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CONVENTIONAL AND INTELLIGENT CONTROLLER FOR QUARTER CAR SUSPENSION SYSTEM

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***Abstract*- Optimal vehicle handling, good driving pleasure, best comfort for passengers, effective and efficient isolation of road noise and vibration in suspension systems has been a key research area. In this paper two control techniques; a conventional Proportional Integral and Derivative (PID) and intelligent Fuzzy Logic Control (FLC) schemes are proposed and compared for the passive quarter car suspension system. MATLAB Simulink environment was used for both designs, investigation of the effects of the two control techniques, their comparison and verification of the results obtained and the results are shows the effectiveness of the controllers.**

***Index Terms*- Proportional Integral and Derivative (PID), Fuzzy Logic Control (FLC), Quarter car.**

I. INTRODUCTION

In the past years there has been widespread interest in using advanced control and automation techniques to optimize the performance of vehicle suspension system. The basic purpose of suspension system is to isolate a vehicle body from road irregularities in order to improve the driving comfort, safety in terms of wear and tear of the vehicle parts, and retain continuous road wheel contact in order to provide road holding [1]. Suspension system connects the wheel and the vehicle body by springs, dampers and some linkages. The spring carries the body mass by storing energy and helps to isolate the body from road disturbances, while damper dissipates this energy and helps to damp the oscillations. In general, during the vehicle project and design development phase, the vehicle industries exploits a combination of design tools such as vehicle modal response from numerical simulation, research laboratory tests with shaker rigs and the results of experimental field road tests, to fine tune the suspension [2]. Even with the efficiency of the numerical simulations, laboratory and experimental tests are still in use, although being time-consuming, costly and restricted to some specific road conditions of the test track. Single random input to a quarter car vehicle model is traditionally used for spectral studies [3].

II. PREVIOUS WORKS

From existing literature, several classical and modern control design approaches have been employed to yield optimal driving comfort, safety and driving stability. Most conspicuous approach includes the back stepping controller design described in [4] which improved the tradeoff between ride comfort and suspension travel, whilst [5] proposed an in depth insight to fuzzy logic control for the quarter car suspension. In [1] Proportional Integral and Derivative and Sliding mode control were developed to improve and track system response. [6] Conducted a comparative experimental verification performance of the rejection of road disturbance by H-∞ and optimized LQR controller for the quarter car suspension system. In [7] a robust pole location for an active suspension quarter-car model through parameter dependent control was proposed which assures to the uncertain loop system a pre specified pole location inside a circle on the left-hand half of the complex plane for system stability. Also [8] presented another control approach for the passive quarter car suspension system using neural networks and LQ adaptive control to mitigate vibrations and consequent adaptation to road disturbances. In [9] a static output feedback controller was developed for an integrated seat and suspension, which also showed a considerable improvement on system performance.

In this paper, comparison between PID and FLC control scheme is presented. The rest of the paper include; section 3 which explains the model description, section 4 gives an insight to the controllers design, while results comparison are presented in section 5. Finally the general conclusion is made in section 6.

III. MODEL DESCRIPTION

The quarter car model used for the design of the controllers is as described in [10]. The schematic representation of the quarter car model is as shown in Figure 1. The model parameters are as shown in Table 1.

Table 1. Parameters of the Quarter Car Suspension Model

Parameters	**Symbol**	**Value**
Mass of sprung	*m1*	466.5 kg
Un-sprung mass	*m2*	49.8 kg
Stiffness coefficient of the suspension	*k1*	5700 N/m
Vertical stiffness of the tire	*k2*	135000 N/m
Damping coefficient of the suspension	*b1*	290 Ns/m
Damping coefficient of the tire	*b2*	1400 Ns/m
Vertical displacement of the sprung mass	*x1*	
Vertical displacement of the un-sprung mass	*x2*	
Road excitation.	*w*	

The roll motion of the tire is ignored, only vertical mass movements are considered.

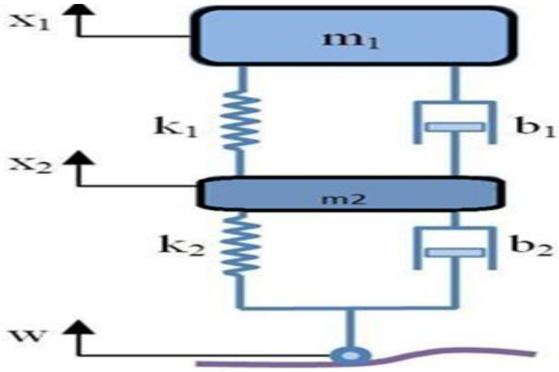

Figure 1: Passive Quarter Car suspension system [10]

The model of the system is obtained using Newton second and third laws of motion which yields the two second order differential equations representing the system. The transfer function was obtained by applying Laplace transform to the differential equations. The mathematical model of the system in transfer function form is represented in equation (1).

$$G(S) = \frac{(b_1 \times b_2)S^2 + (k_1 \times b_2 + k_2 \times b_1)S + k_1 k_2}{(m_1 \times m_2)S^4 + A_1 S^3 + A_2 S^2 + A_3 S + K_1 + K_2} \qquad (1)$$

