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Research Paper | Management

Implementation of Adaptive Controller based on FPGA for Flow System

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ABSTRACT

this paper proposes the model reference tracking based adaptive PID controller with adaptive mechanism. The objective is identify the system to obtain a model of the system from input-output experimental data and using this model, adaptive controller has to be design. The parameters of the PID controller are computed adaptively by using estimation algorithm. The Algorithm is implemented on FPGA – Xilinx Spartan 3E board

KEYWORDS: Adaptive Control, MRAC, System Identification, FPGA, Xilinx Spartan 3E board

I. Introduction

This paper work is on the title "Design and Implementation of Adaptive Controller based on FPGA". Adaptive control is a control method in which one or more parameters are sensed and used to vary the feedback control signals in order to satisfy the performance criteria. Adaptive control has been a remarkable field for industrial and academic research since 1950s. Since more and more adaptive algorithms are applied in various control applications, it is becoming very important for practical implementation.

Adaptive control is the control method used by a controller which must adapt to a controlled system with parameters which vary, or are initially uncertain. It is different from robust control that guarantees that if the changes are within given bounds the control law need not be changed, while adaptive control is concerned with control law changes themselves.

Simply speaking, an adaptive control system consists of two closed loops. One loop is a normal feedback control with the plant and the controller, and the other loop is the parameter adjustment loop, which is shown in the figure 1.

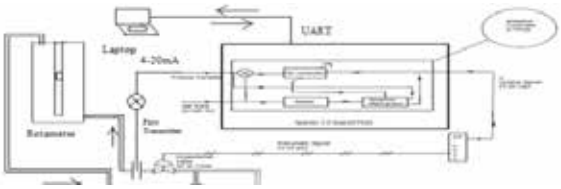

Figure 1. Hardware between FPGA board and Flow kit.

The general idea behind Model Reference Adaptive Control (MRAC) is to create a closed loop controller with parameters that can be updated to change the response of the system. The output of the system is compared to a desired response from a reference model. The control parameters are update based on this error. The goal is for the parameters to converge to ideal values that cause the plant response to match the response of the reference model. Using MRAC, you could choose a reference model that could respond quickly to a step input with a short settling time. You could then build a controller that would adapt to get the desired output response just like the model.

II. Adaptive Control

The tuning of the Flow Controller can be challenging because of the extreme variation in the process dynamics and tuning settings. Control system studies have shown that the most frequent root cause of unacceptable variability in the process is a poorly tuned level controller. The most common tuning mistake is a reset time (Integral time) and the gain setting that are more than an order of magnitude too small.

In this work, we will clarify how tuning settings change with flow dynamics and loop objectives. Finally, we investigate the use of an Adaptive Controller for the flow system in our college lab and discuss the opportunities for all types of flow application.

Adaptive control is the control method used by a controller which must adapt to a controlled system with parameters which vary, or are initially uncertain. For example, as an aircraft flies, its mass will slowly decrease as a result of fuel consumption; a control law is needed that adapts itself to such changing conditions [6]. The design of autopilots for high-performance aircraft was one of the primary motivations for active research on adaptive control in the early 1950s. Aircraft operate over a wide range of speeds and altitudes, and their dynamics are nonlinear and conceptually time varying. Adaptive control is different from robust control in that it does not need a priori information about the bounds on these uncertain or time-varying parameters; robust control guarantees that if the changes are within given bounds the control law need not be changed, while adaptive control is concerned with control law changes themselves.

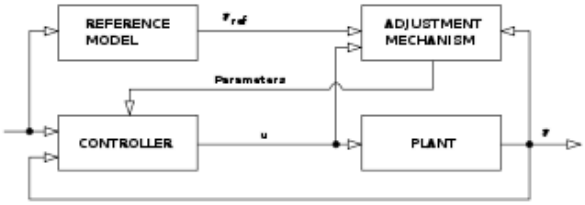

Figure 2. Model Reference Adaptive Control

III. Embedded Control using FPGA

FPGA based control is a problem, the solution for which involves the synergy of developments in control as well as FPGA technology. In order effectively understand the need for FPGA based embedded control, the capabilities of FPGA's and the reasons for using FPGA based embedded controllers in the midst of a bewildering array of embedded controllers must be analyzed. Hence in the first chapter the architecture of FPGA is studied. The second chapter deals with the motivation for use of FPGA in control.

