FUZZY LOGIC CONTROL OF VEHICLE SUSPENSION SYSTEMS FOR BUMPY ROADS

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ÖZET

Bu çalışmanın ilk bölümünde, bulanık mantığa dayalı bir kontrolcü, çok serbestlik dereceli bir taşıt modelinde süspansiyona paralel olarak monte edilmiş ve kontrol gerçekleştirilmiştir. Bu yaklaşımın avantajı, parametre değişimine karşı duyarlılığı ve sistemin lineer olmayan davranışlarına uyum yeteneğidir. Farklı yol profillerinde yolculuk edilmesi durumlarında; gövde sıçraması, kontrol girişleri, kontrol işlemi için harcanan güç, taşıtın gövde yer değişimleri ve ivmesinin frekans cevapları elde edilmiştir. Simülasyon sonuçları kontrolsüz sisteminkilerle karşılaştırılmıştır. Çalışmanın sonunda ise sürüş konforu da göz önüne alınarak, kontrolcünün performansı ve sistem cevabındaki gelişme tartışılmıştır.

SUMMARY

In the first part of this study, a fuzzy logic based controller has been mounted on a multi degrees of freedom vehicle model as parallel to the suspensions and an effective control has been realized. The advantage of this approach is its robustness and ability to handle the non-linear behaviour of the system. In case of travelling on a bump road profile, body bounce, control inputs, the power consumed for control action and frequency response of the vehicle body displacement and acceleration have been obtained. The simulation results have been compared with the uncontrolled system ones. At the end of the study, the performance of the controller and the improvement in the system response have been discussed by also considering the ride comfort.

1. INTRODUCTION

In recent years, the improvement of the vehicle suspensions systems has gained more interest and been the subject of the research and development. This activity has two reasons which are commercial and scientific. The main reason of the commercial activity is the desire of the automotive manufacturers and component suppliers to improve the performance and quality of their products. On the other hand, researchers and control system designers have claimed that the automatic control of the vehicle suspension systems is possible when the developments in actuators, sensors and electronics have been considered. When the performance characteristics of a desired suspension system have been taken into consideration, the suspension control has become more attractive [1-4].

The aim of this study is to apply the fuzzy logic control to automotive suspension systems. The improvements in electromagnetic force sources and sensors has made it possible anymore [5], [6]. Fuzzy Logic has come a long way since it was first presented to technical society in 1965, when Dr. Lotfi Zadeh published his seminal work "Fuzzy Sets" in the journal Information and Control [7]. Since that time, the subject has been focus of many independent research investigations. The attention currently being paid to fuzzy logic is most likely the result of present popular consumer products employing fuzzy logic [8]. The superiorities of this method are applicability to non-linear systems, simplicity good performance and its robust character. It has been proposed for active control of vehicle suspension systems [9], [10]. On these days, this method has been applied to robot control, flight control, motor control and power systems successfully.

2. VEHICLE MODEL

The physical model of the vehicle has been presented in Figure 1. The controller has been placed between sprung and unsprung masses as parallel. The vehicle model has two degrees of freedom which are body bounce y_2 and wheel hop y_1.

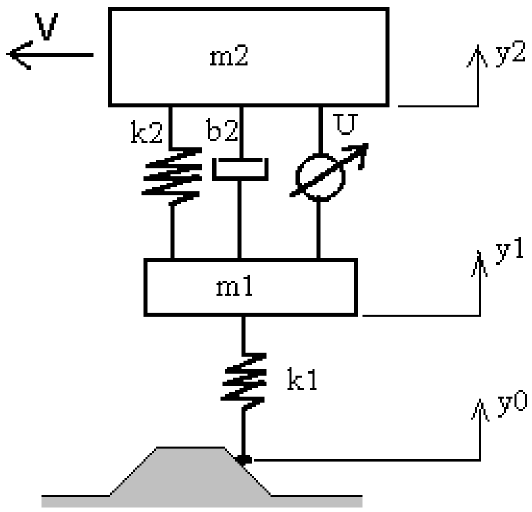

Figure 1. Vehicle model

In this model, m_2 represents body mass; k_2 is suspension spring constant; b_2 is damper coefficient; U is control force input to the vehicle body and it is obvious that it will act on unsprung mass m_1 in the opposite direction; k_1 is stiffness of the wheel; y_0 is the wheel input. The vehicle travels at speed V. The dynamic equations of the system are given below:

