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Research on PID Control of BLDCM based on BP Neural Network

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Abstract

When using the conventional PID control method for brushless DC motor speed regulation, because the controlled object is a multivariable, strong coupling nonlinear system, there will be problems of poor parameter setting and performance, which leads to the motor control is difficult to achieve the ideal effect. In order to solve these problems, BP neural network is used to change the parameters of PID controller on MATLAB platform to control brushless DC motor for simulation. The simulation results show that the speed control system of the motor has better steady-state precision and dynamic performance when using neural network PID control, which can further change the performance of the control system and achieve the purpose of optimization.

Keywords

Brushless DC Motor; BP Neural Network; PID Controller; MATLAB Simulation.

1. Preface

Brushless DC motor has the same advantages as AC motor, such as high reliability in operation, convenience in maintenance and protection and uncomplicated structure. In addition, it also has some other advantages. Compared with brush DC motor, it has better torque speed characteristics, higher speed and lower noise, At the same time, it also solves the disadvantages of radio interference and short availability time. At the same time, the cost of the motor is small, which makes the repair and maintenance of the motor simple. Now it is widely used in industry. In addition, the motor is also a synchronous motor, so it will not have the frequency difference phenomenon of ordinary induction motor.

Artificial neural network (ANN) has been widely used in various fields in recent years. It is often called neural network (NN). It is mainly composed of many units (also known as nodes) and units connected by each other. Neural network can achieve parallel distributed processing and storage of information [1-2]. Now there is a high utilization algorithm in its training, that is, error back propagation (hereinafter referred to as BP network). It is suitable for nonlinear differentiable functions, and is a model method with a wide range of practical applications of neural networks at present. The parameters of the controller can be optimized by BP network.

2. PID Control

2.1 PID Controller and Basic Principle of PID Control

PID controller can be widely used in many aspects of life, such as regulating air conditioning temperature, regulating water temperature and motor speed control. At the same time, it has many advantages, such as high stability, easy adjustment, good reliability and so on. P. I and D respectively represent proportion, integral and differential [3]. It also represents a kind of law, that is, the control law of P, I and D, referred to as PID control, also known as PID regulation. PID controller has achieved the transformation from analog to digital, and has made great progress after a long time of

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tempering. At the same time, all these have been obtained through many explorations, experiments and summaries in the long river of time.

For the PID control system, we can see its schematic diagram as follows, that is, as shown in Figure 1:

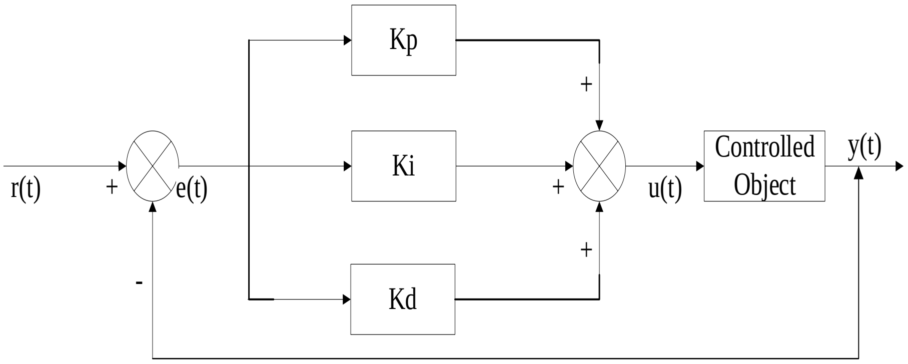

Figure 1. Schematic diagram of PID controller

2.2 Algorithm of PID Controller

The algorithm of analog PID controller is:

$$u(\mathrm{t}) = K_p[\mathrm{e(t)} + \frac{1}{T_i}\int_0^t e(\mathrm{t})\,\mathrm{dt} + T_d\frac{de(\mathrm{t})}{dt}] \tag{1}$$

The letters in the equation mean: KP is the scale factor; TD stands for differential time constant; Ti represents integral time constant; E (T) represents the difference between the set value R (T) and the actual value Y (T). The incremental PID control algorithm used can be expressed as follows:

$$\mathrm{u(k)} = \mathrm{u(k-1)} + \Delta u(\mathrm{k}) \tag{2}$$

$$\Delta u(\mathrm{k}) = K_p[e(\mathrm{k}) - \mathrm{e(k-1)}] + \mathrm{K}_i\, e(\mathrm{k}) + \mathrm{K}_d[\mathrm{e(k)} - 2\,\mathrm{e(k-1)} + \mathrm{e(k-2)}] \tag{3}$$

In the formula, the parameters to be optimized are Ki, KD and KP.

