

Neural Controller Design for Suspension Systems

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Abstract

The main problem of vehicle vibration comes from road roughness. An active suspension system possesses the ability to reduce acceleration of sprung mass continuously as well as to minimize suspension deflection, which results in improvement of tire grip with the road surface. Thus, brake traction control and vehicle maneuverability can be improved considerably. This study developed a new active suspension system for a quarter-car model. The designed system is based on neural network controller with an input as a regressor and it provided through a lag network that includes reference input, system output and control signal system to the previous state. In this paper, the system is based on neural network controller that is a regressor input provided through a lag network, including reference input, system output and control signal to previous state. The neural network outputs are the same control signals applied to the suspension system. Feedback system is taken as the output of the displacement body and is applied to lag network. Roughness of the road surface is considered as a reference input. To train, the neural network uses different idea by introducing a cost function for the system and optimizing it, the best coefficients are selected for the neural network.

Keywords: Neural Network, Active Suspension, Quarter-Car Model, Neural Controller

1- Introduction

Vehicle suspension serves as the basic function of isolating passengers and the chassis from the roughness of the road to provide a more comfortable ride. Suspension systems affect handling and riding quality of cars, so they are currently of great interest to both academia and industry. Several researchers and engineers in the automotive industry have extensively discussed the problem of vehicle suspension control. An active suspension system is more elastic and efficient than other suspension systems, such

as passive or semi-active, and can provide more handling capability and ride quality than other suspension systems. Therefore, active suspension system control has attracted the attention of numerous researchers interested in the handling and the ride quality of a car. Many solutions for active suspension system control have been proposed [1]-[4] to determine handling and riding quality of cars. Active suspension systems have dynamic characteristics with complexities and nonlinearities, so it is difficult to design

model-based controllers for the control of such systems. Fuzzy logic control has extensively been applied to control engineering fields in recent years. Such a control strategy has the specific feature of being able to develop the controller without the need of a mathematical model of the system. A load-dependent controller design approach has been presented to solve the problem of multi-objective control for vehicle active suspension systems by using linear matrix inequalities [2]. Du and Zhang have presented H1 control problem for active vehicle suspension systems with an actuator time delay [3]. An approach has been searched to design static output feedback and non-fragile static output feedback H1 controllers for active vehicle suspensions by using linear matrix inequalities and genetic algorithms [4]. Vibration control performance of a semi-active electrorheological seat suspension system has been searched using a robust sliding mode controller by Huang and Chen [5]. Ieluzzi et al. have investigated about the overall performance of a semi-active suspension control for a heavy truck [6]. Spectral decomposition methods have been applied to compute the rms values for the control forces, suspension strokes and tyre deflection accurately at front and rear in a half-car model with preview [7]. Guclu has presented vibration control performance of a seat suspension system of non-linear full vehicle model using fuzzy logic controller [8]. A multidisciplinary optimization method has been applied to the design of mechatronic vehicles with active suspensions [9]. Neural network control method has been developed

to control a seat suspension system of non-linear full vehicle model [10]. Yıldırım and Uzmay have investigated about the variation of vertical vibrations of vehicles using a neural network [11]. An active horizontal spray-boom suspension, reducing yawing and jolting, has been designed by Anthonis and Ramon [12]. A semi-active control of vehicle suspension system with magneto rheological (MR) damper has been presented by Yao et al. [13]. Spentzas and Kanarachos have presented a methodology for the design of active/hybrid car suspension systems aiming at maximizing passenger comfort [14]. A methodology for the design of active car suspension systems has been presented [15]. Yagiz and Yüksek have researched about sliding mode control of active suspensions for a full vehicle model [16].

In this paper a modern system for Controlling a quarter-car model's active suspension, the system is based on a neural network controller that is a regressor input provided through a lag network, including reference input, system output and control signal to previous states. The neural network outputs are the same control signals applied to the suspension as a reference input. To train the neural network a different idea is used by introducing a cost function for the system and optimizing it.

