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Active Force Control for Semi-Active Suspension with Magnetorheological Damper

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ABSTRACT

The suspension system of an automobile is responsible for smoothing out the ride and maintaining control of the vehicle. However, traditional passive suspension system does not achieve satisfactory performance due to a lack of control over the damping force. Semi-active suspension (SAS) systems are now even more feasible because to their reduced power consumption, which is a result of the quick advancement of electronic sensors and actuator technologyOne of the greatest and most dependable semi-active control components available for suspension systems that can further enhance ride comfort is the magnetorheological (MR) damper, which produces a regulated damping force.This study focuses on developing a controller scheme named Fuzzy logic with Proportional-Integral-Derivative (Fuzzy-PID) and Fuzzy logic with Propor-tional-Integral-Derivative and Active Force Control (Fuzzy-PID-AFC) controllers to control the damping force of the MR damper to achieve better ride comfort by reducing vibration from the simulated road bump. A sinusoidal vibration source is applied to the quarter car test rig to investigate the improvement of ride comfort as well as to ascertain the new hybrid Fuzzy-PID-AFC controller robustness. The study found that a comparison of sprung mass acceleration signals from the passive suspension with Fuzzy-PID and Fuzzy-PID-AFC shows improvement to the sprung mass acceleration by 17.7 % and 32 %, respectively. As a result, the hybrid Fuzzy-PID-AFC controller outperforms the conventional Fuzzy-PID controller in the vehicle vibration control of the SAS system with MR damper. The control system may be further improved by implementing a hybridized iterative learning method to get a more accurate and dynamic estimation of mass for the Active Force Control controller.

1. Introduction

The advancement of the electronic control system has catapulted the automotive industry to the next level. Nowadays, most modern vehicles on the market are equipped with a variety of control

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system technologies, most notably in the area of suspension control. Generally, the suspension system of an automobile is responsible for smoothing out the ride and maintaining control of the vehicle [1,2].

It is common to use passive suspensions with an oil damper because of their simplicity and cost-effectiveness, but their performance is restricted by a lack of control over damping force [3,4]. Therefore, semi-active suspensions (SAS) are being researched to overcome these difficulties, as they offer performance advantages over passive suspensions without the need for significant power sources or expensive technologies [5,6].

Dampers enable the advantages of Magnetorheological Fluid (MRF) to be employed in semi-active control mechanisms that generate massive amounts of pressure by only using powered batteries [7,8]. Controllable damping force can be achieved by a magnetic field generated via direct current to the coil in the MR damper, which causes the MRF to transform from viscous to the semisolid state inside the resistance gap.

Proportional-Integral-Derivative (PID) controllers are well suited to deal with low-frequency disturbances, while AFC can be used when high-frequency disturbances occur in the system [9,10].

In order to enhance the vibration controllability of the vehicle’s suspension system, a new combination of intelligent controllers is introduced in this research. The study's primary contribution is the implementation of a novel hybrid control approach that combines a Fuzzy-PID controller with AFC (Fuzzy-PID-AFC) for the SAS system configuration using an MR damper of a quarter car suspension model. Therefore, experimental works are carried out to evaluate the controller's performance and determine the most effective control parameters through tweaking and testing.

2. Methodology

2.1 Proposed Fuzzy-PID-AFC Controller System

The Fuzzy-PID-AFC controller was designed in this research in Lab-VIEW software to examine its effectiveness in controlling the MR damper to minimize vehicle vibration. Figure 1 illustrates the block diagram schematic of Fuzzy-PID-AFC methods applied to the MR damper. AFC can efficiently accommodate the disturbances by acquiring the acceleration and force measurements using a physical accelerometer and force sensor, respectively. The fuzzy logic component’s input is the acceleration of the sprung body, and the output is the needed, estimated inertia mass (EM) of the system, which is used to feed into the AFC loop [11].

