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FPGA Based Motor Control System Using PID Controller and Sigma-Delta ADC

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Abstract: ***In industrial robotic applications, motors play an important role to move the joints for pick and place, tool positioning, etc. For the accurate movements of joints, the speed of the motor should be controlled. The existing techniques for controlling the motor are not accurate and form steady state error and oscillations at the output. Hence PID (Proportional Integral Derivative) controller based motor control system with a Sigma-Delta Analog-to-Digital Converter (ADC) at the feedback section can be used to rectify this problem. A Sigma-Delta ADC consists of a feedback that helps in the accurate conversion from analog to digital signal. This system can be implemented on FPGA, which offers the advantages such as high performance and concurrent computing. Each module is simulated and synthesized using the Xilinx ISE Design Suite 14.2 and ISim Simulator.***

Keywords: PID, PWM, DC motor, Sigma-Delta conversion, FPGA.

1. Introduction

Many robotic applications are for difficult, dangerous and unpleasant task for human beings. In industrial areas, the robots are mainly used for repetitive, tedious tasks in which human performance might decreases over the time. The movements made by the industrial or laboratory robots are accomplished by making use of the rotation of the motors. Presently, different types of motors are available. Among them, the DC motors are widely used in the servo applications such as conveyors, robotic vehicles, etc. In these applications, the speed and accuracy are very critical and hence to meet this speed of rotation and accuracy requirements, a control system is essential.

There are different types of controllers such as P (Proportional) controller, PI (Proportional-Integral) controller, PD (Proportional-Derivative) controller and PID controller that are used in different robotic applications [9]. Among them, the PID controller which uses a control loop feedback mechanism has been widely used due to their simplicity, robustness and effectiveness. In the industrial process control, more than 95% of the control loops are of PID type [10]. Thus, it becomes an important tool for embedded real time digital control. The PID controller can be implemented either in software using computer-based systems or in hardware using analog components. The emergence of field programmable gate arrays (FPGA) and fast progress of Very Large Scale Integration provide a different dimension for the development of digital PID controller [8]. A PID controller tries to correct the error between a measured output value and a desired set point. This is done by calculating and produces a corrective action as output that can adjust the process accordingly.

Sensors are the critical components in a motor control system. They are used to sense the current position, speed and direction of the rotating motor. The output of the sensor will be an analog signal. The Sigma-Delta ADC digitizes the sensor's output. The Sigma-Delta modulators are widely used either as ADCs or as pulsewidth modulators [1]. This technique has been in existence for many years, but recent technological advances increases the practical use. In conventional ADCs, an analog signal is sampled with a sampling frequency and then quantized in a multi-level quantizer into a digital signal. This will produce quantization noise at the output. The Sigma-Delta ADC combines oversampling and shaping of quantization noise to achieve high accuracy and resolution. It consists of a modulator which produces a bit-stream and a digital low pass filter. In the modulator part, the accuracy of the modulation is improved by passing the digital output through a 1-bit DAC and then adding it to the input analog signal [12].

One of the simple and easy ways to control the speed of a DC motor is by using Pulse Width Modulation (PWM). The speed of the motor depends on load, voltage and the current. For a fixed load, a steady state speed can be maintained by using the PWM technique. Although the output voltage has fixed amplitude, it has a variable duty cycle. That means wider the pulse, higher the speed. By changing (modulating) the width of the pulse applied to the DC motor, the speed of the motor can be increased or decreased [4].

In this work, the controlling of DC motor is done by using the PID controller. In the feedback section, a Sigma-Delta Analog-to-Digital Converter is used in order to increase the accuracy of the system. The purpose of a motor speed controller is to take a signal representing the required speed and to drive a DC motor using PWM wave. The coding can be synthesized by the Xilinx ISE Design Suite 14.2, simulated using ISim simulator and can be implemented using Spartan 3E FPGA.

2. Related Works

Many works has been carried out in the field of motor controllers. A PID controller is incorporated into the robot based agricultural system in order to perform the tilling and de-weeding operations [2]. The controller helps the robot to navigate through the desired directions. The use of micro-controller for the speed control of DC motor is past gaining ground. The controller can be implemented using ATmega8L microcontroller for speed control of DC motor fed by a DC chopper [5]. It is done by controlling the duty cycle of PWM signal fed to the DC motor. The paper by Kurnera, Dayananda and Jayawikrama [13] explains the use of a chopper in collaboration to the PC for the control of DC motor speed. Software was developed and fed into the PC. The commands are given to the chopper via the computer for control of motor.