The best coefficients are selected for the neural network. body and is applied to lag network. Roughness of the road surface is considered system has been presented. Feedback system is taken as the output of the displacement

2- System Description Escription And Mathematical Model

The non-linear quarter-car model of the suspension system used in this study is shown in Fig.1. This quarter-car model has two degrees of freedom. However, due to the physical properties of the tire, usually the damping coefficient of efficiency is assumed. We know from Newton's second law that the resultant external forces acting on an object is equal to the mass of the object multiplied by its acceleration.

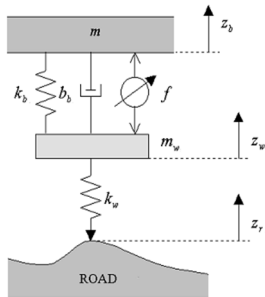


Fig.1. The non-linear quarter-car model[9]

Therefore, the equations governing the suspension are obtained as follows:

$$\sum f = m_w \times a \quad (1)$$

$$K_w(Z_w - Z_r) - K_b(Z_w - Z_b) - b_b(\dot{Z}_w - \dot{Z}_b) - f = m_w \ddot{Z}_w \quad (2)$$

$$\ddot{Z}_w = \frac{K_w(Z_w - Z_r) - K_b(Z_w - Z_b) - b_b(\dot{Z}_w - \dot{Z}_b) - f}{m_w} \quad (3)$$

applying Newton's second law for the offense tire

Newton's second law applied to body mass:

$$\sum f = m \times a \quad (4)$$

$$-K_b(Z_b - Z_w) - b_b(\dot{Z}_b - \dot{Z}_w) + f = m \ddot{Z}_b \quad (5)$$

$$\ddot{Z}_b = \frac{-K_b(Z_b - Z_w) - b_b(\dot{Z}_b - \dot{Z}_w) + f}{m} \quad (6)$$

Now for State-space model, we will try to draw the governing equations of systems as in the form of a matrix tie.

$$\dot{X}(t) = AX(t) + Bu(t) \quad (7)$$

To transfer equations of motion to the state-space, consider four state variables

$$X = [X_1 X_2 X_3 X_4]^T \quad (8)$$

in this regard, the variables' represent concepts are: k_b : Stiffness of car body spring per unit Nm, k_w : Stiffness of tire per unit Nm, b_b : Suspension Damper coefficient in units of Newton per meter per second, z_b : Vertical displacement meter body, z_w : Vertical displacement meter wheel, z_r : Entrance road or road surface roughness meter, f : Power control unit Newton.

$$X_1 = Z_b - Z_w \quad (9)$$

$$X_2 = \dot{Z}_b \quad (10)$$

$$X_3 = Z_w - Z_r \quad (11)$$

$$X_4 = \dot{Z}_w \quad (12)$$

Define the first state variable as a removable suspension, second and third variables are Vertical speed Body and Wheel deflection, respectively.

Considering the state variables, the equations of motion of quarter-car model can be rewritten for suspension system as follows in the state space. Now we can design a controller with this state-space model.

$$\begin{bmatrix} \dot{X}_1 \\ \dot{X}_2 \\ \dot{X}_3 \\ \dot{X}_4 \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & -1 \\ -k_b & -b_b & 0 & b_b \\ m_b & m_b & 0 & m_b \\ 0 & 0 & k_w & 1 \\ -k_b & b_b & m_w & -b_b \\ m_w & m_w & m_w & m_w \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \\ X_3 \\ X_4 \end{bmatrix} \quad (13)$$

$$+ \begin{bmatrix} 0 \\ 1 \\ m_b \\ 0 \\ 1 \\ m_w \end{bmatrix} f + \begin{bmatrix} 0 \\ 0 \\ -1 \\ 0 \end{bmatrix} \dot{z}_r$$

