Automatic control strategy of electronic and electrical engineering based on FPGA

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Abstract. Field Programmable Gate Array (FPGA) have demonstrated significant potential in the field of automation control due to their flexibility, programmability, and high performance. This study designs an FPGA-based automation control strategy for motor control systems, encompassing four core modules: signal acquisition, signal processing, control algorithm, and output drive. The signal acquisition module employs the AD9280 high-speed, high-precision ADC chip to achieve rapid and accurate signal acquisition. The signal processing module utilizes digital filtering and FFT analysis within the FPGA to extract key information such as motor speed. The control algorithm module adopts an adaptive fuzzy control strategy that fine-tunes control rules in real-time to ensure precise control. The output drive module generates PWM signals via the FPGA to drive the motor, guaranteeing efficient and stable operation. Experimental results indicate that the FPGA-based control strategy significantly outperforms traditional methods in terms of response speed and stability, capable of meeting the high-performance requirements of modern industrial motor control systems. This research provides new technical insights and practical references for the field of automation control in electrical and electronic engineering.

Keywords: FPGA, control strategy, electronic and electrical engineering.

1. Introduction

Electronic and electrical engineering automation has become an indispensable part of modern industry. The application of automation technology not only significantly improves production efficiency, but also effectively reduces labor costs, bringing more considerable economic benefits to enterprises [1]. In this context, it is particularly important to explore a more efficient and stable automatic control strategy.

Field programmable gate array (FPGA) technology, with its unique flexibility, programmability and high performance, has shown more and more extensive application prospects in electronic and electrical engineering [2]. Compared with the traditional control methods, the control strategy based on FPGA can be customized according to the actual needs, and a more accurate and rapid control response can be achieved [3]. In addition, FPGA also has the advantages of low power consumption and high reliability, which is very in line with the requirements of modern industry for energy saving, environmental protection and sustained and stable operation.

Therefore, it is of far-reaching significance and practical application value to study the automation control strategy of electronic and electrical engineering based on FPGA. This paper aims to discuss the application of FPGA technology in the automation control of electronic and electrical engineering, analyze its advantages, and put forward the corresponding control strategy design scheme.

2. Fundamentals of FPGA technology

An FPGA is a highly customizable integrated circuit whose basic structure includes Configurable Logic Blocks (CLBs). These CLBs form the core of the FPGA and contain logic units capable of implementing a variety of logical functions. Input/Output Blocks (IOBs) are responsible for handling signal interactions between the chip and the external environment. Programmable interconnect resources allow users to customize the connections between CLBs as needed, thereby enabling complex signal routing. Embedded memory blocks (BRAM) provide data storage functionality and support dual-port or multi-port access modes [4]. Digital Clock Management (DCM) modules are used for the generation and management of clock signals. Additionally, there are dedicated hard cores designed to enhance performance and reduce power consumption, such as pre-designed processor cores and memory controllers.

The working principle of FPGA is based on its programmability. Users can describe the required logical functions by programming language, and then map these logical functions to the physical resources of FPGA. Once programmed, FPGA can run like ASIC, but they are more flexible because they can be reprogrammed without changing the hardware.

Programming of FPGAs primarily utilizes Hardware Description Languages (HDL), with Verilog and VHDL being the most common. These languages enable designers to describe the behavior and structure of circuits in text form, which is then translated into hardware configuration within the FPGA by a compiler [5-6]. FPGAs are capable of executing parallel computations efficiently, making them particularly suitable for applications such as image processing, audio processing, and communication signal processing. In fields like industrial automation, robotics, and automotive electronics, FPGAs can implement complex control algorithms and real-time data processing. Within the communications sector, FPGAs are employed for high-speed data transmission, protocol handling, and network security functionalities. FPGAs can integrate multiple features, such as industrial networking, functional safety, and power-level interfaces, reducing system costs and enhancing performance.

3. Design of automation control strategy for electronic and electrical engineering based on FPGA

3.1. Overall design scheme

In this study, an automatic control strategy based on FPGA will be designed for a specific automation scene of electronic and electrical engineering-motor control system. This strategy aims to achieve efficient and stable control of the motor, so as to meet the high performance requirements of modern industry for the motor control system. The overall design scheme of motor automatic control strategy based on FPGA includes the following core modules: signal acquisition module, signal processing module, control algorithm module and output drive module. The overall design scheme is shown in Figure 1.

