

DESIGN AND IMPLEMENTATION OF CONTROL SYSTEM 6-UPS MEDICAL ROBOT BASED ON FPGA

P.S.Arthy⁽¹⁾, Dr.S.Manjula⁽²⁾

Assistant Professor, Department of Electronics and Communication Engineering⁽¹⁾,

Assistant Professor, Department of Electrical and Electronics Engineering⁽²⁾

Veltech Multitech Dr.Rangarajan & Dr.Sakunthala Engineering College, Avadi, India

Email: arthyps@veltechmultitech.org

Abstract:

The main goal of this paper is to design and implement a high performance control system for 6-UPS Medical Robot based on FPGA. The control system designed utilizes maximum hardware and software reconfigurable features of the FPGA device. The paper contains the description of the Parallel robot and its control components and a then control system general description including the hardware inside it .NIOS II soft core processor module is the programming module and first module of the system. The system can be estimated using a drive test based on RS 232 is carried out. Satisfactory test results demonstrate that the FPGA-based control system is a flexible, high-performance solution to the motion control of our 6-UPS medical parallel robot.

Keywords:- 6-UPS Medical robot, FPGA, HALL module,RS232.

I. INTRODUCTION

Medical robotics has a rapid development in recent years. In addition to its mechanical structure design, the robot's drive and control should meet the medical needs. DC motors are widely used in robots because of its small moment of inertia, small size, low noise, and easy maintenance. In our design of 6-UPS medical parallel robot, six DC brush motors and a brushless DC motor were used. With the development of large scale integrated circuit technology, the digital EDA (Electronic Design Automation) tools have brought great changes for electronic design. Especially the appearance of the hardware description language (Verilog or VHDL) has resolved a lot of inconvenience of the traditional schematic circuit design engineering. Over the past years, many FPGA based systems have been implemented for control and robotics applications. Li *et al.* Many FPGA based systems have been implemented for control and robotics applications. Designed a 6-DOF parallel robot to complete the positioning and grinding between the prosthesis and two bone surfaces for the cervical artificial disc replacement surgery [2]. Shilpa Kale *et al.* designed a FPGA-based controller for a mobile robot [3] J. Mai *et al.* developed FPGA-based gait control system for passive bipedal robots [4]. Charitkuanet *al.* designed a closed-loop control system for robots in the RoboCup small sized league [5]. N. Chakravarthyet *al.* implemented a FPGA- based control system for miniature robots [6]. Chen *et al.* implemented a complete FPGA-based controller for wheelchair [7].Implemented a FPGA-based behavioral control system for a mobile robot [8] and Sam *et al.* designed three PID architectures for FPGA implementation and studied speed and area tradeoffs on the three designs [9].

To control DC motors by FPGA, a large number of logic functions can be integrated on a monolithic IC, the resources are saved, and online programming and erasing are achieved, which makes the design more flexible, the reliability higher and the system architecture extremely compact. In addition, another feature of FPGA showed in many real applications is high-integration.

II. BIOMEDICAL ROBOT

We have designed a 6-DOF parallel robot to complete the positioning and grinding between the prosthesis and two bone surfaces for the cervical artificial disc replacement surgery [9]. The robot will orient the end effector in the space to perform the bone milling cuts between the prosthesis and bones on the patient. The 6-UPS parallel robot (Fig.1) is composed of six UPS (Universal- Prismatic-Spherical) linear actuators that are connected in parallel between the fixed platform and the moving platform, which is the moving end-effector of the robot. The robot is equipped with a milling device, which actively mills bone according to the preoperative grinding planning. The medical parallel robot control system is composed of a parallel robot control system and a burr control system, whose architecture block diagram is shown in Fig. 2. The components and functions for the parallel robot control system are shown as follows:

(1)Host Computer: It Provides user interface, and accepts external control commands and parameters. The robot kinematics calculation and trajectory planning are carried out in the computer, which sends control instructions to the control system;

(2)**Motor controller and driver:** For the low-level control of the robot, the robot drivers and controllers will be designed to achieve 6 DC motors position servo control and a brushless motor open-loop speed control;

(3)**Feedback component:** The position feedback components adopt MR encoders with S-type, 256 lines, 2channels, and 160 KHz maximal operating frequency;

(4)**Photoelectric switch:** Because of the incremental encoders and the positive and negative limits for the system safety, two photoelectric switches are set on each linear actuator body. One can limit and set zero (the odd number in Fig. 2), and the other is only a limit switch (the even number in Fig. 2).



Figure 1. 6-UPS Medical Parallel Robot

III. CONTROL SYSTEM GENERAL DESCRIPTION

We have utilized the hardware and software reconfigurability of FPGA to satisfy the needs of 6-UPS medical parallel robot for high-performance processing and flexible electrical hardware for different tasks to implement its grinding planning. We selected the Altera Cyclone III Cyclone EP3C16F484C6 device as a foundation for the proposed system. One 8MB K4S641632SDRAM chips was adopted to compose a 16-bit width SDRAM with faster data storage. Altera also offers low-cost serial configuration devices to configure Cyclone III devices [11]. In all, the hardware of our control system embedded in the fixed platform is illustrated in Fig. 4.

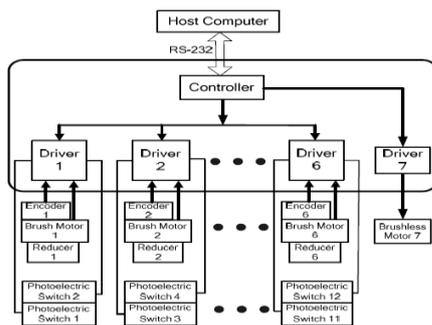


Figure 2. The robot control system architecture block diagram

Programming was finished by Quartus II 7.2 development platform launched by the company ALTERA, which aims to be a simple tool of a complex design, and can simulate and verify the function realization, optimize the circuit to avoid errors.