3- Neural Network (NN) Controller Design for Active Suspension System

Neural Networks are successfully used in a variety of application areas such as control and early detection of machine faults. The feed-forward neural network is usually trained by a back-propagation training algorithm first proposed by Rumelhart [18]. This was the starting point of the effective usage of NNs after the 1980s. With the advantage of high speed computational technology, NNs are more realistic, easily updateable and implementable today. The distributed weights in the network contribute to the distributed intelligence or associative memory properties of the network. With the network initially untrained, i.e. with the weights selected at random, the output signal pattern will totally mismatch the desired output pattern for a given input pattern. The

actual output pattern is compared with the desired output pattern and the weights are adjusted by the supervised back-propagation training algorithm until the pattern matching occurs, i.e. the pattern errors become acceptably small. The impressive advantages of NNs are the capability of solving highly non-linear and complex problems and the efficiency of processing imprecise and noisy data. Mainly, there are three types of training condition for NNs; supervised training, graded training, and self-organization training, namely. Supervised training, which is adopted in this study, can be applied as (1) First, the dataset of the system, including input and output values, is established; (2) The dataset is normalized according to the algorithm; (3) Then, the algorithm is run; (4) Finally, the desired output values corresponding to the input used in test phase.

In this study the Neural Network control is based on lag phase neural network [29] ANN outputs directly applied to the system. In Fig.2 a control block diagram is shown. This controller is implemented based on acts' function on present and past values of the reference input and output of the system as well as the values of the control signal.

$$u_t = f \left(\begin{matrix} r_t, r_{t-1}, \dots, y_t, y_{t-1}, \\ \dots, u_{t-1}, u_{t-2}, \dots \end{matrix} \right) \quad (14)$$

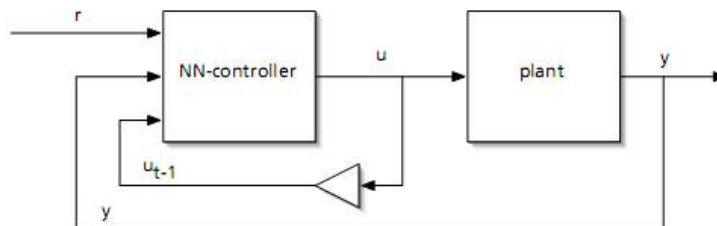


Fig.2. Block Diagram of the control system with a neural network controller[29]

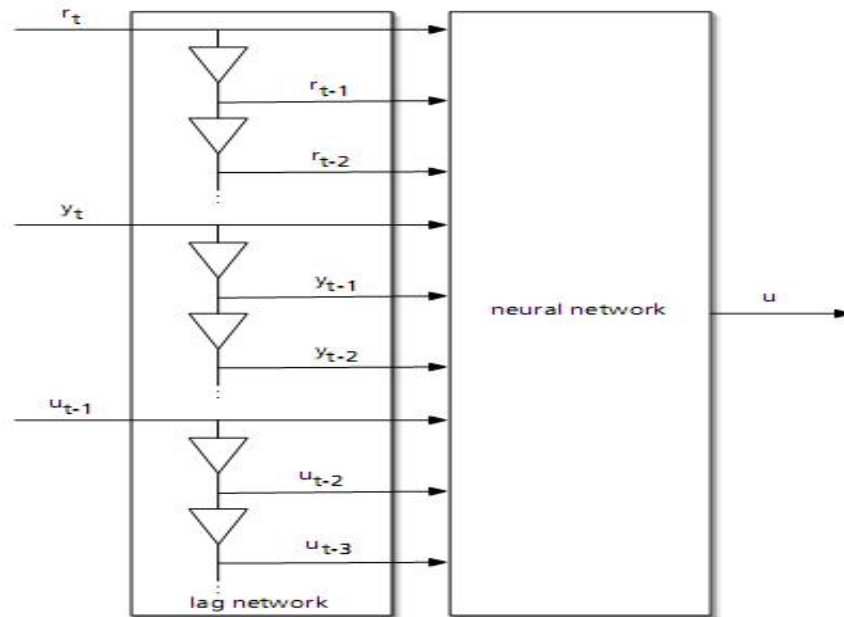


Fig .3. The lag network feeds the neural network[29]

