Implementation of Controller Structures in FPGA Platform

S Meena, K.Chitra, T Ramkumar, G Richie Roberts

Abstract: Field Programmable Gate Arrays are recently replacing general purpose microcontrollers in implementation of digital control systems. This paper includes the proposal of implementing complex controller structures in a Field Programmable Gate Array (FPGA). Till recent, PID controllers are implemented in FPGA Platform. PID controllers are simple, reliable, versatile feedback mechanisms used in most control systems. To reduce various undesirable effects on the output such as overshoot, some variants in the conventional PID controllers, such as the I-PD and IMC are also used. Here all these control controller structures are implemented in MATLAB, compared for best performance and run in the FPGA.

Index Terms: PID controller, I-PD controller, IMC controller, FPGA, Xilinx ISE 14.7 Design tools.

I. INTRODUCTION

FPGA-based controllers are widely used for their elevated speed, power efficiency and advanced functions. Digital feedback systems like magnetic bearings, PWM inverters, induction motors, AC/DC converters, variable-speed drives, and anti-windup compensation of controllers are already in use in FPGA Platform. FPGA-based platforms can do concurrent operations. Hence, simultaneous design of digital controllers can be made.

A PID controller evaluates the difference between a fixed set point and the process variable and computes the error values. By using a manipulated variable, which is proportional to the computed error signal the PID controller controls the output of a system thereby minimizing the error[2].

Previously, the implementation of FPGA was based on the usage of numerous multipliers and adders and was not focused on optimized usage of hardware and hence was not efficient. It required a numerous multipliers and adders. In the old multiplier-based controllers the blocks take up to 64% usage of the chip.

A new idea of implementing the I-PD and also IMC control structures in an FPGA. It is made into application after passing through these general phases: 1) Software Modelling Phase where the design of digital control systems is carried out in software like Matlab / Simulink, 2) Hardware Implementation, to obtain real-time observation. Using modules, the design can be ported into environments such as the Matlab / Simulink, thus greatly reducing the developing time for designers.

The Integral – Proportional and Differential controller is an improvisation of a PID controller which is developed so as to minimize the effect of sudden change in the set point on the controller output. Internal Model Control (IMC) provides a procedure for design in accordance with many modern control techniques, the Q-parameterization concept. This made IMC controllers particularly popular in all industrial applications. Also, the IMC showed greater performance than all controllers. This showed greatly reduced oscillations than the conventional models of controller structures.
II. IMPLEMENTATION OF TEST FUNCTIONS IN MATLAB

The two processes considered for analysis are stable second order and a boiler drum level process. Both the processes are tested with the various structures such as PID, I-PD and IMC based PID. The time domain specifications and the performance indices are compared and the optimized values are identified.

2.(a). Example 1:

A stable second order system is considered.

\[ y_1 = \frac{2e^{-1s}}{50s^2 + 15s + 1} \]  

The above said process is implemented in all PID, I-PD and IMC control structures.

For the example transfer function-1 taken, it is inferred that the IMC control strategy is more optimised comparing with the other control strategies.

III. IMPLEMENTATION OF REALTIME PROCESS

For research purposes, a two-tank interacting system commonly used in food processing industries to obtain accurate proportions of mixture is taken. To understand the effect of interaction, we have considered a two-tank system in experiment. The second tank affects the rate of change of level in first tank and vice-versa. The flow through R1 depends on the difference between h1 and h2. The analysis started by writing mass balance on the tank. Both the balances of the tanks are the same. The flow head relationship for tank 1 is \( q_1 = \frac{h_1}{R_1} \) and \( q_3 = \frac{h_2}{R_2} \).

At steady state, the flow equation is \( (q_{1s} - q_{2s}) = 0 \), \( (q_{2s} - q_{3s}) = 0 \).

By solving all the above equations using Laplace transform, the transfer function can be written as,

\[ H_2(s) = \frac{R_2}{Q_1(s)} = \frac{R_2}{(\tau_1 \tau_2 S^2 + 1)(\tau_1 + \tau_2 + A_1 R_2)S + 1} \]

Experimental Setup : Two tank interacting system

![Two tank Interacting System](image)
By substituting the calculated values from the observed data, equation 7 can be written as the overall transfer function and is given by,

\[
\frac{H_2(s)}{Q_1(s)} = \frac{0.0462}{25.28s^2 + 14.5363s + 1}
\]

(8)

A. IMPLEMENTATION IN MATLAB

The below transfer function which is obtained for two-tank interacting system is taken.

\[
T. F = \frac{0.0462}{25.28s^2 + 14.5363s + 1}
\]

![Fig 1.9 Simulink of IMC for Two-tank Interacting System](image)

![Fig 1.10 Response of IMC](image)

B. IMPLEMENTATION IN FPGA

FPGA software and hardware integration

FPGAs are supported by development software which convert hardware designs into programming bits which determine the actions of interconnects and Configurable Logic Blocks. The ISE Design Suite Embedded Development Kit includes Platform Studio (XPS), Development Kit (SDK), plug and play IP s.