$Q_1 = b_1 + m_1 \times b_2 + m_2 \times b_1$
$Q_2 = m_1 \times k_1 + m_1 \times k_2 + m_2 \times k_1 + b_1 \times b_2$
$Q_3 = b_1 \times k_2 + k_1 \times b_2$

And the state space representation obtained as in equation (2)

$\dot{X} = AX + BU$
$Y = CX + DU$

$$A = \begin{bmatrix} -\frac{b_1}{m_1} & \frac{b_1}{m_1} & -\frac{k_1}{m_1} & \frac{k_1}{m_1} \\ \frac{b_1}{m_2} & \frac{b_1+b_2}{m_2} & \frac{k_1}{m_2} & -\frac{k_1}{m_2} \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix}, \qquad B = \begin{bmatrix} 0 & 0 \\ \frac{b_2}{m_2} & \frac{k_2}{m_2} \\ 0 & 0 \\ 0 & 0 \end{bmatrix},$$

$$C = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & -1 \end{bmatrix} \qquad (2)$$

IV. CONTROLLER DESIGN

In this section the PID and FLC control scheme for the quarter car suspension system is explained.

a. *PID Controller Design*

The in depth controller design analysis and procedure is as described in [11]. The controller was interfaced with the suspension system obtained mathematical model (in transfer function form) which represents the plant. A feedback link is made from the output of the plant and sent back to the controller which measures the error and adjust it accordingly. These adjustments are made with respect to the K_P, K_I and K_D parameters, which were tuned in a way that the error is minimized to the extreme, hence a smooth response was thereby obtained at K_P=10 , K_I =5 and K_D =2. The block diagram of the controller is as shown in figure 2.

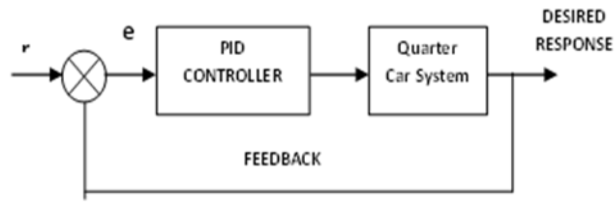

Figure 2. PID Controller Block Diagram

b. *Fuzzy Logic Controller Design*

The fuzzy logic controller transforms a linguistic control strategy into a controller capable of handling the nonlinearities and uncertainties of the suspension system with the aim of maintaining sprung mass acceleration as close to zero as possible in spite of road disturbances. The two inputs of the fuzzy controller are the road disturbance (displacement) error (y) and its derivatives ($\dot{y}$) and a single output obtained based on the impact of road disturbance error and its derivative as shown in figure 3. In this work, Mamdani inference and the centroid de-fuzzification methods are considered with 35 rules fired to the inference engine. The objectives of the fuzzy logic controller for this system are slotted into the fuzzy rule base system which is in the form of linguistic variables using fuzzy conditional statements (i.e. antecedent if clause and the consequent then-clause). Table 2 below shows the rule base of the system, and seven the membership functions that yields an efficient response; negative big (NB), negative medium (NM), negative small (NS), zero (ZE), positive small (PS), positive medium (PM), and positive big (PB) respectively. The first input (error y) ranges from -10 to 10 while the second input that is the error rate ranges from -100 to 100 and finally the output range set at -10 to 10.

Table 2. FLC Rule Base

Y/$\dot{Y}$								
		NB	NM	NS	ZE	PS	PM	PB
ERROR	NM	NB	NB	NB	NM	NS	ZE	PS
	NS	NB	NB	NM	NS	ZE	PS	PM
	ZE	NB	NM	NS	ZE	PS	PM	PB
	PS	NM	NS	ZE	PS	PM	PB	PB
	PM	NS	ZE	PS	PM	PB	PB	PB

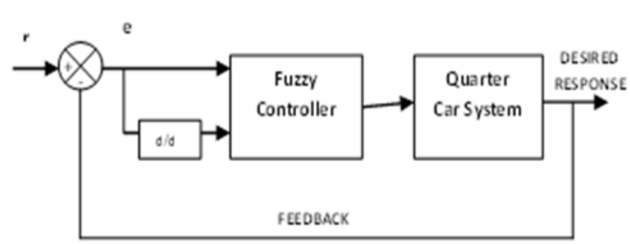

Figure 3: Fuzzy Logic Controller Block Diagram

V. RESULT AND DISCUSSION

The control techniques proposed were designed and implemented using the block diagram environment for multi domain simulation and model based design (SIMULINK). The quarter car suspension Simulink represented systems were later tested using a couple of inputs which represents the different road profile input. Figure 4 below represents the quarter car suspension system with no control.