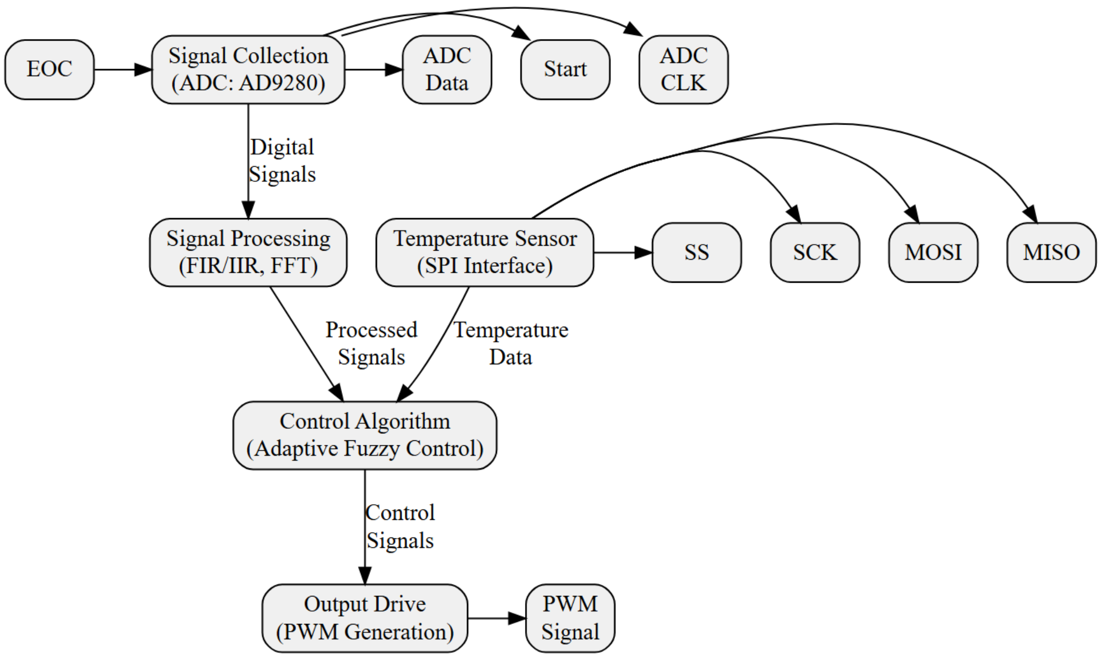

Figure 1. Frame diagram of overall design scheme

3.2. Design of signal acquisition module

The ADC core selects the AD9280, a 12-bit, 80MSPS ADC chip known for its high speed and precision, making it suitable for applications requiring fast and accurate signal acquisition. The FPGA provides a clock signal that matches the sampling rate of the ADC, supplying an 80MHz clock signal to the AD9280 to ensure its proper operation. Given that the AD9280 has 12-bit data output, the FPGA must be configured with corresponding 12 input pins to receive the data output from the ADC. Additionally, the FPGA provides necessary control signals, such as the start conversion signal (START) and end-of-conversion signal (EOC), to effectively manage the operating state of the ADC [7-8].

3.3. Design of signal processing module

In motor condition monitoring, firstly, the motor operation information is collected by sensors and converted into electrical signals. Because there may be high-frequency noise, a low-pass filter is needed for preliminary filtering. After that, the weak signal is amplified and adjusted to an acceptable level (0-3.3V) of FPGA ADC for analog-to-digital conversion. The noise of the converted digital signal is reduced by complex digital filtering (FIR/IIR) in FPGA, and the frequency characteristics are analyzed by FFT to extract information such as motor speed [9]. According to the demand, the key characteristics of the signal are extracted and the parameters such as speed and torque are calculated. Finally, the data is formatted and transmitted to the control algorithm module through the internal bus of FPGA.

3.4. Design of control algorithm module

In the motor control system, the traditional control algorithm may be difficult to achieve the ideal control effect in the face of complex and changeable operating environment and load conditions. Adaptive fuzzy control strategy can adjust control rules according to real-time input by imitating human decision-making process, and realize more accurate and flexible motor control [10].

The design of adaptive fuzzy control algorithm module includes four links: input signal preprocessing, fuzzy logic reasoning, adaptive parameter adjustment and output control signal. In the preprocessing stage, high-speed ADC and signal conditioning circuit integrated in FPGA are used to process real-time operation data from the motor, such as speed, current, voltage and position. Then enter the fuzzy logic reasoning stage, by quantizing the input signal into a fuzzy set and reasoning according to the preset fuzzy control rules, and then defuzzify the reasoning result into a specific control signal; Then, in the adaptive parameter adjustment link, according to the change of motor running state, the parameters of fuzzy control rules are dynamically adjusted by the adaptive algorithm implemented in FPGA to ensure that the system can adapt to different load conditions; Finally, in the output control signal stage, the pulse width modulation (PWM) signal generator in FPGA generates PWM waveform in real time according to the control signal obtained by reasoning, and outputs it through high-speed GPIO to regulate the motor drive.

