Fuzzy PID speed control of BLDC motor based on model design

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Abstract. Brushless direct current (BLDC) motor has been widely used in industrial production. Based on the method of model design, BLDC motor speed control is studied. In Matlab/Simulink, a fuzzy PID speed control model of BLDC motor is established, and C Code is generated by Real-Time Workshop (RTW) technology. After that, Code Warrior is compiled into machine Code and written into ECU. The results show that the fuzzy Proportion Integration Differentiation (PID) controller can improve the speed performance of the BLDC.

1. Introduction

Brushless Direct Current Motor has the advantages of high speed dynamic response, simple structure, high stability, high efficiency, low noise and high torque, so it is widely used in industrial production. However, in the specific design of the Brushless Direct Current Motor speed control system, the design process will be very complex, and there will be a lot of problems in this process, because of the difficulties in the preparation of the underlying hardware driver, the design of the motor phase change program and the compilation of the control system program and so on [1-6]. Model based design method of developing control system don't need to be proficient in various programming languages, it will work tedious code generation to the computer to complete, and there are all kinds of function module and driving module for designers to use, only need to design personnel to understand the principle of work and focus on the algorithm itself, thus to ensure the efficiency and reliability of the code, and greatly reduces the difficulty of embedded system development, significantly shorten the product development cycle, greatly improving the work efficiency.

1.1. Working principle of brushless dc motor

The commutation function of brushless dc motor is achieved by three-phase full control circuit. Due to the lack of carbon brush commutation, when the dc power supply supplies power to any two-phase winding on the stator, there can only be a constant magnetic field, which cannot interact with the permanent magnetic field generated by the moving rotor magnetic steel to ensure the torque in a single direction, so the rotor cannot rotate continuously. It can be seen that the brushless dc motor also needs to add position detection device and electronic switch circuit to replace the traditional permanent magnet dc motor carbon brush and phase changer. The position detection device detects the rotor position information, processes the logic controller, controls the electronic circuit rectifier, the interaction between the stator windings of the armature magnetic field and the permanent magnetic field of the rotor magnetic steel, causes the continuous torque to ensure the continuous operation of the motor.
The stator windings of a brushless dc motor are usually polyphase (three phase, four phase, five equal). The rotor is composed of a certain number of poles. The operating mode of three-phase full control circuit has small torque ripple and high winding utilization rate, so it has a wide application range. Figure 1 shows the three-phase full control circuit adopted in this topic.

![Figure 1. Three-phase full control circuit of brushless dc motor.](image)

1.2. Introduction to model-based design
With the diversification of user demands, embedded system developers are facing more and more challenges, and the system design itself is becoming more and more complex. Model-based design is a fast and effective method for developing dynamic systems. In the design process, the designer can divide the original module into smaller modules, so that it can be implemented and verified, and be used repeatedly in the future design process. The core of the model-based design and development process revolves around the system model, which is closely related to the model from requirement analysis to design, implementation and test [7].

In the traditional design, the model is generally based on assembly language, C language and other programming language tools to achieve the algorithm, but verification is achieved through the test environment. However, model-based design employs the technology of automatic code generation, which can be used to prove the concept of language implementation, and can also be used as a benchmark to check manual code, and can also be used for prototype design, so this technology is quite promising. Of course, the emergence of this new technology does not mean to make the choice between manual code and automatic code, but the combination of each other to get the optimal design results [8].

In this study, the control model based on fuzzy PID model is mainly adopted. PID control technology is established on the basis that the controlled object has accurate mathematical model. When the controlled object is controlled by PID control, the desired control effect can be obtained by adjusting the three control parameters of PID controller, i.e. Kp, Ki and Kd. The mathematical model of the controlled object is accurate and the PID control effect is good. For the complex system which is difficult to establish accurate mathematical model, the PID control effect is not ideal. Fuzzy control does not rely on accurate mathematical model when solving complex systems, and can achieve adaptive adjustment of parameters. Combining PID control and fuzzy control, fuzzy PID control technology has the advantages of adaptive adjustment of parameters of fuzzy control and high control precision of PID control technology [7-11].
2. BLDC motor fuzzy PID controller design

2.1. BLDC motor system structure diagram
The system adopts double closed-loop control of speed loop and current loop, in which the speed loop participates in the speed regulation of the motor and adopts Fuzzy-PID control to output pulse width modulation (PWM) signal to control the motor speed, while the current loop only participates in the control of the motor when the motor current exceeds the rated current, playing a role of overload protection. The whole control principle is shown in Figure 2.

