfully used in vibration control of various devices ranging from suspension systems, helicopter rotors and civil structuresetc.Basically, research and development in the field of magneto-rheological (MR) dampers have led to the success of semi-active technology. MR dampers are attractive choice in semi-active suspension system due to its controllable damping characteristics, compact size and unaffected by temperature variation as well as impurities. In past, MR dampers have been successfully used in semi-active suspension systems [1-2]. Practical feasibility of MR dampers is based on the development of control system due to its highly nonlinear behavior during working period. Researchers have developed and studied various control algorithms as well as compared the performance of each control strategies with each other [3-5]. For development of forward controller, various parametric and non-parametric models have been developed based on the test results of MR damper [6-12]. The experimental results and successful application of non-parametric model for MR damper can be found in [13].

In present paper, vibration control performance of semi-active quarter car system is compared with uncontrolled system. The designed quarter car model is having three degrees of freedom (3 DOF). The designed Hybrid Fuzzy PID controller (HFPID) is integrated in primary and secondary suspension systemof quarter car model for proper working of assembled MR dampers to supply damping force. The parameters selected for comparative analysis are passenger seat acceleration and displacement response respectively. Simulation work is performed and compared under sinusoidal type of road excitation in time domain.

II. SEMI-ACTIVE QUARTER CAR MODEL

The nonlinear quarter car model used in present study having MR dampers in primary and secondary suspension is shown in Fig. 1. Here, vertical motion of complete system is considered where z_1, z_2 and z_3 represents displacement of passenger seat, sprung mass as well as unsprung mass respectively, denoting three degrees of freedom of complete system while z_r is input road profile variation. The mass of passenger seat, sprung mass and unsprung mass are m_1, m_2 and m_3 respectively. While k_1 and k_2 are primary and secondary suspension spring stiffness; c_1 and c_2 are primary and secondary suspension shock absorber damping coefficients and tyre stiffness is k_t . The damping force generated by assembled MR dampers in primary and secondary suspension system are F_1 and F_2 respectively.

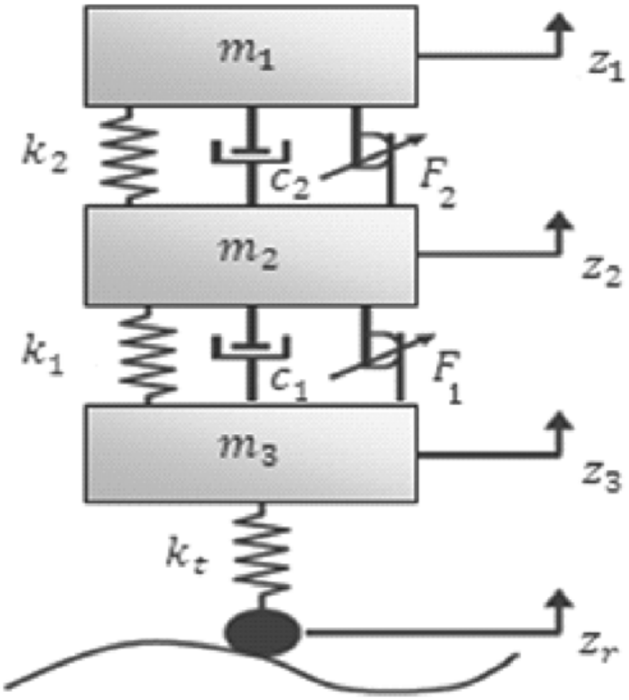


Fig. 1: Semi-active quarter car model

The vertical dynamic equations of motion of semi-active quarter car model is as follows:

$$m_1\ddot{Z}_1 + c_2 (\dot{Z}_1-\dot{Z}_2) + k_2 (Z_1-Z_2) + F_2=0 \quad \ldots(1)$$

