Adaptive PID Controller Based on BP Neural Network

Beitao Guo [1,2]
[1] Shenyang University Of Chemical Technology
[2]School of Mechanical Engineering and Automation, Northeastern University
Shenyang, Liaoning Province, China
guoabt@sohu.com

Hongyi Liu, Zhong Luo, Fei Wang
School of Mechanical Engineering and Automation, Northeastern University
Shenyang, Liaoning Province, China

***Abstract*—Adaptive PID controller based on back propagation(BP) neural network has many merits like that simple algorithm of PID controller and self-study and adaptive functions of neural network. According the requirements of system output performance, the BP neural network can auto-adjust its weights to vary k_p , k_i and k_d . The simulation results of an electro-hydraulic position servo control system using adaptive PID controller based on BP neural network show that it can get better control characteristics and adaptability, strong robustness in the nonlinear and time vary system. At the same time, simulate results provided a theoretical basis for the design and application of electro-hydraulic position servo control system.**

Keywords-PID; back propagation neural network; servo control; simulation.

I. INTRODUCTION

The proportional-integral-derivative (PID) controller is one of the most commonly controllers in the industrial closed loop control system for its simple algorithm, good robustness and stability. But PID controller has its disadvantage that it is not suitable for the control of long time-delay and nonlinear system, in which the P, I and D parameters are difficult to choose and can hardly adapt to time varying of characteristics in wide range.

With the development of modern computer technology and control theories such as fuzzy, neural networks and gray theory are developed. Back propagation (BP) is one of neural network and is powerful computational tools that have been used extensively in the areas of pattern recognition, systems and identification. But BP neural network also has its shortages that have long training time and cannot meet the quick performance of the control system. The adaptive PID controller based on back propagation neural network which is designed combining traditional PID strategy with neural network has created a new concept and a new tool for control. The self-learning ability of BP neural network can tune automatically and modify the robust PID parameters on-line. Simulation results show that the PID controller obtained by the PID controller combining BP neural network can gives satisfactory results.

II. ADAPTIVE PID CONTROLLER BASED ON BP NEURAL NETWORK

A. *Structure of BPNN*

BPNN is composed of input layer, hidden layer and output layer. In figure 1 the structure of BP neural network, whose numbers are determined by complexity of controlled plant. The first layer is input layer, Neurons at the middle layer are in hidden layer, The third layer is output layer including PID parameters k_p , k_i and k_d .

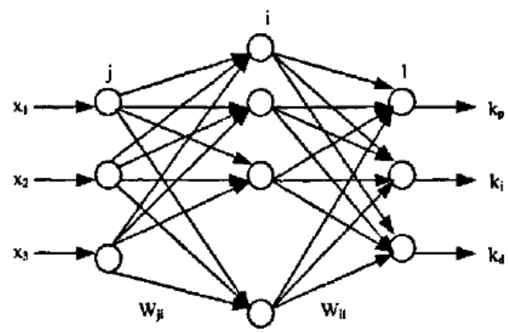

Figure 1. BP neural network structure

B. *Algorithm of BP Neural Network*

The proportional-integral-derivative (PID) controller is the common controller in the industrial closed loop control system. The digital incremental PID algorithm is shown as follow:

$$\begin{aligned} u(k) &= u(k-1) + k_p(e(k) - e(k-1)) + k_i e(k) \\ &\quad + k_d(e(k) - 2e(k-1) + e(k-2)) \end{aligned} \tag{1}$$

Learning algorithm of BP neural network is described as follow:

The network input is x_j (j =1,2,... n), the input and output of hidden layer is shown in formulas (2) and (3).

$$net_h(k) = \sum_{j=0}^{M} w_{ij} x_j \tag{2}$$

$$O_h(k) = f(net_h(k)) \quad h=1,2,\cdots n \tag{3}$$

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Where w_{ij} is the weight value of hidden layer. The activation function of hidden layer adopts symmetrical sigmoid function.

