Simulation and Analysis on PID Control Based on the BP Neural Network

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Abstract

PID control is suitable for to establish certainty relations of accurate mathematical model, but the actual industrial production process often with character of nonlinear and time-varying uncertainty, which is difficult to establish accurate mathematical model. In the actual production, the conventional PID controller parameter setting often bad, performance is poor, poor adaptability of operation condition. In the design of PID controller, it is very important to looking for a suitable control algorithm to realize the parameter setting k_p, k_i and k_d. In this paper, after studying the structure and algorithm of PID controller based on neural network, Using BP neural network to establish parameters k_p, k_i and k_d self-adaptive PID controller. The simulation results show that the PID control based on BP neural network has the advantages of small amount of overshoot and short adjustment time, strong adaptive ability and robustness.

Keywords

PID control, neural network, BP neural network, Simulation and Analysis

1. Introduction

Conventional PID controller has simple structure, high reliability and good stability, but in the practical process control it is often difficult to satisfy the steady-state accuracy and dynamic stability, the stability and rapidity demands at the same time, so the conventional PID control effect is not ideal at times[1]. For a complex control object, the conventional PID control parameters will change with the change of the external conditions, so the conventional PID controller has the problems of hard parameter setting and poor anti-interference ability. In order to overcome these problems, improve the adaptability, reliability and stability of the controller. In this paper, based on the BP neural network PID control was proposed and simulation analysis was carried on.

2. Basic BP Neural Network

The BP neural network is a one-way transmission of multi-layer forward network, its structure is shown in figure 1[2].Like the figure show, BP network is one kind of neural networks with more than three layer or three layer, including the input layer, hidden layer and output layer. Between the upper and lower level can realize the whole connection, while there is no connection between each layer of neurons. When a pair of learning samples was provided to network, the neuronic activation values from the input layer through the hidden layer to output layer, the network input response will be got in the output layer of the network. Next, according to the direction of reduces the target output and the actual error. The connection weights can be modified step by step from the output layer through the hidden layer, this algorithm called "error back propagation algorithm, and it is BP algorithm.

With the ongoing correction of the reverse spread of this kind of error, the accuracy of network to the input mode response is also rising.

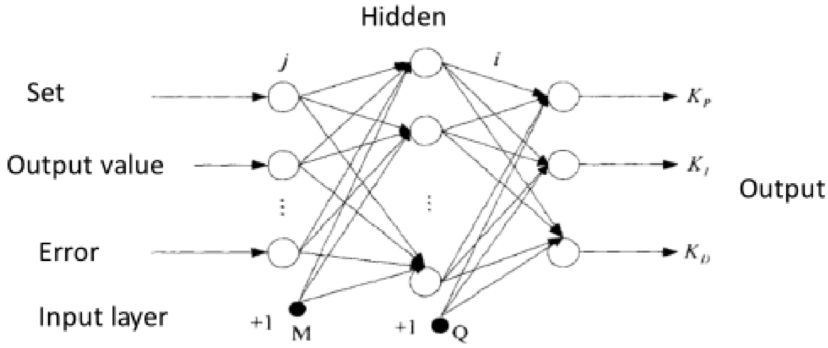

Fig.1 The structure of the BP neural network

3. BP Neural Network Learning Algorithm

It is known that the input vector of the network u is n-dimension, the output vector is m-dimension, and the length of input/output samples is L. BP learning algorithm is composed of forward and reverse transmission.

In the forward transmission, the input signal from the input layer through the hidden layer to output layer. If the output layer gets the desired output, the learning algorithm ended, otherwise, turn back to the reverse transmission.

Reverse transmission is to calculate the error signal (the difference between the sample output and network output) reversely according to the original connecting path, and by the gradient descent method to adjust the weights of each neuron and threshold, and to reduce the error signal[3].

PID control algorithm based on BP network is summarized as follows:

1) To make the BP neural network structure is determined, to determine the nodes and the number 'm' of the input layer, the number 'q' of the hidden layer, and given the initial value of weight coefficient of each layer $w_{ij}^{(2)}(0)$ and $w_{li}^{(3)}(0)$, selected the learning rate ' η ' and inertia coefficient ' α ', $k=1$.