FPGA - is an acronym for Field Programmable Gate Array. It belongs to a class of user programmable digital devices called Programmable Logic Devices (PLD's). A programmable logic device is an integrated circuit that enables the user to configure it in many ways, enabling the implementation of various digital logic functions, of varying sizes and complexities.

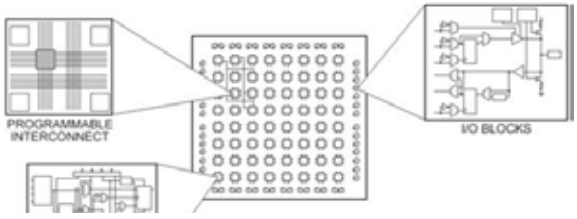

Figure 3. Schematic diagram of FPGA

IV. System Identification

The "System Identification" toolbox of MATLAB will then preprocesses the data and by using the new processed data, it will estimate the transfer function of the model by correlating with different types of estimation algorithm.



Figure 4. System Identification Toolbox of MATLAB

On the basis of System Identification toolbox in MATLAB®, there is a good procedure to obtain the system transfer function. The procedure consists of two steps: First, random signals are to apply on the system and the output for all those inputs has to be recorded. The signals given as an Input signal can be of any type. PRBS signal can also be provided to the system for obtaining experimental data. Second, this information is provided to the System Identification toolbox of the MATLAB®. The MATLAB will try to fit the data with the typical transfer functions and then find the most closely related transfer function to the system.

The Transfer function obtained is as follow:

$$G(s) = e^{-5.25*s} * \frac{1.668}{12s+1}$$

This is the most common process first order model used in the practical applications. By observing this process model, it can be said that the system contains an apparent dead time L of 5.25 seconds. And the time constant T of the system is 12. And the gain K is 1.668. This model can be used in designing the Adaptive controller for the control of the Flow Control Trainer Kit.

V. MATLAB Simulink Software

The Adaptive Block-set for Simulink is an attempt to remedy the situation and the basic design of the block-set is not limited to adaptive control enabling its use as a general framework for other types of controllers.

The intuitiveness of the graphical representation of the standard indirect adaptive controller shown in figure 2 is normally not matched by the equivalent C or MATLAB implementation.

The aim of the Adaptive Blockset is to transfer this intuitiveness to the graphical specification of an adaptive controller in the Simulink environment. This first step makes simulation and experiments simpler as this can be done in a well-known standard environment with easy access to the analysis and design facilities of MATLAB. The second step is to convert the verified Simulink block diagram of the adaptive controller to an Adaptive controller in HDL language by the use of the HDL code generation tool for Simulink.

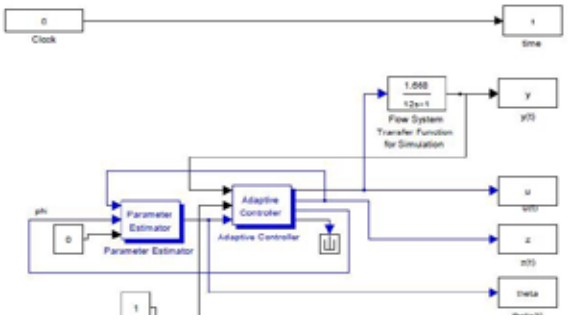

Figure 5. Adaptive Controller in Simulink.

The plant output tries to track the required output of the reference model and to attain that, the controller gives the output accordingly. The system was considered having the transfer function that was previously obtained by the System Identification and the reference model that was required having desired settling time and rise time. By observing the result, it can be deduced that the plant output trace the reference model response for the same signal.

