FUZZY CONTROL OF ACTIVE SUSPENSION

Mohammad reza Fallahi Hamid reza Ghoohestani

Department of Automation and Instrumentation,

Petroleum University of Technology, Tehran, Iran
mreza_fal2004@yahoo.ca, ghoohestani@yahoo.com

Abstract: 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 suspension systems, many studies based on adaptive control methods, preview control, sliding mode control, H_∞ control etc. have been done. In this paper, fuzzy logic is used to control active hydro pneumatic suspension. It is one of the most active research and development areas of artificial intelligence at the present time, particularly in the automobile industry because fuzzy logic can improve vehicle ride comfort and road handling performance. The ride comfort is improved by means of the reduction of the body acceleration caused by the car body when road disturbances from uneven road surfaces, pavement points etc. act on the tires of running cars.

Key words: vehicle, suspension, one-quarter-car model, fuzzy logic control, ANFIS

1 Quarter-car model

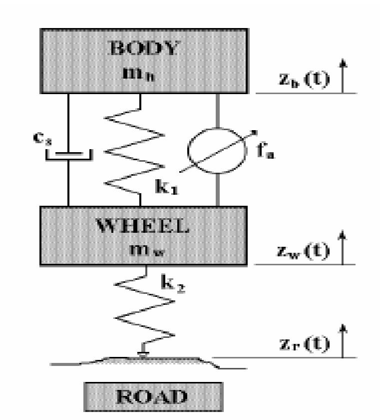

Fig.1. One-quarter-car model

In this paper, we are considering a quarter car models with two degrees of freedom. This model uses a unit to create the control force between body mass and wheel mass. The motion equations of the car body and the wheel are as follows:

$$m_s \ddot{z}_s = -k_s(z_s - z_u) - b_s(\dot{z}_s - \dot{z}_u) + f_a - F_f$$
$$m_u \ddot{z}_u = -k_s(z_s - z_u) - b_s(\dot{z}_s - \dot{z}_u) - k_t(z_u - z_r) - f_a + F_f$$

$$F_a = 240 \ \mathrm{sat}(\dot{z}_s - \dot{z}_u)$$

With the following constants and variables:

- ms body mass (one quarter of the total body mass) 290 kg
- mu wheel mass 59 kg
- ks spring constant (stiffness) of the body 16 812 N/m
- kt spring constant (stiffness) of the wheel 190000 N/m
- fa desired force by the cylinder

- bs damping ratio of the damper 1000Ns/m
- zr road displacements
- zs body displacement
- zu wheel displacements

To model the road input let us assume that the vehicle is moving with different constant forward speeds. Approximately true for most of real roadways. To transform the motion equations of the quarter car model into a space state model, the following state variables are considered:

x=[x1, x2, x3, x4]T

$$\begin{cases} x_1 = z_s \\ x_2 = \dot{x}_1 \\ x_3 = z_u \\ x_4 = \dot{x}_3 \end{cases} \qquad \begin{cases} \dot{x}_1 = x_2 \\ \dot{x}_2 = \frac{1}{M_s}\left(-K_s(x_1 - x_3) - b_s(x_2 - x_4) + F_a - F_f\right) \\ \dot{x}_3 = x_4 \\ \dot{x}_4 = \frac{1}{M_u}\left(K_s(x_1 - x_3) + b_s(x_2 - x_4) - K_t(x_3 - z_r) - F_a + F_f\right) \end{cases}$$

2 Fuzzy logic controller

The fuzzy logic controller used in the active suspension with pd-controller has two inputs: : body vertical displacement with respect to tire(dz) , body vertical velocity with respect to tire velocity (dv) , and one output : desired actuator force fa. The control system itself consists of three stages: fuzzification, fuzzy inference machine and defuzzification.

The fuzzification stage converts real-number (crisp) input values into 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 defuzzification stage.

The fuzzy logic system that we use is Adaptive Neuro-Fuzzy Inference System (ANFIS) which uses singleton fuzzifier , weighted average (wtaver) defuzzifier, gbell mf for inputs and linear mf for output. Membership parameters will be tuned using backpropagation algorithm in combination with a least squares method.

