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Suspension System Control with Fuzzy Logic

Alireza Rezaee[1], Mazyar Pajohesh[2]
[1]Assistant Professor at Department of Mechatronics and Systems Engineering, Faculty of New Sciences and Technologies
University of Tehran
Tehran, IRAN
[2]Adiban university, Garmsar, Semnan, Iran
arrezaee@ut.ac.ir, mazyarpaj@gmail.com

***Abstract*—In this paper, fuzzy logic is used to control active suspension of one-quarter car model. The main role of a car suspension system is to improve the ride comfort and to better the handling property. It usually consists of a spring and a damper to improve the properties of a suspension system. The fuzzy logic method is one of the most active research and development area on artificial and intelligence at the present time, particularly in the automobile industry. One quarter of the car is modeled by springs, masses, dampers and force actuator and the state space equations are derived by lagrangian method. The ride comfort is improved by means of the reduction of the body acceleration caused by the car body when road disturbance from uneven road surfaces, pavement point etc. act on the tires of a running car. Here, a logic fuzzy controller is designed in which, the number of rule bases are reduced in comparison with some traditional one which have been introduced in other papers. At the end, a comparison of active suspension fuzzy control and traditional passive suspension is shown using MATLAB simulations. Results show that, active suspension improves the ride comfort by reducing acceleration, compared with the performance of passive suspension.**

Keywords—Active suspension; Fuzzy logic controller; One-quarter-car model; Vehicle.

I. INTRODUCTION

Replacement of the spring-damper suspension of automobiles by active systems has been the potential of improving safety and comfort under nominal conditions. Research and development of active suspension systems for car models are increasing much in recent years, because the active suspension systems offer good riding comfort to passengers [1]. For the design of the active suspension, we know how to build a model and how to define the objective of the control in order to reach a compromise between contradictory requirements like ride comfort and road holding by changing the force between the wheel and body [2]. Body acceleration is the most important element in the ride comfort. By reducing the acceleration of the car body, we can get more comfort in riding. The core of this work is to evaluate the benefits of fuzzy controller under impulse input for road velocity. There are taken the velocity of the body and deflection velocity between body and wheel, as input data for fuzzy controller and active force as its output data. The objective of the control is to minimize the body acceleration and displacement when road disturbances are acting on the tires of running cars.

II. ONE-QUARTER-CAR MODEL

In this paper, we are considering a one-quarter-car model that includes body mass, wheel mass, two springs, one damper and one force actuator (HYNIOVÁ, STŘÍBRSKÝ and HONCŮ, 2001, [3]) as presented in Fig. 1.

This model is used to create control force between body and wheel. The model has two degree of freedom: X_b and X_w. We can use the Lagrangian method presented below.

$$\frac{d}{dt}\frac{\partial(K.E.)}{\partial \dot{q}_i} - \frac{\partial(K.E.)}{\partial q_i} + \frac{\partial(P.E.)}{\partial q_i} + \frac{\partial(D.E.)}{\partial \dot{q}_i} = 0 \qquad (1)$$

Where:

$$K.E. = \tfrac{1}{2} m_b (\dot{x}_b)^2 + \tfrac{1}{2} m_w (\dot{x}_w)^2$$

$$P.E. = \tfrac{1}{2} K_1 (x_b - x_w)^2 + \tfrac{1}{2} K_2 (x_w - x_r)^2 \qquad (2)$$

$$D.E. = \tfrac{1}{2} C_s (\dot{x}_b - \dot{x}_w)^2 - f_a (\dot{x}_b - \dot{x}_w)$$

If $i=1$, for $q_1=x_b$

$$m_b \ddot{x}_b + K_1 (x_b - x_w) + C_s (\dot{x}_b - \dot{x}_w) - f_a = 0 \qquad (3)$$

and if $i=2$, for $q_2=x_w$

$$m_w \ddot{x}_w - K_1 (x_b - x_w) + K_2 (x_w - x_r) - C_s (\dot{x}_b - \dot{x}_w) + f_a = 0 \qquad (4)$$

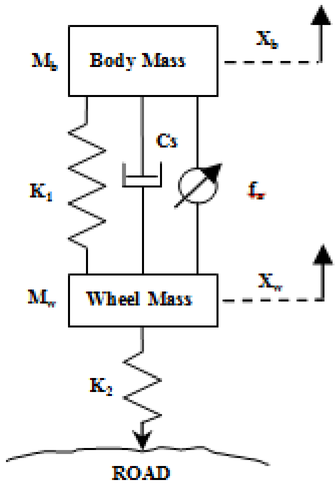


Fig. 1. One-quarter-car model (2 degree of freedom).