3.5. Design of output driver module

PWM signal is the key technology to adjust the motor speed and torque by changing the pulse width. The PWM signal is generated by using counters and comparators in FPGA. The counter counts at a fixed frequency. When the counter value reaches the set comparison value, the output state of PWM signal changes, thus forming a signal with a specific duty ratio.

In order to control the DC motor to run at 50% duty cycle and 1kHz frequency, a counter is designed in FPGA, and its maximum count value is set to 1000, so as to realize a period of 1 millisecond and a frequency of 1 kHz. At the same time, a comparator is set with a comparison value of 500 to ensure a 50% duty cycle. In the aspect of driving circuit design, an H-bridge circuit composed of four N-channel MOSFETs is adopted, which controls the switching state of the MOSFETs according to the PWM signal generated by FPGA, thus adjusting the rotation of the motor.

The PWM signal is output through the I/O pin of FPGA and connected to the control end of the H-bridge driving circuit to control the driving current of the motor.

3.6. Interface design and implementation

To monitor the motor temperature and ensure its safe operation, an interface for a temperature sensor based on the SPI (Serial Peripheral Interface) protocol was designed. SPI supports full-duplex communication and is easy to implement in an FPGA. It requires four lines: MISO (Master In Slave Out), MOSI (Master Out Slave In), SCK (Serial Clock), and SS (Slave Select). An SPI Master module is designed in the FPGA to complete the communication. Meanwhile, to achieve precise control of the motor speed and torque, communication with the motor driver is carried out using PWM signals. Only one line is needed to send the PWM signal, and the corresponding PWM control signal is generated in the FPGA.

The following is the SPI Master module realized by VHDL, which is used to communicate with the temperature sensor:

```
library ieee;
use ieee.std_logic_1164.all;
use ieee.numeric_std.all;

entity spi_master is
    Port ( clk          : in    STD_LOGIC;
           rst          : in    STD_LOGIC;
           ss           : out STD_LOGIC;
           sck          : out STD_LOGIC;
           mosi         : out STD_LOGIC;
           miso         : in    STD_LOGIC;
           spi_data     : out STD_LOGIC_VECTOR (7 downto 0));
end spi_master;

architecture Behavioral of spi_master is
    signal sck_cnt : integer range 0 to 7 := 0;
    signal mosi_reg : std_logic_vector(7 downto 0) := (others => '0');
begin
    -- Clock divider for SCK
    Process (clk, rst)
    begin
        if rst = '1' then
            sck_cnt <= 0;
        elsif rising_edge (clk) then
            if sck_cnt < 7 then
                sck_cnt <= sck_cnt + 1;
            else
                sck_cnt <= 0;
            end if;
        end if;
    end process;

    -- Generate SCK
    sck <= '1' when sck_cnt = 7 else '0';

    -- Shift data out on MOSI
    process(clk)
    begin
```

```
        if rising_edge(clk) then
            if sck = '0' then
                mosi_reg <= std_logic_vector(unsigned(mosi_reg) sll 1);
            end if;
        end if;
    end process;

    -- Shift data in on MISO
    process(clk)
    begin
        if rising_edge(clk) then
            if sck = '1' then
                spi_data <= spi_data(6 downto 0) & miso;
            end if;
        end if;
    end process;

    -- Slave Select
    ss <= '0' when sck_cnt = 7 else '1';

    -- MOSI output
    mosi <= mosi_reg(7);
end Behavioral;
```

4. Experimental analysis

In order to verify the automation control strategy of electronic and electrical engineering based on FPGA, a hardware platform including FPGA development board, motor control system, signal acquisition module and temperature sensor is constructed, in which Xilinx Zynq-7000 series is selected as the FPGA development board. The motor control system includes DC motor, motor driver (such as H bridge circuit), power supply and necessary sensors. The signal acquisition module uses high-speed and high-precision ADC chips such as AD9280, and the FPGA provides accurate clock signals for data acquisition. The temperature sensor is used to monitor the motor temperature and communicate with FPGA through SPI interface.

In the software environment, we use Vivado tools to program HDL to realize control logic and algorithm, and use ModelSim and other tools to simulate the function and timing of FPGA code. The upper computer software is developed to monitor and control the running state of the motor, and communicates with FPGA through serial port.

Fig. 2 shows the changing trend of the rotational speed (RPM) and temperature of the motor with time respectively. The average speed of the motor is about 3000 RPM, the fluctuation range is between 2800 and 3200 RPM, and the standard deviation is 100 RPM, which shows that the speed is relatively stable although it changes. The average motor temperature is about 30°C, the fluctuation range is 28°C to 32°C, and the standard deviation is 2°C, which also shows the stability of temperature. Long-term observation shows that the fluctuation of both speed and temperature is random rather than trend, which indicates that the motor and its control system can maintain stable operation for a long time without obvious performance degradation.