Other controllers such as Proportional controller had a great influence in past control systems. A Proportional controller is used for differential steering control [6]. It predicts the velocities of the wheels and maintains the direction of the robot. The model for speed control of induction motor is designed using indirect vector control through PI speed controller [3]. The simulation of the human motion is done using a PD controller in the computer. A PD provides a simple framework to compute control forces that track a joint trajectory's kinematic state [7].

3. Methodology

The control system consists of a forward loop and a feedback loop. The forward loop helps to change the control parameters in order to produce a desired output and the feedback loop helps to find the error between the system output and the desired output so as to make the system output equal to the desired output.

3.1 System Overview

The basic block diagram for the PID controller based motor control system using Sigma-Delta ADC is shown in Figure 1.

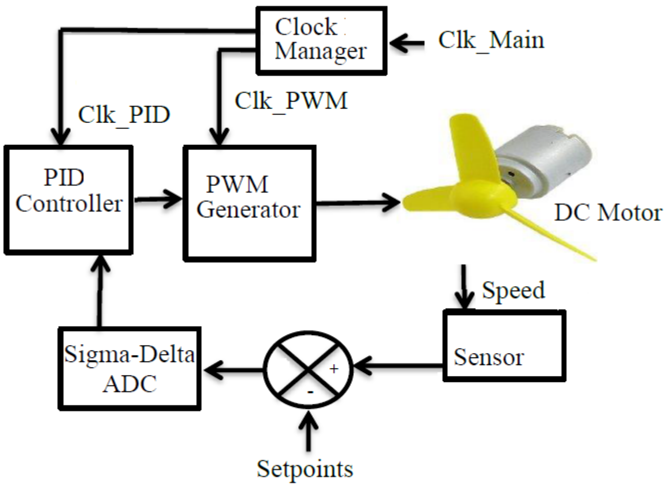

Figure 1: Block Diagram of control system

It is the speed of the motor that needs to be controlled. So it is monitored by using a sensor, whose output will be an analog signal. The analog signal cannot be directly fed into a digital system like FPGA. So initially it needs to be converted into a digital signal. For this purpose, an ADC is used in the feedback section. The digital signal obtained from the ADC is given to the PID controller for producing appropriate control signal. This control signal will act as a reference to the PWM generator for producing a PWM wave for driving the DC motor.

3.2 PID Controller

The PID controller mainly consists of three types of control actions: the proportional control, the integral control and the derivative control. The block diagram for the PID controller is shown in Figure 2.

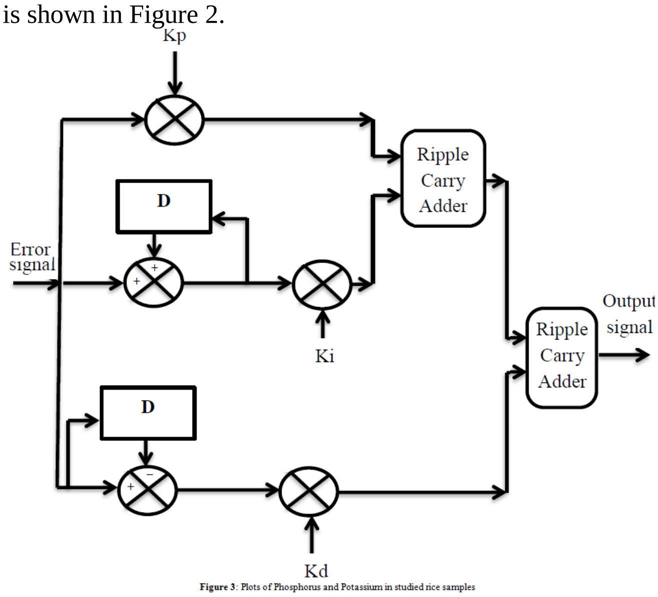

Figure 2: Block Diagram of PID Controller

The Proportional Control depends on present errors, integral control depends on the accumulation of past errors and the derivative control predicts the future error by using the current rate of change of errors. The weighted sum of these three actions is used to adjust the process by using a control signal.