The output of this neural network is the active suspension control signal applied to the input of the network. It is considered φ_t as a regressor. In fact, φ_t is the result of mapping specific data in time t .

$$\varphi_t = \varphi \left(\begin{matrix} r_t, r_{t-1}, \dots, y_t, y_{t-1}, \\ \dots, u_{t-1}, u_{t-2}, \dots \end{matrix} \right) \quad (15)$$

As noted, the number of neural network outputs is constant and equal to control signal, but the number of input network and the number of hidden layers are as well as adjustable. In Fig.3 the lag phase network is shown for the production of inputs to the neural network or the regressor.

The number of input signals can be obtained using analysis of variance in time series. A very simple plan for regressor can be considered as follows:

$$\varphi_t = [r_t, y_t, u_{t-1}]^T \quad (16)$$

Complex regressors need principle component decomposition ways to reduce the vector size of the neural network output. Hence, in this study, these three signals are used as neural network inputs. For active suspension systems, body displacement is considered as the output of the system and the roughness of the road surface as the input of the system. Neural network controller is designed with a hidden layer. Hidden layers have hyperbolic tangent transfer functions and the output layer is linear.

3.1. Neural Network Training

Training of the neural network is done by iteratively simulating the system consisting of controller and plant, and then evaluating the resulting time series of plant outputs (y_1, y_2, \dots, y_n) and control signals (u_1, u_2, \dots, u_N) with respect to a given cost function J .

An optimization algorithm is used to minimize the cost function through this iterative process

$$J = \min F(z) = \text{RMS}[\ddot{Z}_b(t)] \quad (17)$$

To optimize the cost function is used f_{\min} search way in Matlab software that in fact it is an unconstrained nonlinear optimization. For active suspension system, Root mean square (RMS) is as cost function that should be minimized .Root mean square of a function is defined as follows:

$$f_{\text{rms}} = \sqrt{\frac{1}{T_2 - T_1} \int_{T_1}^{T_2} [f(t)]^2 dt} \quad (18)$$

4- Simulation

In this study, the codes of the tool written in Matlab, R2011a Version are used. After determining the values for parameters, simulation results for both passive and active suspension systems with proposed neural network controller ,are presented for three different models of road roughness. To simulate, the parameters in suspension system equation are chosen using Table 1.

Table. 1.The amount allocated for parameters

| |
|----------------------------|
| $m = 250 \text{ kg}$ |
| $m_w = 50 \text{ kg}$ |
| $k_b = 16000 \text{ N/m}$ |
| $k_w = 160000 \text{ N/m}$ |
| $b_b = 1500 \text{ Ns/m}$ |

In this paper, the input of load surface roughness is considered as a step function, but to prove the optimal performance of the proposed system, we considered three different types of roughness.

First Roughness: it is intended in the form of a pulse shown in Fig. 4 and are defined as follows:

$$Z_r \quad (19)$$

$$= \begin{cases} 0.1, & 1 < t < 4 \\ 0, & \text{otherwise} \end{cases}$$

Second Roughness: The road surface is considered as shown in Fig.5 and is defined as follows:

$$Z_r \quad (20)$$

$$= \begin{cases} (t - 1)/6, & 1 < t < 2 \\ (3 - t)/6, & 2 < t < 3 \\ 0, & \text{otherwise} \end{cases}$$

4-1. Simulation for Active Suspension System with Proposed Controller

Third Roughness: This is much like the roughness of safety in the streets that is defined with two different heights.

$$Z_r \quad (21)$$

$$= \begin{cases} 0.07(1 - \cos(8\pi t)), & 0.5 < t < 0.7 \\ 0.04(1 - \cos(8\pi t)), & 3.5 < t < 3.7 \\ 0, & \text{otherwise} \end{cases}$$

The main purpose of suspension systems is occupant comfort. Hence, that is why we offer the most attention to the results of the displacement and vertical speed body.

