FUZZY PROPORTIONAL DERIVATIVE APPROACH FOR VIBRATION CONTROL OF VEHICLES

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Abstract: *In this paper a fuzzy logic proportional derivative controller is proposed for suppressing vertical vibrations of vehicles. Initially quarter vehicle model is presented. Afterwards fuzzy proportional derivative approach is described in order to minimize vertical displacement of vehicle body. The proposed controller is applied to quarter vehicle model to demonstrate and evaluate performance of the controller. Time responses of vehicle body displacement, acceleration and suspension deflection are compared between controlled and uncontrolled cases. The proposed controller exhibits promising behavior.*

Keywords: FUZZY LOGIC, PROPORTIONAL, DERIVATIVE, VIBRATION CONTROL, QUARTER VEHICLE

1. Introduction

Traditionally vehicle vibrations are controlled by passive suspension systems. A passive suspension system is composed of spring and damper elements. The control objectives cannot be achieved in broadband frequencies with these systems. Therefore, there occurs tradeoffs between ride comfort and road holding in passive suspensions [1-2]. The desired suspension system has to suppress the vehicle body displacement and acceleration together while providing adequate suspension deflection to maintain road holding. Active suspension systems have great potential to achieve these achievement goals. [3-5].

In this study, a new fuzzy logic approach is proposed in order to provide the suppression of vehicle body bounce and acceleration using active suspension system. The controller is applied on a quarter vehicle model in order to indicate the performance of the proposed controller comparing with passive case.

2. Quarter Vehicle Model

Vertical dynamics of a vehicle can be analyzed by quarter vehicle model shown in Figure 1 [6-7]. The model has two degrees of freedom which are the wheel-axle and body bounces. m_1 and m_2 are the wheel-axle and body masses, respectively. Wheel and suspension spring stiffnesses are denoted as k_1 and k_2, respectively. b_2 is damping coefficient of viscous damper and u corresponds to the control force that is produced by the actuator. y_0 is the road profile changing by time which is to wheel. y_1 and y_2 are the absolute displacements of the unsprung and sprung masses respectively.

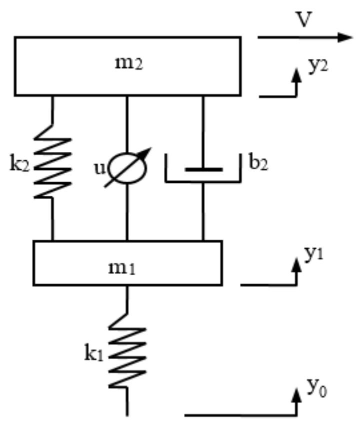

Fig. 1 *Quarter vehicle model.*

Equations of motion for the quarter car model are given below:

$$m_1\ddot{y}_1 + b_2(\dot{y}_1 - \dot{y}_2) + k_2(y_1 - y_2) + k_1(y_1 - y_0) = -u \tag{1}$$

$$m_2\ddot{y}_2 + b_2(\dot{y}_2 - \dot{y}_1) + k_2(y_2 - y_1) = u \tag{2}$$

In this study, the quarter car model is subjected to the road input as shown in Figure 2 and vehicle model vibrates as it passes over the road profile with the constant velocity V at first second of its travel. For the given numerical parameters in Table 1, both uncontrolled and controlled cases are computed.

