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Digital P-I-D Controller Implementation for Speed Control Applications Using FPGA

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Abstract: ***This paper deals with the implementation of PID controller for a DC fan controller application on FPGA platform (both hardware and software). The PID controller is implemented on Spartan 3E FPGA by using Xilinx software version 9.2. The PWM signal is generated by FPGA Spartan 3E board, which further given to DC fan for its speed control. The PID controller is prototyped and verified on the Xilinx Spartan 3E Field Programmable Gate Array (FPGA) platform and a test bench is written for top module (PID controller) which is simulated by using ModelSim simulator. The verification of DC fan operation is checked using generated PWM signal generator.***

Keywords: Analog to Digital Converter (ADC). Field Programmable Gate Array, (FPGA), Proportional-Integral-Derivative (PID controller), Pulse Width Modulation (PWM signal generator), Very High Speed Integrated Circuit Hardware Description Language (VHDL)

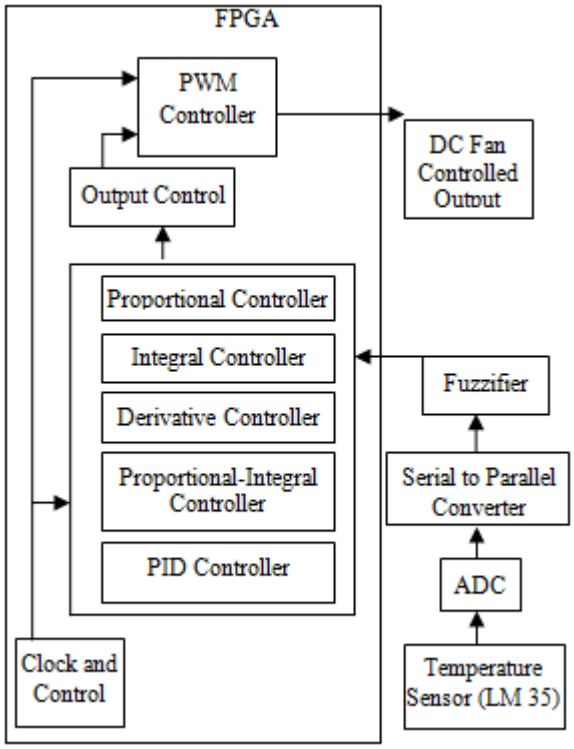
1. Introduction

There are two approaches for implementing control systems using digital technology. The first approach is based on software which implies a memory-processor interaction. The memory holds the application program while the processor fetches, decodes, and executes the program instructions. Programmable Logic Controllers (PLCs), microcontrollers, microprocessors, Digital Signal Processors (DSPs), and general purpose computers are examples of control systems with software implementation. The second approach is based on hardware. Field programmable gate arrays are configurable ICs and used to implement logic functions and are a soft wired hardware. In control systems, the majority of actuating signals and sensor returns are analog signals. Therefore, analog to digital and digital to analog conversion plays an important role in digital controllers. In addition, a pulse width modulation (PWM) device will be designed. This is used as building blocks in many control applications such as speed and position control. In the proposed work a PID (proportional integral derivative) controller will be realized by Field Programmable Gate Arrays (FPGAs). The Proportional Integral Derivative (PID) controller is one of the most common types of Feedback controllers used in dynamic systems. This controller has been widely used in many different areas such as aerospace, process control, robotics, and transportation systems and also used extensively in real time digital control. . Recently, Field Programmable Gate Arrays (FPGA) has become an alternative solution for the realization of digital control systems, previously dominated by the general-purpose microprocessor systems. The FPGA-based controllers offer advantages such as high speed, complex functionality, and low power consumption. Another advantage of FPGA-based platforms is their capability to execute concurrent operations, allowing parallel architectural design of digital controllers.

2. Current Problem And Proposed Solution

The Existing approach is Software based implementation only. But this results in low control speeds, and cannot handle multiple PID controls in real time. So for a multi channel PID controls, it requires more processors which results in high power solution.

So, we propose a hardware based solution, where FPGA is used for implementing the PID control loop by using Xilinx software. That results in high speed controlling and also a single PID controller can be multiplexed for multi channel realization hence results in low power solution. So, in the proposed project we implement the system in hardware and software by writing the code and test benches for the required modules using Xilinx software which is tested by the FPGA Spartan 3E kit (Hardware).