2) To get $rin(k)$ and $yout(k)$ by sample, and calculate the error, $error(k)=rin(k)-yout(k)$.

3) Calculate the input and output of each layer 'NN' of neural network, the output of the output layer 'NN' is the three adjustable parameters k_p, k_i, k_d of PID controller.

4) Calculate the output of the PID controller $u(k)$;

5) Make neural network learning, and adjust the weighting coefficient $w_{ij}^{(2)}(k)$ and $w_{li}^{(3)}(k)$ online.

6) Set $k=k+1$, and return 1.

The algorithm flow chart is shown in figure 2:

4. PID Control Based on the BP Neural Network

PID control system structure based on BP (Back Propagation) neural network is shown in figure 3. The controller consists of two parts, first, the classical PID controller: make a Closed-loop control to controlled object directly, and the three parameters k_p, k_i and k_d are in the way of online adjustment. Second, BP neural network: Adjust the parameters of PID controller according to the system running state, and to make it reach the optimization of a certain performance index, it is to say that make the output state of output layer neurons corresponding to the three adjustable parameters k_p, k_i and k_d of PID controller. Through the neural network self-learning and the weighted coefficient adjusting to make it a steady state corresponding to the PID controller parameters under a certain optimal control law[4].

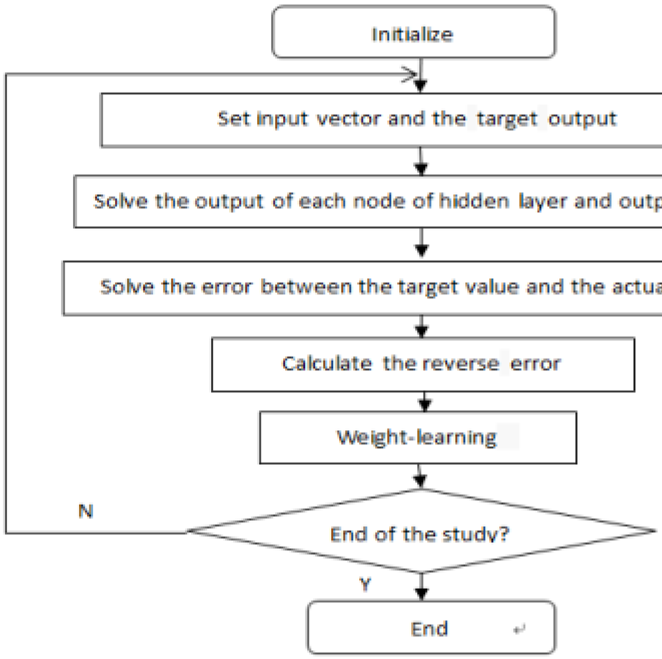

Fig.2 The BP neural network algorithm flow chart

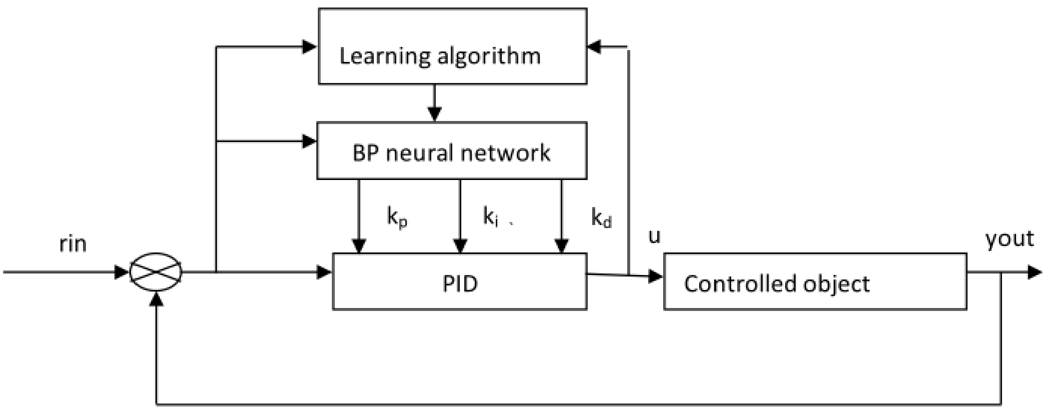

Fig. 3 The structure diagram of the BP neural network PID controller

Classic incremental digital PID control equation:

$$u(k)=u(k-1)+k_p(e(k)-e(k-1))+k_i e(k)+k_d(e(k)-2e(k-1)+e(k-2)) \qquad (4\text{-}1)$$

In the equation: k_p is the ratio coefficient, k_i is the integral coefficient and k_d is the differential coefficient.