The model has the constants and variables which respect to the static equilibrium position presented in Tab. I.

Table I. MODEL PARAMETERS

x_b	Body displacement
x_w	Wheel displacement
x_r	Road displacement
f_a	Desired force
C_s	damping ration of the damper = 980 Ns/m
m_b	body mass (one-quarter of the total body mass of the car)= 250 Kg
m_w	Wheel mass= 35 Kg
K_1	Stiffness of the body= 16000 N/m
K_1	Stiffness of the body= 16000 N/m

III. STATE-SPACE MODEL

To model the road input, let us assume that the vehicle is moving with a constant forward speed. Then the vertical velocity can be taken as a white noise process which is approximately true for most of real roadways [1].

To transform the motion equations of one-quarter-car model into a state space model, the following state variables are considered:

$x_1 = x_b - x_w$ … Body displacement

$x_2 = x_w - x_r$ … Wheel displacement

$x_3 = \dot{x}_b$ … Absolute velocity of the body

$x_4 = \dot{x}_w$ … Absolute velocity of the wheel

Using Eq.3 and Eq.4 we can compute:

$$\dot{x}_3 = \frac{1}{m_b}\left(-K_1(x_b - x_w) - C_s(\dot{x}_b - \dot{x}_w) + f_a\right) \qquad (5)$$

$$\dot{x}_4 = \frac{1}{m_w}\left(K_1(x_b - x_w) - K_2(x_w - x_r) + C_s(\dot{x}_b - \dot{x}_w) - f_a\right) \qquad (6)$$

These equations can be written in state space form as follows:

$$\dot{x} = A.x + B.f_a + L.v_1$$

where:

$$A = \begin{bmatrix} 0 & 0 & 1 & -1 \\ 0 & 0 & 0 & 1 \\ \frac{-K_1}{m_b} & 0 & \frac{-C_s}{m_b} & \frac{C_s}{m_b} \\ \frac{K_1}{m_w} & \frac{-K_2}{m_w} & \frac{C_s}{m_w} & \frac{-C_s}{m_w} \end{bmatrix}$$

$$B = \begin{bmatrix} 0 \\ 0 \\ 1/m_b \\ -1/m_w \end{bmatrix} \qquad L = \begin{bmatrix} 0 \\ -1 \\ 0 \\ 0 \end{bmatrix}$$

by considering the state space as:

$$\begin{cases} \dot{x} = Ax + Bu \\ y = Cx + Du \end{cases}$$

we have:

$$B = \begin{bmatrix} 0 & 0 \\ 0 & -1 \\ 1/m_b & 0 \\ -1/m_w & 0 \end{bmatrix} \qquad u = \begin{bmatrix} f_a \\ \dot{x}_r \end{bmatrix}$$

$$C = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & -1 \end{bmatrix} \qquad D = 0$$

The form of C is arbitrary; depending on the necessary data which should be appear in output of state space equations. There are three outputs for state space as bellow:

$$y = \begin{bmatrix} y_1 \\ y_2 \\ y_3 \end{bmatrix} = \begin{bmatrix} Body\ displacement : (x_b - x_w) \\ Body\ velocity : (\dot{x}_b) \\ Deflection\ velocity : (\dot{x}_b - \dot{x}_w) \end{bmatrix}$$

IV. FUZZY LOGIC CONTROLLER

The fuzzy logic controller is used in this active suspension system. The control system itself consists of three stages: fuzzification, fuzzy inference engine and defuzzification [4]. In Fig. 2 is presented the fuzzy logic.

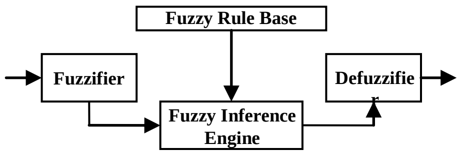


Fig. 2. Fuzzy function.