$$f(x) = \frac{e^x - e^{-x}}{e^x + e^{-x}} \tag{4}$$

Inputs and outputs of output layer is formulated as follow:

$$net_o(k) = \sum_{j=0}^{M} w_{ij} O_h \tag{5}$$

$$O_o(k) = g(net_o(k)) \qquad h = 1,2,\cdots n \tag{6}$$

$$O_1 = k_p \tag{7}$$

$$O_2 = k_i \tag{8}$$

$$O_3 = k_d \tag{9}$$

III. CONTROL MODEL SIMULATION RESEARCH

The classical electro-hydraulic position servo control system is shown in figure 2. In figure 2 there are electro-hydraulic servo valve and hydraulic cylinder etc in the system.

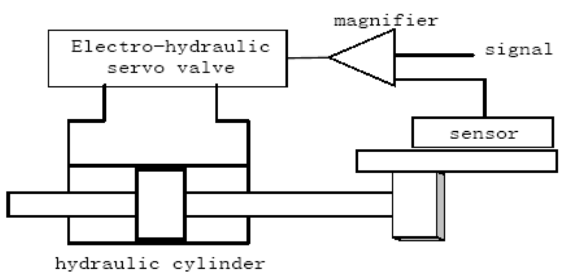

Figure 2. The sketch graph of electro-hydraulic position servo control system

The electro hydraulic servo-drive is equipped with an actuator and a servo valve. Its transfer function between the actuator piston rod displacement and the servo valve command signal is defined as follows:

$$K_o(s) = K_{SV}(s)K_A(s) = \frac{k_{SV}}{\frac{s^2}{\omega_{SV}^2} + \frac{2\xi_{SV}}{\omega_{SV}} + 1} \times \frac{k_A}{s(\frac{s^2}{\omega_A^2} + \frac{2\xi_A}{\omega_A}s + 1)}$$

Where $K_{sv}(s)$ is the transfer function of the servo valve; $K_A(s)$ is the transfer function of the actuator; k_{sv} is the servo valve gain coefficient; k_A is the actuator gain coefficient; ω_{sv} is the servo valve natural frequency; ω_A is the actuator natural frequency; ξ_{sv} is the servo valve damping ratio; and ξ_A is the actuator damping ratio.

The control method is adaptive PID control based on BP neural network. The structure of adaptive PID control based on BP neural network is shown in figure 3.

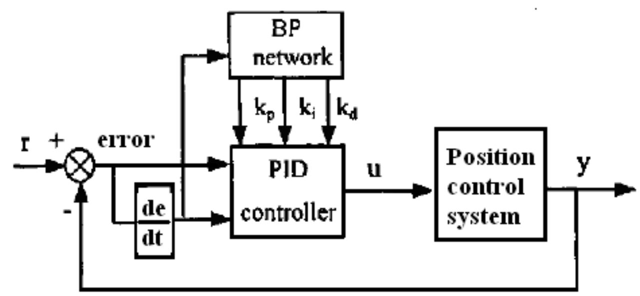

Figure 3. Structure of adaptive PID control based on BP neural network

The algorithm and step of adaptive PID controller based on BP neural network is described as follow:

(1) Choosing the structure of the BP neural network , selecting the node number of each layer and giving the initial value of the learning speed rate η and inertial coefficient α ;

(2) Sampling input variety r(k) and y(k), calculating error(k), e(k)= r(k) –y(k);

(3) Calculating input and output of nerve cell of each layer of BP neural network. The output varieties of output layer of BP network is namely three adjustable parameters of PID controller k_p , k_i , k_d .

IV. SIMULATION RESULTS

The simulation method combines SIMULINK module and M functions, and the main program is realized in SIMULINK. PID parameter on-line adjustment method based on BP neural network is described as follow: The structure of learning BP neural network is 4-5-3, learning speed $\eta = 0.21$, inertial coefficient $\eta = 0.06$, and initial connecting value between each node is random value at [-0.5, 0.5]. The results of simulation are shown in figure 4, figure 5, figure 6.