First of all as far as the system is nonlinear we will design a non-linear controller and then implement it by anfis. The desired non-linear controller is

```
If (abs(dz) <= 0. 016) & (abs(dv) <= 0. 15)
Fa = 3 * ks * dz

elseif (dz * dv) >= 0
Fa = -0. 88 * ks * dz + 0. 07 * bs * dv

else
Fa = -0. 88 * ks * dz - 0. 07 * bs * dv
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The first section is a case that we call it sliding surface, that is whenever the response gets to a vicinity of the rest condition and its velocity is slow, we will accelerate the response. The second section is when both inputs have the same sign and the third section is for the case in which the inputs have different signs. At section one we have a p-controller and in section two and three we have pd-controller.

We approximated this non-linear controller by anfis and obtained input and output member ship parameters as follows:

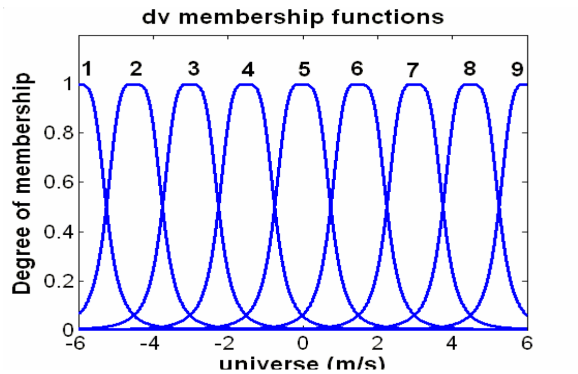

Fig.2: Membership function of dv obtained from anfis

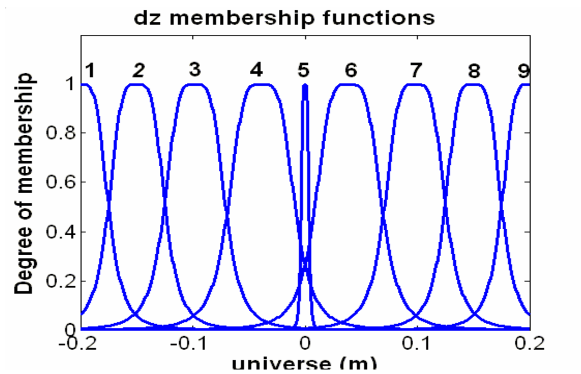

Fig.3: Membership function of dz obtained from anfis

And output linear memberships:

Fa(i)=a*dz+b*dv+c i=1 to 81

Parameters a,b,c are as follows:

Table 1

dz	dv	a	b	c	dz	dv	a	b	c
1	1	-15080	67.28	-75.03	5	6	42790	31.01	3.225
1	2	-15010	66.68	-59.75	5	7	128700	31.38	5.22
1	3	-14960	62.06	-60.26	5	8	198900	31.49	7.264
1	4	-14750	47.66	-31.61	5	9	264700	31.51	9.423