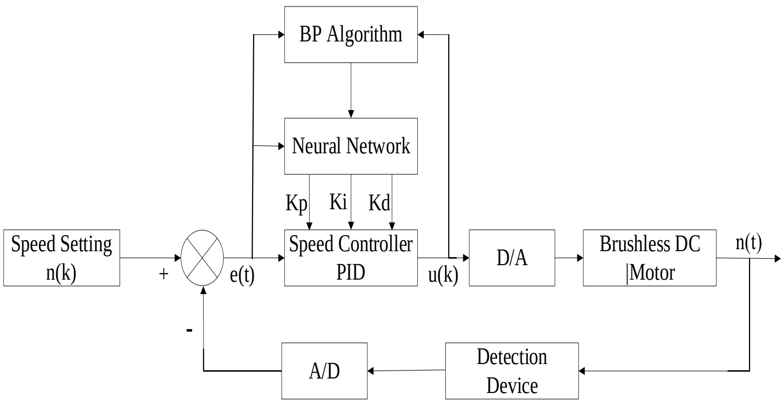

Figure 2. Speed regulation system of Brushless DC motor based on BP network

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By analyzing Fig. 2, it can be concluded that in this speed regulation system, the values of the rotator parameters Ki, KD and KP are determined by the function of neural network, and the corresponding three parameters are obtained from the third layer of the network. The BP algorithm is used in this process. The conventional PID is used to change the motor speed, and then the closed-loop control is used. For the neural network module, its role in the whole is to change the PID parameters according to the actual situation according to the latest information obtained, so that the expected optimal performance index can be obtained by the system. This network can be used to achieve the best change of the corresponding PID parameter values. At the same time, the network can be used to adjust the weighting coefficient, the ability to adapt to complex environments and the strong self-learning ability, so as to adjust the rotation speed of the motor and facilitate it to obtain the best performance index. This system adopts one of many algorithms in neural network, namely BP algorithm. This system uses incremental PID algorithm, and the corresponding relationship can be known from the figure.

3. PID Control Algorithm based on BP Neural Network

3.1 Relationship between BP Neural Network and PID Control

BP network has strong generalization ability. For the mapping relationship between input and output, it can store a lot, and does not need to be presented in advance of the mathematical method to describe this relationship. Gradient descent method is its criterion. The two important values in this system, namely critical value and weight, are debugged by using reverse propagation to minimize the sum of squares of errors in the network. The weight is the probability of realizing this path. The steady-state error can be reduced by integral until it is completely eliminated, but this may increase the overshoot; The speed of the inertial system can be accelerated by differentiation, and the overshoot trend can be weakened at the same time. The algorithm used in PID control is generally divided into two types, i.e. position type and incremental type [4]. However, the second method is often used in engineering in the industrial field.

Combining BP and PID, BP can approach any non-linear function [5] and has the ability of self-learning. It can change PID parameters online, effectively control complex controlled objects, greatly improve the function of PID controller, and illustrate the potential advantages of this network in solving two problems, These two aspects are dealing with complex nonlinear and indeterminate systems.

In this paper, BP and PID are combined to analyze their limitations. The BP algorithm [6] of BP network is used, that is, the algorithm of BP network advancing in reverse. Its basic theory is gradient descent method. In this process, using the composition of BP network, the signal obtained from the input layer is transmitted to the hidden layer, and then using the weighting coefficients and rules between neurons, it is transmitted to the output layer through the hidden layer, and the output results are compared. If it does not meet the requirements, the weighting coefficients of each layer are changed by using the error back propagation of neural network until the required parameters are obtained.

3.2 2.2 PID control algorithm of BP network

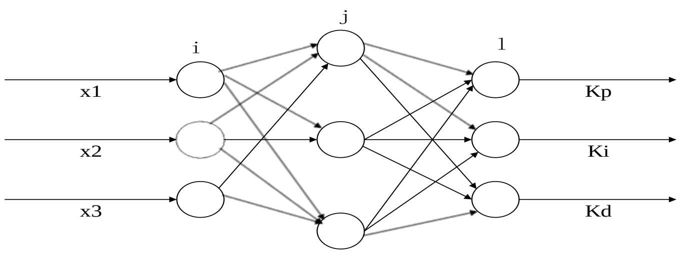

Figure 3. Structure of BP neural network

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The process of BP algorithm consists of two forms: forward propagation and back propagation [7]. BP network is a multi-layer network, which can approach any nonlinear function. At the same time, its structure and algorithm are very simple and clear. Because it has its own learning advantage, it can be used to obtain the best Ki, KD and KP. Figure 3 shows the neural network structure.