Block Diagram of the Proposed System

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3. FPGA

A Field Programmable Gate Array (FPGA) is a reconfigurable digital integrated circuit that can be programmed to do any digital function. FPGA approach for implementation of digital controllers is selected because of its controller architecture which can be optimized for space or speed and SRAM based FPGA's provide reconfigurable hardware designs and they can process information faster than a general purpose DSP. FPGAs are programmed using support software and a download cable connected to a host computer. Once they are programmed, they can be disconnected from the computer and will retain their functionality until the power is removed from the chip. The FPGAs can be programmed while they run, because they can be reprogrammable in the order of milliseconds. The FPGA consists of three major configurable elements Configurable Logic Blocks (CLBs) arranged in an array that provides the functional elements and implements most of the logic in a FPGA. Input-Output Blocks (IOBs) that provide the interface between the package pins internal signal lines. Programmable interconnects that provide routing path to connect inputs and outputs of CLBs and IOBs to the appropriate network. There are two main advantages of an FPGA over a microcontroller chip. FPGA has the ability to operate faster and it supports hardware that is upwards of one million gates.

4. PID Controller Module

Proportional–integral–derivative controller (PID controller) is a generic control loop feedback mechanism (controller) widely used in industrial control systems – a PID is the most commonly used feedback controller. A PID controller calculates an "error" value as the difference between a measured process variable and a desired set point. The controller attempts to minimize the error by adjusting the process control inputs. The PID controller calculation (algorithm) involves three separate constant parameters, and is accordingly sometimes called three-term control: the proportional, the integral and derivative values, denoted P, I, and D. Heuristically, these values can be interpreted in terms of time: P depends on the present error, I on the accumulation of past errors, and D is a prediction of future errors, based on current rate of change. The weighted sum of these three actions is used to adjust the process via a control element The PID controller, improve stability and steady state errors .The proportional, integral, and derivative terms are summed to calculate the output of the PID controller. Defining u (t) as the controller output, the final form of the PID algorithm is:

$$u(t) = K_p e(t) + K_p/T_i \int_0^t e(t)dt + K_p T_d [de(t)/dt]$$

Where
K_p: Proportional gain
T_i: Integral Time Constant.
T_d: Derivative Time Constant.
Error=SP-PV.
t: time or instantaneous time (the present).

As far as this project is considered, the function of the PID controller is to maintain the reference value which was given by the user by performing the required action i.e. if the output value exceeds the reference value then derivative action takes place, there by maintain the value at reference. Similarly, if the output value is below the reference value, integrator action is performed to maintain the reference. By writing the code for this type of operation the simulation results can be obtained. The logic symbol for PID controller is given in the fig(1).

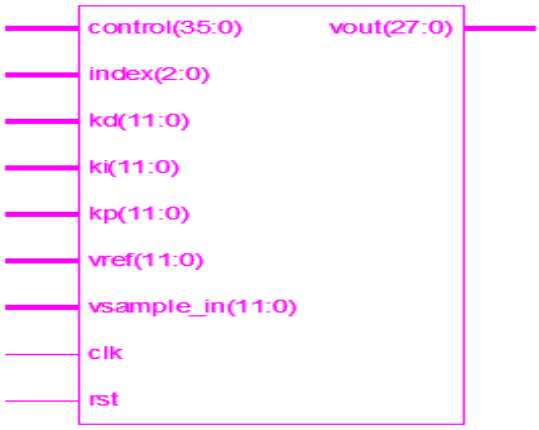

Figure 1

The simulation results of the PID controller is shown in the fig (2)

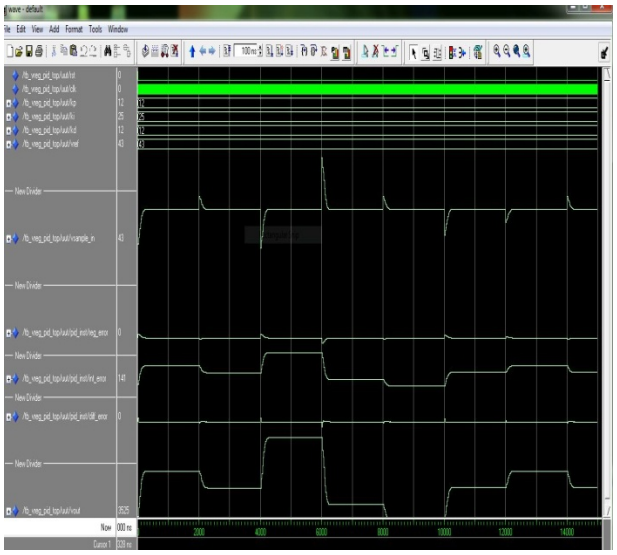

Figure 2

4.1 PID Controller Top Module

The PID Controller Top module is the Main Top level VHDL module in the hierarchy. The sub modules involved in it are ADC, Fuzzifier, P-I-D Controller, Output Control, PWM signal generator. It interconnects all the signals and interacts with the external world. The logic symbol of Top module is shown in Fig (3).