The information for FPGA is programmed as bitstream and the hardware designer provides bitstream and it has been generated in the embedded platform .Programming is the integrating a bitstream into FPGA. In this phase, the FPGA programming is carried out using menu options in SDK, transferring the bitstream to the FPGA. The non-volatile memory has bitstream and hardware will program FPGA when turned on.

![Fig 1.11 Hardware Architecture of FPGA](image)

The Xilinx Software Development Kit (SDK), which is a Development Environment (IDE), used for embedded software applications.

Parallel design of Hardware platform with software development is facilitated. SDK update of hardware platform specification when pointed to a different version is also supported.

Programming the FPGA

- Select Xilinx Tools > Program FPGA.
- Bitstream and BMM File will be filled by itself. If necessary, those files need to be specified to upload bitstream to the FPGA
- SDK finds processors, automatically. In Software Configuration, select the executable (.elf) file. select BootLoop from drop-down menu or Browse any ELF file.
- Click Program.
Thus the real time process which was implemented in MATLAB has been converted into FPGA compatible language, integrated with XPS (Xilinx Platform Studio) & implemented SDK (Software Development Kit) of FPGA platform.

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IV. CONCLUSION

For research purposes, we have taken two test transfer functions and they were successfully implemented in MATLAB for PID, I-PD and IMC control. And it is inferred from the experiments that the IMC control strategy provides better results than other controllers such as lesser rise time, lesser peak time, lesser settling time and lower overshoot. Therefore, The IMC control strategy was taken and implemented for any industrial process (Two-tank interacting system) in FPGA platform successfully. It is also inferred that we can obtain higher quality solution with better computational efficiency in FPGA.

REFERENCES

1. V.Rajnikanth and K.Lathal-PD Controller Tuning For Unstable System Using Bacterial Foraging Algorithm: A Study Based On Various Error Criterion, Hindawi Publishing Corporation Applied Computational Intelligence And Soft Computing Volume 2012, Article Id 329389, 10 Pages Doi:10.1155/2012/329389.
2. P.A. BalakrishnanOptimization Of I-PD Controller For A FOLIPID Model Using Particle Swarm Intelligence, International Journal Of Computer Applications (0975 – 8897) Volume 43– No.9, April 2012.
3. Motonasa Ogawa And Tohru Katayama A Robust Tuning Method For I-PD Controller Incorporating A Constraint On Manipulated Variable, Trans. Of The Society Of Instrument And Control Engineers Vol.E-1, No.1, 265/273 (2001).
4. S J Suji Prasad Optimization Of I-PD Controller Parameters With Multi Objective Particle Swarm Optimization, Journal Of Theoretical And Applied Information Technology 20th August 2014. Vol. 66 No.2.
5. Gao, Ruiyao And O’dwyer, Aidan And Coyle, Eugene: A Non-Linear PID Controller For CSTR Using Local Model Networks. Proceedings Of The IEEE 4th World Congress On Intelligent Control And Automation (Wcica 2002), Shanghai, China, 10-14 June.
6. A Nassirsharad, N Hoq,H S TsouDesign Of Nonlinear PID Controllers Using System Step Response.
7. Poonam M BaikarDesign Of PID Based Information Collecting Robot In Agricultural Field .International Journal Of Advanced Research In Electrical, Electronics And Instrumentation Engineering, Vol. 3, Issue 8, August 2014.
8. Meena S, Chitra K. A New approach of PID tuning for Nonlinear SISO system based on Particle Swarm Optimization Techniques.International Journal of Applied engineering Research 2014;9(23):21701-11.
9. S.Meena, K.Chitra, R.VijayAnand. Development of I-PD controller on Embedded platform. International Conference on Signal Processing , Communication, Power and Embedded Sysytems. (scopes- 2016).
10. K.J. Astrom and B. Wittenmark, Computer Controlled Systems, Prentice Hall, New Jersey, USA, 1997.
11. F. Krach, B. Frackelton, J Carletta and R. Veillette, “FPGA-Based Implementation of Digital Control for a Magnetic Bearing,” American Control Conference, Vol.2, pp. 10801085; June 2003.
12. S.L. Jung, M.Y. Chang, J.Y. Jyang, L.C. Teh, Y.Y. Tsou, “Design and Implementation of an FPGA-Based Control IC for AC-Voltage Regulation,” IEEE Trans. on Power Electronics, Vol. 14, pp. 522-532, May 1999.
13. S. Ferreira, F. Hafner, L.F Pereira, F. Moraes, “Design and Prototyping of Direct Torque Control of Induction Motors in FPGAs, “ IEEE Symposium on Integrated Circuits and Systems Design, pp. 105-110, Sept. 2003.
14. F. Ricci, H. Le-Huy, “An FPGA-Based Rapid Prototyping Platform For Variable-Speed Drives”, IEEE Industrial Electronics Society Annual Conference, vol.2, pp. 1156-1161, Nov. 2002.

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