The network used in this paper has three layers, with three input points and three output points.By observing and analyzing Figure 3, it can be found that the nodes of the input layer are:

$$\mathrm{o}_j^{(1)} = x(\mathrm{j}) \qquad (\mathrm{j} = 1, 2, \ldots\ldots \mathrm{M}) \tag{4}$$

Meanwhile, the above equations (1) to (3) represent the input layer, the hidden layer and the output layer respectively; OJ (1) is the output value of the jth node of the first layer.

Hidden layer input and output of BP network:

$$\mathrm{net}_i^{(2)} = \sum_{j=0}^{M} w_{ij}^{(2)} o_j^{(1)} \tag{5}$$

$$o_i^{(2)}(\mathrm{k}) = \mathrm{f}(\mathrm{net}_i^{(2)}(\mathrm{k})) \qquad (\mathrm{i} = 1, 2, \ldots\ldots\mathrm{Q}) \tag{6}$$

The connection value of the hidden layer is Wij (2), and the input value of the ith node of this layer is Neti (2). Sigmoid[8] function is used for the output of the second layer:

$$\mathrm{f(z)} = \tanh(\mathrm{x}) = \frac{e^x - e^{-x}}{e^x + e^{-x}} \tag{7}$$

The input and output of the network output layer are:

$$\begin{aligned}
&net_l^{(3)}(\mathrm{k}) = \sum_{j=0}^{Q} w_{li}^{(3)} o_i^{(2)}(\mathrm{k}) \\
&\mathrm{o}_l^{(3)}(\mathrm{k}) = \mathrm{g}(\mathrm{net}_l^{(3)}(\mathrm{k}))(\mathrm{l} = 1, 2, 3) \\
&\mathrm{o}_1^{(3)}(\mathrm{k}) = K_p \\
&o_2^{(3)}(\mathrm{k}) = \mathrm{K}_i \\
&o_3^{(3)}(\mathrm{k}) = \mathrm{K}_d
\end{aligned} \tag{8}$$

It can be seen from the above equation that the output nodes of the third layer correspond to Kp, Ki and Kd respectively. Since the three values are not positive but negative, using the Sigmoid function, the output layer is:

$$g(\mathrm{x}) = \frac{1}{2}[1 + \tanh(\mathrm{x})] = \frac{e^x}{e^x + e^{-x}} \tag{9}$$

The error performance index is:

$$E(\mathrm{k})=\frac{1}{2}[\mathrm{n}_{ref}(\mathrm{k})-\mathrm{n}(\mathrm{k})]^2 \tag{10}$$

By using the descent method to adjust the relevant values, it can also be said that e (k) is used to adjust the negative gradient orientation of the weighting coefficient [8]. At the same time, in order to quickly shrink the search to the global minimum, an inertia term is added. As follows:

$$\Delta w_{li}^{(3)}(\mathrm{k})=-\eta\frac{\partial E(\mathrm{k})}{\partial w_{li}^{(3)}}+\alpha w_{li}^{(3)}(\mathrm{k}-1) \tag{11}$$

It can be concluded from the above that the PID control algorithm [9] of BP network can be summarized as the following steps:

(1) The first step is to define the composition of the network, that is, to determine the number of nodes in the input layer and the hidden layer, as well as the weighted values of the connected layers, as well as the inertia coefficient and learning rate used in the network, k=1;

(2) Using y (k) and r (k) obtained from sampling, the error of corresponding time is obtained;

(3) The input and output values of each layer of the network can be calculated accordingly, and the required PID value is the output value obtained at the third layer node;

(4) The output value u (k) of PID control is obtained through incremental PID;

(5) The control changes the corresponding parameters in an adaptive way. This process is to change the weights used to connect each layer through self-learning to complete adaptive adjustment;

(6) Set k=k+1 and return to step 1.