The fuzzification stage converts real-number (Crisp) input values in to fuzzy values while the fuzzy inference machine processes the input data and computes the controller outputs in cope with the rule base and data base. These outputs which are fuzzy values are converted into real numbers by the deffuzzification stage [2].

The fuzzy logic controller has two inputs; absolute velocity of the body and deflection velocity and one output; desired force. The number of input data of the fuzzy controller is reduced from three to two in comparison with the model in ref.3. A possible choice of membership function for active suspension system represented by a fuzzy set is as follow:

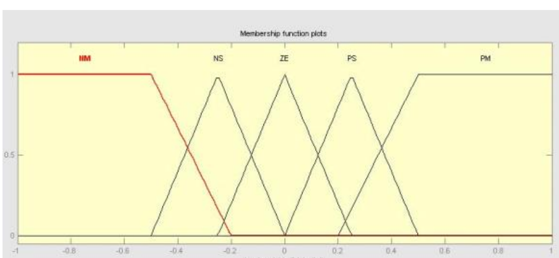


Fig. 3. Membership function for body velocity.

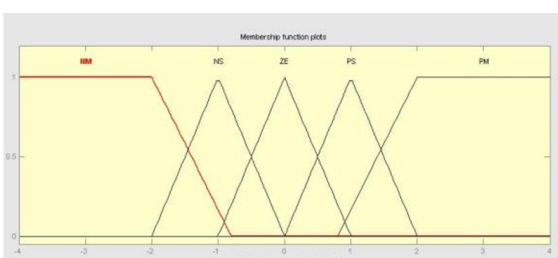


Fig. 4. Membership function for deflection velocity.

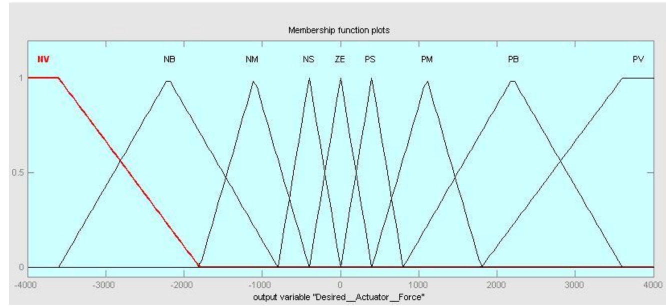


Fig. 5. Membership function for desired actuator force.

One-quarter-car is modeled in ADAMS/view to get better rules by means of exact data as can be observed in Fig. 6. The number of rule base of the fuzzy controller is reduced from 75 to 25 in comparison with some traditional one as presented in [3]. The rule base used in the active suspension system for one-quarter-car model is represented by 25 rules with fuzzy terms derived by modeling the designer's knowledge and experience and ADAMS's data.

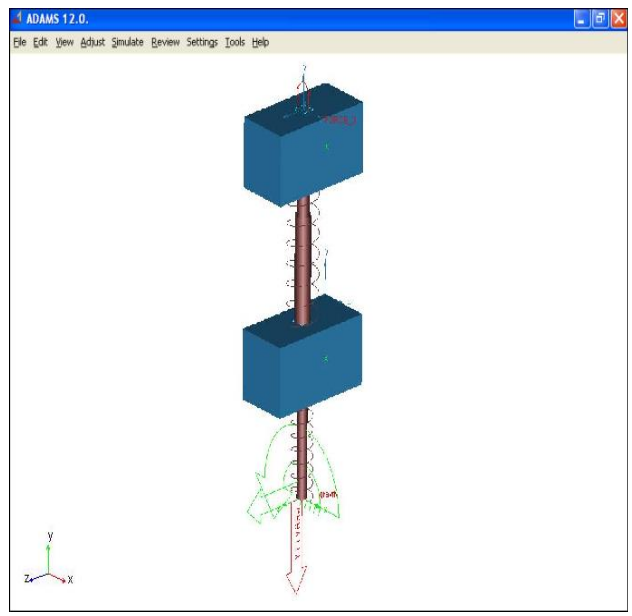
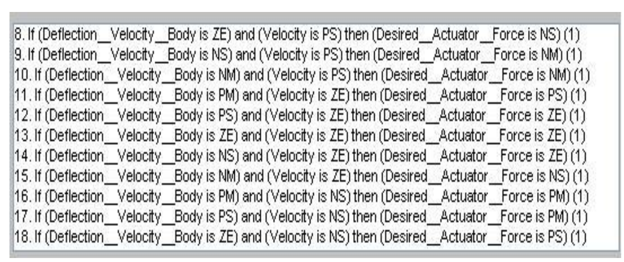


Fig. 6. One-quarter-car model in ADAMS/view.