IV. DESIGN OF MODULES

The FPGA's internal design uses a centralized control method, i.e., all control signals are produced by a core control module of the system, and the other modules only perform certain functions. Each function module is controlled by the control signals

generated by the control module to achieve the overall function of FPGA, which is easy to debug and integration by block. The system control module is responsible for coordination and control among the various modules.

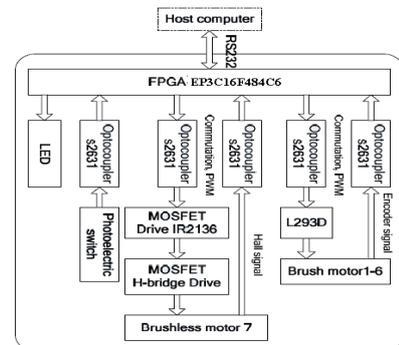


Figure 3. FPGA-based multi-motor drive and control block diagram

A. NIOS II soft core processor module: The low-cost Nios II soft processor family features a general-purpose RISC CPU architecture designed to address a wide range of embedded applications in Altera FPGAs .A soft-core NIOS-II embedded in EP3C16F484C6 carries out PID calculation to achieve the brush motors position closed loop control, and the calculated PWM values are sent to the internal PWM generator in FPGA. The 32-bit medium-speed soft-core CPU with hardware floating-point multiplier is integrated in Nios II soft-core, whose input clock is 20 MHz and can converted to 100MHz frequency doubling by the internal PLL module. RESET signal comes from the power chip 7333.

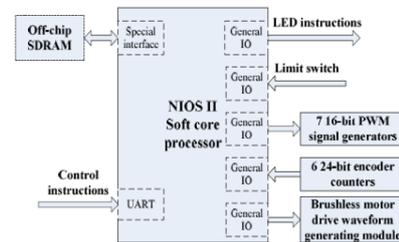


Figure 5. NIOS II soft core processor internal structure

B. HALL module

HALL functions are achieved by a process written by VHDL.

The brushless DC motor magnetic commutation is realized by the process according to the rotation direction of the external demands.

C. PWM_OUT module

A counter is set up in PWM_OUT module, which works in the symmetrical counting mode. That is to say, the counter begins forward counting after initialization, and until the counter reaches the cycle value set, the counter starts backward counting. And when the counter value is greater than the outside set value, PWM output is low, otherwise the output is high.

The counter PWM output contains fewer harmonics in a symmetrical counting mode than in the oneway increase counting mode. In the actual device, the cycle value is fixed at 9999, i.e. PWM fundamental frequency is10KHz. PWM

module pins distribution and their functions description are shown in Fig. 7. PWM module simulation waveform with a 100MHz CLK input is shown in Fig.8.

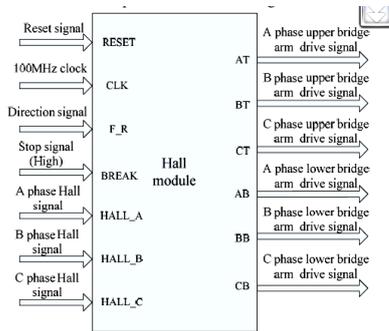


Figure 6. HALL module pins distribution and their functions description

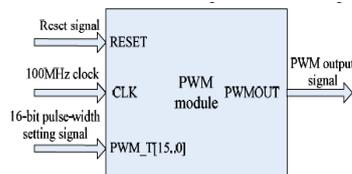


Figure 7. PWM module pins distribution and their functions description

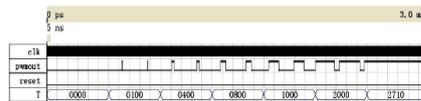


Figure 8. PWM module simulation waveform

D. DC_MOTOR_DRIVER module

DC_MOTOR_DRIVER module is used to implement the commutation operation of DC brush motors. The PWM signal outputted by PWM_OUTn is outputted to nth DC_MOTOR_DRIVER module. According to the high and low of the direction control signals DIRn outputted by CPU, DC_MOTOR_DRIVER module will determine the output from UP and DOWN pin to be a low level or PWM signals. Fig. 9 shows the DC_MOTOR_DRIVER module pins distribution and their functions description.

E. COUNTER module

COUNTER module is used to implement the forward and reverse counting from the encoder signals for the robot joint position detection. A complete description of the robot stroke needs a 24-bit width counter, which consists of three submodules, including the low 16-bit counter, high 8-bit counter and low and high integration output device. The low 16-bit counter outputs the motor direction of rotation and change count by detecting voltage from the encoder A and B phase, compared with detection results from the previous clock.

F. Soft-core Software Design

The instructions from the host computer are waited for in the break way. If a new command arrives, the motors will be driven after the instructions are parsed. The 1ms control period for the motors is generated by the timer.

V. CONCLUSION

This paper reports our technical progress in developing FPGA-based control system for our 6-UPS medical parallel robot. We

have implemented various function modules in single FPGA chip, including NIOS II soft core processor module, HALL module, PWM signal module, DC motor drive module, encoder signal processing module, and the soft-core software design. All the modules can be duplicated and reconfigured to control as many motors as needed. Finally, to estimate the control system, a driving tests based on RS232 has been carried out.

Satisfactory test results demonstrate that the FPGA-based control system is a flexible, high-performance solution for the motion control of our 6-UPS medical parallel robot. In future, we will study the robot motion control, including its kinematics and grinding planning. Then, the host computer software will be developed by using the serial port control instructions. The control system will continue to be improved and perfected, so as to apply it in our medical experiments.

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