Speed Control of Brushless DC Motor Based on CMAC and PID Controller*

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Abstract – The brushless DC motor (BLDCM) has such advantages as simple structure, convenient to control, high reliability, high efficiency, and has been applied in many industrial fields. Conventional controllers suffer from uncertain parameters and the nonlinear of the BLDCM. To overcome the shortcomings of the conventional controller, this paper presents a novel strategy on the basis of compound control using cerebellar model articulation controller (CMAC) and PID controller. Through compound control using CMAC and PID controller the system realizes double-fed control. CMAC forms feedforward controller of the system and realizes the dynamic model of the controlled device; conventional PID controller is used to make up of feedback controller which ensures system stability and depresses disturbance. In this paper, a program written in Visual C++ functions to adjust the compound controller off-line. At last, a TMS320LF2407A digital signal processor (DSP) is used to fully prove the flexibility of the control scheme in real time. The system realizes the self-adjustment pursuit of the speed reference model to a better degree, has the advantages of flexible control, strong adaptability, and achieves higher control accuracy and better robustness.

Index Terms - Brushless DC motor, Cerebellar model articulation controller, PID control.

I. INTRODUCTION

BLDCM receives wide attention for industrial applications because of their favourable electrical and mechanical properties such as high torque density, high efficiency and reliability [1]. Due to their merits such as simple structure, high efficiency and easy implementation, the Conventional PID is widely used in most servo applications such as actuation, robotics, machine tools, and so on. Conventional PID control used to the electrical engineering appearance is based on linear model, but BLDCM is a nonlinear system, conventional controllers suffer from uncertain parameters and the nonlinear of the BLDCM, and it is impossible to control and identify the system accurately [2]. In recent years artificial neural network has gained a wide attention of many researchers in control applications because they have capability of pattern recognition and any nonlinear function imitation. In addition, artificial neural network have the advantage of fast parallel computation, noise immunity and fault tolerance [3-4]. As a result, to combine the artificial neural network with the conventional PID controller and then apply them to motor control field recently becomes research highlight of scholars [5-6].

CMAC as one of the intelligence controller is widely used in non-linear system in recent years [7]. It is a learning structure that imitates the human cerebellum to decide with quick response like conditioned reflex but doesn’t contemplate. CMAC does not use a numerical calculation method to analyze the dynamics of the control problem. It uses a table look-up method to compute control functions referring to memory table. Consequently, the CMAC is localized-learning, fast responding and simple learning. It provides excellent nonlinear approximate and much better follow-up compared with conventional PID regulating strategy. Therefore, it makes practical sense to combine the CMAC with PID controller and apply them to BLDCM control.

This paper presents a novel approach of compound control for BLDCM control using CMAC and PID controller. Its performance is verified by experimental results.

II. CMAC

The CMAC neural network, which was proposed by Albus in the 1970’s, has been widely recognized as an important part of one kind associative memory neural network. It, which can learn random multi-dimensional nonlinear mapping, is a self-adaptive neutral network expressing complex nonlinear functions by table inquiry, and can change the table’s content through learning, possesses the ability of storing the information after classifying them.

A CMAC neural network can be depicted into three mappings from its input until its output: an activation mapping at the input space, which determines which nodes or neurons will remain active for the current input vector and at which strength they will be processed; an internal mapping, which generate the outputs for the CMAC memories, based on the activation of the input neurons and the parameters of the linear equations; and a linear output mapping, which performs a weighted sum of the outputs of the active CMAC memories and generates the overall outputs to the network [8]. Fig.1 shows a schematic diagram of the CMAC structure.

CMAC networks are considered local algorithms because, the mapping can be seen as a set of multidimensional interlaced receptive fields, each one with finite and sharp

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CMAC is a direct proportion with the exponential of the relational expression: 

At the same time, the size smaller than the number of hypercubes is a common case with the memory. It is more demand that the number of primary function should be smaller than the number of divided unit, which increases the efficiency of the training process, minimizing the computational efforts needed to perform adaptation in the whole network. They present the following features:

1. The input mapping can be chosen by the designer, through the definition of the superimposing pattern for the receptive fields;
2. The network outputs are linearly dependent to the weight set, as opposed to MLP model where the input receptive fields; the definition of the superimposing pattern for the input space needs to define generalization parameter $c$, which influences the exciting fields.

A finite interval, $R^i = \{X_i | X_{i_{\text{min}}} \leq X_i \leq X_{i_{\text{max}}}\}$, is a hypercube unit. The demarcation of the input space needs to define generalization parameter $c$, which influences the exciting fields.

The middle layer is constituted by several identification units, every input vector fall into a hypercube unit. The number of hypercubes is $n$. Because the number of primary function should be smaller than the number of divided unit, the case with the memory size smaller than the number of hypercubes is of more interests. Normal algorithm is only suitable to low dimension input. If the dimension is higher, hash mapping technique should be applied.

Hash mapping may associate several hypercubes to a memory location, and in this memory location stores data which ever occupies abundant memory space, then the more to less mapping will be completed.

3. Output mapping

Mapping the input vectors to the $c$ units of physical memory locations of which every unit is stores with the corresponding weights. The output of CMAC is the sum of physical memory locations. The weight adjustment is partial, during the every time of learning, the adjustment occurs only among $c$ weights. Regarding close input, only a small part of weights take changes, a large part of weights will not be affected. In this way, the speed of network learning is accelerated and learning disturb is minimized.

III. COMPOUND CONTROL

Through compound control using CMAC and PID controller the system realizes double-fed control. In detail, CMAC forms feedforward controller of the system and realizes the dynamic model of the controlled device; conventional PID controller is used to make up of feedback controller which ensures system stability and depresses disturbance. Fig.2 shows a schematic diagram of the structure of compound controller using CMAC and PID.

