Design and Realization of Control System of Brushless DC Motor Based on ARM

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Abstract. With the development of science and technology, people are demanding more and more sophisticated technology products, especially in some advanced and high-end research fields. For example, in terms of medical devices, home appliances, and transportation vehicles, there are higher demands on them that they can become more and more compact and sophisticated to meet people's needs better. Most of the daily products are inseparable from the motor drive, and the convenience of motor drive will bring about rapid development and improvement in these fields to make these technologies meet people's requirements. Based on the powerful simulation function of SIMULINK, the brushless DC motor control system simulation was completed. In the thesis, through the establishment of two simulation models, the theoretical analysis of the principle and mathematical model of brushless DC motor is carried out. Finally, the brushless DC motor control system is designed on the basis of simulation and theoretical analysis, and the hardware selection and circuit design are carried out. The main control chip of the control system is the LPC1766 of NXP Company, which is based on ARM's latest Contex-M3 kernel. Besides, the data transmission is realized by the Modbus bus protocol in this control system, and the software programming is carried out in the U-Vision4 development environment, of which the implementation process is presented by flowchart.

1. Introduction
The DC motors can be divided into brushed DC motors and brushless DC motors, and the DC motors have the advantages of superior speed control performance, good starting performance, high operating efficiency, which are widely used in industrial production and people's daily life. However, the brushes are usually used in the conventional DC motors to mechanically change direction, and thus there are relative mechanical frictions in the DC motors, which brings about fatal and weak points such as noise, sparks, radio interference, and short lifespan. In addition, there are many other shortcomings in the DC motors such as high manufacturing costs and difficult maintenance, which have greatly limited its scope of application [1]. The type of motor mainly includes AC motor and DC motor. However, the traditional DC motor commutates mechanically because of the brush, which introduces many inherent weaknesses in motor operation, thereby greatly limiting its application range. Because of some inherent deficiencies for DC motors in the production process of industry and agriculture, the AC motors have been used in place of previous DC motors in many cases. The AC synchronous motor has good running performance, but its starting performance is poor; and the AC induction motor has the characteristics of simple structure and reliable operation, but its speed performance is poor [2]. As a result, people are looking for a more practical motor.

With the development of power electronics and the gradual application of permanent magnetic materials, the brushless DC motors have emerged. The brushless DC motor mainly changes the brush control structure of the traditional brushed DC motor, and the power electronic components are adopted
for commutation, which reduces the adverse effects caused by brushes [3]. In addition, the brushless DC motors have many advantages over other motors such as high reliability, high efficiency, and excellent speed control performance [4].

The history of the development of brushless DC motors can be traced back to 1917, in which Boliger proposed that the brushed DC motor can be replaced with a rectifier tube, thus the basic idea of a permanent magnet brushless DC motor is created [5]. In the 1930s, the DC brushless motors are developed where the electronic commutation is used to replace the brush mechanical commutation. However, because the high-power electronic devices were only in the primary development stage at the time, such motors only stayed in the laboratory development stage and could not be promoted. In 1955, D. Harrison et al. [6] firstly applied for a patent that the application of transistor commutation instead of motor commutation. Afterwards, the commutation-free DC brushless motor with Hall elements was finally introduced in 1962 [7]. In 1978, the original Malinesmalm Company in the Federal Republic of Germany formally launched the MAC classic permanent magnet brushless DC motor and its drive system at the Hanover Trade Fair, marking that the brushless DC motor has truly entered the practical stage.

Brushless DC motor is a typical integrated system of power electronics and motors, which is an organic combination of power electronics, motors, and controls. The three parts of the brushless DC motor interact with each other. Without control, the variability of power is also meaningless. The entire motor integration system constitutes a feedback regulation with automatic control, and the optimal control of the brushless DC motor is also the overall optimization of its integrated system, of which the shielding, integrity and completeness make the system free from interference outside.

Based on the aforementioned research background, this paper mainly introduces the basic control strategy and problems of brushless DC motors, and a brushless DC motor control system for DC electric actuators is designed. This design firstly achieved the theoretical verification of the brushless DC motor control system through the simulation of MATLAB, and completed the simulation of the brushless DC motor control system through the powerful SIMULINK simulation function. The hardware circuit of the brushless DC motor control system is designed, and the data transmission is achieved in the control system via the Modbus bus protocol. The main control chip of the control system is LPC1766 of NXP company, which is based on the kernel of Contex-M3 of ARM company.

2. Basic Theory of Brushless DC Motor and Control System
The development of brushless DC motors has undergone the following stages in general: (1) Analog Circuit: according to the system's task, a large number of discrete components are connected to achieve the motor commutation, motor drive, speed controlling and other functions, which is characterized by good real-time. However, the structure of the analog circuit is complex, of which the reliability and scalability are also poor, making it difficult to implement complex algorithms. (2) Application-Specific Integrated Circuit: with the development of power electronics, many companies have also introduced their own dedicated motor control chips of brushless DC motors such as MC33035, TB6537B and so on. Most of these chips can be used to compose modular hybrid control systems. The reliability of this circuit has been greatly enhanced, which can meet the application in basic situations, but its intelligence and scalability are poor, which still limits the large-scale application of this circuit [8]. (3) The Microcontroller: the 8-bit or 16-bit microcontrollers are used as the core of microcontroller, combined with some discrete components or application-specific integrated circuits, to form a control system with high control accuracy, strong adaptability, and implementation of complex algorithms. The microcontroller can satisfy the application in most occasions, but due to its complex structure, low computing speed, and poor real-time performance, its applications in high-precision and high-speed occasions are restricted. (4) DSP: the company TI introduces a variety of DSP chips such as DSP24 series, DSP28 series in order to meet the motor control requirements, which adhere to the advantages of MCU, and integrate multiple motor control dedicated modules, which enhances processing speed greatly and can meet the application requirements of high speed and high precision.
2.1 Basic Structure of Brushless DC Motor System
In general, the definition of brushless DC motors in the academia is presented as follows: only the brushless DC motors with trapezoidal or square-wave back-EMF waveforms can be referred to as brushless DC motors, while the brushless motor with back-EMF is sine-wave cannot be called brushless DC motor, which is called permanent magnet synchronous motor [9]. According to the definition, the brushless DC motor is a self-controlled inverter-type synchronous rotary motor, which can be regarded as an electromechanical integrated control system consisting of a power electronic commutation circuit, a position sensor and a motor body. The specific structure of brushless DC motor is shown in Figure 1.

