FPGA Based Five Axis Robot Arm Controller

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Abstract: The hardware and software co-design for five axes robot arm, is aimed to perform pick and place operation by controlling the speed and position, using FPGA, H-bridge driver and Sensor circuit. Digital PWM is used to control speed of DC motor. The hardware functional block designed in software module with the help of VHDL coding as FPGA technology has blurred the distinction between hardware and software. Interfacing of different hardware blocks with software module for real time application is very challenging and demanding in every field to achieve better command over control through software without disturbing the hardware circuitry. This designed work is an educational based concept as robotic control is an exciting and high challenge research work in recent year.

Keywords: FPGA, Robot Arm, Hardware and Software Co-Design, Speed Control, Position Control.

1. INTRODUCTION

In present era, Robotic Arm controller is the challenging and demanding activity in industrial field as well as military and other applications. This designed project is the educational based concept. Embedded system provides solutions to the implementation of robot control system very easily in digital way. The introduction of field-programmable gate array (FPGA) technologies has blurred the distinction between hardware and software [3]. Traditionally a hardware circuit used to be configured at manufacturing time. With field programmable technology, it is possible to configure the gate-level interconnection of hardware circuit after manufacturing [8]. This flexibility opens new application of digital circuits, subsequently; the FPGA can be reprogrammed to perform another specific function without changing the underlying hardware. Thus from a user perspective, a reprogrammable hardware board can perform a function indistinguishable from that of a processor. Nevertheless, the programming mechanisms and the programmer's view of the hardware are very different [9].

The present paper involves the Hardware/software co-design for robot arm control application which is controller include three main parts like controller, H-bridge driver circuit, Robot arm model with DC motor and Rotary Encoder Fig. 1 indicate the overall diagram of system which show the interconnection between different system blocks. The design composed three different parts, in which two different physical property devices combine on one application platform with software thread. FPAG controller is the software part, which provides free environment to user interface [7]. H-bridge diver circuit is the hardware part and Robot arm with functional gripper is the mechanical part of system. All parts are interconnected with each other to perform the designed algorithmic task to achieve pick and place operation.

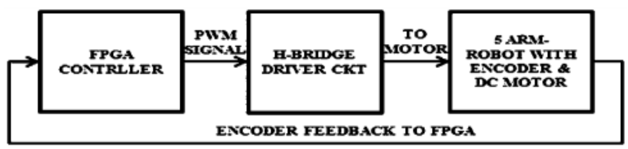

Figure.1: Overall Block Diagram

With each movement the motor, rotary encoder reads the position of a disk attached to the motor. This position information is sent back to the FPGA Controller so it knows how much further the motor needs to be turned or if the motor has turned too far [10].

2. FPGA CONTROLLER

The FPGA controller is the sole of whole system which provides free environment to user interface with design. Motor control strategies vary according to the type of motors and control algorithms used. To build an efficient motor controller, an FPGA provides a flexible platform as a starting point to which designers can add the necessary inputs to suit their requirement. FPGA to a robot am controller is very attractive, it makes robot more versatile, adding some new features to the design of robot like reconfigurable control, hardware reuse, lower cost, fault-recovering, and software/hardware co-design [4]. To obtain the required output of the system, complete design source code is divided in three main parts shown in Fig.2 (FPGA controller diagram-1) namely Data controller, Heart of controller system (FSM) and Data path. These three main parts is subdivided in many modules (shown in Fig.3 FPGA controller diagram-2) which put great efforts in system performance. Data controller includes the PWM module

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with various frequencies to drive all 5 motors at same duty cycle or all 5 motors with different duty cycles at same time. It also activates all other modules in design system so that it called as data controller [2]. The detail FPGA controller with all main modules is shown in Fig. 3 (FPGA controller diagram-2)0in which each module contribution plays vital role in system performance.

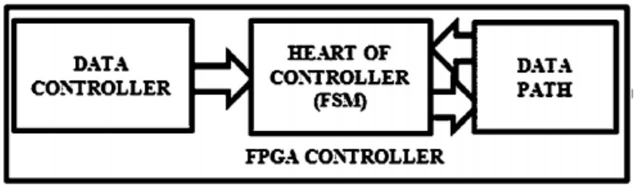

Figure. 2: FPGA Controller Diagram-1

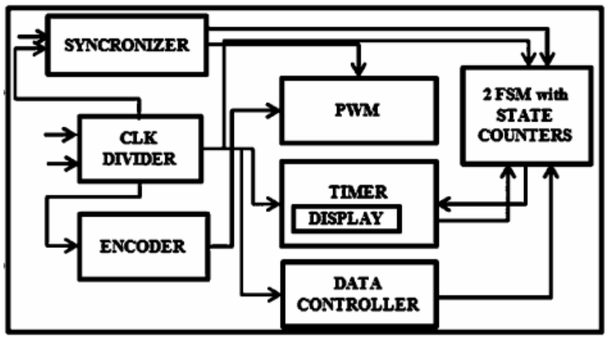

Figure.3: FPGA Controller Diagram-2

FSM is the heart of whole controller mechanism, which performed according to the algorithmic tasks. It is control by data controller and the data path. Data path, which includes the timer and displays, it sends the signals to the FSM so as to control the states of FSM while performing the algorithmic task.

2.1. Data Controller

PWM generator is performed the main function in data controller. The digital logic device is to generate high frequency PWM control signal, which is more accurate and gives very smooth and minute control[8]. This PWM for controller is designed with a 20ms cycle, that's the pulse width, can be as small as 0 and as large as 20ms. However, the motors placed on robot arm model generally don't move until about 7ms or so.

