PID Parameters Prediction Using Neural Network for A Linear Quarter Car Suspension Control

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Abstract: Providing control for suspension systems in vehicles is an enhancing factor for comfort and safety. With the improvement of control conditions, it is possible to design a cost-efficient controller which will maintain optimum comfort within harsher environmental conditions. The aim of this study is to design an adaptive PID controller with a predictive neural network model, which will be referred as NPID (NeuralPID), to control a suspension system. For this purpose, a NN (Neural Network) model is designed to produce outputs for PID's Proportional (P) parameter to provide optimum responses for different road inputs. Also, reliability of the system outputs, which is using adaptive Proportional parameter, is tested. PID parameters for linear quarter vehicle model are decided through Zeigler-Nichols method. An ideal PID model, where Integral (I) and Derivative (D) parameters are bound to Proportional parameter, is used in the system. When the outputs of different controlled and not controlled systems, which are free, PID and NPID, are compared; it has been seen that NPID outputs are more convenient. In addition, it is possible to design controllers, with adaptively adjusting P parameter, which are operating cost-effective.

Keywords: Neural Network, PID, Quarter Car Model, 2-DOF, Suspension Control, MATLAB

1. Introduction

Active suspension systems are a topic, that researched intensively, which is progressing forwards day by day. The development process of controllers, which started with PID controllers, is continuing with Fuzzy Logic, Neural Network, Genetic Algorithm controllers, etc., which are able to adept themselves to the situation. Nowadays, these self-adapting controllers are often being used in a combination with PID controllers. Fairley T.E., discusses the effects of waist problems on driving safety, also their effects on the economy due to health problems, labour loss, etc. [1]. Deprez K. et al. in their work which is based on Fairley T.E.'s, discuss about tractor comfort [2]. Evers W.J. et al. as an addition to Deprez K.'s work discuss and share results about the need of vibration control in trucks [3].

PID controller is a type of controller, which is designed to eliminate settling time delay, maximum amplitude and oscillating behaviour of the output, via gathered error information from reference value and feedback signal. Even as a fundamental controller, PID is a substantial method for controlling certain systems. Ekoru J.E.D. et al., control a vehicle with non-linear hydraulic actuators via PID controllers [4]. Hussin M. et al., discuss performances of Ziegler-Nichols and Iterative Learning methods which are used for deciding PID parameters for hydraulic actuators [5]. Mhaskar P. et al. define an optimization algorithm to classical tuning methods for determining PID parameters in a non-

linear dimension [6]. Onat C. et al., designed a non-linear H∞ controller for optimizing the conflict between suspension stroke and comfort; and discuss its performance [7].

Fuzzy logic algorithms are developed especially utilizing human decision ability. For this purpose, data about the problem first made blurred, after that made decided via a deducing unit and finally results are gathered via clarifying method [8]. Sahraie B.R. et al., used a Type 2 Fuzzy Logic system for controlling a vehicle suspension system; and discuss the effects of noise in the signal [9]. Sakman E.L. et al., designed a Fuzzy Logic controller for a 4 DOF vehicle where velocity and acceleration were inputs to controller [10]. Pekgokgoz R.K. worked on an active suspension system controller application which was controlled by a Genetic Algorithm optimized Fuzzy Logic controller [11]. Neural Networks (NNs) are algorithms designed from human brain neuron models which can learn and deduce results despite missing information. NNs are especially used for solving non-linear problems. Some researchers used NN control methods in their works. In Table I studies where NN were used, are summarized.

Using multilayer architectures in NN systems sometimes may cause unreliable behaviors to be seen. Most of literature points out about this. The reason that causes this unreliability problem is the uncertainty of the mathematical model in the hidden layers. While working NN determines a mathematical model to itself and computes according to it. Whereas superior part of a NN system is also this mathematical flexibility which enables it to adept. In this study reliability of NN systems are discussed.

