Fuzzy control of a quarter-car suspension system

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Fuzzy Control of a Quarter-Car Suspension System

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Abstract

This paper describes the design of a fuzzy logic controller for a quarter-car model. The car suspension system with designed fuzzy logic controller is simulated to obtain the ride performance under various road conditions. Simulation results indicate the feasibility of the designed controller. The designed fuzzy logic controller is simple and suitable for real time implementation.

1. Introduction

The suspension, as a common property to all automobiles, isolates the car body from road disturbances for comfortable ride and controls vehicle body attitude. It also reacts to control forces produced by the tires–longitudinal (acceleration and breaking) forces, lateral (cornering) forces, and breaking and driving torques [1].

In resent years, there has been a great interest in the design and development of suspension systems incorporating semi-active and active components [2] to improve the overall vehicle performance.

Various techniques and design methodologies have been proposed [3]. Velocity feedback control [4], linear quadratic control [5], and adaptive control [6], among other techniques, have been used to reduce the parameter and environmental sensitivity of closed-loop suspension systems.

The adaptive control scheme proposed in [6] is composed of an indirect pole assignment algorithm and a simple fuzzy logic gain scheduler that enabled adaptation for different road conditions.

Fuzzy logic controllers have been successfully implimented in the control of linear and nonlinear systems [7]. Unlike conventional controllers, fuzzy logic controllers do not require mathematical modelling and they can easily deal with the nonlinearities and uncertainties of the controlled systems [8].

This paper describes the design of a simple fuzzy logic controller that is applied to an active suspension system of a small car. Simulations of a quarter-car model with the designed fuzzy controller under various road conditions are used to confirm the validity of the proposed controller.

2. Quarter-Car Model

The quarter-car model shown in Figure 1 below is often used to model the dynamics of the suspension system of an automobile.

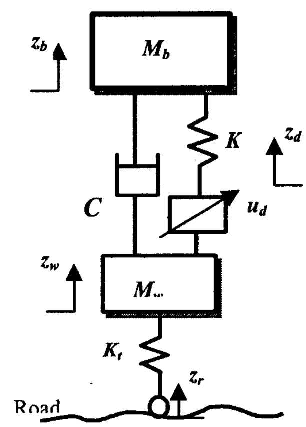

Figure 1: The quarter-car suspension model.

In this model, M_b and M_w denote the body or sprung mass and the wheel or unsprung mass, respectively. The tire is modeled by a simple spring with stiffness K_t. The sprung mass is resting on the suspension that has stiffness K and damping C. This model is limited to the study of vehicle dynamic behavior in the vertical direction only.

A first order displacement actuator is used for active control to improve the quality of ride performance. The response of this actuator can be taken as:

$$T\dot{u}_d + u_d = u_c, \quad u_d = z_d - z_w$$

where u_c and T denote the actuator controlled input and actuator time constant, respectively. It may be noted that this arrangement (a series connection of a spring with a displacement actuator in parallel with a damper) constitutes a band-limited suspension system [2].

The equations of motion for the above quarter-car model can be written as:

$$M_b \ddot{z}_b + C(\dot{z}_b - \dot{z}_w) + K(z_b - z_d) = 0 \qquad (1)$$

$$M_w \ddot{z}_w - C(\dot{z}_b - \dot{z}_w) - K(z_b - z_d) + K_t z_w = K_t z_r$$
(2)

$$T(\dot{z}_b - \dot{z}_w) + (z_d - z_w) = u_c \quad (3)$$

where z_r is road displacement input and u_c is actuator independent control input. The outputs of the above model are defined as follows:

- $y_1 = z_b - z_w$ denotes suspension working space (SWS). Small cars are usually designed to have a usable suspension space of 10–15cm.
- $y_2 = \ddot{z}_b$ is the vehicle body acceleration and it is a measure of vibration isolation.
- $y_3 = z_w - z_r$ represents dynamic tire load.

In this work, only the SWS signal is used for feedback in the fuzzy feedback controller. However, y_2 and y_3 are used in simulations to evaluate the performance of the designed controller.

3. Fuzzy Logic Controller

The structure of the proposed fuzzy logic controller is shown in Figure 2.

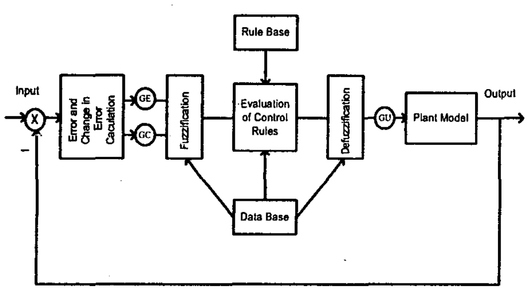

Figure 2: Fuzzy logic controller structure.