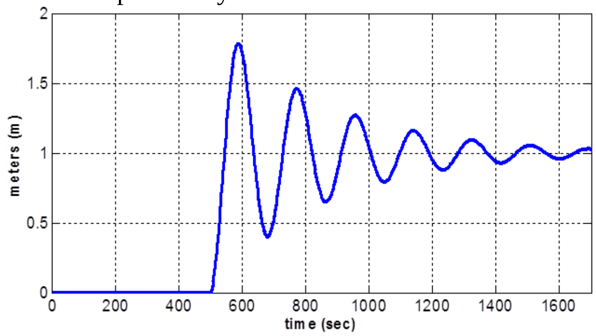

Figure 4: Quarter Car Step Input Response (No Control)

The results obtained from the two control techniques using different input signal types is compared in this section. The FLC and PID control for the suspension displacement with respect to step, ramp, pulse and sinusoidal inputs are displayed in figures 5, 6, 7 and 8 respectively.

From figure 4, that is system with no control it can be observed that the system oscillates hysterically with large overshoot, lots of oscillations and high settling time. Therefore with the implementation of the PID and FLC as in figure 5 with a step input it can be noticed that the FLC has a lower rise time than the PID controller while the later have a smaller steady state error, both having no overshoot and almost the same settling time. It can also be observed from figure 6 below using a ramp input signal both PID and FLC are tracking the reference signal with a negligible steady state error, therefore with ramp input the behavior of the suspension system with respect to the two controller designs can said to be same. In the case of pulse input signal, it was observed that the PID controller makes the system effectively track the input eliminating all possible vibrations for the entire time period while the FLC only tracks the input at the first half cycle and out controlled by series of oscillations for the rest of the time period. Finally, for the sinusoidal inputs signal it was observed that the PID controller has a little setback in terms of tracking the input. The FLC tracks and balance the suspension system with respect to this kind of input with a higher rate of efficiency than the PID controller.

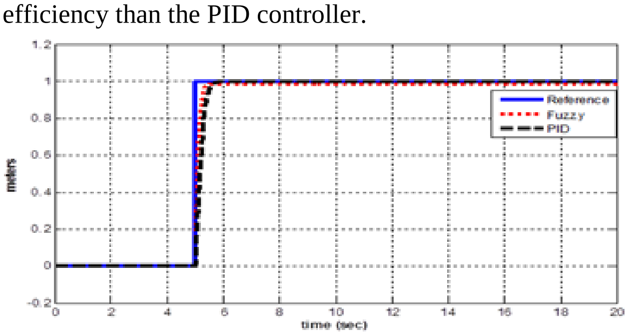

Figure 5: Step Input Response

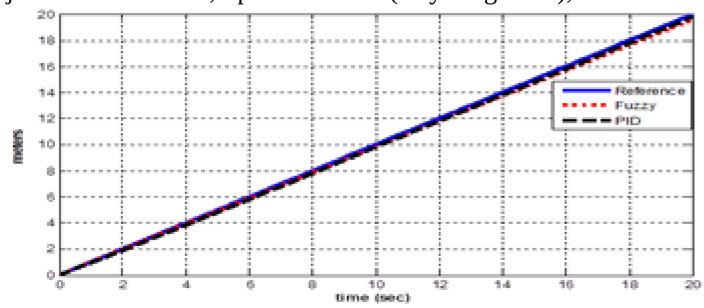

Figure 6: Ramp Input Response

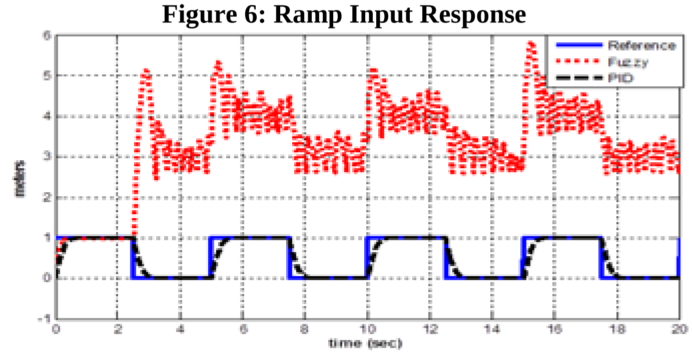

Figure 7: Pulse Input Response

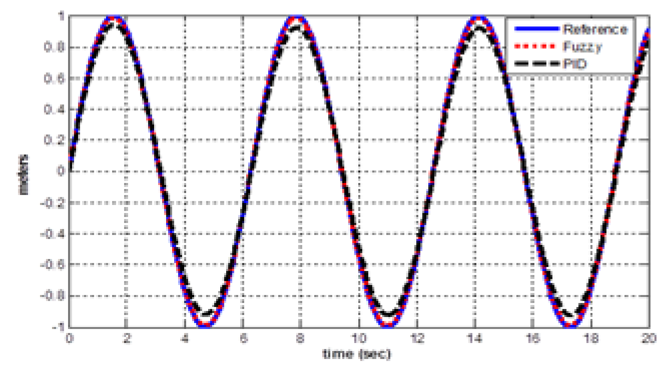

Figure 8: Sinusoidal Input Response

VI. CONCLUSIONS

A performance comparison of an intelligent controller FLC and conventional PID controller in controlling the suspension system of a quarter car was presented. From the results and observations, it can be clearly comprehended that both control logics implemented performed very well to some extent. A future work is to apply the control scheme to half and full model car system, and also test the performance using real practical system.

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