In this part, the results for third roughness presents like the previous section.

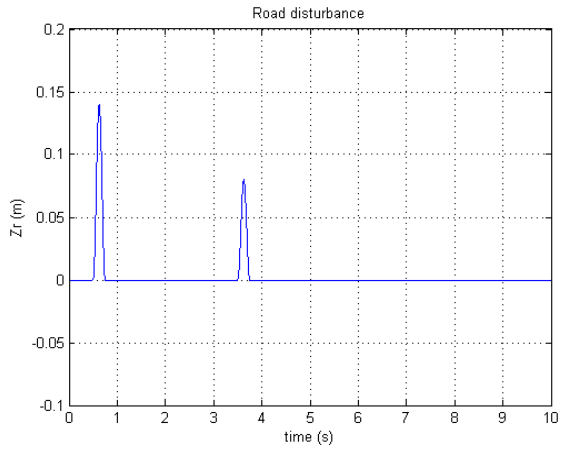


Fig.4. Third Roughness for road surface

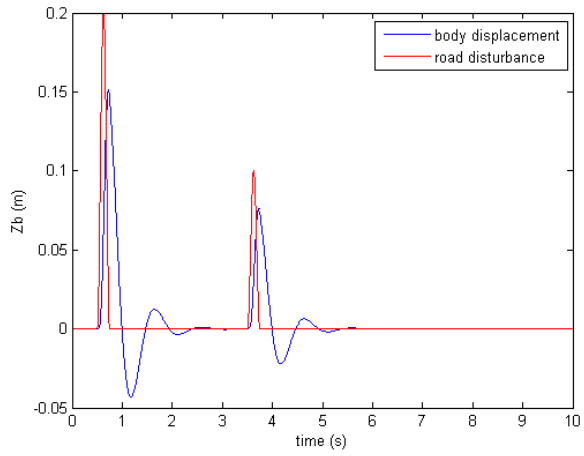


Fig.7. Body displacement for Third Roughness

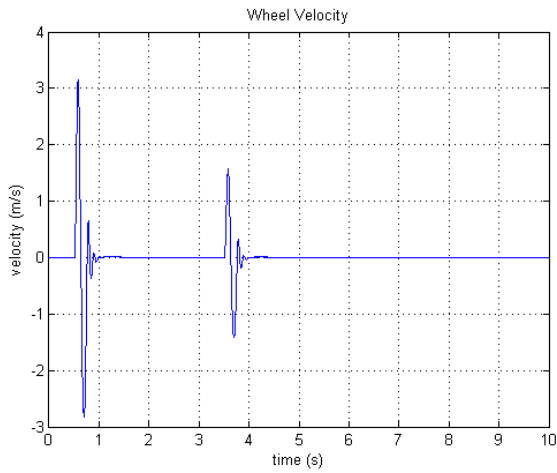


Fig.5. Vertical Speed of body in Third Roughness

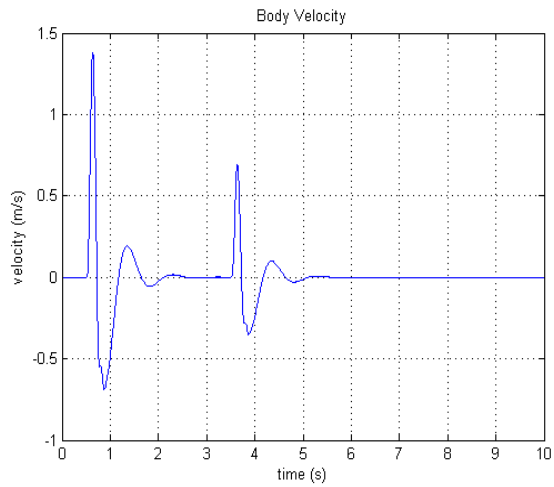


Fig.8. Vertical Speed of body in Third Roughness

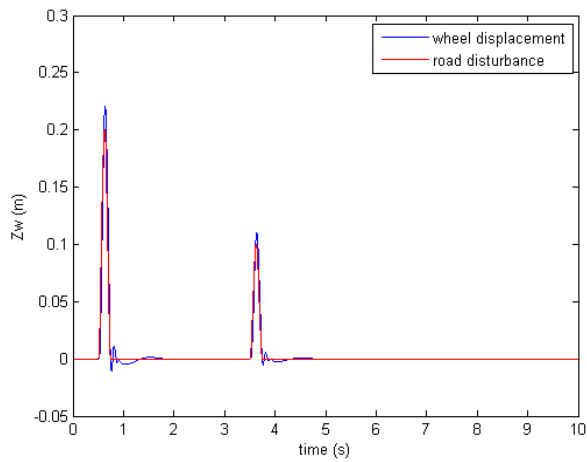


Fig.6. Wheels displacement for Third Roughness

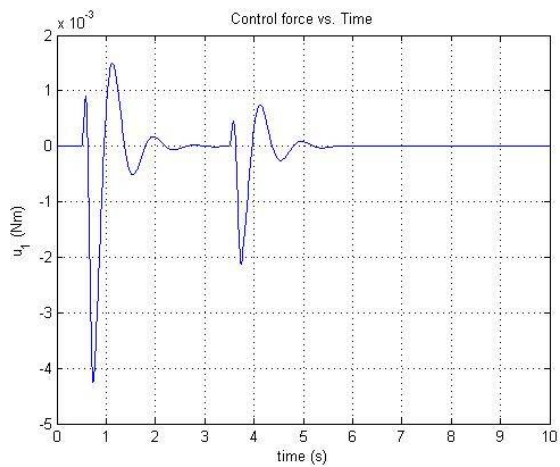


Fig.9. Controlling force by purposed controller

4.1. Comparing Simulation Result

In this subsection, the results obtained in the earlier part are compared with passive suspension system for body displacement in every roughness. Figure 10 shows vehicle body displacement for first roughness in two passive and active suspensions with purposed controller. As it stands, in the passive suspension when crossing the roughness, the body is experiencing a huge leap. Then it moves swinging that cause discomfort to the occupants and the wear of parts.