The design steps are summarized as follows:

1. The membership functions (MFs) used to fuzzify inputs and output of suspension system are chosen.
2. The heart of the fuzzy system, the fuzzy inference system (FIS) is implemented by a series of IF-THEN rules.
3. The implication of the MFs using an appropriate fuzzy logical operator and rule's weight is determined.
4. The aggregation and defuzzification process of the FIS output produces the controller output. The centroid defuzzifi-cation method is used here.

The Fuzzy Logic Toolbox is used to design the proposed FLC. The fuzzy inference system (FIS) is used to edit and visualize used rules and membership functions. The resulting FIS model is then tested using the Simulink Toolbox, which also gives the convenience of building and analyzing dynamical systems graphically.

The following IF-THEN rules are used:

1. **IF** (SWS is OK) **THEN** (output is Z)
2. **IF** (SWS is N) **THEN** (output is LP)
3. **IF** (SWS is P) **THEN** (output is LN)

It is clear that the rules for this FLC are simple and limited in number.
The Mamdani inference mechanism is chosen for the designed FLC. Figure 3 shows the graph of input and output membership functions (MFs) of the FLC.

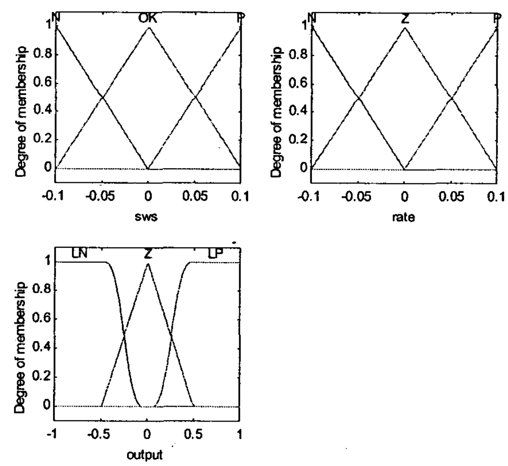

Figure 3: Membership functions for the FLC

Figure 4 below is a 3-D plot that relates the two inputs to the output of the FLC.

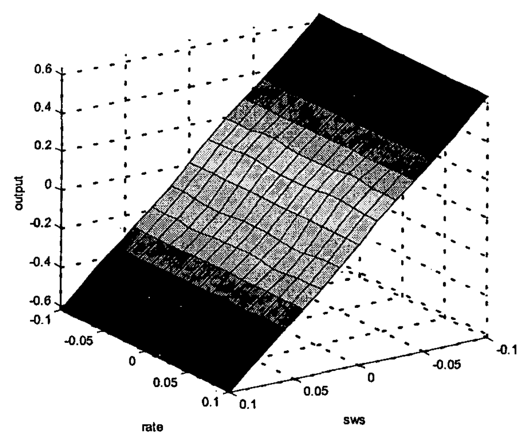

Figure 4: Inputs and output of the FLC in 3-D

4. Simulation Results

The Simulink Toolbox is used to build and test the complete suspension system. Figure 8 shows the complete quarter-car suspension system with all components needed for simulation including the designed FLC.

The controller gains used to obtain simulations are GE = 1, CE = 0.625, and GU = 0.095. The model constructed is tested under the following road conditions:

a) Step input

The first input chosen to test the closed loop suspension system performance is a step input signal of 0.1m. This signal represents an abrupt change of road height of 10cm, e.g. pavement. Figure 5 shows the input signal (road profile), the suspension working space, and the car body response. From this figure, it clear that the system response is more than satisfactory. Oscillations in the body ride and the SWS are well damped.

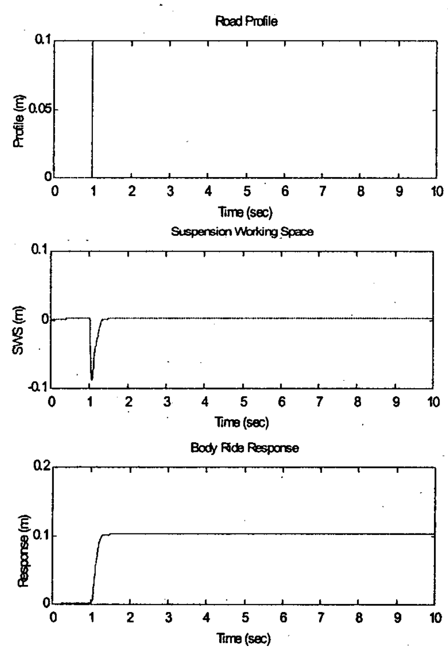

Figure 5: Step response under FLC feedback.

b) Pulse input

The second input signal used is a pulse that represents an abrupt change of road height of 10cm lasting for 1 sec as shown in Figure 6. Again, the FLC produces a well damped response.

