Performance Comparison of PID Controllers Using FPGA Technology

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***Abstract*— This paper deals with the performance analysis and implementation of robust PID (Proportional-Integral-Derivative) Controller on FPGA platform. The recent research work done in the field of control engineering related to the closed loop PID controller, it has been seen that with unity feedback system and PWM converter for controlling a system under control there are lot of limitations related to the power consumption and time delay. In this paper, we focused our works designing on building a robust PID controller and simulated it using Field Programmable Gate Arrays (FPGAs). We can conclude from this research that we can minimize the cost of overall system by eliminating the PWM Modulator and A/D Convertor which can all give advantages over Power Consumption and Delay. FPGA technology is utilized here due to simple modelling of the control system and the need of fast result with reduced complexity of the system. The research presented in this paper applies the newest Field-Programmable-Gate-Arrays to implement system controller devices in accordance with the actual core-based design in Xilinx ISE 9.1i.**

***Keywords*— ASIC, DSP, FPGA, PID, PWM, SOC, VHDL.**

I. INTRODUCTION

Control is also the name for a research area in which the design of controllers is studied at the engineering level and in which synthesis of controllers is studied at a theoretical level. Automatic control system are found in abundance in all sectors of industry, such as quality control of manufactured products, automatic assembly line, machine-tool control, space technology and weapon system, computer control, transportation systems, power systems, robotics and many others. General control objectives include: stability of the state function, optimization of performance, robustness with respect to noise signals and poorly modeled dynamics, and avoidance of unsafe states.

There is a large body of literature on control of linear systems. In the last decades much attention has been given to robust control of linear systems. Currently there is attention for control of systems with saturations and with space constraints such as linear systems for artificial neural nets. Motivated by the use of computers for control, there has been developed a control and system theory for discrete-event systems. Research for the class of hybrid systems is primarily motivated by the use of computers for control of engineering systems. The interaction between the discrete and the continuous dynamics is in some models so tight that these must be treated jointly.

A PID (Proportional Integral Derivative) controller is a common instrument used in industrial control applications. A PID controller can be used for regulation of speed, temperature, flow, pressure and other process variables. Field mounted PID controllers can be placed close to the sensor or the control regulation device and be monitored centrally using a SCADA system. The development of PID (Proportional-Integral-Derivative) control theories has already 60 years so far, PID control has been one of the control system design method of the longest history. However, this method is still extensively used now [17].

Recently, Field Programmable Gate Arrays (FPGA) has become alternative solution for the realization of digital control systems. The FPGA based controllers offer advantages such as high speed computation, complex functionality, real time processing capabilities and low power consumption [1].

Using synthesis tool, the design is then targeted to the FPGA board. The FPGA is a superior alternative to mask programmed ASICs. FPGAs avoid the high initial cost, the lengthy development cycles, and the inherent inflexibility of conventional ASICs[22]. Also, FPGA programmability permits design upgrades in the field with no hardware replacement necessary, an impossibility with ASICs.

II. CONTROL SYSTEM

The basic ingredients of a control system can be described by:

1. Objectives of control.
2. Control system components.
3. Results or output.

An industrial control system comprises of an automatic controller, an actuator, a plant, and a sensor (measuring element). The controller detects the actuating error command, which is usually at a very low power level, and amplifies it to a very high level. The output of the automatic controller is fed to an actuator, such as a hydraulic motor, an electric motor or a pneumatic motor or valve (or any other sources of energy). The actuator is a power device that produces input to the plant according to the control signal so that the output signal will point to the reference input signal.

A. Proportional-plus-integral-plus-derivative controllers

The PID controller was first placed on the market in 1939 and has remained the most widely used controller in process control until today. PI controllers are fairly common, since derivative action is sensitive to measurement noise.