CMAC adopts the supervised learning algorithm. After every control cycle, the corresponding output $u_n(k)$ of CMAC will be calculated and compared with control input $u(k)$, and then change the weight. The aim of learning is to make the difference between control input and CMAC the smallest. Through the learning the values of control input only depend on CMAC. Whereas, the normal controller adopting conventional PID controller, makes the learning of CMAC only depending on the measured value and changed rate of system error.

For a quantized state is distributively stored in memory locations. Assume that $c$ is the number of hypercubes. The number of hypercubes is $n$. Using the CMAC technique, a stored data can be mathematically expressed as

\[
   u_n(k) = \sum_{i=1}^{n} a_i w_i(k) \quad (4)
\]

\[
   u(k) = u_n(k) + u_p(k) \quad (5)
\]
where \( a_i \) is a memory element selection vector, and \( w_i(k) \) is the corresponding weight; \( u_n(k) \) is the output of CMAC; \( u_p(k) \) is the output of conventional PID controller.

The adjusting index of CMAC is:

\[
E(k) = \frac{1}{2} (u(k) - u_n(k))^2 \frac{a}{c} \tag{6}
\]

\[
\Delta w(k) = \eta \frac{u(k) - u_n(k)}{c} a_i = \eta \frac{u_s(k)}{c} a_i \tag{7}
\]

\[
w(k) = w(k-1) + \Delta w(k) + \alpha (w(k) - w(k-1)) \tag{8}
\]

where \( \eta \) is the learning speed, \( \eta \in (0,1) \); \( \alpha \) is inertia compensation, \( \alpha \in (0,1) \).

\[
w(k) = (w_1(k), w_2(k), \ldots, w_i(k))^T \tag{9}
\]

At the beginning, we set \( w = 0 \), then \( u_n = 0 \), system is controlled by conventional controller. Through the study of CMAC, the output \( u_p(k) \) of the PID controller tends to zero, and the output \( u_n(k) \) of PID tend to total output \( u(k) \).

Although the control algorithm of CMAC is trained by PID controller, it is not a simple duplication of conventional PID controller. Adding PID controller is to judge the performance of CMAC, to strengthen the system’s stability and to suppress disturbance. When system is controlled by PID controller itself, gain \( k_p \) decides the control effect to a large degree. Whereas, if the compound controller using CMAC and PID controller is adopted, the control effectiveness will not depend on \( k_p \), and \( k_p \) is only demanded within a reasonable domain.

At beginning it is PID controller that mainly takes effect, after the continuous learning of conventional controller, gradually CMAC take the control effect. The addition of CMAC takes much better effect than PID controller single. The system greatly minimizes overshoot and accelerates respond speed, embodies the characteristics of CMAC to the full. In the case of being added disturb, the system can come back to stable condition quickly. To some extent, the compound controller overcomes the shortcomings that the conventional controller cannot avoid, and promotes the controlling effect.

**IV. RESULTS**

At last, this paper verifies the performance of the proposed strategy by experiments, in which TMS320LF2407A DSP based control system is applied to prototype. Fig.3 shows the block diagram of the structure of hardware. Setting command of control parameter and corresponding control algorithm are both realized by software.

The TMS320LF2407A DSP is used to generate the PWM and an IR2130 is used to drive the MOSFET. The A/D Unit is used to sample the current of the motor. The position signal of the rotor is gained by the Capture Unit of the DSP, and the speed value is calculated from the position information.

Parameters of prototype is listed below:

- Rated voltage \( U_N = 36V \);
- Rated torque \( T_N = 0.4N\cdot m \);
- Rated speed \( n_N = 3600r/min \);
- Phase resistance \( R = 0.66\Omega \);
- Effective inductance \( L = 1.4mH(\pm1.3\%) \);
- Back electromotive force coefficient \( K_e = 0.067V/(rad/s) \);
- Rotational inertia coefficient \( J = 1.57\times10^{-5}kg\cdot m^2 \).

Fig. 4 and Fig. 5 shows the speed curve when the motor speed is 2000 r/min and the motor is carrying idler. Fig. 4 is the result of the conventional PID controller, and Fig. 5 is the speed curve of the proposed controller in this paper.
Through the comparison of Fig. 4 and Fig. 5, we can see that under the control of CMAC, motor has a fast responding, small overshoot and ripple torque. The control system solves the contradiction between fast responding and big overshoot of conventional PID controller, and indicates satisfying static performances.

Fig. 6 and Fig. 7 shows the speed curve when the motor speed is 2000 r/min and system is greatly disturbed under different control methods. Fig. 6 is the result of the conventional PID controller, and Fig. 7 is the speed curve of the proposed controller in this paper.

Through the comparison of Fig. 6 and Fig. 7, we can see when the system is greatly disturbed, motor can regulate itself immediately under the compound controller using CMAC and PID controller, the system has good adaptability and strong robustness.

Fig. 9 shows the result of the compound controller tracking the step speed reference model, which is shown by Fig. 8, from stall.

From Fig. 9 we can see that under the compound controller the system has better dynamic response capability, efficiently reduces the effect brought by parametric variation and fluctuation of load, and has good traceability, stability and strong adaptability.

V. SUMMARY

Under the condition that multi-variable parameter and non-linear structure of the controlled device, the paper presents a compound control method using CMAC and PID controller for BLDCM. This method realizes satisfying speed control of BLDCM. Through the analysis of speed response curve under different condition, it can be seen that this compound controller has an excellent control performance for BLDCM and solves the shortcomings of conventional PID controller applied to non-linear system control. It promotes the system’s ability of anti-disturb and has high control precision, good static and dynamic performance and strong robustness.

REFERENCES