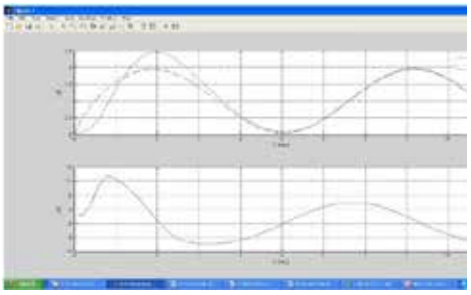

Figure 6. Plant, Reference Model and Controller Output

VI. FPGA – Xilinx Spartan 3E board

Adaptive module must able to collect real-time parameter easily from a field and process it to derive required control efforts based on the reference model. According to this requirement, a most simple, basic and reliable device for designing FPGA will be required, Spartan 3E board. The Spartan-3E family 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. Also, FPGA programmability permits design upgrades in the field with no hardware replacement necessary, an impossibility with ASICs.

Selection of particular microcontroller among all is little difficult and crucial work. So, before going directly to that it will be better to become familiar with the Spartan 3E starter kit structure and functioning.

VII. Hardware Implementation

To perform the experimental tests on a Flow trainer kit with adaptive controller implemented on FPGA, following are the components required:

A Flow trainer kit with Flow transmitter and Control Valve.

A multi-processor host computer running windows, enabling to log the controller output at each time step connected with FPGA kit using UART.

Spartan 3E starter kit to compute the Adaptive controller output in real time by getting the feedback from the flow transmitter and compare it with the output of reference model.

The signal conditioning circuit to make the output signal of sensor in 4-20 ma into 1.65-2.90 V DC that is acceptable in the analog capture circuit of Xilinx Spartan 3E board.

The DAC is required to convert the 8-bit data coming out of the FPGA into 4-20 ma which is required to the I/P converter which then control the operation of the Control Valve.

The power supply for the sensor, I/P converter and signal conditioning circuits to operate.

The RS-232 interfacing wire which connects the FPGA and the computer which logs the data in real time.

The JTAG cable to download the program into the FPGA board.

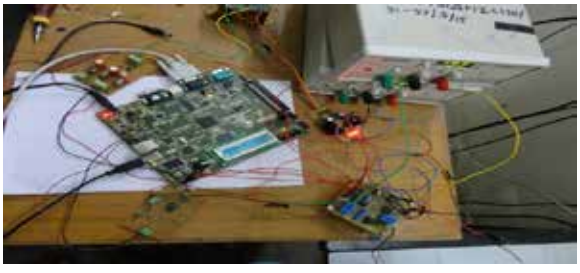

Figure 7. Adaptive Controller with the Flow kit

VIII. Results

The resultant data obtained by implemented Adaptive Control on Flow

trainer kit. The set point is kept changed after the required tracking of the plant output with the set point for testing and validation of the design. Observing this figure, it can be said that the Adaptive Controller is tracking the set point very efficiently. The sampling time for this data to record is 0.1 second.

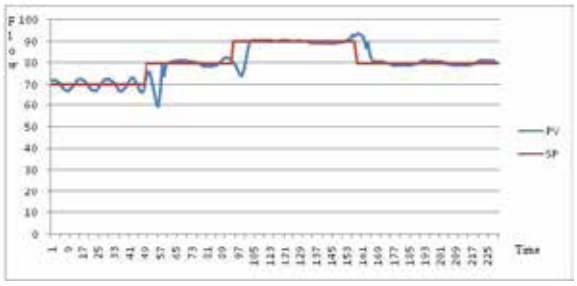

Figure 8. Adaptive Controller tracking the different set point.

Conclusion

In this paper, Adaptive algorithm for flow control is successfully simulated using MATLAB®, Xilinx® and ModelSim tool. It has been implemented on FPGA and validated by changing the disturbances at random time. The determining of the Model of the Flow System which has to be controlled has done by using System Identification toolbox of MATLAB®. The algorithm for the Adaption law has been developed by using Adaptive Blockset of Simulink. And the Adaptive Controller code is generated in HDL using Simulink HDL Coder. Adaptive Control system is flexible for different applications like the flow, level, temperature etc.

`In the presence of the FPGA system, speed optimization has been done, power consumption is also low, reliability increased, measurement precision is high, structure is simple and usage is convenient. Due to the generic design, the device also can be re-used in many different industrial applications with the same features.

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