First, quarter vehicle model is presented. Then, quarter car with a PID controller is put forth and its ideal working conditions were determined. After that, NN is added to the system for prediction of PID parameters. Hypothesis which is proposed is that NN should not pass the ideal gain ration. While working, if NPID keeps itself

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Table 1. Summary of studies where nn control were used

Researcher	Controller Component(s)	Applied System	Neuron Layer Count Neuron Count Training Method	Results
Xu J. Et al.[12]	NNC	Non-linear Quarter Vehicle	2 7+2 Backprop. LMA	Effectively Imitating The Analytical Model
Kayhan G. et al. [13]	NNC	Non-linear Full Vehicle	2 9+8 CBA	Best Comfort Condition
Dawai L et. Al.[14]	NNI, NNC	Simpack- Full Vehicle	2+2 Unspecified Backprop., Regressive Algorithm	Improvement in Main Body Movement
Fang M.C. et al. [15]	2x NN, PID	Ship Model	2 Unspecified Backprop.	Improvement in Main Rigid Body Movement
Eski İ. et al.[16]	Robust NN, PID	Linear Full Vehicle	2 Unspecified Backprop. LMA	High Success Road Following
Pedro O.J., et al., [17]	Direct Adaptive NN, PID	Non-linear Quarter Vehicle Model	2 30+2 Feedback Linearization	Better Than PID
Dahunsi O.A. et al.[18]	PID, NN	Non-linear Quarter Vehicle Model	2 5+2 Backprop. Algorithms were tried. Best result: LMA	High Success Road Following
Lin Jeen et al. [19]	Self Org. Fuzzy, Radial Basis Func. NN	Non-linear Quarter Vehicle Model	2 40+2 Backprop. LMA with Radial Basis Function	Fast Learning and High Success Road Following
Kenan Muderrisoglu et al.	NN Predictive Controller, PID Controller	Quarter Vehicle Model	2 500 Backprop.	Better Than Classical PID and Adaptive NeuralPID Config.

in the boundaries of ideal gain ratio and follows the road input better than classic PID, reliability of NN for this system will be proven higher. Developed controller is applicable.

2. Material and Method

2.1. Quarter Car Model and PID Control

In this work the model which was controlled is a quarter car model that is shown as Figure 1. The model consist of,

• The main body mass of car as m_1
• The wheel mass as m_2
• The suspension stiffness as k_1 and damping as c_1
• The wheel stiffness as k_2 and damping as c_2
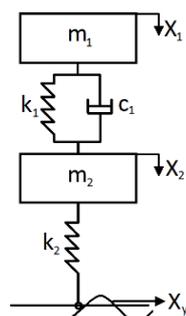• Road entry as pulse signal.

Figure 1. Quarter car model

The mathematical MATLAB equations (1) and (2) of the quarter car model is,

$$Function1 = (-1/m_1)(c_1(\dot{x}_1 - \dot{x}_2) + k_1(x_1 - x_3)) \quad (1)$$

$$Function2 = (-1/m_2)(c_1(\dot{x}_2 - \dot{x}_1) + k_1(x_2 - x_1) + k_2(x_3 - x_y)) \quad (2)$$

In the study, the coefficients of the PID controller which are wanted to work adaptively were identified via Ziegler-Nicholes method according to step response. The purpose is a PID controller with controlled variables; therefore, the ideal PID model was chosen that I and D coefficients were been able to set depending on P coefficient which is the output of neural network.

P, I and D coefficients of PID controller was found by the method of Ziegler-Nicholes. The transient time decreased %85 when the system was controlled by these parameters. But the first amplitude of response and accelerations on suspension system were too high. So other coefficients were identified by PID simulation based. I=0.00005 and D=0.025 found proportional depend on P parameter and maximum P was taken as 12000. When P was given as more than 12000, the response went infinity for more than 100 seconds solution.

