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Hardware Realization of Advanced Controller Design Methods using FPGA

Ján Cigánek, Michal Kocúr, Štefan Kozák

Faculty of Electrical Engineering and Information Technology,
Slovak University of Technology in Bratislava
Bratislava, Slovakia
e-mail: jan.ciganek@stuba.sk, michal.kocur@stuba.sk, stefan.kozak@stuba.sk

Abstract: The presented paper deals with design, experimental verification and comparison of three controller design methods (Internal Model Control, Pole-Placement, PID by Magnitude Optimum) applied in the control for processes with complex dynamics. The presented and tested control methods guarantee robust stability and high performance of controlled system. Proposed algorithms were successfully implemented and tested using the Field Programmable Gate Array (FPGA) technology for the velocity control of real DC motors system.

Keywords: Algebraic theory, Control system, Closed-loop, Factorization, Filter, Internal model control, Pole-placement, FPGA, Implementation

1. INTRODUCTION

A development of advanced control methods based on robustness, optimality and prediction is an important and challenging task. In recent years, a new control approaches have emerged to replace or augment conventional control engineering methods.

The automatic control is crucial for practically all engineering activities. The automation technology is understood to be the use of such methods, control strategies, processes, and installations (hardware and software) which are capable of fulfilling defined objectives without the constant interference of a man in a largely independent manner, i.e. automatically.

Motivated by the practical success of conventional control engineering methods in consumer products and industrial process control, there has been an increasing amount of work on development of new methods which are based on new optimization techniques, soft computing strategies, and effective hardware realization of control algorithms. The automatic control methods with integration of information and communication systems are today pervasive in all fields of people's activities.

The research, development and implementation of new control principles in automation field have been very dynamic. Implementation of controllers has gone through several stages of evolution, from the early mechanical and pneumatic designs to the embedded microprocessor based systems. Moreover, in typical control processes (e.g. thermal processes, power plants, robotic drives etc.) it is often necessary to modify the mentioned classical control methods of tuning taking into account the time delays, unmodeled dynamics, change of working conditions and disturbances.

The improvement of classical methods is possible under the assumption that the original control algorithm is extendable with respect to changes in process parameters, yields stability of the closed loop even in the presence of large time delay and is applicable in real-time control (Baotić et al., 2008), (Cutle and Ramaker, 1979).

To date, the most popular control algorithm used in industry is the ubiquitous PID controller which has been implemented successfully in various technical fields. However, since the evolution of embedded microcomputers and mainly during the number of modern and advanced control algorithms have been also developed and applied in a wide range of industrial applications.

The Internal Model Control (IMC) algorithm is based on the fact that an accurate model of the process can lead to the design of a robust controller both in terms of stability and performance. IMC is famous in both theoretical field and industry for its advantages, to be more exact, easy framework, good performance in follow up control, powerful robustness, high denies quality in immeasurable disturbance. This paper proposes enhanced controllers, using Internal Model Control (IMC) and MPC control strategies.

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 tools for software implementation.

On the other hand, the second approach is based on hardware. Early hardware implementation is achieved by magnetic relays extensively used in old industry automation systems. Then, it became achievable by means of digital logic gates and Medium Scale Integration (MSI) components.

If the system size and complexity increases, Application Specific Integrated Circuits (ASICs) are utilized. The ASIC must be fabricated on a manufacturing line, a process that

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takes several months, before it can be used or even tested. FPGAs are configurable ICs and used to implement logic functions. Today's high-end FPGAs can hold several millions gates and have some significant advantages over ASICs. They ensure ease of design, lower development costs, more product revenue and the opportunity to speed products to market. At the same time, they are superior to software-based controllers as they are more compact, power-efficient, while adding high speed capabilities.

2. MODERN CONTROL ENGINEERING APPROACHES

Advanced Control is the use of new numerical methods, information and communication technology, facilitated by various computer-based techniques, to implement a control strategy that executes, reacts, and/or predicts actions based on process or operating conditions.

This results in providing a more consistent, higher quality product, by increasing throughput, or by utilizing energy and material resources in a more efficient manner.

Advanced Control solutions are most often applied in the process industry. Complex systems that must produce precise results (outputs) based upon various requirements and under various disturbances (inputs), exist in all industries (Brosilow and Joseph, 2002), (Seshagiri Rao, Rao and Chidambaram, 2009).

Modern controller design is based on four basic properties: optimality, robustness, adaptability, intelligence. Realization of modern control structures is derived from the basic feedback structure, in Fig.1.

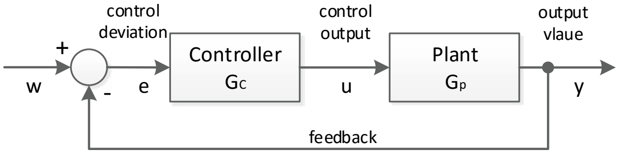

Fig. 1. Control block scheme

During last years, most common and widely used control structures are:

a) feedback structures with PID controller (transport delay compensation, constrained control action, IMC structures),
b) combination of feedback and feedforward structures,
c) cascade structures,
d) combination of feedback, feedforward and cascade structures.

In this paper we analysed three methods: Direct synthesis method with two approaches (pole-placement and PID by Magnitude Optimum) and IMC method.

Direct synthesis method is not suitable for the systems with numerator roots (zeros) in the right half-plane, because zeros of the model are poles of controller and therefore controller is unstable for processes with non-minimal phase. This problem is solved by the IMC method.

2.1 PID by Magnitude Optimum

Magnitude Optimum is a method for the synthesis of PID controllers. This approach is based on the requirement for the control system transfer function (1) to be in a form:

$$G_{ref} = G_{y/w}(s) = 1 \tag{1}$$

In ideal case, step response of process variable is equal to the set point. In frequency domain it corresponds width:

$$\begin{gathered} G_{y/w}(j\omega) = 1 \Longrightarrow \left|G_{y/w}(j\omega)\right| = 1 \Longrightarrow \\ A_{y/w}(\omega) = 1 \end{gathered} \tag{2}$$

where $A_{y/w}(\omega)$ is the magnitude of the control system of F-transfer function $G_{y/w}(j\omega)$and ω is the angular frequency.

Condition (2) cannot be satisfied in reality, however it can be proven that control process ends the fastest when amplitude characteristics $A_{y/w}(j\omega)$ will be flat at first and then it will monotonically decreasing. Description of this method can be found in (Åström and Hägglund, 1995).

2.2 Internal Model Control

IMC methods are applicable for various systems (stable, astatic, unstable, with transport delay ...). In comparison with direct synthesis methods, IMC methods are applicable also for non-minimal phase systems. Unstable parts of model and parts containing transport delay are not inverted in controller proposal. The main principle of IMC method is:

•factorization of model for invertible and non-invertible parts,

•proposal of IMC controller for IMC structures,

•transformation of IMC controller to standard form,

•implementation of PID algorithm to standard PID form.

Let separate the model into two factors, one invertible and the second one with all non-invertible terms.

$$G_p = G_p^- G_p^+ \tag{3}$$

The "invertible" factor G_p^- has an inverse that is causal and stable, which results in an acceptable controller. The gain of this factor is the same as the model gain *K*.

The "non-invertible" factor G_p^+ has an inverse that is non causal or unstable. The factor contains models elements with transport delays and positive numerator zeros. The gain is the 1.

IMC controller could be calculated by (4-5).

$$G_{c\_IMC}(s) = \frac{1}{G_p^-(s)} G_f(s) \tag{4}$$

$$G_f(s) = \frac{1}{(\tau_c s + 1)^{N_f}} \tag{5}$$