"PID control" is the method of feedback control that uses the PID controller as the main tool. The basic structure of conventional feedback control systems is shown in Figure 1, using a block diagram representation. In this figure, the process is the object to be controlled. The purpose of control is to make the process variable y follow the set-point value r. To achieve this purpose, the manipulated variable u is changed at the command of the controller.

The process variable y is the temperature of the liquid, and the manipulated variable u is the flow of the fuel gas. The "disturbance" is any factor, other than the manipulated variable, that influences the process variable. Figure below assumes that only one disturbance is added to the manipulated variable. In some applications, however, a major disturbance enters the process in a different way, or plural disturbances need to be considered. The error e is defined by e = r – y. When used in this manner, the three element of PID produces outputs with the following nature:

a. P element: proportional to the error at the instant t, this is the "present" error.

b. I element: proportional to the integral of the error up to the instant t, which can be interpreted as the accumulation of the "past" error.

c. D element: proportional to the derivative of the error at the instant t, which can be interpreted as the prediction of the "future" error.

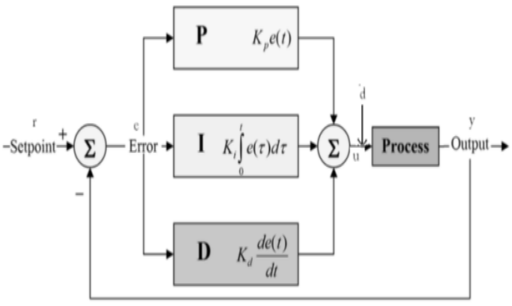

Fig. 1. Block diagram of Proportional-plus-integral-plus-derivative controllers

Thus, the PID controller can be understood as a controller that takes the present, the past, and the future of the error into consideration. The transfer function Gc(s) of the PID controller is :

$$G_c(s) = K_p\left(1 + \frac{1}{sT_i} + T_d\, s\right) \quad (1)$$

B. Robust Control

It considers the design of decision or control rules that fare well across a range of alternative models. Thus robust control is inherently about model uncertainty, particularly focusing on the implications of model uncertainty for decisions. Robust control originated in the 1980s in the control theory branch of the engineering and applied mathematics literature, and it is now perhaps the dominant approach in control theory.

The basic issues in robust control arise from adding more detail to the opening sentence above – that a decision rule performs well across alternative models. To begin, define a model as a specification of a probability distribution over outcomes of interest to the decision maker, which is influenced by a decision or control variable. Then model uncertainty simply means that the decision maker faces subjective uncertainty about the specification of this probability distribution. A first key issue in robust control then is to specify the class of alternative models which the decision maker entertains.

With the model set specified, the next issue is how to choose a decision rule and thus what it means for a rule to "perform well" across models.

III. CONVENTIONAL PID CONTROLLERS FOR SYSTEM CONTROL

A typical closed loop system using a PID controller is shown in Fig.2. The control system usually requires units to interface it to the environment. For instance, a converter to PWM (*Pulse-Width Modulation*) may be needed when con-trolling DC motors [2,6]. The purpose of integral action is to increase the low frequency gain and thus steady state error reduces. The derivative action adds phase lead, which improves stability and increases system bandwidth. Firstly, actuator saturation can cause integrator windup, leading to sluggish transient response [18]. Secondly, the pure differentiation term amplifies noise, leading to deterioration of the control command. Finally, the differentiation term acts on the error signal, taking the derivative of the command signal as well.

The output of PID controller is continuous equation:

$$u(t) = K_p\left(e(t) + \frac{1}{T_i}\int_0^t e(\tau)\, d\tau\right) + K_p\, T_d\, d\frac{e(t)}{dt} \quad (2)$$

where K_p is the Proportional gain, T_i is the Integral time, T_d is the derivative time, $e(t)$ is the error signal and $u(t)$ is the output of the controller.

For the input of PWM modulator [9] the continuous equation has to be represented in discrete form using discretization equations[6]. Equation (2) can be transformed into a discrete-time description by using discretization methods either direct or indirect[9].