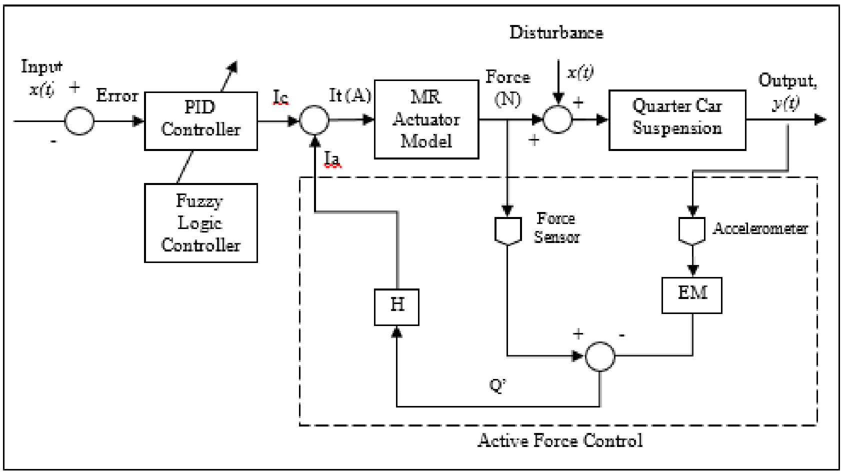

Fig. 1. Schematic block diagram of Fuzzy-PID-AFC controller

2.2 Experimental Setup

When the SAS control system with MR damper had been successfully developed, the system was ready to be tested to evaluate its performance in suppressing vibration. The experiments were conducted on a quarter-car suspension test rig fitted with a SAS system equipped with an MR damper as shown in Figure 2. This research test rig enables laboratory testing since it represents the actual concept of a SAS system [12].

Using LabVIEW software, all of the experimental data was captured, gathered, and prepared for analysis and discussion [13]. Table 1 summarized the experiment's independent, dependent, and controlled variables. The testing in this study was separated into two parts: determining the most appropriate membership functions of the fuzzy logic algorithm and determining the optimal estimated mass of AFC for this SAS application [14].

For the first part, the optimized fuzzy logic algorithms were determined using trial and error method by observing the effect of varying proportional gain Kp, while keeping the Ki, and Kd constant, and vice versa. Table 2 represents the tested sets of membership functions for output (Kp, Ki, and Kd) to determine the optimized fuzzy logic algorithms. The goal is to create a fuzzy-PID controller system that can regulate the damping force of the MR damper and determine the ideal range of parameters for the membership functions of the Kp, Ki, and Kd gains in order to get the greatest performance outcomes [15].

In the second part, the optimized estimation mass (EM) was determined using trial and error method. Table 3 provides information on the experiment parameters for determining the estimation mass (EM) of the Fuzzy-PID-AFC controller [16]. Finally, the best-optimized fuzzy logic algorithm and estimated mass were incorporated into two controllers (Fuzzy-PID and Fuzzy-PID with AFC), and their vibration controllability performance was evaluated in the next section [17].

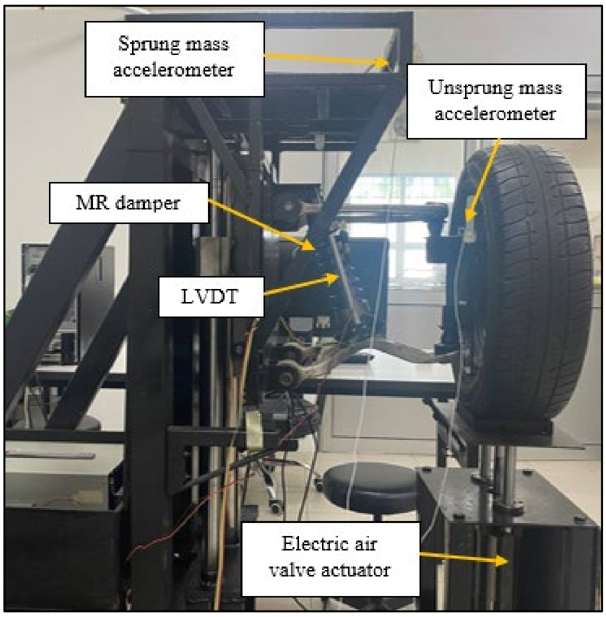

Fig. 2. Position of MR damper, LVDT, accelerometers, and air valve on the quarter car test rig

Table 1
Experimental independent, dependent and controlled variables

Category	Variables	Description
Independent	MR damper controller	Fuzzy-PID or Fuzzy-PID-AFC
Dependent	Sprung mass vertical acceleration	Observing sprung mass vertical acceleration to evaluate vibration control performance
Controlled	Sample rate	1000
	Time taken	10 s

Table 2
Tested sets of output membership functions (Kp, Ki, and Kd)