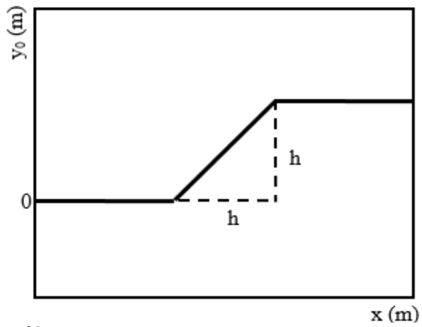

Fig. 2 *Road profile.*

Table 1: *Numerical parameters of the quarter vehicle model.*

Parameter	***Value***	***SI Unit***
m_1	36	kg
m_2	240	kg
b_2	980	Ns/m
k_1	160000	N/m
k_2	16000	N/m
V	72	Km/h
h	0.035	m

3. Fuzzy Proportional Derivative Controller

Fuzzy logic theory was first presented by Zadeh [8]. Fuzzy logic control provides ability to use the experience of vehicle suspension system experts. In proposed fuzzy proportional derivative controller, the gains are varied by time while classical proportional derivative controller includes constant gains. Each controller gain is calculated by a fuzzy logic unit. In figure 3 representative unit is shown with a single input - single output relation.

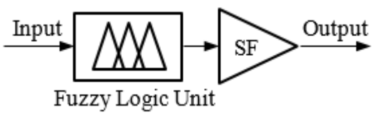

Fig. 3 *Fuzzy logic input-output representation.*

Time varied gains of fuzzy PD are obtained from two fuzzy logic units that are for proportional and derivative gains. The input is the related variable and the output is the related variable gain of the proposed controller. SF is the related scaling factor. In Table 2, the input-output relations are given for the related terms of proposed fuzzy PD controller. Actuator control force computed from the proposed fuzzy PD controller is the sum of these terms and is obtained by equation (3). Error is also defined in equation (4).

$$u = K_{FP} e + K_{FD} \frac{de}{dt} \tag{3}$$

$$e = y_0 - y_2 \tag{4}$$

Table 2: *Fuzzy logic input-output relation.*

Input	*Scaling Factor (SF)*	*Output*
e	PSF	K_{FP}
de/dt	DSF	K_{FD}

For each fuzzy logic unit of the proposed controller, Mandani type fuzzy inference with triangular membership functions is utilized and centroid method is used for defuzzification. Fuzzy rule base is very simple and given in Table 3. It involves the same rules for each fuzzy logic unit.

Table 3: *Fuzzy logic input-output relation.*

Input		*Output*	
e	de/dt	K_{FP}	K_{FD}
S		SG	
M		MG	
B		BG	

- If input is small (S) then output gain is small (SG)
- If input is medium (M) then output gain is medium (MG)
- If input is big (B) then output gain is big (BG)

4. Simulation Results

Passive and active suspension system comparisons are computed as it is mentioned in section 2. Both cases are evaluated by time responses of body bounce, acceleration, suspension deflection and control force.

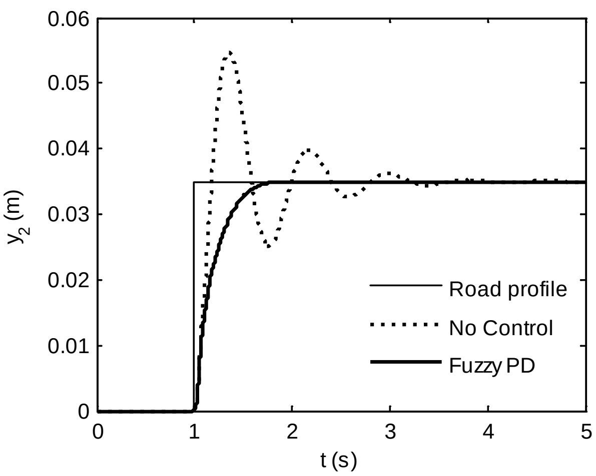

Fig. 4 *Comparison of body bounce responses.*

In Figure 4, the vehicle body overshoots the height of the road profile after it reaches over the obstacle in passive suspension case that is denoted as no control in the figure legend. If the active suspension case is considered for the proposed controller; Fuzzy PD, the vehicle body settles on its steady state value very smoothly as seen in the same figure.