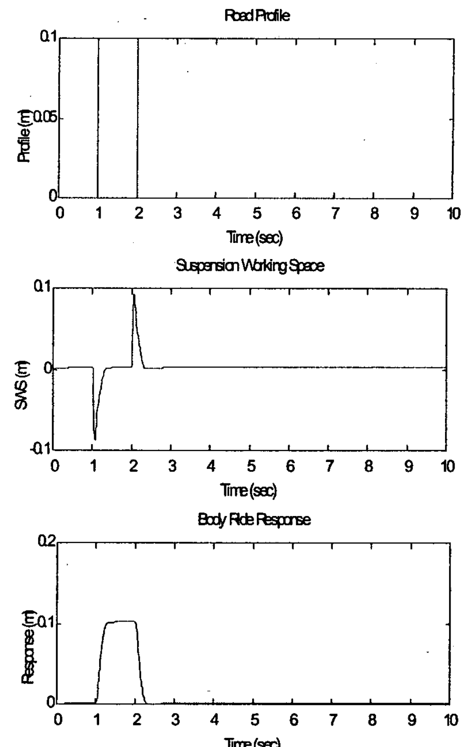

Figure 6: Response to a pulse input under FLC feedback.

c) Humps

To simulate a more realistic road driving conditions, the following signal is used [5]:

$$\dot{z}_o = \begin{cases} a\pi \sin 20\pi(t), & t\in [0.3,0.4] \\ 0 & \text{otherwise} \end{cases}$$

where *a*, as an input signal parameter, controls the road pump height. A small value of *a* means nominal size of road pavement gravel, where medium or large *a* represents normal to large road man-made humps. Figure 7 illustrates the response of the vehicle body and suspension system under the influence of the applied signal with *a* = 0.2m. The resulting response clearly indicates that the control is functioning well especially for large values of *a*.

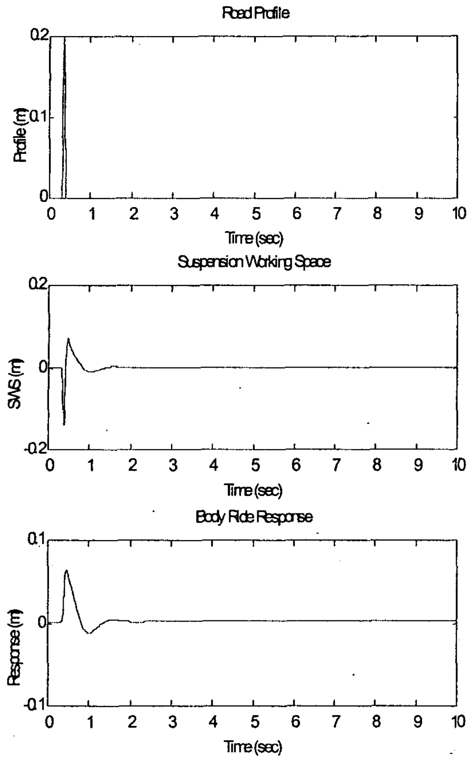

Figure 7: Response to a large hump under FLC feedback.

5. Conlusions

A fuzzy logic controller for a quarter-car active suspension system is designed. The designed FLC greatly enhanced the ride performance. Both the body ride and suspension work space responses exhibited good damping capabilities for different road inputs. The designed controller structure is simple which makes it suitable for real time implementation using, for example, micro-controllers or DSPs.

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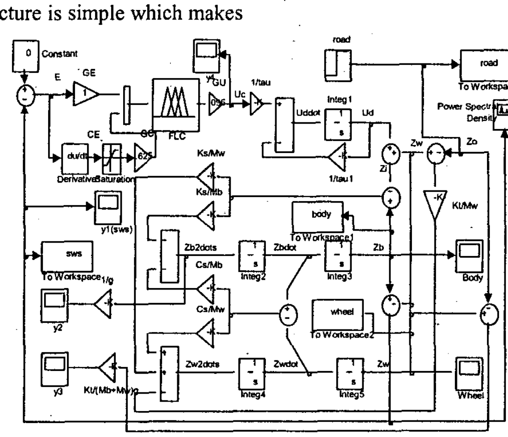

Figure 8: Simulink model of the quarter-car model with proposed FLC.