8. If (Deflection__Velocity__Body is ZE) and (Velocity is PS) then (Desired__Actuator__Force is NS) (1)
9. If (Deflection__Velocity__Body is NS) and (Velocity is PS) then (Desired__Actuator__Force is NM) (1)
10. If (Deflection__Velocity__Body is NM) and (Velocity is PS) then (Desired__Actuator__Force is NM) (1)
11. If (Deflection__Velocity__Body is PM) and (Velocity is ZE) then (Desired__Actuator__Force is PS) (1)
12. If (Deflection__Velocity__Body is PS) and (Velocity is ZE) then (Desired__Actuator__Force is ZE) (1)
13. If (Deflection__Velocity__Body is ZE) and (Velocity is ZE) then (Desired__Actuator__Force is ZE) (1)
14. If (Deflection__Velocity__Body is NS) and (Velocity is ZE) then (Desired__Actuator__Force is ZE) (1)
15. If (Deflection__Velocity__Body is NM) and (Velocity is ZE) then (Desired__Actuator__Force is NS) (1)
16. If (Deflection__Velocity__Body is PM) and (Velocity is NS) then (Desired__Actuator__Force is PM) (1)
17. If (Deflection__Velocity__Body is PS) and (Velocity is NS) then (Desired__Actuator__Force is PM) (1)
18. If (Deflection__Velocity__Body is ZE) and (Velocity is NS) then (Desired__Actuator__Force is PS) (1)

Fig. 7. Schematic rule base.

The rules of the controller have the general form of:

$$Rule_i : \text{IF } (\dot{x}_b - \dot{x}_w = P_i) \text{ AND } (\dot{x}_b = Q_i) \text{ THEN } (f_a = R_i)$$

where $\boldsymbol{P_i}$, $\boldsymbol{Q_i}$ and $\boldsymbol{R_i}$ are labels of fuzzy sets representing the linguistic values of $\dot{x}_b - \dot{x}_w$, $\dot{x}_b$ and f_a, respectively which are characterized by their membership functions. The output of the fuzzy controller is in fuzzy set, thus, the method which is used for diffuzzification is “Center of Gravity Method”. The rule base is represented in Tab. II and in Tab. I hare presented the abbreviation.

Table I. ABBREVIATION USED

Abbreviation	Explanation
NV	Negative very big
NB	Negative big
NM	Negative medium
NS	Negative small
ZE	Zero
PV	Positive very big
PB	Positive big
PM	Positive medium
PS	Positive small

Table II. RULE BASE

	$\dot{x}_b - \dot{x}_w$	$\dot{x}_b$	f_a
1	PM	PM	ZE
2	PS	PM	NS
3	ZE	PM	NM
4	NS	PM	NM
5	NM	PM	NB
6	PM	PS	ZE
7	PS	PS	NS
8	ZE	PS	NS
9	NS	PS	NM
10	NM	PS	NM
11	PM	ZE	PS
12	PS	ZE	ZE
13	ZE	ZE	ZE
14	NS	ZE	ZE
15	NM	ZE	NS
16	PM	NS	PM
17	PS	NS	PM
18	ZE	NS	PS
19	NS	NS	PS
20	NM	NS	ZE
21	PM	NM	PB
22	PS	NM	PM
23	ZE	NM	PM
24	NS	NM	PS
25	NM	NM	ZE

V. SIMULATION RESULTS

In this section, the controller was tested and analyses have been developed to compare the results of active suspension system with a traditional passive one. The pulse response of the model is shown in Fig..8. The input of the controller is road velocity. We consider the pulse as its input with a magnitude of 10. This value is equal to the step with 10cm height as road displacement.

