Setting Neuro-Fuzzy PID Control In Plant Nonlinear Active Suspension

Aprildy Randy Andrew Ferdinandus¹, Anggara Trisna Nugraha² and Jamaaluddin Jamaaluddin³

¹ Department Electrical Engineering, Institute Technologi Sepuluh Nopember Surabaya, Jl. Teknik Kimia, Keputih, Kec. Sukolilo, Kota SBY, Jawa Timur 60111, Indonesia
², ³ Electrical Engineering, Universitas Muhammadiyah Sidoarjo, Jl. Mojopahit, Celep, Kec. Sidoarjo, Kabupaten Sidoarjo, Jawa Timur 61271, Indonesia

Email: aprildy.ferdinandus@gmail.com

Abstract: The main problem in vibration in the vehicle is caused by the road surface. For that reason it is necessary to regulate the vibration of the vehicle suspension directly related to the road surface. Neuro-fuzzy PID controller is used to set the active suspension of the vehicle. The suspension model used is the active suspension quarter-car with nonlinear model. Faulty road surfaces are used as a disturbance in the system, interference changes in amplitude (height / depth) in the range of -25cm to 25cm. The simulation results show the performance of the PID neuro-fuzzy setting method that can overcome 77% of the amount of road noise.

Keywords: Nonlinear active suspension, PID controller, neuro-fuzzy.

1 Introduction

In the development of current suspension system technology, active suspension systems have started to be widely used, including used in passenger cars. Active suspension modeling and setting using PID controller [1]. Hinf controls for active suspension system by taking into account delay time on actuator [2]. Research to regulate active suspension system using fuzzy logic control [3]. Adjustable skyhook adaptive neuro active force control method to adjust the active suspension quarter-car [4]. Robust PID control and combined with neural network predictive control to regulate full-car active suspension [5].

In this paper, the method of setting the neuro-fuzzy tunning PID to adjust the active suspension of non-linear quarter-car. In the end the effectiveness of the proposed regulatory system.

2 The Non-Linear Quarter-Car Active Suspension

To obtain the mathematical model equations from the suspension it can be derived by using the dynamic model of the suspension. Where Ms and Mu are sprungmass and unsprungmass. Ks, Kt, Cs, Ct and F are the suspension spring constant, the tire spring constant, the suspension damper constant, the tire damper constant and the force of the actuator. While Zr, Zu and Zs are the position of the road, the position of the tire axle and the position of the vehicle body.
\[ F_{k(g)} = KZ + K' \frac{Z^3}{n} \quad (1) \]
\[ F_{c(z)} = CZ + C_n Z^2 \text{sgn}(Z) \quad (2) \]
\[ F = u \quad (3) \]

Using the nonlinear equations of springs and dampers in equations (1) and (2) the mathematical model equations of the suspension can be written down.

\[ M \ddot{Z} + F_{cs} + F_{ks} = u \quad (4) \]
\[ M \ddot{u} + K_{u}(Z_{u} - Z_{r}) + C_{u}(\dot{Z}_{u} - \dot{Z}_{r}) - F_{cs} - F_{ks} = -u \quad (5) \]

With

\[ F_{ks} = K_{s}(Z_{s} - Z_{u}) + K_{ns}(Z_{s} - Z_{u})^3 \quad (6) \]
\[ F_{cs} = C_{s}(\dot{Z}_{s} - \dot{Z}_{u}) + C_{ns}(Z_{s} - Z_{u})^2 \text{sgn}(Z_{s} - Z_{u}) \quad (7) \]

For force actuators on active suspension hydraulic actuators are used with the model shown in Fig. 1. Hydraulic actuators are formed using electro-hydraulic servovalves and added to the semiactive suspension, which can produce force forces on the suspension between sprung and unsprung mass. By changing the position of the spool \((u_1)\) then the force given by the actuator will change depending on the position of the spool. The equation of the hydraulic actuator can be written as follows.

\[
\hat{F}_A = A_p a (C_{d_1} \mu_1) \frac{P_s - \text{sgn}(u_1)P_L}{\rho} \]
\[-C_{d_2} \mu_2 \text{sgn}(P_L) \]
\[-\frac{2P_L}{\rho} - C_{m_1} P_L - A_p (X_s - X_u) \]
\[ \ddot{u} + u = kv \quad (9) \]
\[ P_L = \frac{F_A}{A_p} \]  \hspace{1cm} (10)

where \( A_p \) is the piston area, \( C_{di} \) is the coefficient of discharge, \( \alpha \) is the hydraulic coefficient, \( w \) is the spool valve width, \( P_s \) is the supply pressure, \( P_L \) is the pressure caused by the load, \( \rho \) is the hydraulic fluid gravity and \( C_{tm} \) is the wasted coefficient. The parameters of the suspension system can be seen in table 1.