When considered k_p , k_i and k_d to be the adjustable coefficient, which is dependent on the system operating status, the(4-1) will be described as:

$$u(k)=f[u(k-1),k_p,k_i,k_d,e(k),e(k-1),e(k-2)] \qquad (4\text{-}2)$$

In the equation, $f(\bullet)$ is nonlinear function, which have a relationship with k_p , k_i , k_d , $u(k-1)$ and $y(k)$, and it will find such an optimal control law by BP neural network training and learning. In this paper, the three layer BP neural network structure will be used, its structure as shown in figure 4.

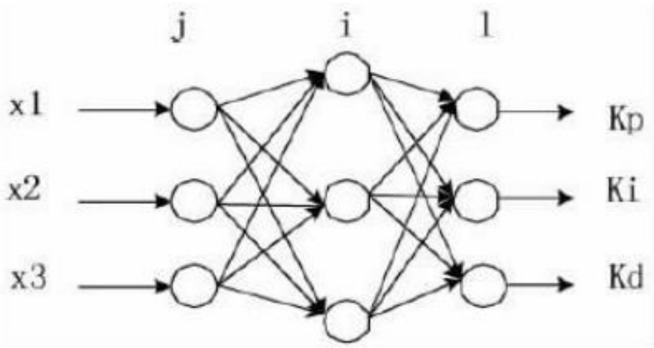

Fig. 4 Three layer BP neural network structure

As the figure shown, the input to the BP neural network is:

$$O_j^{(1)} = x(j) \qquad j = 1,2,\ldots,m \tag{4-3}$$

$$O_i^{(2)}(k) = f(net_i^{(2)}(k)) \qquad i = 1,2,\ldots,q \tag{4-4}$$

In the equation, $\{w_{li}^{(2)}\}$ is the weighting coefficient of hidden layer,the superscript (1), (2), (3) represent the input layer, hidden layer and output layer, f(x) is the hyperbolic tangent function : $f(x) = (e^x - e^{-x})/(e^x + e^{-x})$.

Lastly,the input and output of the three nodes of network is:

$$net_l^{(3)}(k) = \sum_{i=0}^{q} w_{li}^{(3)} o_i^{(2)}(k) \tag{4-5}$$

$$o_l^{(3)}(k) = g(net_l^{(3)}(k)) \qquad l = 1,2,3 \tag{4-6}$$

So as:

$$\left.\begin{array}{l} o_1^{(3)}(k) = k_p \\ o_2^{(3)}(k) = k_i \\ o_3^{(3)}(k) = k_d \end{array}\right\} \tag{4-7}$$

In the equation, $w_{li}^{(3)}$ is the weighting coefficient of output layer, the neuron activation function of output layer: $g(x) = e^x / (e^x + e^{-x})$.

Performance index function:

$$E(k) = \frac{1}{2}(rin(k) - yout(k))^2 \tag{4-8}$$

Corrected the weights of the network by the steepest descent method, it is that to do searching adjustment on the negative gradient direction of the weighted coefficient according to 'E', and attach a global minimum inertia item to make the search astringe fast, like:

$$\Delta w_{li}^{(3)}(k) = -\rho \frac{\partial E(k)}{\partial w_{li}^{(3)}} + \gamma \Delta w_{li}^{(3)}(k-1) \tag{4-9}$$

ρ learning rate,γ Inertia coefficient。While:

$$\frac{\partial E(k)}{\partial w_{li}^{(3)}} = \frac{\partial E(k)}{\partial y(k)} \cdot \frac{\partial y(k)}{\partial u(k)} \cdot \frac{\partial u(k)}{\partial o_l^{(3)}(k)} \cdot \frac{\partial o_l^{(3)}(k)}{\partial net_l^{(3)}(k)} \cdot \frac{\partial net_l^{(3)}(k)}{\partial w_{li}^{(3)}} \tag{4-10}$$