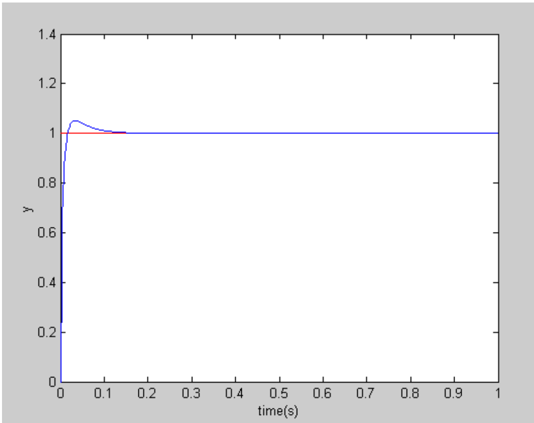

Figure 4. The step response of electro-hydraulic position servo control system.

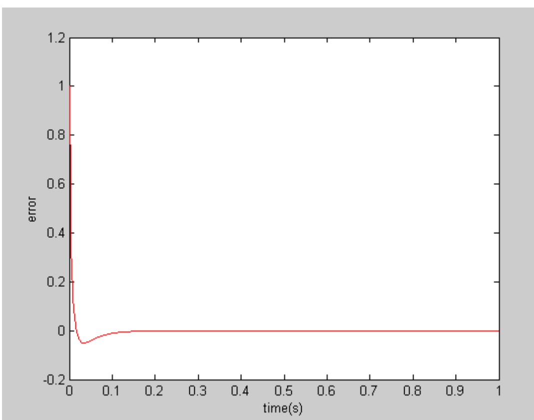

Figure 5. The error (r(t)-y(t)) value

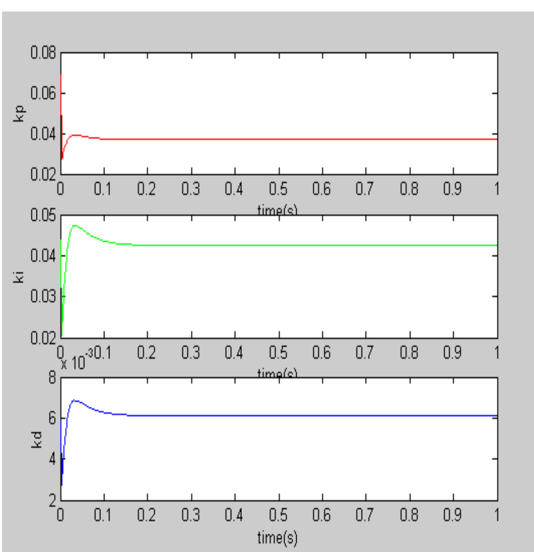

Figure 6. Parameter adaptive turning curves of the step

The system output tracts the reference input satisfactorily and the performance of the proposed controller is better than that of the conventional PID controller as shown in figure 4. The PID parameters k_p, k_i, k_d is adjusted by self-learning of BP neural network until error approach zero as shown in figure 5 and figure 6. We can get a satisfied simulate curve of closed-loop control of electro-hydraulic position servo system. Simulation results prove that adaptive PID controller based on back propagation neural network control has better dynamic characteristic and the self-learning ability, at the same time, simulate results provided a theoretical basis for the design and application of electro-hydraulic position servo control system.

V. Conclusion

Adaptive PID controller based on BP neural network is proposed in this paper. The proposed controller has advantages of both self-learning capability of neural network and simplicity of PID controller. The simulation results of an electro-hydraulic position serve control system using adaptive PID controller based on BP neural network show that it can get better control robustness such as advantages of fine control precision, good self-adaptive, excellent robustness, convenient parameter setting and simple control algorithm. Also, it can be realized easily and has great prospect in artificial intelligent field.

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