4. Simulation and Verification

4.1 Working Principle of Brushless DC Motor

Brushless DC motor and brushless DC motor are different in structure. The former realizes brushless commutation. At the same time, the realization of motor commutation without brush requires placing permanent magnet steel on the rotor and armature winding on the stator. However, the fixed magnetic field generated in this way can not interact with the magnetic field generated by the rotor during movement, so the commutation device [10] composed of power logic switch, control circuit and position sensor is also used, so that the electrical angle of the magnetic field generated by the stator and rotor during motor operation can always be maintained at about 90 degrees in space.

The motor selected in this paper is a double closed-loop system using speed and current. Because the waveform generated by the motor is not a sine wave but a rectangular wave, and only the current amplitude needs to be controlled, PWM mode is selected. In this way, the voltage signal generated by the current regulator and the triangular wave generator is compared by the PWM generator, and then the corresponding pulse width signal is obtained, and then the driving circuit is used to control the on and off of the switch [11]. If the voltage signal of triangular wave is relatively large, the duty cycle of PWM waveform is also large, and the winding current is also large; Otherwise, they are relatively small.

4.2 System Simulation

The relevant parameters of Brushless DC motor are as follows:

Brushless DC motor: voltage 220V, current 136A, $n=1460r/\min$, $C_e=0.132V\cdot\min/r$. The available overload multiple is $l=1.5$. The resistance of the armature circuit is $R=0.5\Omega$; The amplification factor of thyristor device is $K_s=40$. The time constant is $T_i=0.03s$, $T_m=0.18s$ .The

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current and speed feedback coefficients are respectively $\beta = 0.5V/A$ and $\alpha = 0.007V \cdot \min/r$. At the same time, the current overshoot is specified is $\sigma \le 5\%$.

The current regulator uses a PI regulator, and its transfer function is:

$$W_{ACR}(\mathrm{s}) = \frac{K_i(\tau_i\,\mathrm{s}+1)}{\tau_i s} \tag{12}$$

The sum of time constants is:

$$T_{\Sigma i} = T_S + T_{oi} = 0.0037s \tag{13}$$

PI regulator is also used for speed loop, and the transfer function used is:

$$W_{ASR}(\mathrm{s}) = \frac{K_n(\tau_n\,\mathrm{s}+1)}{\tau_n s} \tag{14}$$

The sum of time constants is:

$$T_{\Sigma n} = \frac{1}{K_I} + T_{on} = 0.0074s + 0.01s = 0.0174s \tag{15}$$

Lead time constant of this ring:

$$\tau_n = hT_{\Sigma n} = 5 \times 0.0174s = 0.087s \tag{16}$$

$$K_n = \frac{(\mathrm{h}+1)\beta\,\mathrm{C}_e T_m}{2h\alpha RT_{\Sigma n}} = 11.7 \tag{17}$$

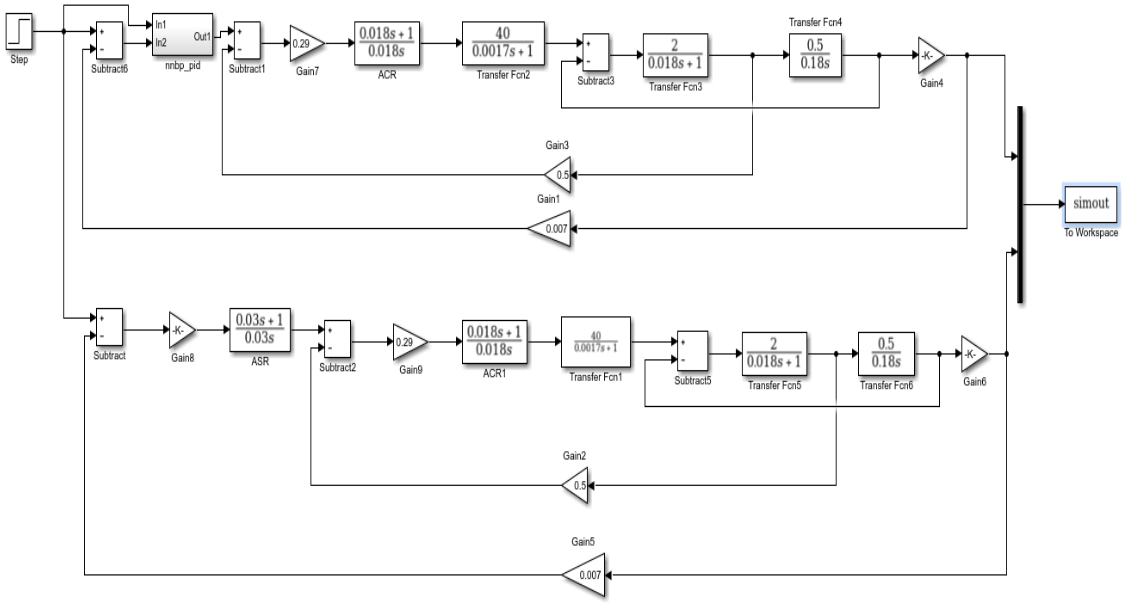

Figure 4. Simulation diagram under no load

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The system simulation under no-load is shown in Figure 4.