$$\begin{bmatrix} m_1 & 0 \\ 0 & m_2 \end{bmatrix}\begin{bmatrix} \ddot{y}_1 \\ \ddot{y}_2 \end{bmatrix}+\begin{bmatrix} b_2 & -b_2 \\ -b_2 & b_2 \end{bmatrix}\begin{bmatrix} \dot{y}_1 \\ \dot{y}_2 \end{bmatrix}+\begin{bmatrix} k_1+k_2 & -k_2 \\ -k_2 & k_2 \end{bmatrix}\begin{bmatrix} y_1 \\ y_2 \end{bmatrix}=\begin{bmatrix} k_1 \\ 0 \end{bmatrix}y_o+\begin{bmatrix} -U \\ U \end{bmatrix} \tag{1}$$

3. THE FUZZY LOGIC CONTROLLER

Linguistic variables (Small, Medium, Big, etc.) are used to represent the domain knowledge, with their membership values lying between 0 and 1. Basically, a fuzzy logic controller has got the following components.

- (i) The fuzzification interface to scale and map the measured variables to suitable linguistic variables (fuzzyfier).
- (ii) A knowledge base comprising linguistic control rule base.
- (iii) A decision making logic to infer the fuzzy logic control action based on the measured variables, which resembles the human decision making (fuzzy reasoning engine).
- (iv) A defuzzification interface to scale and map the linguistic control actions inferred to yield a non-fuzzy control input to the plant being controlled (defuzzyfier).

The fuzzyfier converts each input variable value into the relevant fuzzy variable value using its own set of linguistic variables (fuzzy sets) and their pertinent membership functions. For example (Figure 2.a), for a generic input variable y_i the fuzzy sets NEGATIVE BIG, NEGATIVE SMALL, ZERO, POSITIVE SMALL, POSITIVE BIG **(nb, ns, zo, ps, p**b) are defined in the universe of discourse of y_i . Any values of y_i in its universe of discourse belong at the same time to different fuzzy sets with different degree of membership, by the related membership functions (The most used kind of membership function are bell shaped, trapezoidal and triangular). The value 0.5 of y_3 is both **ps** with a membership tag 0.6 and **zo** with a membership tag 0.17 while is **nb, ns** and **pb** with a membership tag 0. The fuzzy reasoning engine converts the values of fuzzy input variables into the fuzzy sets of output variables It consists of a set of fuzzy logic rules of the kind: **IF** {RULE PREMISE} **THEN** {RULE CONSEQUENCE}. The {RULE PREMISE} block is a set of fuzzy logic operations, whose result, differently from a set of Boolean logic operations, is any real values between 0 and 1. The basic operators of fuzzy logic are fuzzy intersection (AND), fuzzy union or disjunction (OR) and fuzzy complement (NOT); their operands are fuzzy sets. The result of the AND (OR) operation is the minimum (maximum) of the membership functions of its two fuzzy set operands; the result of the NOT operation is the complement of the membership function of its fuzzy set operand. The {RULE CONSEQUENCE} provides a linguistic value for each output variable; its truth value is the numeric result (between 0 and 1) of the {RULE PREMISE}. Fuzzy sets and their pertinent membership functions have to be defined for each output. In the example of Figure 2.b, supposing that in the k^{th} rule the premise result is 0.4, the consequence, in the universe of discourse of the output u_2 (by its own **PB** fuzzy set), is the evidenced curve. The defuzzyfier is responsible for the translation of the fuzzy reasoning engine results to a crisp set of output values. A variety of methods are used to perform defuzzyfication; the most common are:

- i) The Mamdani method that returns the centroid of the output fuzzy region as the crisp output of the fuzzy interface system (Figure 2.c).

ii) The TVFI (Truth Value Flow Inference) method that returns a weighted average as the crisp output of the fuzzy interface system [11].