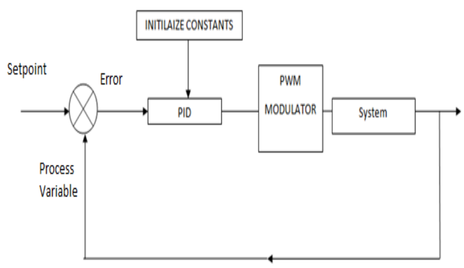

Fig. 2. Conventional closed loop PID controller

In conventional PID controller using PWM modulator there was considerable amount of delay in getting the output. Also power consumed in the process was extremely large. In this paper work we are trying to reduce the delay and power consumption by using robust PID controller and sensor in place of PID controller and PWM modulator.

IV. DISCRETISING A PID CONTROLLER

Fig.3. shows a control loop where controller is implemented in a computer. The computer registers the process measurement signal via an A/D converter (from analog to digital). The A/D converter produces a numerical value which represents the measurement. As indicated in the block diagram this value may also be scaled, for example from volts to percent. The resulting digital signal, $y(t_k)$, is used in the control function, which is in the form of a computer algorithm or program calculating the value of the control signal, $u(t_k)$.

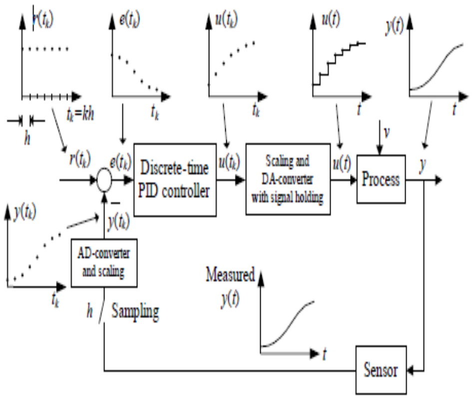

Fig. 3. Control loop where the controller function is implemented in a computer

The starting point of deriving the discrete-time PID controller is the continuous-time PID (proportional + integral + derivate) given by :

$$u(t) = K_p e(t) + \frac{K_p}{T_i}\int_0^t e d\tau + K_p T_d \dot{e}_f(t) \qquad (3)$$

Where u is the controller output (the control variable), e is the control error:

$$e(t) = r(t) - y(t) \qquad (4)$$

Applying the Backward differentiation method gives:

$$\frac{u(t_k)-u(t_{k-1})}{h} = K_p \frac{e(t_k)-e(t_{k-1})}{h} + \frac{K_p}{T_i} e(t_k) + K_p T_d \frac{\dot{e}_f(t_k)-\dot{e}_f(t_{k-1})}{h} \qquad (5)$$

Applying the Backward differentiation method on $\dot{e}_f(t_k)$ and $\dot{e}_f(t_{k-1})$ gives:

$$\frac{u(t_k)-u(t_{k-1})}{h} = K_p \frac{e(t_k)-e(t_{k-1})}{h} + \frac{K_p}{T_i} e(t_k) + K_p T_d \frac{\frac{e_f(t_k)-e_f(t_{k-1})}{h} - \frac{e_f(t_{k-1})-e_f(t_{k-2})}{h}}{h} \qquad (6)$$

Solving for $u(t_k)$ finally gives the discrete-time PID controller.

V. PROPOSED METHODOLOGY

We are proposing a sensor by eliminating PWM Modulator and A/D Convertor, which can reduce the power consumption and overall Delay for system. In block diagram shown in fig. 4 there is a difference between General PID Controller and proposed PID Controller.