![Figure 2. whole principle of the system.](image)

2.2. Fuzzy PID controller design
Brushless dc motor of the input variable of Fuzzy - PID controller has two, respectively, velocity error E and error change rate EC, according to different velocity error E and error change rate of EC, the Fuzzy controller according to the Fuzzy rules table offline automatic query change parameters Kp, Ki, Kd to meet different E and EC to the different requirement of the control parameters. The principles of BLDC motor system fuzzy rules are as follows [12]:

- When E and EC are large, give Kp a large value and increase the response speed of the system. In order to avoid overtuning of the system, when E and EC are large, the corresponding Kp value should be reduced. At the end of regulation, E and EC are both small, and increase the Kp value slightly to make the system responsive and reduce the steady-state error.
- When E and EC is very big, to Ki a small value, preventing integral saturation, avoid system overshoot, when E and EC is moderate, as to the value of the Ki to appropriately increase, to ensure the stability of the system, when up to the end of regulation, E and EC are smaller, will increase the value of the Ki, make the system responsive, and eliminate the steady-state error.
- As for the BLDC motor system, the relation between E and Kd should ensure the inverse ratio, so as to increase the response speed of the system and avoid overshoot. However, for EC, when the EC is large, the Kd value should be reduced to ensure the stability of the system. When the EC is small, the Kd value can be increased correspondingly to improve the response speed of the system.

Error E actual field range of [-750, 750], the error rate of the EC scope of practical theory of domain for [-12, 12], set system error E and error change rate of EC established fuzzy comprehensive domain: E = {-10, -2, 0, 1, 2, 10}, EC = {-6, -4, -2, 0, 2, 4, 6}, its fuzzy subset is E, EC, Kp, Ki, Kd = {NB, NM, NS, ZO, PS, PM, PB}.

In the PID control system based on fuzzy theory, the fuzzy controller analyzes and adjusts the parameters of PID controller and makes appropriate fuzzy rules, so as to get the ideal tuning value of...
PID parameters. In order to better control the motor system, the control rules can be described in the form of a control decision table, as shown in Table 1.

| E      | NB | NM | NS | O  | PS | PM | PB |
|--------|----|----|----|----|----|----|----|
| NB     | PM | NB | PB | NB | PS | NS | O  |
| NM     | PM | O  | PM | NS | PB | PS | PS |
| NS     | PS | O  | PB | NM | PM | PB | PB |
| O      | PS | PM | PS | O  | NB | PM | NM |
| PS     | O  | PM | O  | PB | NM | O  | NB |
| PM     | O  | PS | NM | PS | O  | NM | PS |
| PB     | NB | PS | NM | PS | PB | NM | PM |

Table 1. Fuzzy control decision table.

3. Modeling, testing and analysis

The ECU chip used in this system is Freescale MPC5604. The schematic diagram of the designed system structure is shown in Figure 3. According to the requirements of system response speed and hardware performance, the ECU sampling time is set as 1ms.

![Figure 3](image_url)

Figure 3. Overall principle of the system.

Import the values generated by the fuzzy logic editor into the table lookup module and connected with the PID control module to form the fuzzy PID controller, which is connected with the motor drive module and the input signal module to form the overall module of the system [13]. Add measurement speed in the module to observe the motor speed in real time and check the control effect. Set the fuzzy rule table and the expected speed as the standard quantity through the M file. Later in the MeCa measurement and calibration software, set the speed and optimize the rule table online according to the response effect of the motor speed [14, 15].

Using the automatic Code generation function of Simulink, the control system will generate C Code, and then through Code Warrior compiled into machine Code, brush write to the ECU control motor. Use the built-in data saving function of MeCa to save the collected data into Microsoft Excel file, and then make curve diagram [16].
4. Conclusions
In this paper, through the introduction of the design of a model based on Fuzzy PID, compared with the PID, Fuzzy PID response time more quickly smoothly, can be seen from the Figure 4, the response time of 2 ms, PID control overshoot is 3%, and in order to eliminate the overshoot of the system, speed down to about 1700 RPM, away from the target speed, smooth and Fuzzy - PID control system response fast, response time is 2 ms, and no overshoot, and the speed stability at about 1800 RPM. The results show that the fuzzy PID controller can improve the speed control performance of BLDC.

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