1	5	-15450	0.005988	-147.4	6	1	-17660	-79.79	89.23
1	6	-14790	-47.65	-40.06	6	2	-16930	-79.91	65.91
1	7	-15000	-62.05	-77.15	6	3	-16340	-80.83	46.07
1	8	-15140	-66.67	-85.26	6	4	-1.4850	-81.28	0.003632
1	9	-15250	-67.27	-108.6	6	5	-18440	-0.4071	193.1
2	1	-15170	67.89	-73.8	6	6	-14710	80.45	-3.963
2	2	-15070	67.33	-58.26	6	7	-16070	79.99	38.18
2	3	-15010	63.04	-58.18	6	8	-16520	79.07	53.99
2	4	-14740	49.53	-30.27	6	9	-1.7110	78.95	73.57
2	5	-15600	-0.01804	-145.1	7	1	-15960	-65.29	155.7
2	6	-14790	-49.56	-37.55	7	2	-15660	-64.53	120.9
2	7	-15100	-63.08	-72.73	7	3	-15430	-58.73	106.8
2	8	-15210	-67.37	-80.25	7	4	-14780	-41.14	49.97
2	9	-15360	-67.93	-102.7	7	5	-16450	0.0914	191.6
3	1	-15620	65.48	-119.4	7	6	-14700	41.33	40.91
3	2	-15410	64.72	-93.31	7	7	-15260	58.92	88.75
3	3	-15260	58.92	-88.6	7	8	-15410	64.72	93.53
3	4	-14700	41.33	-40.85	7	9	-15620	65.47	119.7
3	5	-16450	0.09154	-191.6	8	1	-1.5360	-67.93	103
3	6	-14780	-41.15	-49.88	8	2	-15220	-67.37	80.49
3	7	-15430	-58.73	-106.6	8	3	-15100	-63.08	72.89
3	8	-15660	-64.53	-120.6	8	4	-14790	-49.56	37.62
3	9	-15950	-65.29	-155.3	8	5	-15600	-0.01801	145.2
4	1	-17110	78.93	-73.49	8	6	-14740	49.53	30.31
4	2	-16520	79.06	-53.93	8	7	-15010	63.04	58.3
4	3	-16060	79.98	-38.15	8	8	-15070	67.33	58.44
4	4	-14710	80.43	3.961	8	9	-15170	67.89	74.03
4	5	-18440	-0.4077	-193	9	1	-15250	-67.27	108.9
4	6	-14850	-81.26	0.02425	9	2	-15140	-66.67	85.54