Figure 1. Brushless DC Motor System

2.2 Working Principle of Brushless DC Motor
In this study, the three-phase brushless DC motor operating in a three-phase, six-state, two-two-conduction mode is taken as an example to illustrate the working principle of brushless DC motor, which is shown in Figure 2. Assuming that the pole pair number of the motor is P=1, and the windings are star-connected.

When the rotor is in the position (0°) as shown in the left of Figure 3, the Z, B, and X phase bands are below the magnetic pole of N pole, and the C, Y, and A phase bands are below the S pole: based on the rotor position of sensor, the output signals make the VT1 and VT6 tubes conducted. The current flows from the positive electrode through the VT1 tube into the AB winding and returns to the negative electrode through the VT6 tube. At this point, the stator and rotor magnetic fields are interacted with each other, causing the rotor of the motor to rotate clockwise. After turning 60° electrical angle, the rotor position is shown in the right figure of Figure 3. In order to avoid inconsistent current directions of some of the conductors in the armature windings under the same magnetic pole, when the rotor is turned to the position of the right figure of Fig 3, it must be phase-inverted so that phase B is de-energized and A is positively energized.
3. Brushless DC Motor Control System Software and Hardware Design

In this section, the hardware circuit of position sensor is constructed. The control system of the brushless DC motor is mainly applied to a DC variable frequency electric actuator. However, the DSP chip is not suitable for the development of many low-end products because of its high cost [10], and therefore the ARM chip of the Cortex-M3 core processor is used as the master chip in this design. The ARM processor of the Cortex-M3 series is rapidly occupying the R&D market in many fields such as automotive electronics, industrial control, and data communications. In this paper, the LPC1766 microprocessor with the Cortex-M3 kernel is used, based on which a peripheral hardware circuit is built.

3.1 The Overall Design of Control System

The brushless DC motor control system mainly includes the following modules: main control circuit, main power circuit, detection circuit, drive circuit, protection circuit, and display circuit. The main control circuit is the core of the entire control system, and it can calculate and judge the output control signal to the drive circuit after receiving the rotor position signal [11]. The drive circuit is used to drive power device to realize the operation of the motor, and the voltage and temperature protection signals are transmitted back to the main control circuit by sensors. The main control chip used in this study is NXP's LPC1766 microprocessor, and the hardware platform for the brushless DC motor control system is shown in Figure 4.
3.2 The Hardware Design of Control System
The hardware design of the brushless DC motor control system mainly includes the peripheral circuit design based on the LPC1766 chip such as the driver circuit, the power supply circuit, and the serial port circuit. The overall block diagram design of the control system is shown in Figure 5. The Hall sensor sends the position signal of the motor to the GPIO port and the quadrature encoder port of the microprocessor; the encoder can calculate the rotation speed of the motor based on the position signal of the rotor; the A/D port in the circuit accepts the current and voltage signals of the inverter bus, and the overcurrent and overvoltage conditions can be judged in time through the protection circuit.
3.3 The Software Design of Control System

In the software design, the motor control PWM of LPC1766 is mainly applied, and the motor control PWM includes three channels. Each channel includes a 32-bit timer/counter, a 32-bit limit register, a 32-bit match register, a 10-bit dead time register and corresponding counter, a 32-bit capture register as well as three interrupts (period interrupt, pulse width interrupt and capture interrupt). Each channel of the motor control PWM has two outputs that can drive a pair of transistors. By setting the dead time, it is ensured that the upper and lower bridges in the inverter will not be turned on at the same time. Current is obtained from the AD port connected to the microprocessor.
Start

Initialize MCPWM, ADC, UART, GPIO and other ports

Activate

Interrupt Control

Current detection and regulation

Position detection and speed calculation

RS485 communication

Output Of Control PWM

Locale

Holding

Reading QEI's speed register and Calculate speed difference

Call speed PI adjustment subroutine

Call current adjustment subroutine

Read A/D conversion

Adjust PWM duty cycle

Return

Figure 6. Main Program Flow Chart

Figure 7. A/D Interrupt Program Block Diagram
The main flow chart of the software design is shown in Figure 6, including the system initialization, interrupt control, current detection and regulation, speed calculation and adjustment, and serial communication port RS485 (the Modbus protocol is implemented in the serial communication port). Besides, the A/D interrupt program block diagram is presented as Figure 7 shows.

4. Conclusion
In this paper, the design and realization of control system of brushless DC Motor based on ARM is conducted. Based on the mathematical model and characteristics of the motor, the simulation model of the motor was built firstly. Then, the basic control strategy of the brushless DC motor were analyzed, to conduct the hardware and software design of brushless DC motor control in the electric actuator project. The NXP's microprocessor LPC1766 is adopted as the main control chip in the control system, of which the core is the ARM's latest core Contex-M3. Finally, the hardware circuit for the brushless DC motor control system was built, and the selection and design of hardware were introduced in detail in this paper. In addition, the Modbus protocol applied in this control system enables peripheral bus communication, and a networked control scheme for brushless DC motors was realized in this study.

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