3.3 PWM Generator

The average value of voltage or current fed into the load is controlled by turning the switch on and off at a higher speed by the PWM. The block diagram for the PWM Generator is shown in Figure 3.

It is a counter-comparator based PWM Generator. It basically consists of a comparator with two inputs and an output. The first input is a reference signal coming from the PID controller and the other is a sawtooth wave generated by an up-counter. The sawtooth wave produced by the up-counter is compared with the reference voltage signal. Thereby changing the duty cycle of the PWM wave according to the reference signal as shown in Figure 4(a) and 4(b).

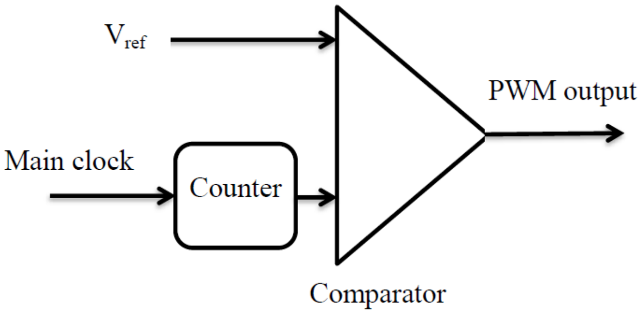

Figure 3: Block diagram of PWM Generator

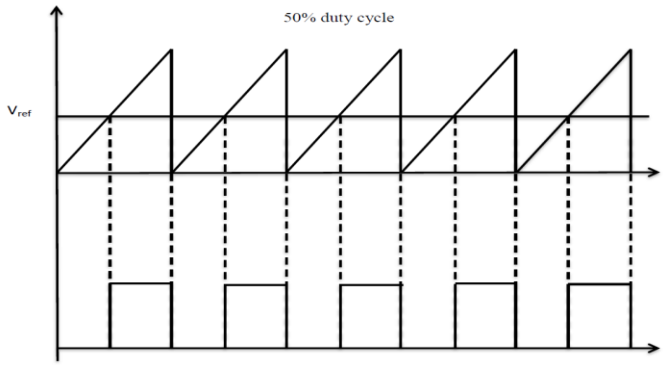

Figure 4(a): PWM with 50% duty cycle

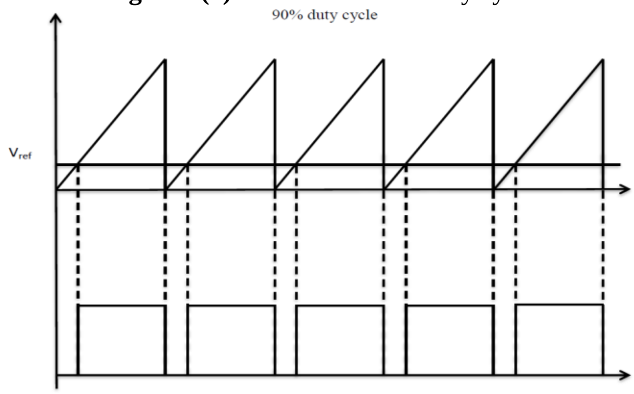

Figure 4(b): PWM with 90% duty cycle

3.4 Clock Manager

The clock frequency of the FPGA is very high, this makes the working of the motor difficult. Also, it is not easy to include an external clock to the circuit due to the increase in the complexity. Hence, the system clock, with the help of a clock divider circuit is utilized to produce the required clock frequency for the functioning of the motor.

3.5 Sigma-Delta ADC

The Sigma-Delta ADC utilizes the Sigma-Delta modulation noise shaping property and oversampling techniques to allow high-resolution conversion [11]. The noise shaping property places most of the quantization noise in the high frequency range to minimize the in-band noise. The noise shapes depends on the order of the modulator. The block diagram for the second order Sigma-Delta ADC is shown in Figure 5.

The second order Sigma-Delta ADC provides better noise shaping characteristics compared to the first order modulator. Higher order modulator allows high in-band noise reduction. But, single loop single-bit modulators higher than two have some instability issues.