4	7	-16340	-80.82	-45.98	9	3	-15040	-62.05	77.33
4	8	-16930	-79.9	-65.76	9	4	-14790	-47.65	40.13
4	9	-17650	-79.78	-89.03	9	5	-15450	0.005979	147.5
5	1	264400	31.76	-7.087	9	6	-14750	47.66	31.66
5	2	198700	31.75	-5.442	9	7	-14960	62.06	60.4
5	3	128500	31.68	-3.829	9	8	-15010	66.68	59.95
5	4	42720	31.45	-2.437	9	9	-15080	67.28	75.3
5	5	51850	30.59	0.02877					

The linguistic control rules of the fuzzy logic controller obtained from the table above are as follows:

R18: IF (dz=2) AND (dv =9) THEN (fa= -15360 *dz -67.93 * dv -102.7)

R6: IF (dz=1) AND (dv=6) THEN (fa=-14790 *dz -47.65 * dv -40.06)

And so on …

3 Road inputs

One of the most important parts of designing an appropriate and efficient controller is to specify a correct form of inputs. Here, in this paper we have considered three different kinds of inputs in order to model a real road. First, we apply a soft (filtered) step which models a two-level road e.g. the junction between two different roads. Second, we apply one half of a sine wave to model those obstacles made to reduce the speed of the car (bump). Third, we will introduce a more complex input which is a filtered white noise to model an uneven road which is approximately true for most of the roads.

In each section we will assume that the car velocity is constant and does not vary with respect to time. This assumption does not affect the generality of the problem.