The variable needed here is $\partial y(k)/\partial u(k)$, as $\partial y(k)/\partial u(k)$ is unknown, so replaced by the approximate, and then the effect of inaccurate calculation will be followed, and the effect can be compensated by adjust the learning rateρ. By (4-7):

$$\left.\begin{aligned}\frac{\partial u(k)}{\partial o_1^{(3)}(k)} &= e(k)-e(k-1)\\ \frac{\partial u(k)}{\partial o_2^{(3)}(k)} &= e(k)\\ \frac{\partial u(k)}{\partial o_3^{(3)}(k)} &= e(k)-2e(k-1)+e(k-2)\end{aligned}\right\} \tag{4-11}$$

In this way,the BP neural network output layer weight calculation equation is:

$$\Delta w_{li}^{(3)}(k)=\rho\delta_l^{(3)}o_i^{(2)}(k)+\gamma\Delta w_{li}^{(3)}(k-1) \tag{4-12}$$

$$\delta_l^{(3)}=e(k)\frac{\partial y(k)}{\partial u(k)}\frac{\partial u(k)}{\partial o_l^{(3)}(k)}g'(net_l^{(3)}(k)) \quad l=1,2,3 \tag{4-13}$$

In the same way, the weight calculation equation for the hidden layer is:

$$\Delta w_{ij}^{(2)}(k)=\rho\delta_i^{(2)}o_j^{(1)}(k)+\gamma\Delta w_{li}^{(2)}(k-1) \tag{4-14}$$

$$\delta_i^{(2)}=f'(net_i^{(2)}(k))\sum_{l=1}^{3}\delta_l^{(3)}w_{li}^{(3)}(k) \quad i=1,2,\ldots,q \tag{4-15}$$

5. Simulation and Analysis on PID Control Based on the BP Neural Network

In this paper, the nonlinear first-order system $yout(k)=\frac{1.2*(1-0.8\bullet\exp(-0.1\bullet k))\bullet y(k-1)}{(1+y(k-1)^2)}+u(k-1)$ will be used to simulation . The simulation of the BP neural network PID control and single neuron PID control will be done by MATLAB respectively. The results of the simulation as shown in table 5-1

Table.5-1 the comparison of dynamic performance parameters

control method / Performance indicators	K=1.2		K=2		Add delay link	
	BPPID	SNPID	BPPID	SNPID	BPPID	SNPID
t_p (s)	0.044	0.05	0.029	0.03	0.029	0.021
δ (%)	0	0	0.89	0.96	0.27	2.09
t_s (s)	0.044	0.05	0.17	0.206	0.07	0.123
PID parameters	K_p=0.05 K_i=0.06 K_d=0.01	ω_{kp}=8.89 ω_{ki}=4.04 ω_{kd}=−0.67	K_p=0.04 K_i=0.05 K_d=0.01	ω_{kp}=8.68 ω_{ki}=2.32 ω_{kd}=−0.74	K_p=0.07 K_i=0.09 K_d=0.01	ω_{kp}=−0.76 ω_{ki}=0.26 ω_{kd}=−0.49

After analysis table 5-1, it shows that PID parameters change in the moment, which verifies the based on neural network PID control has the adaptive ability and the parameter can be adjusted online. PID control based on BP neural network and single neuron PID control, when the controlled object is same there is a little difference between their dynamic performances. But when the controlled object parameters change, compared with SNPID control system, the BP neural network PID control system has more advantages, such as less overshoot, short setting time, the strong adaptive ability and strong robustness. So this method is better than that of based on single neuron PID control, and it is also superior to the traditional PID control.

6. Conclusion

In this paper, the PID control based on BP neural network has been studied. The structure of BP network is simple, and it is able to self-learning and finds the PID parameters under the optimal control. Do simulation to the controlled object of nonlinear slowly-varying by MATLAB. The simulation results show that, When the controlled object parameters change, The control system can still make the controlled object to achieve better effect on control values. It is also verified the BP neural network has strong adaptability and robustness, and compared with the traditional PID control, this algorithm has a better effect.

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