2.2. Making the Simulink Model

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The system is a 2-DOF quarter car suspension model. The quarter car model and PID Simulink model is given in Figure 2.
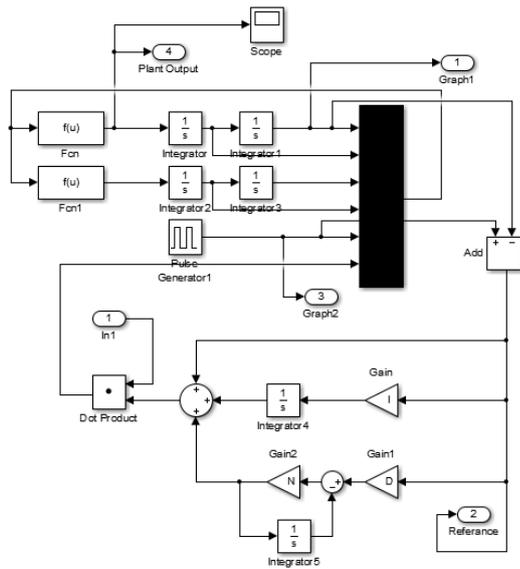

Figure 2. Quarter car and PID Simulink model

Different coefficients for different conditions were the goal. But standard PID module was not enough. So the ideal PID model was established. The aim was optimization of parameters using changing proportional coefficient with constant I and D values. So PID controller has to be controlled by a decision mechanism which
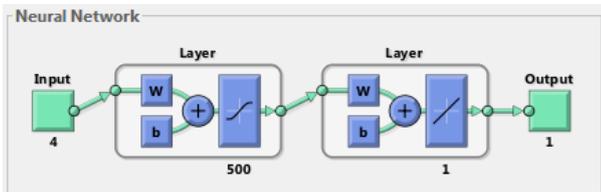

Figure 3. NN schema

is predictive and keep the error minimum. For healthy control result, a neural network model was developed.
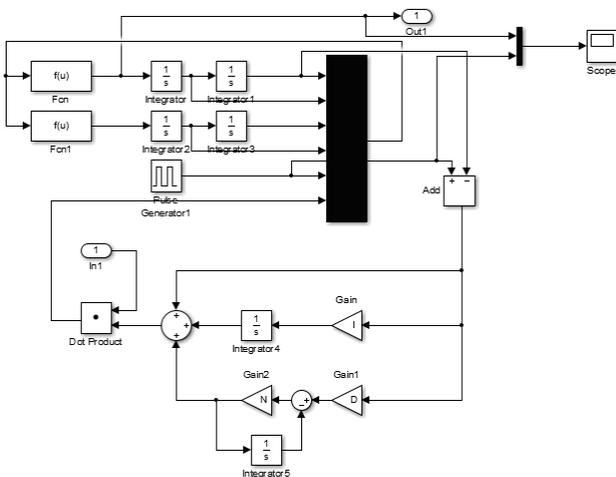
2.3. Neural Network (NN) Model

Figure 4. NN training model

In this work, the purpose of NN is estimate the P parameter of PID controller. Developed NN model is shown as Figure 3.

First of all, it was researched what kind of changings were needed due to the NN module structure. Next, the suspension control model was revised in two different ways in Simulink. First one is the training model which was introduced in NN module. Second one is the system which was controlled with NN output. These two systems are different. NN module wants a system to educate which has one-input one-output. The first model is shown as NN training model in Figure 4 that input is P and output is the acceleration of main mass of the car. For the second system as Figure 2, P is the main control input as In1, output is the oscillation of the main mass of the car and the others are the graph outputs.