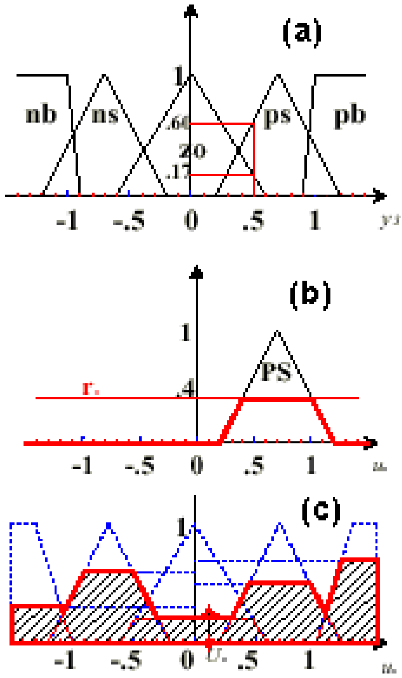

Figure 2. A basic fuzzy logic action

4. SIMULATION

The structure of the fuzzy logic control system for the vehicle suspension system uses the error in vehicle body motion (y_{2r} -y_2) and the derivative of it as the two input variables while the control force U is its output as shown in Figure 3.

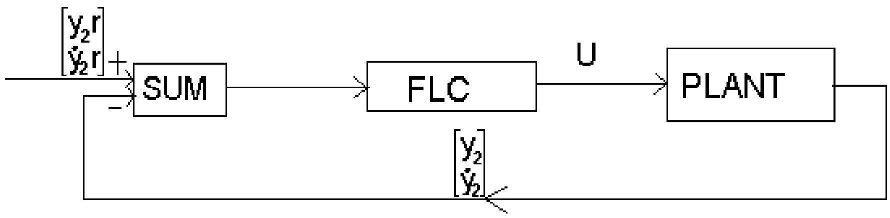

Figure 3. Closed loop model of the vehicle with fuzzy logic controller

The rule base developed by heuristics with error in body bounce motion and velocity as input variables, are given in Table 1. Where; P, N, Z, 3, 2, 1 represent Positive, Negative, Zero, Big, Medium and Small respectively. A trial and error approach with triangular membership functions has been used to achieve a good controller performance.

Table 1. Rule base for fuzzy logic controller

Error of dy_2/dt

Error of y_2		VN	VZ	VP
	XNB	UN3	UN2	UN1
	XNS	UN2	UN1	UZ
	XZ	UN1	UZ	UP1
	XPS	UZ	UP1	UP2
	XPB	UP1	UP2	UP3

By defining the mathematical model of the system, the simulation has been realized. In Figure 4., in case of bump road surface input to the vehicle (Figure 4.a), the response of the system has been given. The vehicle travels over this bump at 72 km/h. As demonstrated in Figure 4.b, the motion of the passengers in vertical direction follows the “0” reference quickly when fuzzy logic controller exists. When the body bounce has been compared with the uncontrolled one, the success of the controller becomes obvious. Control force per suspension is around 150 N. and power input is 60 Watts as seen in Figures 4.c and 4.d. When we check the frequency response of the system without controllers, two resonance frequencies are observed around 1.1 Hz. and 10 Hz. of body motion and wheel hop in Figure 5.a. On the other hand, when the controller is active, resonance of the body motion disappears and the amplitude of the motion throughout the frequency range considerably gets smaller as presented in the same figure. In Figure 5.b, the similar conclusions can be reached if frequency response of the acceleration of the body bounce which is very dominant when ride comfort is taken into consideration.