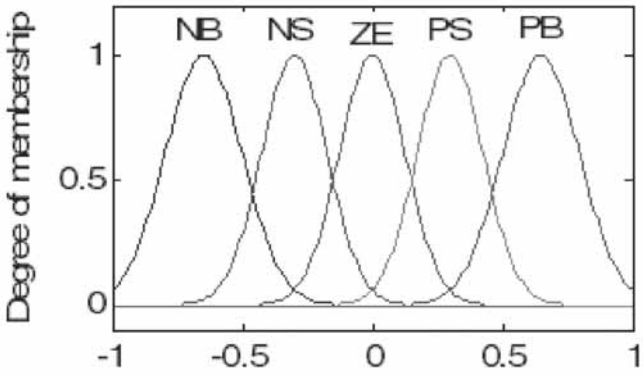
$$m_2 \ddot{Z}_2-c_2 (\dot{Z}_1-\dot{Z}_2) -k_2 (Z_1-Z_2) + c1 (\dot{Z}_2-\dot{Z}_3) + k_1 (Z_2-Z_3) - F_2+F_1 = 0 \quad \ldots(2)$$

$$m_3 \ddot{Z}_3-C_1 (\dot{Z}_2-\dot{Z}_3) -1 (Z_2-Z_3) + k_t (Z_3-Z_r) -F_1 = 0 \quad \ldots (3)$$

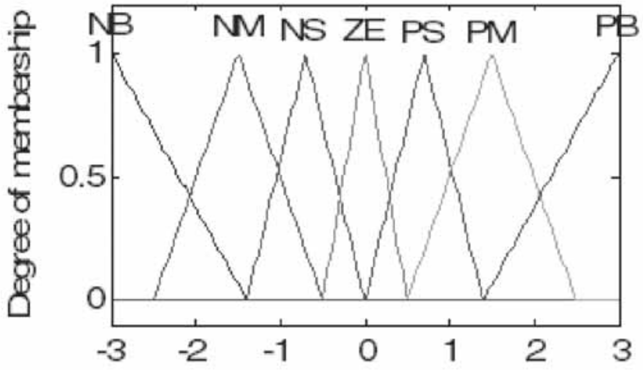
III. HYBRID FUZZY PID CONTROLLER

In present case, Hybrid Fuzzy PID Controlled (HFPID) is designed for application in semi-active suspension system.HFPID controller is the combination of Fuzzy and conventional PID controller. A PID controller is highly used in industries for control system problems due to its design simplicity and effectiveness. It provides superior results for linear systems requiring controlling near set point value with little deviations. However, its performance is reduced for highly nonlinear systems. While, Fuzzy logic controller (FLC) can successfully work for systems having design complexity and nonlinear characteristics.

Fuzzy logic controller is designed based on the experience or expertise of the operator about the working of the system to be controlled. Fuzzy controller can be used for highly complex and nonlinear systems without knowledge about the system's complete technical structure. The inputs supplied to fuzzy controller are error signal, [e (t) = Y_{ref} - y] and change of error signal, [de (t) = V_{ref}-V] calculated from the position of the piston rod of MR damper. The generated output from fuzzy controller is the desired damping force signal, F_d.The linguistic variables used are: NB (Negative Big), NM (Negative Medium), NS (Negative Small), ZE (Zero), PM (Positive Medium), PS (Positive Small) and PB (Positive Big). The membership function shapes with intervals is shown in Fig. 2. The written rule bases are represented in Table 1. Mamdani method has been selected for fuzzy inference whereas for defuzzification stage centroid method has been applied.



(a) Input side, *e*and*de*



(a) Output side

Fig. 2: Membership functions of FLC

Table 1: Fuzy Rule Base

e/de	NB	NS	ZE	PS	PB
NB	NB	NB	NB	NM	ZE
NS	NB	NS	NS	ZE	PM
ZE	NB	NS	ZE	PS	PB
PS	NM	ZE	PS	PS	PB
PB	ZE	PM	PB	PB	PB

The designed HFPID controller uses the attractive characteristics of both Fuzzy and PID controller during working period of system. The proposed HFPID controller structure is shown in Fig. 3. The working of designed controller is dependent on the calculated actuating error signal, *e (t)*, based on the MR damper piston movement as follows: Delta position of piston rod (ΔP) i.e., e (t) = Reference position value (y_{ref}) - Current position value (y) and Delta velocity of piston rod (ΔV) i.e., de (t) = Reference velocity value (ν_{ref}) - Current velocity value *(v)*.