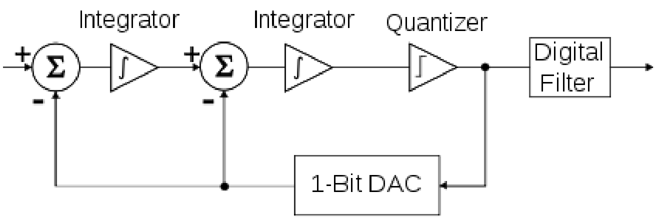

Figure 5: Block Diagram of Second order Sigma-Delta ADC

4. Results and Discussion

The forward loop of the PID controller based motor control system basically consists of three main blocks PID controller, a PWM Generator and a clock manager. Initially the coding for the individual block was completed and then all the modules were combined by using the structural modeling. Simulation is carried out using Xilinx ISim simulator and then synthesis is done using Xilinx ISE 14.2. The RTL schematic view of the PID controller based motor control system is shown in Figure 6.

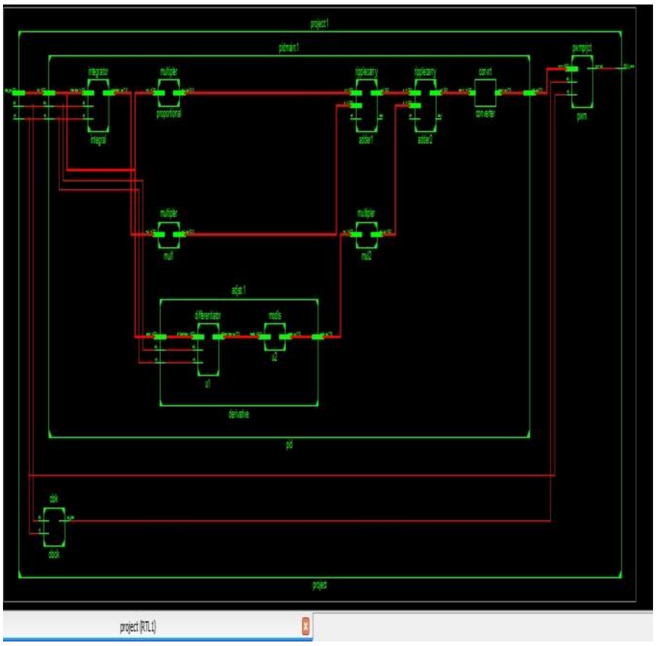

Figure 6: RTL-Schematic of Motor Control System

The simulation result of the PID controller based motor control system is shown in Figure 7. The speed of the motor is continuously monitored using a sensor, whose output is an analog voltage signal. The voltage signal is then converted into corresponding digital signal by Sigma-Delta ADC. Here, the input to the PID controller is the digitized feedback signal from Sigma-Delta ADC.

The PID controller uses the feedback signal for calculating its proportional, integral and derivative responses. This control signal from the PID controller will help to generate the PWM wave with the help of PWM Generator. The output of the simulation is a PWM wave. It helps to drive the motor accordingly.

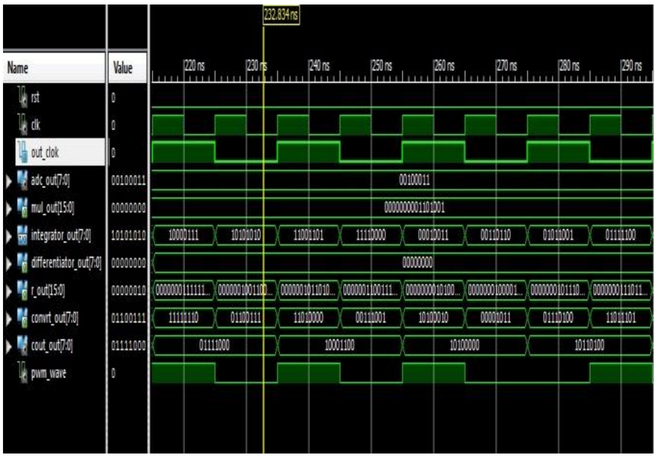

Figure 7: Simulation Result of Motor Control System

5. Conclusion

The FPGA based motor control system using PID controller and Sigma-Delta ADC has been introduced. The practical disadvantages found in the case of other controllers are solved by using this control system. The PID controller system continuously checks and corrects the speed of the motor by taking proportional, integral and derivative responses of the error signal measured from the output and the desired set points. The use of Sigma-Delta ADC in the feedback section provides high resolution and accurate conversion. The role of the FPGA is to acquire the data about the speed from the sensor through the ADC and generate control signals to the actuator after processing of acquired data. Implementation in FPGA improves the speed, accuracy, ease of design and cost effectiveness.

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