Part A: Varying K_p				
Parameter		Small	Middle	Big
	Set 1	0 - 0.5	0.25 -1.75	1.5 - 2.0
K_p	Set 2	0 - 0.3	0.15 - 1.2	0.9 - 1.5
	Set 3	0 - 0.8	0.9 - 1.4	1.5 - 2.0
K_i		0 - 0.3	0.15 -0.85	0.7 - 1.0
K_d		0 - 0.4	0.2 - 0.8	0.6 - 1.0
Part B: Varying K_i				
Parameter		Small	Middle	Big
K_p		0 - 0.3	0.15 - 1.2	0.9 - 1.5
	Set 4	0 - 0.3	0.4 - 0.7	0.8 - 1.0
K_i	Set 5	0 - 0.5	0.6 - 0.8	0.9 - 1.0
	Set 6	0 - 0.2	0.3 - 0.6	0.7 - 1.0
K_d		0 - 0.4	0.2 - 0.8	0.6 - 1.0
Part C: Varying K_d				
Parameter		Small	Middle	Big
K_p		0 - 0.3	0.15 - 1.2	0.9 - 1.5
K_i		0 - 0.5	0.6 - 0.8	0.9 - 1.0
K_d	Set 7	0 - 0.6	0.7 - 1.3	1.4 - 2.0
	Set 8	0.5 - 0.8	0.9 - 1.3	1.4 - 1.8
	Set 9	0.3 - 0.7	0.8 - 1.5	1.6 - 2.0

Table 3
Tested range for estimated mass, EM

Kp	Ki	Kd	EM
Small: 0 - 0.3	Small: 0 - 0.5	Small: 0 - 0.6	2
Middle: 0.15 - 1.2	Middle: 0.6 - 0.8	Middle: 0.7 - 1.3	4
Large: 0.9 - 1.5	Large: 0.9 - 1.0	Large: 1.4 - 2.0	6

3. Results

MATLAB software was used to generate the graph based on thousands of data collected from the LabVIEW software. The MATLAB software was used as a coding platform to generate a graph of acceleration (ms-2) against time (s) and power (ms-2)2/Hz) against frequency (Hz). The graph generated from the coding based on Fast Fourier Transform (FFT) method which were commonly used to analyze vibration.

Table 4 summarized the optimized setting for Kp, Ki and Kd parameters range for the self-tuning Fuzzy-PID controller and the best estimated mass gain for the Fuzzy-PID-AFC controller. The overall performance of the Passive, Fuzzy-PID and Fuzzy-PID-AFC controllers is compared by considering the amplitude of sprung mass acceleration during the experimental period. The results are presented in both time and frequency domains as illustrated in Figures 3 and 4. Based on the graph in Figure 3, the performance of the Fuzzy-PID-AFC controller (black) outperforms the other controllers noting that it minimizes the amplitude of sprung mass acceleration peaks with great system stability.

Table 4
The optimized setting for Kp, Ki, and Kd range for the Fuzzy-PID controller and the best estimated mass gain for the Fuzzy- PID-AFC controller

Parameters	Fuzzy-PID	Fuzzy-PID-AFC
Kp	Small	0 - 0.3
	Middle	0.15 - 1.2
	Large	0.9 - 1.5
Ki	Small	0 - 0.5
	Middle	0.6 - 0.8
	Large	0.9 - 1.0
Kd	Small	0 - 0.6
	Middle	0.7 - 1.3
	Large	1.4 - 2.0
EM	6	

Under pure passive control without any controller, the amplitude of the peak recorded was at 0.2396 ms-2 under road disturbances. For Fuzzy-PID and Fuzzy-PID-AFC controllers, the highest peak amplitude was recorded to be 0.1972 ms-2 and 0.1623 ms-2, respectively. Implementing the Fuzzy-PID controller to MR damper has improved the system peak from that passive control system by 17.7%. Furthermore, 32% of peak improvement is recorded by integrating the Fuzzy-PID-AFC controller into the suspension system. As a result, the suggested hybrid Fuzzy-PID-AFC controller exhibits excellent efficiency and robustness even when subjected to various disturbances.

From Figure 4, the natural frequency occurs at 0.9765 Hz, where the highest amplitude peak is observed, and the graphs for all controllers are stacked within the same frequency range. According to [18], a natural frequency ranging from 0 Hz to 2 Hz is typical for commercial passenger car suspension systems. Therefore, the experiment is verified to resemble the actual operation of a conventional car suspension system.