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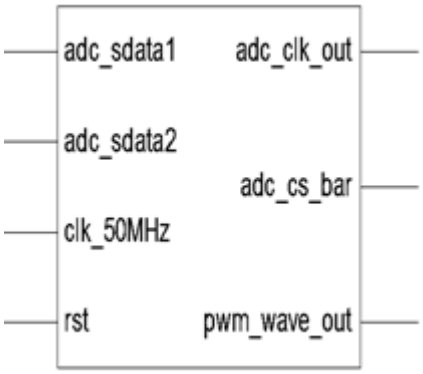

Figure 3

The simulation result of the top module is given in the fig (4).

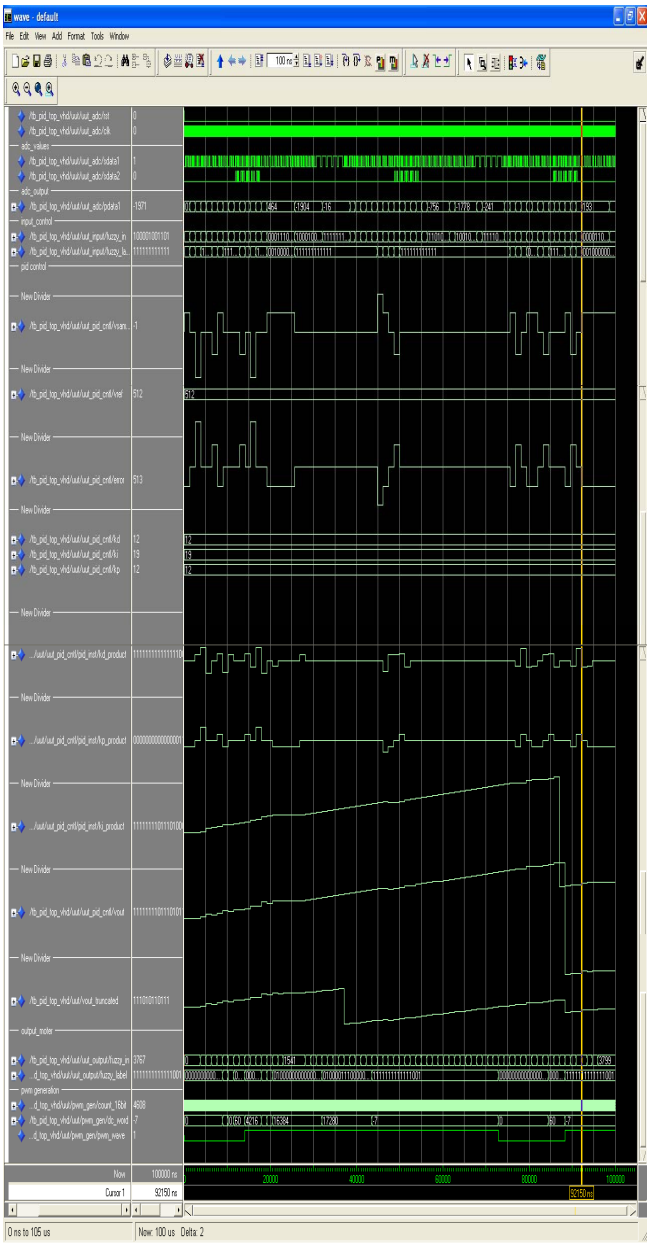

Figure 4

4.2 PWM Signal Generator

FPGA PWM synthesis module is given in the fig (5)

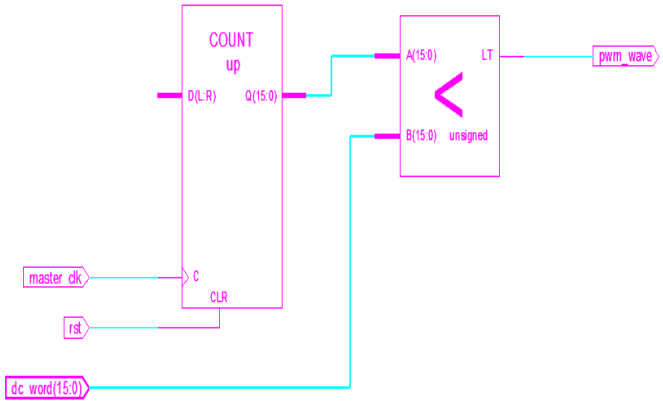

Figure 5

Rst is used to reset module or clear previous data, master_clk is used for the synchronization, count_16 bit is a 16 bit counter that will be compared with dc word when dc word is greater than count_16bit then pwm_wave is logic'1' else '0'.The simulation results are shown below. Fig(6) dcword<count_16bit, Fig (7) dcword>count_16bit.