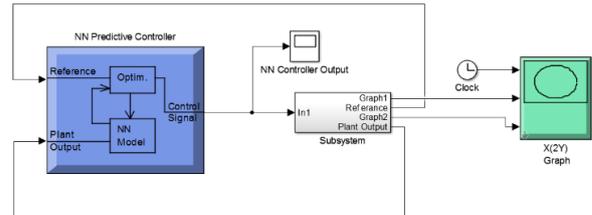The general NN structure is as Figure 5. NPID controller was

Figure 5. General NN structure

designed for the quarter car model. The error between road displacement input and main body displacement output was used as a reference input for NN controller. The acceleration response of the main mass is identified as NN input. Also there is two inputs inside module as optimization and NN model. So NN consists of 4 inputs, 1 output and 2 hidden layers.
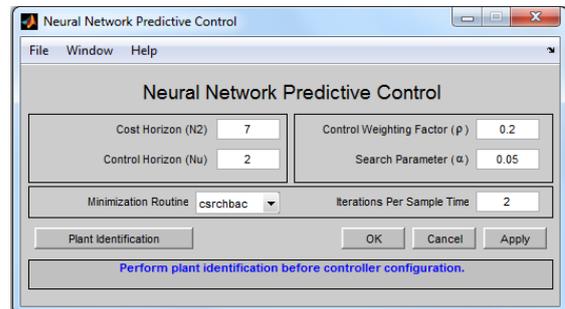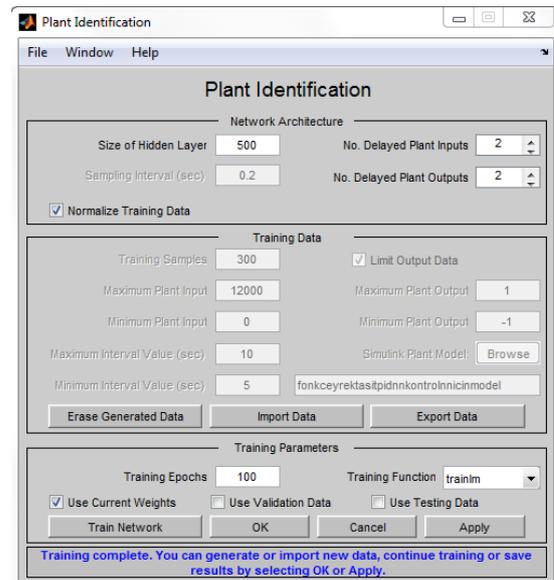

Figure 6. Preferences of NN 1

Figure 7. Preferences of NN 2

500 neurons was found appropriate in consequence of tries. The training method was chosen as Levenberg-Marquardt (trainlm). Back propagation method was chosen as learning method due to 2
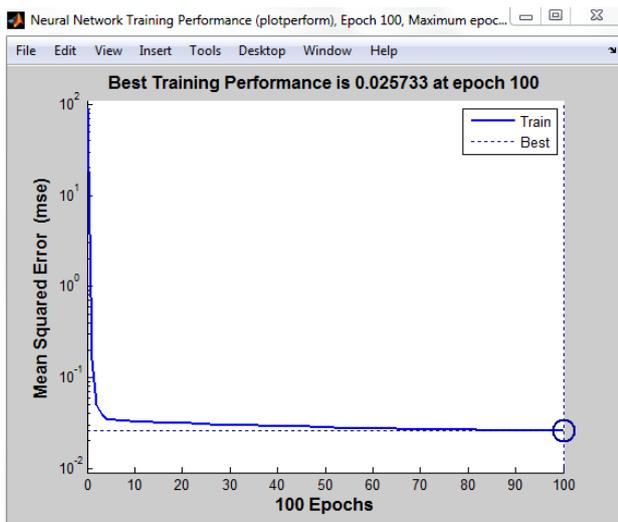

Figure 8. NN training performance

layer NN structure. 300 training data was generated and 100 epochs was preferred. The preferences of NN is shown as Figure 6 and Figure 7.

Via chosen parameters and methods, the performance of system was reached maximum level at the beginning of epochs around 3×10^{-2} error level as Figure 8.