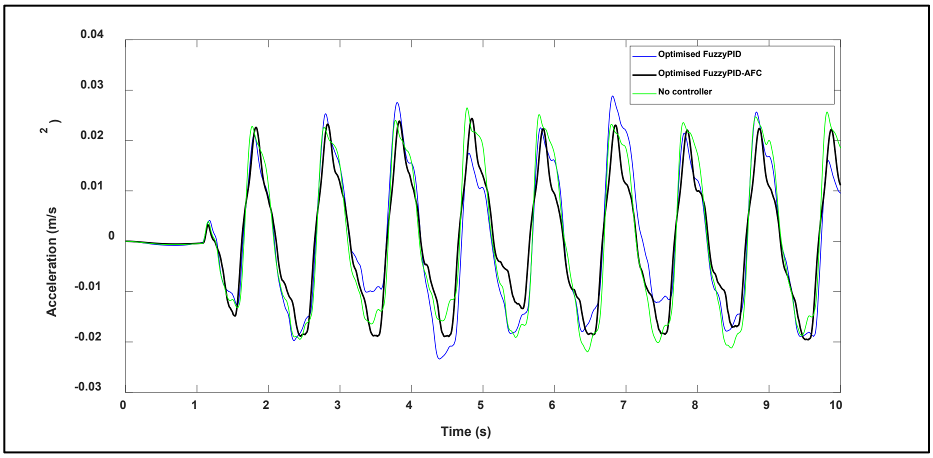

Fig. 3. The sprung mass acceleration response in time domain for Passive, Fuzzy-PID and Fuzzy-PID-AFC controllers

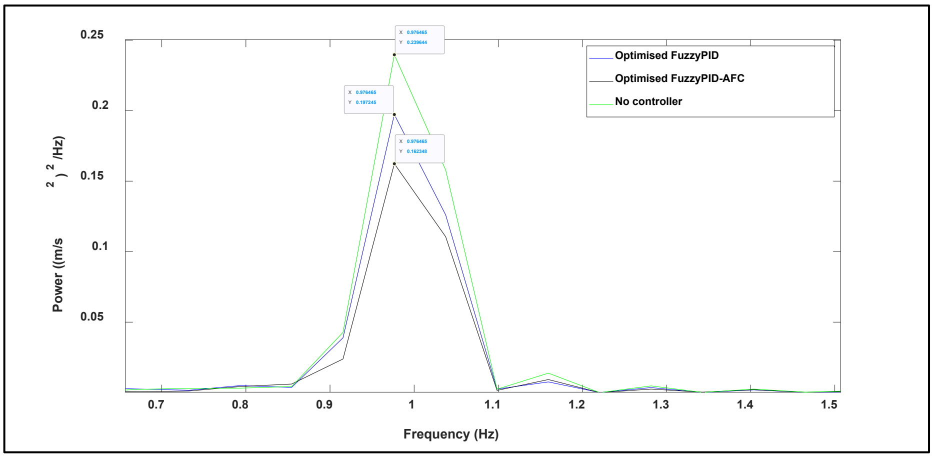

Fig. 4. The sprung mass acceleration response in the frequency domain for Passive, Fuzzy-PID, and Fuzzy-PID-AFC controllers

The comparison of sprung mass acceleration amplitudes for the three controllers is listed in Table 5. From the comparison, the sprung mass acceleration is further reduced with the implementation of Fuzzy-PID-AFC controller to the MR damper and it recorded a total reduction of 32%, which is better than the counterpart Fuzzy-PID controller. Therefore, this proves that the Fuzzy-PID-AFC controller developed in this study has better performance and exhibits significant improvement in controlling vehicle sprung mass acceleration (SMA). The hybrid Fuzzy-PID-AFC controller is more robust and rapid in minimizing sprung mass acceleration (32% reduction). As a result, the Fuzzy-PID-AFC controller designed in this work has superior performance and a considerable improvement in managing vehicle sprung mass acceleration.

Table 5
The comparison of the controllers

	Type of Controller			%Reduction	
	Passive	Fuzzy-PID	Fuzzy-PID-AFC	Fuzzy-PID	Fuzzy-PID-AFC
SMA (ms^{-2}) from experiment	0.2396	0.1972	0.1623	17.7%	32%

4. Conclusions

In summary, the Fuzzy-PID controller integrated into the MR damper managed to suppress vehicle vibration by 17.7% compared to passive suspension. Furthermore, the integration of AFC with the Fuzzy-PID con-troller further enhanced the MR damper vibration suppression ability and it reduced sprung mass acceleration by 32% compared to passive suspension. Therefore, the hybrid Fuzzy-PID-AFC controller outperforms the conventional Fuzzy-PID controller in the vehicle vibration control of the SAS system with MR damper.

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