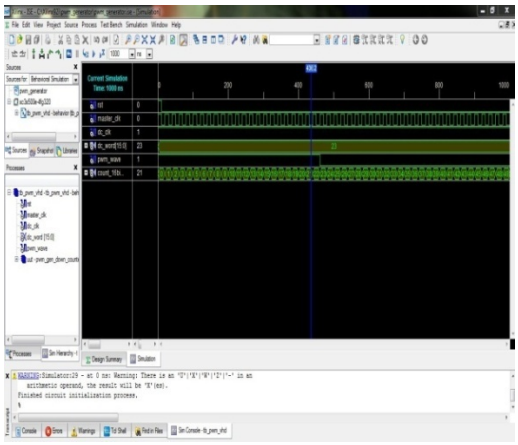

Figure 6

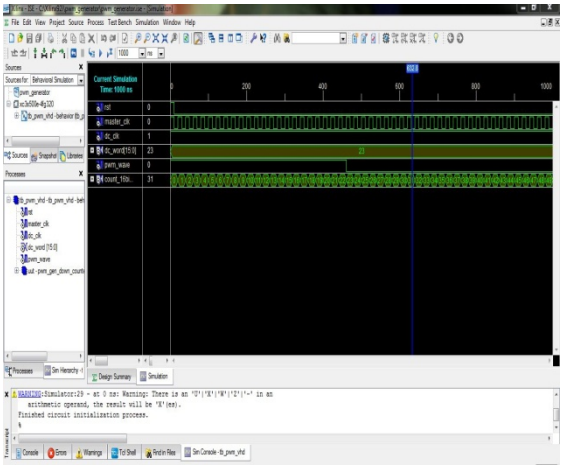

Figure 7

5. Analog To Digital Converter

An analog-to-digital converter (ADC, A/D, or A to D) is a device that converts a continuous physical quantity (usually voltage) to a digital number that represents the quantity's

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amplitude. The conversion involves quantization of the input, so it necessarily introduces a small amount of error. Instead of doing a single conversion, an ADC often performs the conversions ("samples" the input) periodically. The result is a sequence of digital values that have been converted from a continuous-time and continuous-amplitude analog signal to a discrete-time and discrete-amplitude digital signal.

5.1 Proposed System Advantages

- Speed is high compared with processor design.
- Digital PID controller implemented in FPGA technology is a configurable controller in terms of latency.
- High bit width controllers in FPGA technology.
- Latency of the controller.
- Reuse arithmetic elements such as multiplier and adders.
- Adaptive algorithm to improve the flexibility hardware system.
- Accuracy, power, compactness, and cost improvement over processor based implementation techniques.

5.2 Applications

- Industrial automation applications.
- Temperature controlling cambers.
- Servomotor controlling.
- Power electronics converter controller.
- Robotic controller.
- Motion controller.
- Voltage Regulator controller.
- Fan speed controller.

6. Conclusion

This paper presents a digital PID controller for speed control applications using FPGA. Here, a digital PID controller is successfully implemented using the FPGA and its performance is verified and tested on a DC fan speed control for real-time control. The test results showed that with PID controller added, the error is eliminated and the desired output speed is obtained. The implementation of controller has reduced the total hardware complexity and cost. In brief, the role of FPGA, in measurement and control point of view, is to acquire the data from analog to digital converter, do the processing on the acquired data and then generate control signals, which intern controls the parameter being measured. FPGAs ensure ease of design, lower development costs, more product revenue, and the opportunity to speed products to market. Building PID controllers on FPGAs improves speed, accuracy, power-efficient, compactness and cost effectiveness over other digital implementation techniques.

7. Future Enhancement

The process developed in this project is working satisfactorily. In this project single channel PMOD AD1 (analog to digital converter) is used. In future work multichannel analog to digital converters can also be used. In my project work, digital controller is developed to control the speed of a dc fan. So in future work we can plan to investigate implementation of fuzzy logic controllers on FPGAs instead of digital controllers. Same setup can be extended by using DA (Distributed Arithmetic) based system.

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