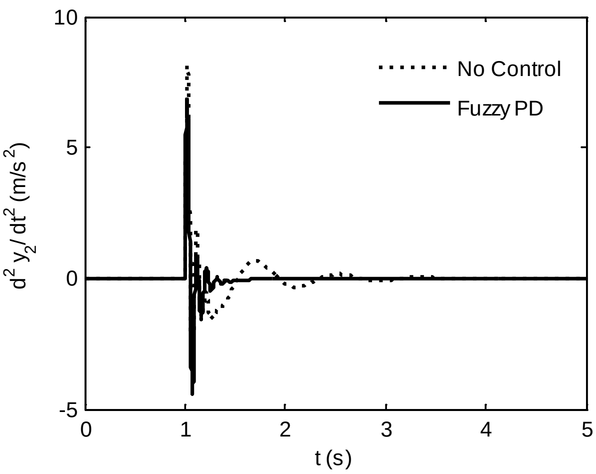

Fig. 5 *Comparison of body acceleration responses.*

The body acceleration is also decreased by the proposed control strategy and acceleration oscillations have declined rapidly as seen in Figure 5.

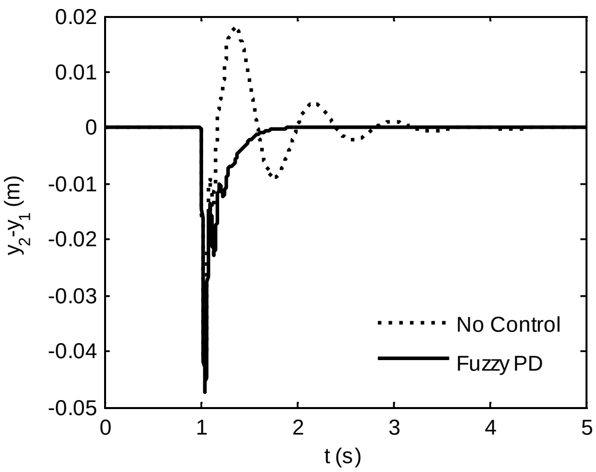

Fig. 6 *Comparison of suspension deflection responses.*

There isn't any permanent deflection in suspension for proposed controller case in figure 6. It is seen that the suspension system gets back to its original position after reaching to the top of the obstacle. Therefore, in both cases, the suspension deflection reaches to zero as the vehicle body settles seen in Figure 4.

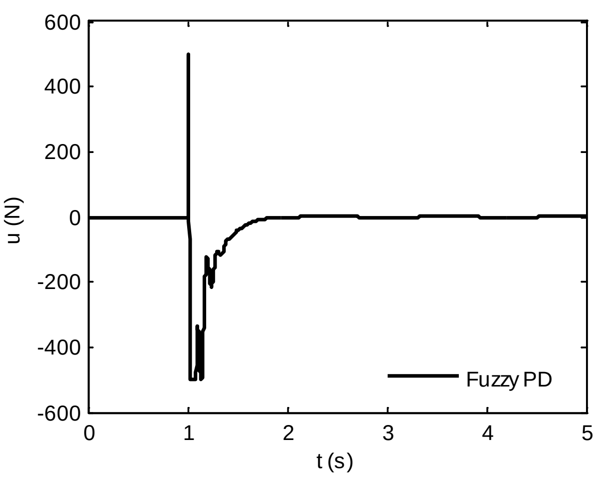

Fig. 7 *Time response of control force.*

Control force given in Figure 7 acts on both vehicle body and wheel-axle masses simultaneously. Actuator force is saturated at 500 N during computations. This situation is seen as the truncation of force value at ±500 N in control force diagram. Actuator force is also reaches to zero as the vehicle body settles seen in Figure 4.

5. Conclusion

Proportional and derivative gains varied by two single input-single output fuzzy logic controller is proposed in this study in order to reach to the suspension system objectives that aim providing ride comfort without any suspension working space degeneration. Time responses demonstrate that the vehicle body settles smoothly with decreasing body acceleration and preserving suspension working space. The results indicate that the proposed controller exhibits promising behavior.

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