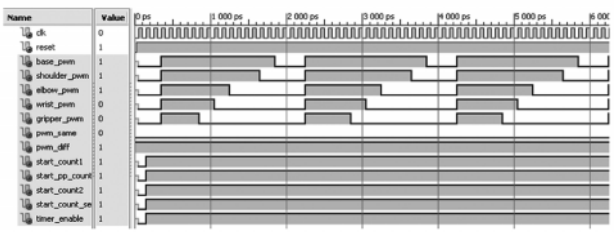

Figure. 4: Text Bench Result for Different Duty Cycle PWM Signal to Each Motor

To get a 20ms cycle, the clock needs to be a 1 KHz clock. Finally, the frequency time is a 5 bit number, limited internally to 20, The PWM controller works by having a counter and comparators that counts up from zero to nineteen and compare different frequency time to generate different PWM signal for 5 motor, and then resets itself. If the count is greater than the frequency time, then the output is set high, and vice versa. Data controller decides that which PWM signal will send to FSM. It can send same duty cycle signal to all motor or different duty cycles signal to each motor with the help of data shifter module and encoder signal input. Encoder signal plays the important role to control the on-off operation of PWM signal. The Fig. 4 shows the text bench result for PWM signal with different PWM signal.

2.2. Heart of Controller – FSM

The designed algorithm for pick and place operation is implemented using FSM in VHDL, so as FSM is referred as the heart of FPGA controller. When it is controlled the action of arm, then the position control and speed control are the main issue. It must be controlled such that the robot can pick the object at certain place accurately and place it at the desired place accurately as well. It is the role of the controller to achieve this goal. One can use many algorithms to achieve it but the goal is one, i.e. to pick and place object accurately, fast and with small overshoot. [1] The design algorithm is for pick and place five wooden blocks with weight 50 gram each and makes a one complete word "RKNEC". In algorithm, there are many repetitive action but these all are manage in one sequence which is to be followed by state machine in VHDL.

2.3. Data path

Data path provides the timing parameter for whole controller system. In which timer plays the important role and seven segment display shows the current counting position of timer for specified state of FSM. State timer is activated by the signal provided timer enable signal by data controller and start timer and signal by FSM.

3. INTERFACING OF H-BRIDGE DRIVER AND DC MOTOR

H-Bridge is the link between digital circuitry and mechanical action. An H-bridge driver is an electronics circuit which enables a voltage to be applied across a load in either direction. The Driver circuit gives the required current to drive the motor and it takes both speed and position feedback from the motor [6]. These circuits are often used in robotics and other applications to allow DC motors to run in clockwise direction when direction signal is logic 1 and in anticlockwise direction when direction signal is logic 0. The motor can be configured for position control. H-bridges are available as integrated circuit, or can be built from discrete components. L298 Chip is well known H-Bridge which allows driving DC motor in both direction but also can vary its speed with PWM inputs. In this controller generates signals needed to drive motor to selected direction and speed. The three L298 ICs are used to control the five motor located at robot arm. Each IC can drive two motors simultaneously.

4. INTERFACING OF DC MOTOR AND ROTARY ENCODER

A rotary encoder is an electro-mechanical device for converting the angular position of a shaft or axle to a digital code. When, working with DC motors, a shaft encoder is the most common and accurate way of providing feed-back to the controller.

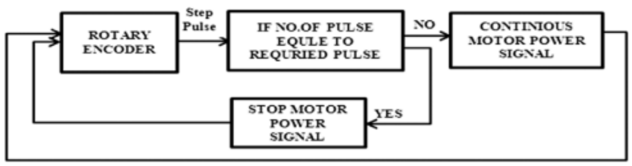

Figure. 5: Encoder Sending Signal to the Controller to Count the Required Signal

An incremental rotary encoder provides information about the instantaneous position of a rotating shaft in term of pulses[5]. FPGA controller verify the signal status and sends the corresponding signal that weather motor keep on or stop shown in Fig. 7. The frequency of those pulses is directly proportional the speed of rotation of the shaft and the number of those pulses correspond to the angular displacement of the shaft. The shaft encoder sensor sends information, in the form of electronic signals back to the controller.

5. ROBOT ARM

The design concept is implemented with the help of robot arm model. Robot Arm is a 5 axis robotic manipulator each has two possible orientations consist of a rotating base, three links and a gripper. The five axes consist of the Shoulder, elbow, wrist having 180, 300, 60 degree rotational limit with vertical movement. The axis at base is having 270 degree rotational limit with horizontal movement. The control signals to the motor define the movement of each arm in three phases. Each of the joints performs 3 actions (Except the gripper) - Stay, Obtuse angle turn and acute angle turn. So two bits are required to represent each of the movement. Finger0(functional gripper) is having +/- 7 resolutions with open and close movement. Fig. 8 shows the robot arm model in working with kit.

6. CONCLUSION AND FUTURE WORK

Motor control design is tough work. The written VHDL code is simulated using ModelSim®, & XILINX ISI 11.1. The simulation results for different PWM signal are shown Fig. 4. This paper discussed a hardware and software co-design of a Robot Arm Controller with 5 motors. This advantage makes the system very convenient since it allows the increase of the number of motors, simply using a larger FPGA. Researcher/Designer can easily add the flexibility in operation by modify its behavior, changing a parallel ADC for a serial one (or vice-versa) is a minor effort in an FPGA but can be very troublesome in a software solution. Once a technology is carefully set up, Researcher/Designer can easily apply it to different systems; Researcher can say it is multipurpose system.

Future work will focus on enhancement of drive control tasks and further application development. Regarding the drive control tasks, control algorithms like a cascade control featuring position/speed plus current feed-back or a state control with a state feed-back is to be implemented. Further applications of the drive controller include piezo-electric actuators.

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