**BLDC speed control system based on neuron PID**

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**Abstract:** In order to solve the problems of long adjustment time and weak anti-interference, a brushless DC motor speed control system based on neuron PID was proposed. Improved Hebb learning algorithm with property of self-learning and self-organizing was applied for the online adjust of PID control parameters. The step response of brushless DC motor speed control system was measured when the control system parameters change dynamically. The three parameters of the PID controller can be adjusted in real time and the rotational speed of the brushless DC motor can be effectively controlled. The results show that this control method has strong adaptability to coupling system and strong anti-interference ability.

1. **Introduction**

Since the 1980s, with the development of Thyristor, surface mount technology and microsystem technology, the well-known companies in the world have been competed to develop DC speed regulation, and the results are remarkable. Static-dynamic performance of brushless DC motor control system has been improved. BLDCM’s anti-interference ability and control accuracy have also been developed and improved. This is the reason why brushless DC motor is widely used. In modern industrial production activities, brushless DC motor is not only used in mining, but also applies to medical devices. Brushless DC motor has become an important part of the automatic control system.

Many scholars have studied the operation of Brushless DC motor, and the research results are remarkable. The mathematical model of BLDC motor established by Yang Haodong, analyzed the operation principle of Brushless DC motor and started from the voltage formula of armature circuit [1]. The defect of this model is that the control of the motor is not analyzed. Automatic control principle was proposed by Hu Shousong, from which we can find many classic control problems and solutions in the field of control [2]. The dual closed loop control system based on the traditional PID algorithm is established by Liu T [3]. The better algorithm of controlling the BLDC motor is analyzed by Seol H S, so that it can well cope with more complex external environment, improve the anti-interference ability and robustness of BLDC motor [4].

On the basis of previous research, the mathematical model and simulation model of Brushless DC was established [5]. The kernel code of neuron PID controller was written by the S-function. The experimental results show that the neuron PID controller can effectively control the motor and improve the stability of the system [6]. The three PID parameters can be modified in real time.
2. Neuron PID controller

2.1. PID controller
The PID controller is processed by the error based on feedback, and the output signal of the controller is obtained by superposition the proportion, integral and differential operation. The conventional PID control system simulation model is shown in figure 1.

The control algorithm is as follows:

\[ u(t) = K_p e(t) + \frac{K_i}{T_i} \int_0^t e(t) \, dt + K_p \tau \frac{de(t)}{dt} \]  \hspace{1cm} (1)

The transfer function is:

\[ G_i(s) = K_p + \frac{K_i}{s} + K_D s \]  \hspace{1cm} (2)

In the formula, \( K_p \) is the proportional coefficient, \( T_i \) is the integral time constant, \( \tau \) is the differential time constant, these are all adjustable parameters. In practical applications, the adjustment order of three parameters of PID is generally determined by P and I. Finally, D is determined according to the dynamic performance of the system. The process is very long, and only experienced talents can do well.

2.2. Neuron PID controller
The design of neuron PID controller, as shown in figure 2, looks very familiar with the general closed loop control. The difference is that we need to get the three-deviation value to perform neuron self-tuning. One single artificial neuron, also known as a sensor, can be used as a controller for motor control. The feedback signal may be obtained through the transfer function \( f \) neuron output signal \( y \). Weight correction of single neuron control system is achieved through the learning algorithm. Then we use an improved Hebb learning algorithm to fix the parameters.

\[ r(k) \rightarrow e(k) \rightarrow x_1(k) \rightarrow x_2(k) \rightarrow x_3(k) \rightarrow \text{SUM} \rightarrow K \rightarrow \text{detailU}(k) \rightarrow U(k) \rightarrow \text{Controlled object} \rightarrow y(k) \]

**Figure 2.** Neuron PID controller system block diagram.
In the figure, \( x(1), x(2), x(3) \) are variables, calculated by the calculus module, \( x(1) = e(k) \), \( x(2) = e(k) - e(k - 1) \), \( x(3) = e(k) - 2e(k - 1) + e(k + 1) \). Using the improved Hebb learning algorithm, the rules for the correction of three weights can be expressed as

\[
\begin{align*}
    w_1(k) &= w_1(k - 1) + \eta_p e(k)u(k)[e(k) - \Delta e(k)] \\
    w_2(k) &= w_2(k - 1) + \eta_d e(k)u(k)[e(k) - \Delta e(k)] \\
    w_3(k) &= w_3(k - 1) + \eta_i e(k)u(k)[e(k) - \Delta e(k)]
\end{align*}
\]

\((3)\)

\( \eta_p \) means ratio learning rate, \( \eta_d \) means differential learning rate and \( \eta_i \) means integral learning rate. Simultaneously, these variables can be used as the state variables of the system, then the control rate expression can be written as

\[
u(k) = u(k - 1) + K \sum_{i=1}^{3} w_i^0(k)x_i(k)
\]

\((4)\)

Normalized weights:

\[
w_i^0(k) = \frac{w_i(k)}{\sum_{i=1}^{3} |w_i(k)|}
\]

\((5)\)

3. System simulation research

The control system consists of two parts, the first is the mathematical model of the brushless DC, the second is to build a neural PID controller based on the speed control system [7]. Before setting up the mathematical model of the brushless DC motor, brushless DC motor needs to simplify the description. We can get to the essence of the motor, and not be troubled by other detail problems. Many reasonable assumptions of brushless DC motor were raised for facilitate analysis [8].

MATLAB/Simulink provides an integrated environment for dynamic system modeling, simulation and comprehensive analysis. S-function is a short name for system function which refers to a non-graphical way to describe a function block. It accepts the relevant information from the Simulink solver and responds appropriately to the commands issued by the solver. The S-function module is the heart of the entire Simulink dynamic system. Brushless DC motor speed control system simulation diagram can be shown as in figure 3. The simulation model of the motor is established through the mathematical model, the part of control is built by the S function.

\[\text{Figure 3. BLDC control system simulation based on neuron PID.}\]

When the motor is running, the phase voltage varies can be shown as in figure 4 and the torque is shown in figure 5.
When the motor is running, the waveform of the armature current is shown as shown in figure 6.
4. Simulation experiment

4.1. Step experiment
The experiment of the control system is as follows. Firstly, the PID speed control system is subjected to the step response experiment. The experimental results are shown in figure 7. Then, the step response of the neuron PID control system is taken as the target output. The experimental results are shown in figure 8.

4.2. Disturbance experiment
The disturbance experiments of the system are as follows. When 1.8S is added, the external disturbance of 2.5N is added to the system. The experimental results of PID controller are shown in figure 9. The experimental results of neuron PID controller are shown in figure 10.
The result of disturbance experiment is very obvious. When encountering external disturbance, the PID controller cannot adjust the speed of motor to 215 rpm, while neuron PID can recover to the set speed quickly.

The simulation results show that the S-function can realize the system simulation model of complex control algorithm. Combining with the neuron PID controller, the three parameters of the PID controller can be adjusted in real time and the rotational speed of the brushless DC motor can be effectively controlled. Parameters change are shown in figure 11.

5. Conclusions
In the MATLAB environment, the speed loop of the brushless DC motor control system is simulated by PID controller. Based on this theory, the neuron PID controller is designed, and the simulation model of Brushless DC motor speed regulation system is established. Besides, the experiment of given input and load disturbance is carried out. Comparing the neuron PID controller curve with the conventional PID controller simulation results, the static and dynamic parameters are greatly improved, especially the neuron PID controller can adjust the PID in real-time and have strong learning, adaptive and anti-disturbance ability, stability and good robustness. So, the effectiveness of the proposed method has been proved.
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