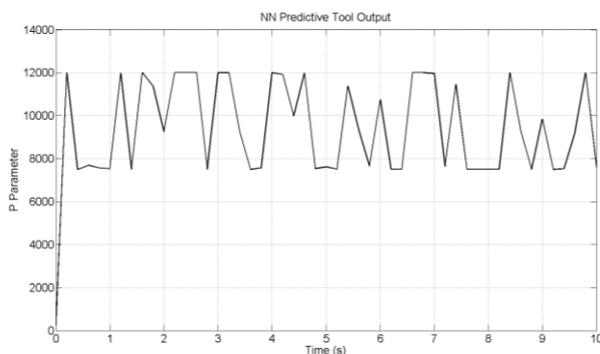Control of the main body mass displacement was achieved via

Figure 9. NN output P

acceleration of this mass. At this point, accuracy of NN was tested. It shows that maximum chosen value as 12000 is right as well as NN is trying to work in minimum error to take this value as the maximum in Figure 9. When NN trained, validating was cancelled. Because it stops after 6 validation. So NN couldn't finish the training.

3. Results and Discussion

In the system model, disturbance defined as a road input which is a pulse function with characteristics of 2 seconds period, 20 percent duty cycle and 10 cm amplitude.

Figure 10 shows displacement of the main mass of the system in Free uncontrolled, PID and NPID controlled conditions with disturbance input.

Free system shows 5 cm peak main mass displacement and more than 2 seconds of settling time output for disturbance input. Here, there are uncontrolled oscillations in the system which decreases
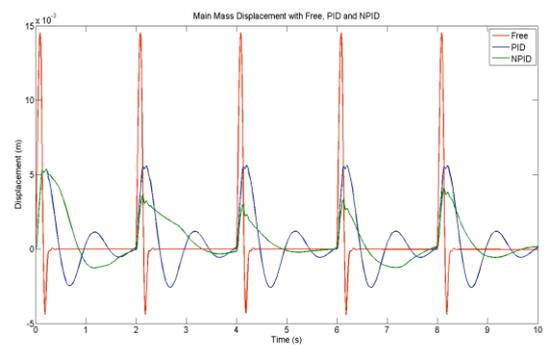

Figure 10. Main mass displacement in Free uncontrolled, PID and NPID controlled systems

comfort conditions. To raise the comfort conditions applying control is suggested. When the systems is controlled with PID parameters which found through Ziegler-Nichols, the result has been made worse and system shows almost 15 cm of maximum main mass displacement and approximately 0.3 seconds of settling time. However this sudden increase in displacement and such short settling time causes high acceleration values which put the system out of the boundaries of comfort zone. This shows divergence of PID control outputs from desired results under limit conditions. NPID system, which has parameters which were found by simulation methods as D=0.025, I=0.00005 and NN output limits between 0-12000, for P coefficient shows 3-5 cm of peak main mass displacement and averagely 1-2 seconds of settling time. Displacement based, NPID system shows up to 2 times improvement from free system and up to 5 times improvement from PID controlled system. Additionally, having an adaptive controller in the systems decreases the amount of oscillation in the system output. With both low amplitude peak displacements and less oscillation raise in comfort is achieved. As a result, NPID system works better and improves comfort better than Free uncontrolled and PID controlled systems.

4. Conclusion

In this study, linear quarter vehicle model has been controlled with using PID Method. Due to adaptive PID parameter estimation, Artificial Neural Networks has been built. Therefore, NN efficiency has been observed. Ideal PID parameters has been obtained with using Ziegler-Nichols Method. Because of insurance of the PID efficiency, proportion parameter amount has been limited to ideal proportion of controller. NN tool has been trained using Back-Propagation Method with Levenberg-Marquet Algorithm. Algorithm has been operated on random road profile. In results, NN tool configuration are giving hope. While Trained NN tool has been operated on system, proportion parameter has been selected by NN tool more adaptively, due to tracking of the road profile. Furthermore, NN tool has been tried to predict RMS value of the road profile. Herewith, it can be said that, high reliability level of NN tool can be obtained, if suitable method and training algorithm has been established. This study has been made using 2 neuron layer. If we would understood the mechanism between the layers, it could be possible to make a NN system more than 2 layers in practical. With that, ganglion type NN system can be made in future and it can be improved capacity and capability of the NN controller significantly.

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