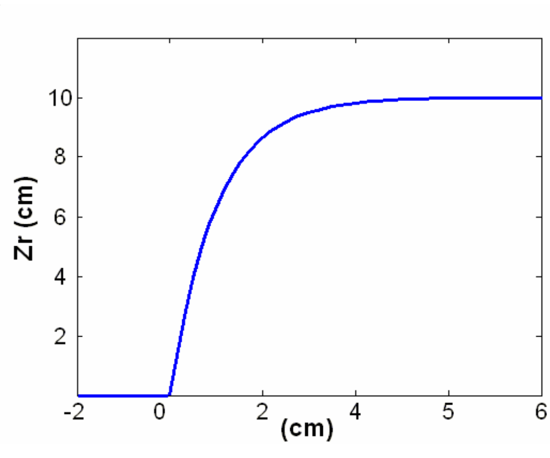

Fig.4: bi-level road

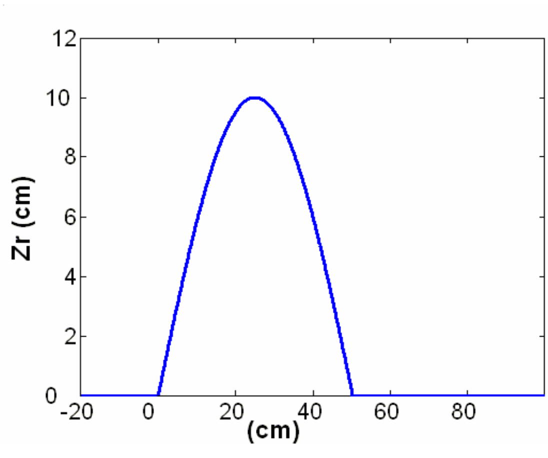

Fig.5: bump

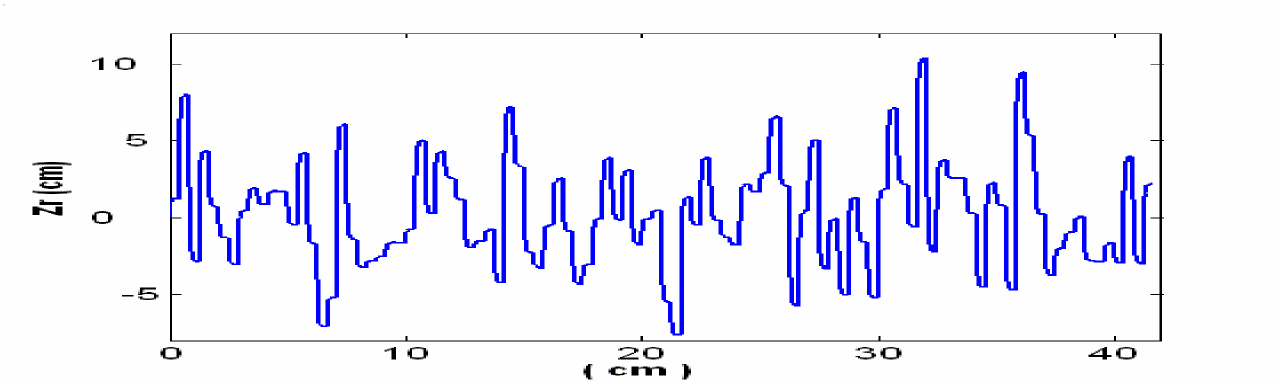

Fig.6: uneven road

4 Simulation results

In this section, the controller is tested to compare the results of traditional passive controller with active controllers.

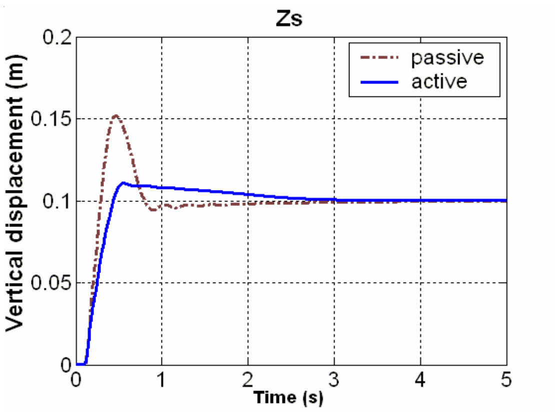

Fig.7: system response for bi-level road

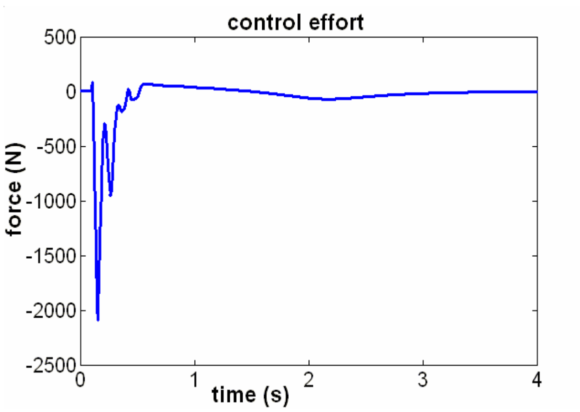

Fig.8: control effort for bi-level road

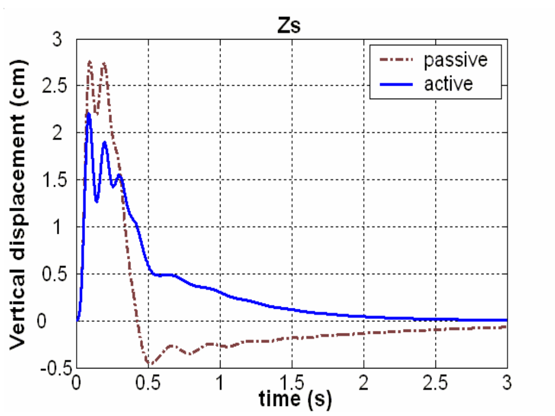

Fig.9: system response for bump

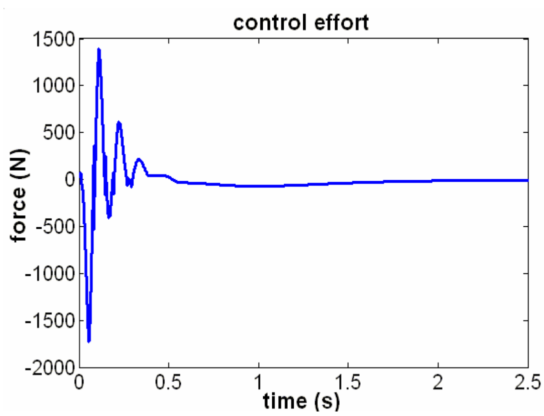

Fig.10: control effort for bump

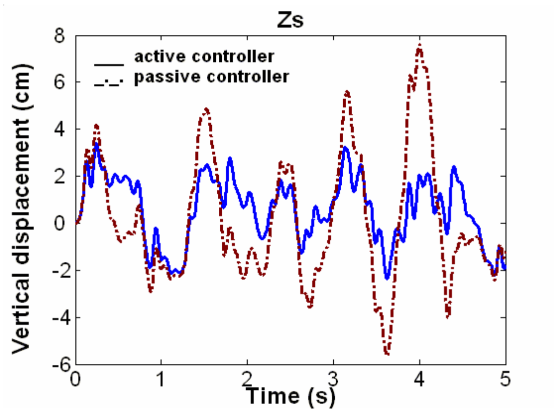

Fig.11: system response for uneven road

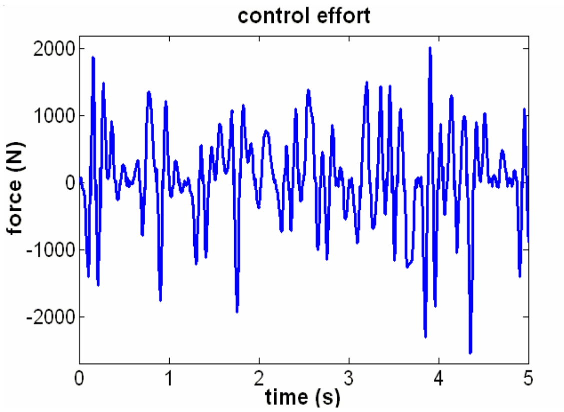

Fig.12: control effort for uneven road

5 Conclusion

In this paper, the new active suspension control system is proposed to achieve both ride comfort and good handling. This aim was achieved with respect to the results of the simulation ; e.g. in the case of uneven road, body deflection of the car has reduced considerable according to the following results:

For passive response: $\int_0^5 |Zs| dt = 0.1085$

For active response: $\int_0^5 |Zs| dt = 0.0648$

The results of the active suspension system based on the fuzzy logic controller also show the improved stability of the one-quarter-car model.

References

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