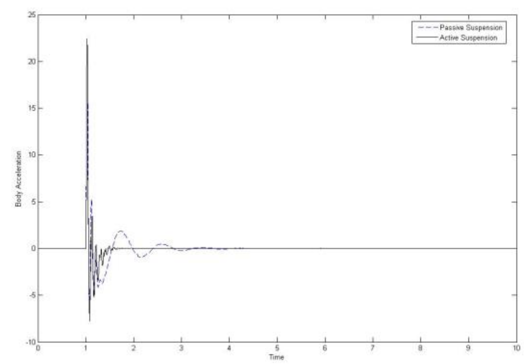


Fig. 8. Variations of acceleration magnitude vs. time

It is clear that the acceleration has been dumped less than 0.5 seconds. The fuzzy command is shown in Fig. 9.

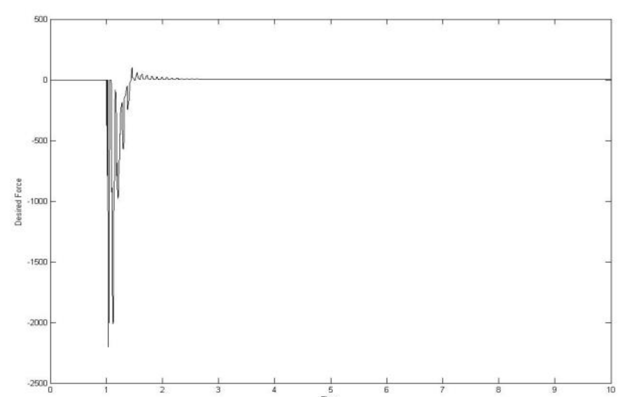


Fig. 9. Fuzzy command vs. time.

As shown in Fig. 8, the magnitude of the acceleration decreased to some extend by using fuzzy controller that improves the ride comfort index. The solid curve is related to the active suspension system and the dashed one is for traditional model.

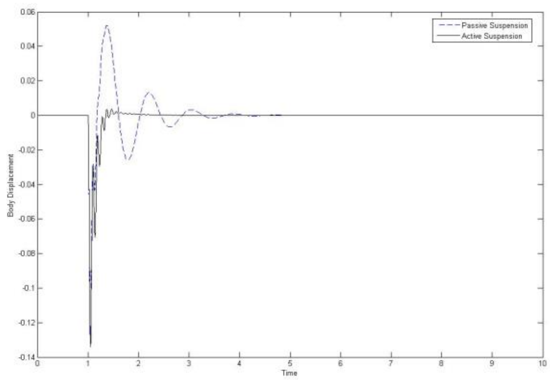


Fig. 10. Body displacement vs. time.

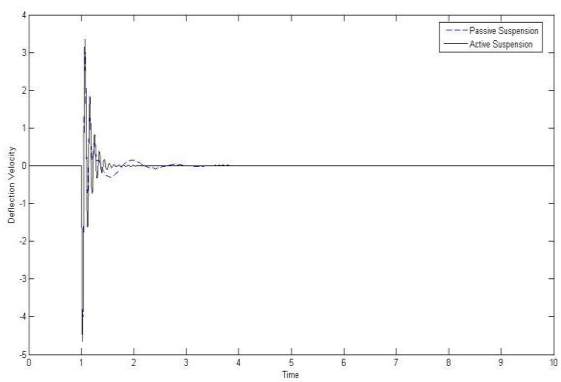


Fig. 11. Deflection velocity vs. time.

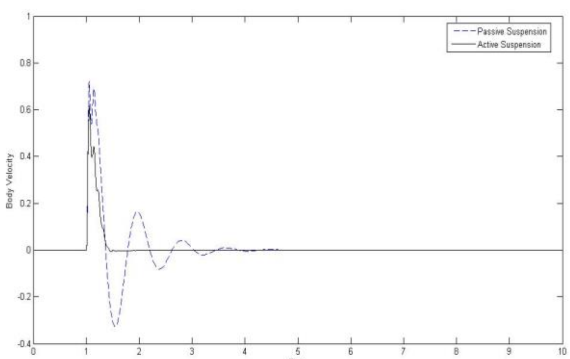


Fig. 12. Body velocity vs. time.

VI. CONCLUSION

By replacing the traditional model by active suspension, we can control and reduce the displacement and acceleration to achieve ride comfort. The effects of active suspension on acceleration have been investigated. Results show that active suspension improves the ride comfort by reducing the acceleration compared with the performance of the passive one.

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