The working of Fuzzy or PID controllers is decided by the integrated switching mechanism. The switching mechanism transfers the control between Fuzzy or PID controller as per the set threshold value "*w*" in the designed HFPID controller as follows:

$$\text{Switch} = \begin{cases} 1, \text{ if } |e| > w \text{ Fuzzy controller} \\ 0, \text{ if } |e| < w \text{ PID controller} \end{cases} \quad \dots (4)$$

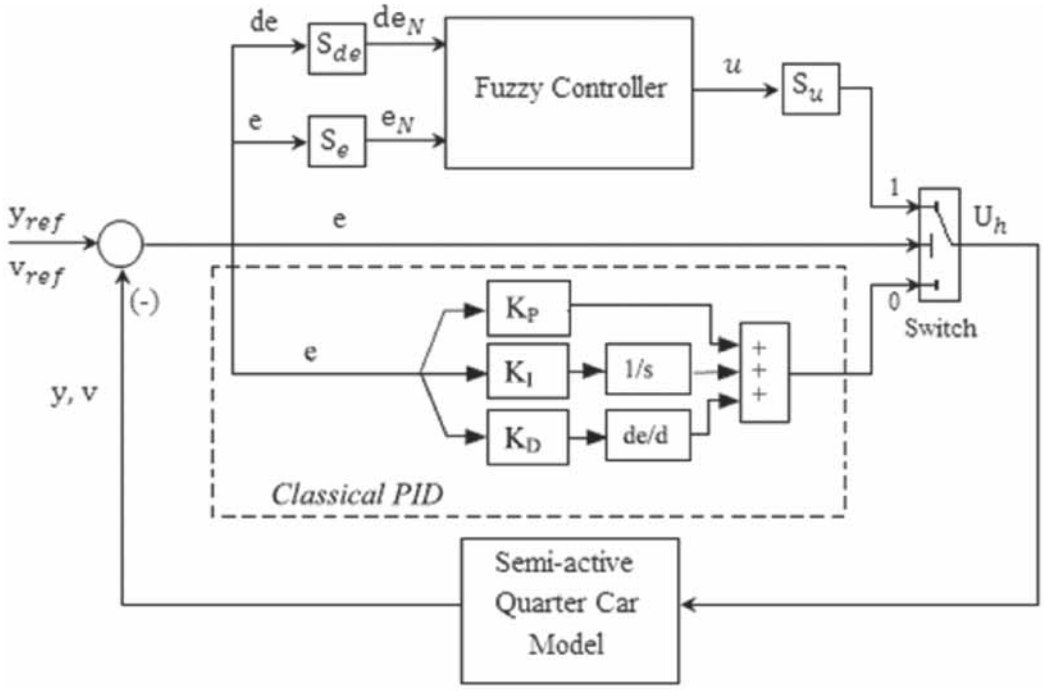


Fig. 3: Hybrid Fuzzy PID controller

IV. SIMULATION RESULTS

The performance evaluation of the designed quarter car system is evaluated using Simulink/Matlab software under sinusoidal road profile with 20 rad/sec as shown in Fig. 4 (a). The values of the quarter car system parameters used for simulation purpose are as follows: m_1 = 75 kg, m_2 = 320 kg, m_3 = 45 kg, k_2 = 9,000 N/m, c_2 = 800 N/m/s, k_1 = 21,000 N/m, c_1 = 1500 N/m/s and k_t = 1, 85,000 N/m respectively. Since the main objective is to improve the passenger ride comfort and safety, hence only passenger seat response is taken into account for calculation purpose.The response of the uncontrolled and controlled systems plotted in terms of passenger seat acceleration and passenger seat displacement are shown in Fig. 4 (b)-(c). From Figs. 4 (b)-(c), it can be seen that fully controlled semi-active suspension system integrated with MR shock absorbers successfully suppresses the effects of vibrations as transmitted from unsprung mass to passenger seat resulting into improved performance related to passenger seat acceleration and passenger seat displacement compared to the uncontrolled one. The damping force signal supplied by assembled primary and secondary suspension MR damper can also be seen in Fig. 4 (d)-(e).