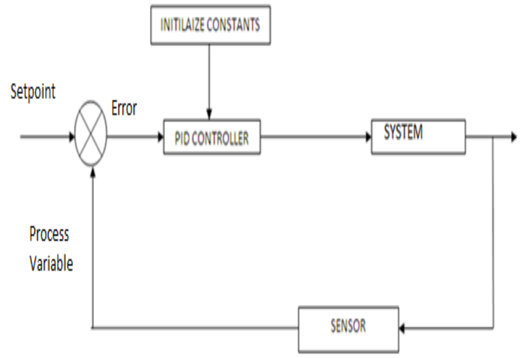

Fig. 4. Robust PID controller

VI. RESULTS

Test input-- Input is e_in=100

Output is updated for every clock pulse

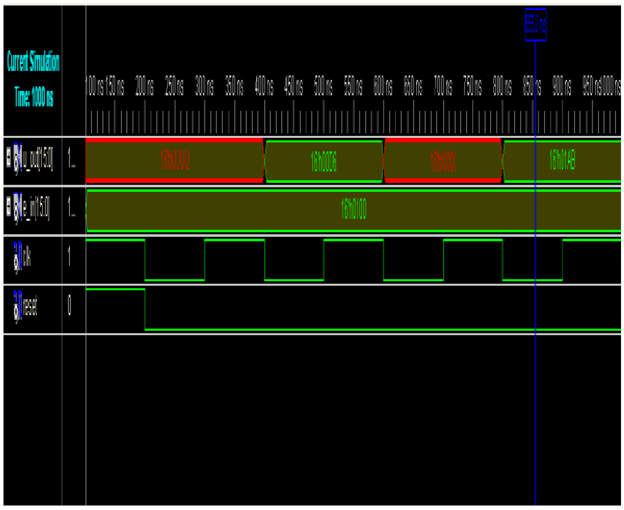

Fig.5. Conventional PID controller response

Test input - Input din=0012,Address=1A
The output is updated for every clock pulse.

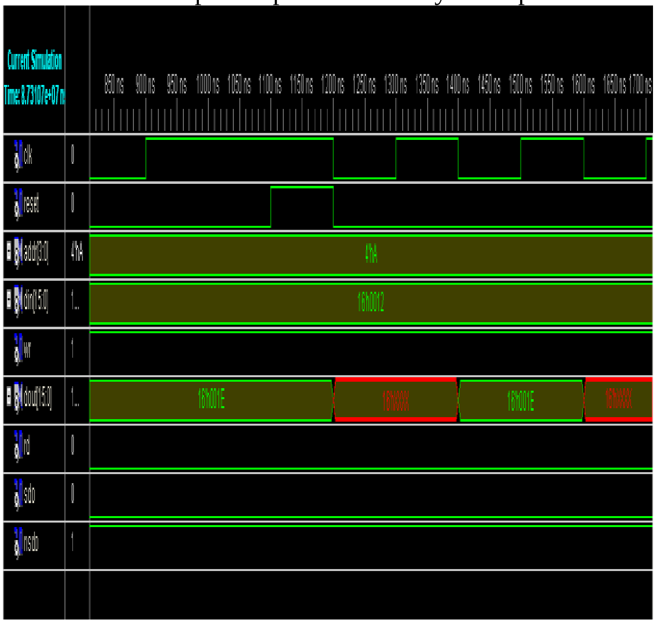

Fig.6. Robust PID controller response

TABLE I
Result analysis

entity	PID	Robust PID
Path Delay	11.117ns	9.39ns
Power Consumption	27 mw	23 mw
No. of Slices	44 out of 768	54 out of 768
No. of Slice Flip Flop	64 out of 1536	72 out of 1536
No. of 4 input LUTs	72 out of 1536	80 out of 1536
IOs	34	36

VII. CONCLUSION

The study of performance of PID controller has been done for two cases i.e. conventional and robust controllers .In conventional PID controller using PWM modulator there was considerable amount of delay in getting the output. Also power consumed in the process was extremely large. In this paper work we are trying to reduce the delay and power consumption by using robust PID controller and sensor in place of PID controller and PWM modulator.

ACKNOWLEDGMENT

The author acknowledges the department of electronics and telecommunication, RITEE.

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