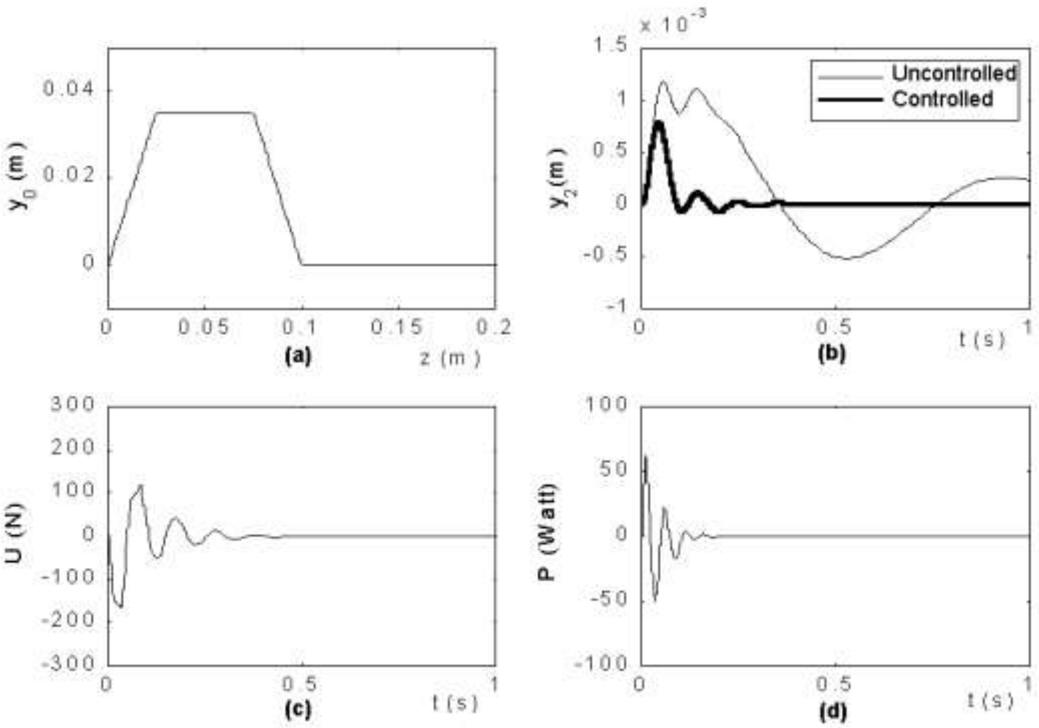

Figure 4. The system response of the vehicle in case of bump road surface input

(a) bump road surface input (b) body bounce with and without fuzzy logic controller
(c) suspension control force (d) power consumed for control

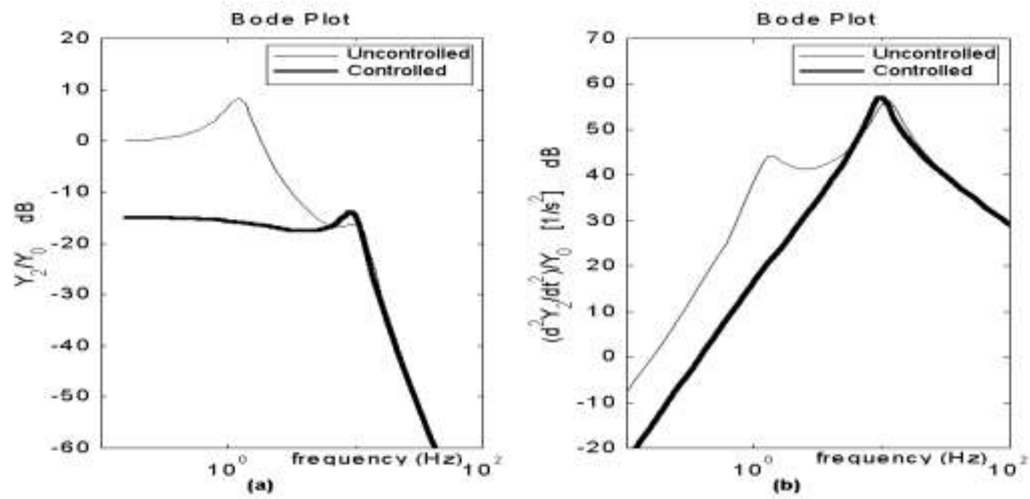

Figure 5. Frequency response of the body displacement and acceleration

5. CONCLUSION

In this study, a fuzzy logic controller for a vehicle has been designed and simulation results have been presented. The main idea behind proposing this controller is its robustness and the ability of using these type of controllers on vehicles with developing technology. Since vehicle dynamics changes with load and road conditions, this method becomes important. The results of this study prove that the performance of active suspension of this type is superior than the one of passive one. Against the disturbances coming from the road, the passengers are almost insensitive and it is possible that they feel ride as if on an excellent road surface. The excellent improvement in resonance values and decrease in vibration amplitudes support this result.

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