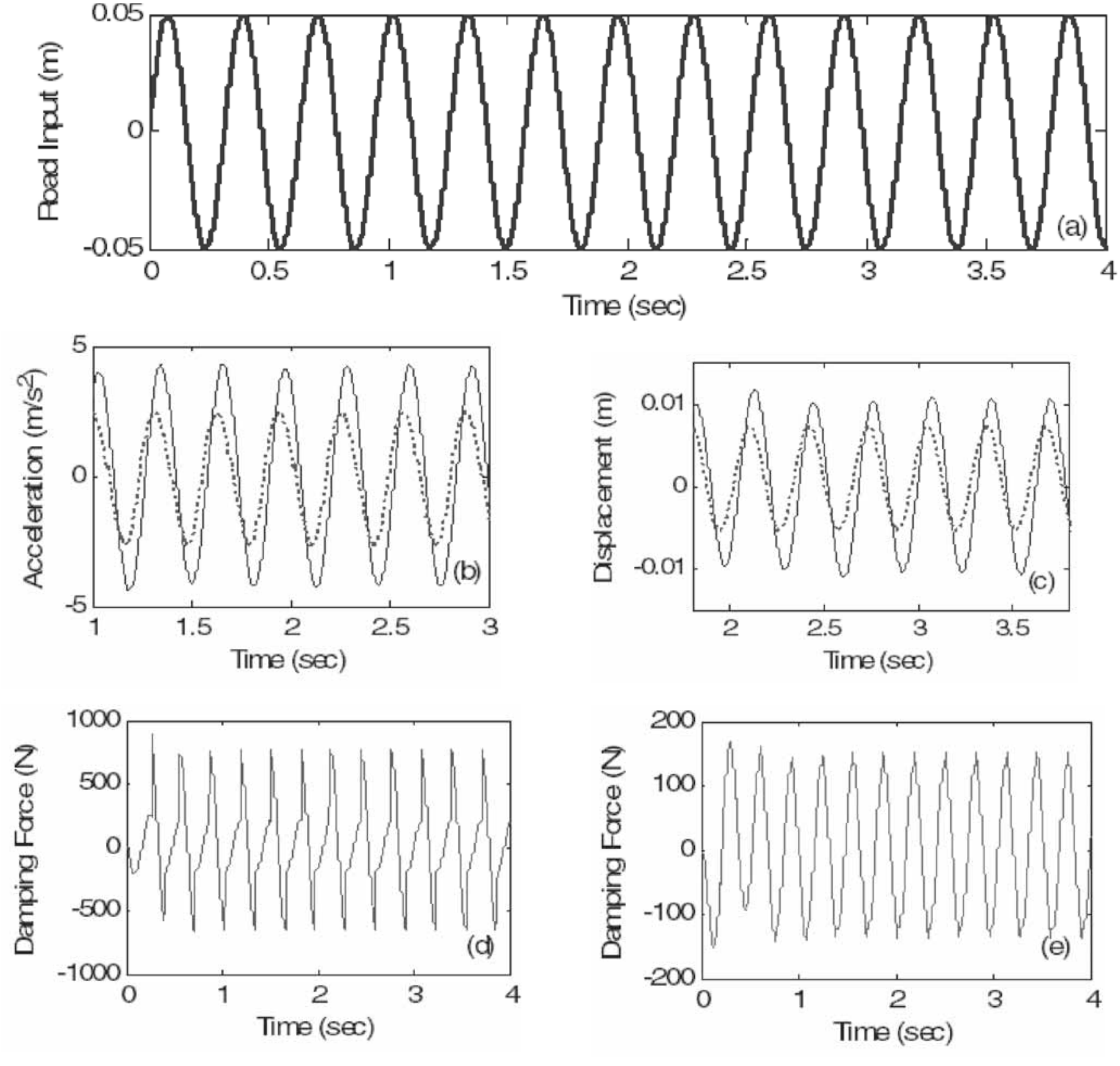


Fig. 4 (a) Sinusoidal road profile, (b) Passenger seat acceleration, (c) Passenger seat displacement, (d) Primary suspension MR damping force (e) Secondary suspension MR damping force (—— Uncontrolled, ... Fully Controlled)

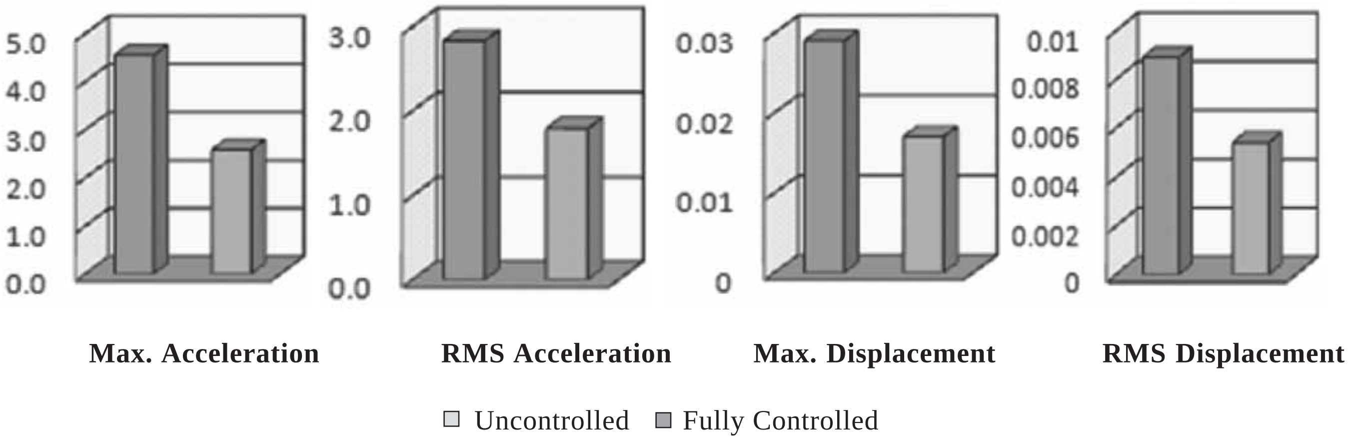


Fig. 5: Max. and RMS value plots of passenger seat acceleration and displacement response

Table 2: Performance comparison of quarter car results under Sinusoidal road profile

Controller Type	Acceleration (m/s^2)		Displacement (m)	
	Max.	RMS	Max.	RMS
Uncontrolled	4.548	2.829	0.029	0.009
Fully Controlled	2.5808 (-43.25)	1.7879 (-36.81)	0.017 (-41.38)	0.0054 (-39.33)

The Max.androot-mean-square (RMS) values of the response plots are presented in Table 2 and same is presented in Fig. 5. Negative values in Table 2 shows percentage improvement in response of fully controlled semi-active suspension system compared to uncontrolled one. It can be seen from Table 2 that the fully controlled semi-active suspension system provides good performance in terms of passenger seat acceleration (z_1), and passenger seat displacement (z_1) response compared to that of uncontrolled suspension system.

V. CONCLUSION

In present paper, fully controlled semi-active quarter car model performance is compared with uncontrolled system. The parameters selected for comparison purpose are passenger seat acceleration and displacement response under sinusoidal type of road excitation. Simulation results show that fully controlled semi-active system provide best results in terms of passenger ride comfort improvement by vibration suppression compared to uncontrolled suspension system.

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