| Parameter | Nilai (SI) |
|-----------|------------|
| Ms        | 360 kg     |
| Mu        | 25 kg      |
| Cs        | 500 N s/m  |
| Ks        | 1000 N/m   |
| Ct        | 0          |
| Kt        | 300000 N/m |
| Ap        | 0.0044 m²  |
| C_{di}    | 0.7        |
| \alpha    | 2.273e9 N/m³ |
| w         | 0.008 m    |
| Ps        | 20684 kN/m² |
| \rho      | 3500       |
| C_{tm}    | 15e-12     |

2.1 PID controller

PID controller consists of proportional controller P, integral I and derivative D. The control signal \( u(t) \) is given by

\[ u(t) = K_p e(t) + K_i \int e(t) dt + K_d \frac{de(t)}{dt} \]  \hspace{1cm} (11)

with \( e(t) \) is error

\[ e(t) = y_r(t) - y_0(t) \]  \hspace{1cm} (12)

where \( y_r(t) \) is the desired reference or response and \( y_0(t) \) is the output response. \( K_p, K_i, K_d \) are proportional gain, integral gain and derivative gain respectively.

2.2 Neuro-fuzzy
The fuzzy system can be represented in the layer structure as in the neural network. With the aim of optimizing the parameters in the fuzzy system, the learning algorithm of neural network is used, this approach is called neuro-fuzzy modeling.

Figure 2 shows an example of a neuro-fuzzy model representation with two rules. Where can a control of Takagi-Sugeno fuzzy system with two rules:

if $x_1$ is $A_{11}$ and $x_2$ is $A_{21}$ then $y = b_1$
if $x_1$ is $A_{12}$ and $x_2$ is $A_{22}$ then $y = b_2$

![Fig. 2. Neuro-fuzzy with two rules](image)

By using two inputs and each one has two conditions in this paper is used neuro fuzzy with neuro-fuzzy structure as shown in Figure 2 and has 2 rules as in the example above with

$$b_1 = \beta_1 (K_{p1} e + K_{d1} \frac{de}{dt})$$

$$b_1 = \beta_2 (K_{p2} e + K_{d2} \frac{de}{dt})$$

where $\beta_1$ and $\beta_2$ are normalizations of $\beta_1$ and $\beta_2$.

$$\beta_k = \frac{\beta_k}{\beta_1 + \beta_2} : i = 1, 2$$

![Diagram of neuro-fuzzy system](image)
Fig. 3. The system architecture of suspension settings uses neuro-fuzzy PID

Figure 3 shows the design of the suspension control system discussed in this paper. Setting the suspension using the method of setting the neuro-fuzzy tuning PID.

2 Simulation Results

Several simulation results are presented in this paper to demonstrate the performance of the neuro-fuzzy PID control in adjusting the non-linear quarter-car active suspension. Figure 4 shows the output response of the suspension without the controller (open-loop). The yellow line shows the vertical displacement of the sprung mass (body of the vehicle), the red line indicating the vertical displacement of the unsprung mass and the blue line indicating the vertical displacement of the path. The wheel axle (unsprung mass) is as high as 35cm from the road surface and the vehicle body is as high as 65cm from the road surface.

![Open-loop suspension system output response](image)

(a) Road disturbances as high as 15cm, (b) road disturbances as high as 25cm

Figure 5 shows the output response of the non-linear quarter-car actuator suspension system using the neuro-fuzzy PID method. What is set is the vertical displacement of the vehicle body (sprung mass).

![Non-linear quarter-car actuator suspension system output response](image)

(a)
It can be seen that in disturbances as high as 10cm, the vehicle body moves vertically by 2.3cm or 23% of the magnitude of the disturbance. Furthermore, on road disturbances as high as 25cm, the vehicle body moved vertically by 3.2cm or 14% of the magnitude of the disturbance.

3 Conclusion

In this paper, the PID neuro-fuzzy tuning method is designed to adjust the active suspension of quarter-car with nonlinear models. The performance of the regulatory method can be seen in chapter 4. Using the PID neuro-fuzzy tuning method, the suspension can face major road surface disturbances and the vertical displacement of the vehicle body is smaller than the vertical displacement of the disturbance. With disturbances as high as 15cm, the vehicle body moves vertically by 23% of the disturbance and when disturbances are as high as 25cm, the vehicle body moves vertically by 19% of the disturbance. It can be seen that the PID neuro-fuzzy setting method can overcome 80% of road noise. For further research can add delay time from the actuator and other considerations so that the system can be closer to the real plant.

References

[1] Chen, Po-Chang. & Huang, An-Chyau. (2005): Vehicle active suspension systems with time- varying loadings, Journal of Sound and Vibration 282, 2005, 1119-1135.
[2] Donahue, Mark D. (2001): Implementation of an active suspension, preview controller for improved ride comfort, University of California at Berkeley.
[3] Dowds, P., & O’dwyer, A. (2005): Modelling and control of a suspension system for vehicle applications, School of Electrical Engineering System ARROW@DIT.
[4] Du, H., & Zhang, N. (2007): Hinf control of active vehicle suspensions with actuator time delay, Journal of Sound and Vibration 301, 236-252.
[5] Eski, I., & Yildirim, S. (2009): Vibration control of vehicle active suspension system using a new robust neural network control system, Simulation Modelling Practice and Theory 17, 778-793.)