The system simulation with load is shown in Figure 5:

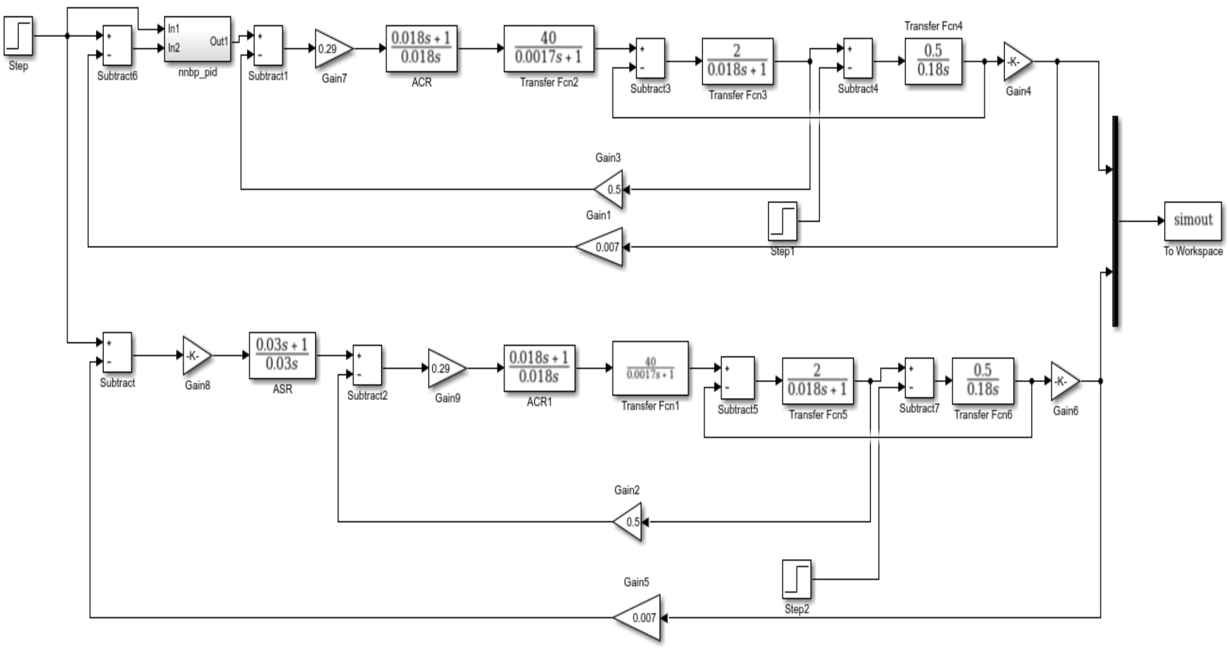

Figure 5. Simulation diagram with load interference

4.3 Analysis of Simulation Results

In order to test whether the overall design is effective, PID and BP network are combined [12], then the working process of the motor is studied, and then the double closed-loop system is used to design by using the advantages of both. The application of PID and BP network is realized through the simulation function in MATLAB, and the two different situations of PID control with and without BP network are analyzed. Observe the speed response of PID control and BP network PID control with and without load through the simulation results, as shown in the following figure:

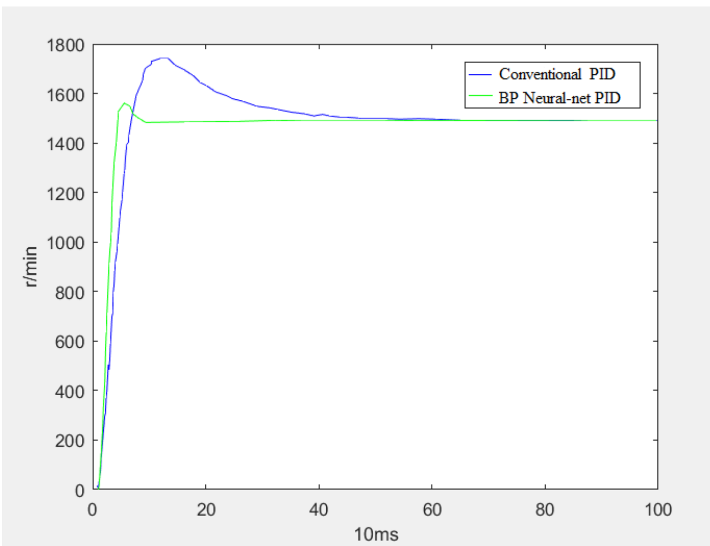

Figure 6. Comparison of speed response between conventional PID and BP network PID control under no-load

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This is the result obtained in the first case. Put them on the same diagram and compare them. We can clearly observe the differences between them when they are unloaded. From the diagram, it can be clearly seen that under the effect of these two different methods, the overshoot of the system is smaller when using BP network PID algorithm. At the same time, it can be seen that under these two different conditions, the motor can reach the stable state faster by using BP network PID control. So as to verify our idea and prove whether the conclusion we want to get is correct.

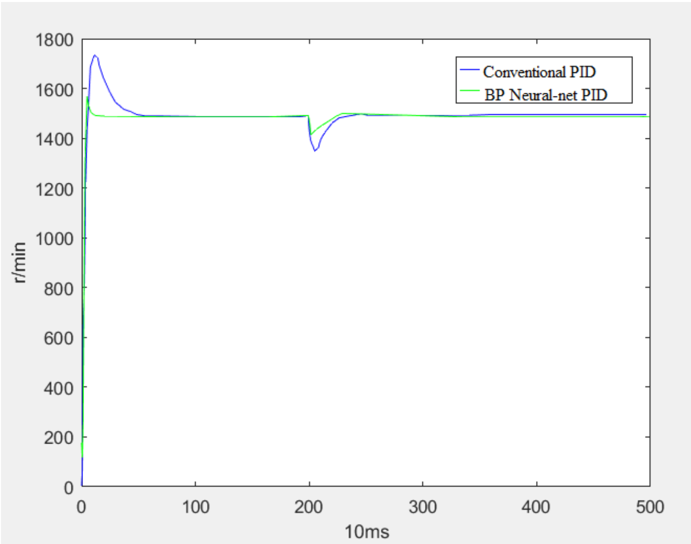

Figure 7. Comparison of speed response between conventional PID and BP network PID control under load

As can be seen from Figure 7, the results obtained by using two different methods for the motor will also be very different. When the motor is loaded at 2 seconds, it can be found that the adjustment time for BP network PID control to reach stability is shorter than that for PID control, that is, the former is easier to reach a stable state, and the anti-interference ability of the motor under BP network PID control is stronger.

It can be seen from Figure 6 and 7 that the overshoot value of the system controlled by BP network PID is smaller whether the motor is loaded or not, and the motor can reach a stable state faster. Compared with PID control, the adjustment time it takes is also shorter. At the same time, by observing the experimental results, it can be found that it has faster response speed, and the length of time it takes when it is in a stable state, and its anti-interference ability is also good. When the load changes suddenly, the system controlled by BP network PID has less disturbance. Also in this experiment, we can find that the static and dynamic performance of the system becomes better after using BP and PID.

5. Conclusion

Through the above research, it can be seen that PID control has the characteristics of uncomplicated structure, high reliability and easy implementation in industry, so it can be widely used in many fields. For the motor used in this paper, it belongs to a nonlinear system and there will be many problems when it is combined with some devices. In order to avoid these problems, this paper selects the combination of BP network and PID control, and uses their advantages together to select the double closed-loop brushless DC motor. By using these two methods to determine the rotation speed of the motor, it is proved that the combination of BP network and PID control is more conducive to the adjustment of the rotation speed of the motor. This method is also widely used in the industrial field. Perhaps this method can also be used in fields that have not been discovered by us so far, but it is

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undeniable that this method has brought negligible impact and convenience to our lives, greatly promoted the development of many fields, and proved that its existence has great value. I hope we can continue to work hard in the next days, with our own strength, to study these theories and explore the undiscovered. I believe that as long as we study and explore, we can have many unexpected gains. Personal ability is limited. In order to make the application of BP and PID in this field better and develop faster, and make the future development of this field shocking the world, everyone who loves this field needs to continue to work under the condition that our predecessors have provided us with a lot of convenience.

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