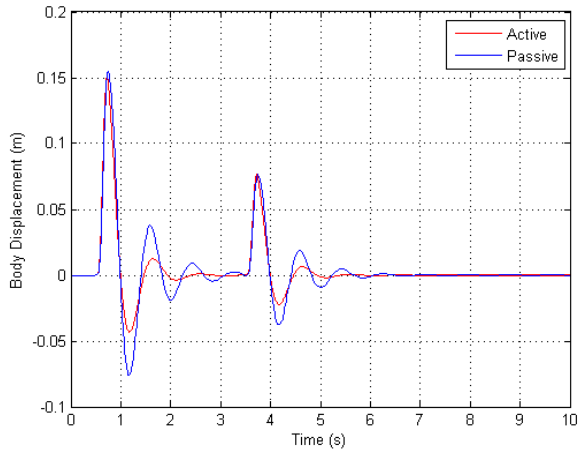


Fig.10. Comparison of body displacement for the third roughness between passive suspension and purpose

5- Conclusion

The aim of this study was the development of a Neural Network (NN) based controller for a non-linear two-degree-of-freedom vehicle model with active suspensions. In this paper, after a variety suspension system, a new control scheme is provided to control the vehicle active suspension system. The proposed controller is based on neural networks. This controller combines a neural controller with a lag network. For training,

this controller has used a different way based on non-linear optimizing a cost function. Simulation results prove that the proposed system has good performance both in terms of body displacement and vertical speed, and compared with passive suspension it is very efficient.

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