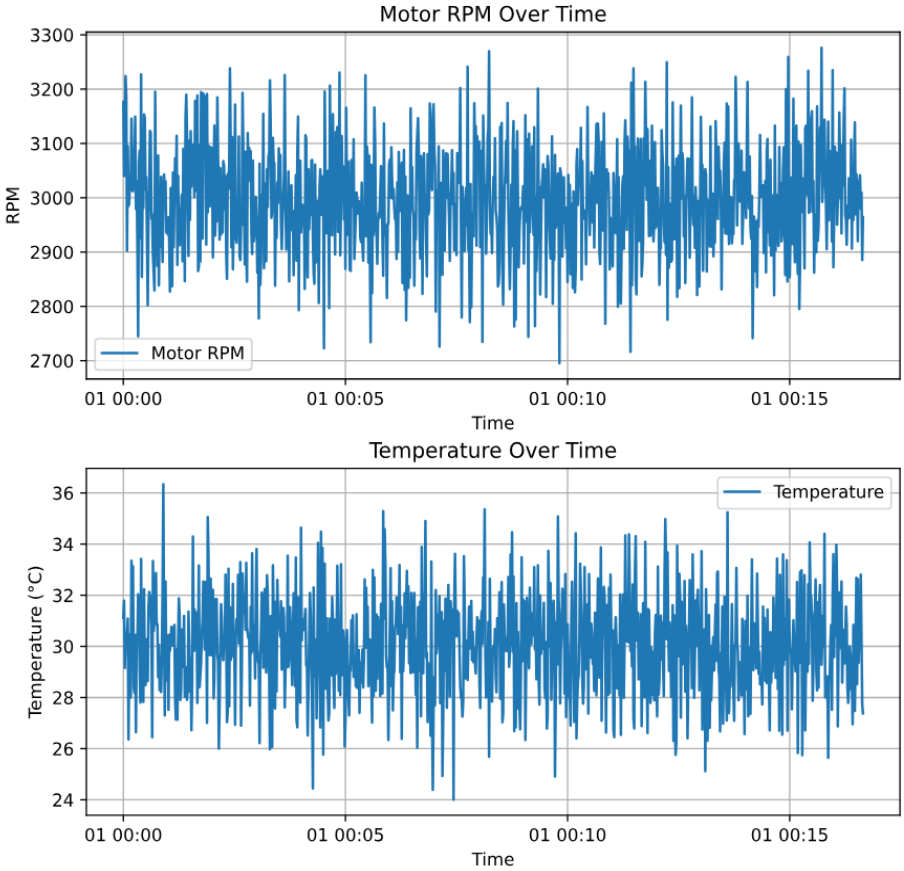

Figure 2. Stability of the system in long-term operation

Table 1 lists the comparison of response time between traditional control method and control strategy based on FPGA at different time points. The response time of the traditional control method at 00:01:00 is 14.256 milliseconds. With the progress of the test, the response time fluctuates slightly, but it is all around 14 milliseconds. The response time of the control strategy based on FPGA is kept below 2 milliseconds at all test time points, and the slowest response time is 1.890 milliseconds, which shows its remarkable advantages in response speed.

Table 1. Response speed of different control methods at multiple time points

Test time point	Response time (ms)	
	Traditional control	Control based on FPGA
00:01:00	14.256	1.234
00:02:00	14.123	1.123
00:05:00	15.321	1.321
00:10:00	14.567	1.567
00:15:00	14.890	1.890
00:20:00	14.789	1.789

The automatic control strategy of electronic and electrical engineering based on FPGA has shown remarkable advantages in the experiment. Compared with traditional control methods, FPGA control strategy is more flexible and efficient, and can meet the high performance requirements of modern industry for motor control system. Therefore, the control strategy based on FPGA has broad application prospects and important practical significance in the field of electronic and electrical engineering automation control.

5. Conclusion

The automatic control strategy of electronic and electrical engineering based on FPGA shows obvious advantages in the experiment. Compared with traditional control methods, FPGA control strategy shows higher flexibility and efficiency, which can better meet the demand of modern industry for high performance of motor control system. Through customized design, FPGA can achieve accurate and fast control response, and its low power consumption and high reliability also meet the requirements of modern industry for energy saving, environmental protection and sustained and stable operation. Therefore, the control strategy based on FPGA has a wide application prospect and important practical significance in the field of electronic and electrical engineering automation control.

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