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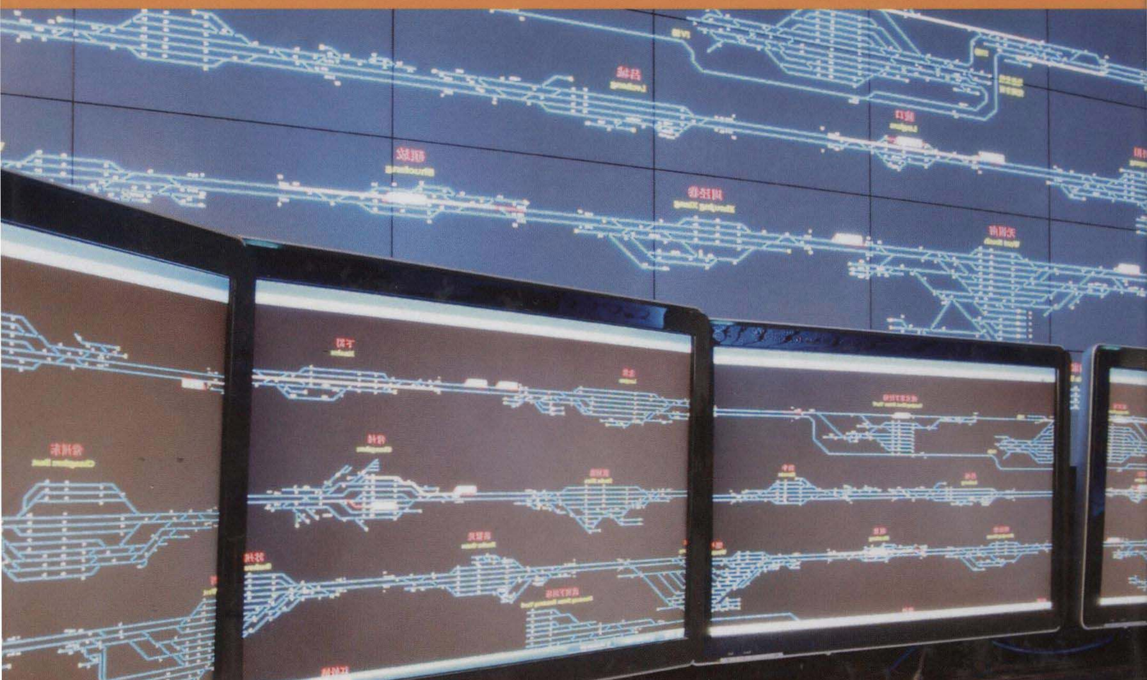
Command-control for Real-time Systems



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Chapter 1

Introduction

The topic of this book is automation engineering applied to real systems. We use the term "real systems" to denote any complex system which forms an integral part of an industrial system, experimental system or onboard system in a vehicle or industrial machine. The peculiarity of these systems is that they are guided by real-time targets in a distributed environment.

Current research in the field of automation engineering relates mainly to systems of finite or of large dimensions, time-delayed systems, discrete event systems, hybrid dynamical systems, incomplete linear systems, etc., the modeling of such systems, identification of them, analysis of their stability, controlling them by coming up with different control laws such as:

– sliding mode control;

– predictive control;

– robust control;

– fuzzy control;

– etc.

The applications for such systems are many, and include applications in all sectors:

– electrical machines;

– environmental systems;

– vehicle dynamics;

– robotics;

– life sciences;

– process engineering;

– communications networks;

– aircraft;

– aeronautics and aerospace;

– etc.

The tools available in modern automation engineering serve many purposes, such as identification, parametric estimation, creation of correctors and observers, fault diagnosis, surveillance, etc.

The aim of the research reported herein relates to the computing of correctors for industrial systems of different physical natures, their implementation on real-time industrial targets (API/SCADA systems, embedded systems with distributed networks, Networked Control Systems (NCSs)) and their validation by means of simulation. When creating correctors, we use identification techniques or knowledge modeling. The primary approach in these various research projects is the optimization of industrial systems at the level of their control by making use as fully as possible of the resources available to us in industrial computing, communications networks and minimizing the realization time. In terms of control, 90% of regulation loops have a simple PID (Proportional/Integral/Derivative) control which, in addition, is often not optimized. Certain tools are lacking, as yet, for which we need to write control laws.

The considerable majority of procedures do not have knowledge models, so there is a clear advantage to developing efficient tools to identify knowledge on the basis of ground measurements.

The works presented in this book all stem from research carried out in an industrial context, and published in doctoral theses and masters dissertations:

– in the context of the regional project DIVA (research hub in Picardie, 2002–2005), the topics were: i) kinematic modeling of a hydraulic mechanical polyarticulated system; and ii) the building of a test array around a distributed computer structure for the excavator-loader created as part of the regional project "Aide à la conduite et détection de situations critiques pour engins intelligents de chantier" (driving support and critical situation detection for smart building machines);

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– in the SEDVAC project (financed by the region of Picardie and FERDER, 2008–2012, UPJV-UTC collaboration; project leader: M. Chadli), the topic was the development of systems to support the driving of an automobile. The objective was to develop risk indicators based on the vehicle's dynamics and observer-based estimation techniques (estimation of road curvature, of slope, etc.);

– thermodynamic modeling of a cryogenic exchanger for the NA48 calorimeter at CERN was performed in the context of a partnership between the UPJV/ESIEE of Amiens and CERN to overhaul the control/command system of the NA48 experiment. Computation of the TDC (Time Delay Control) corrector for the overhaul of the control/command system of the NA48 experiment was done (thesis of Eng. M. Pezzetti, 2010). The collaboration with CERN also involved the description of the UNICOS framework object, the implementation of the object Multi-controller, the creation of digital models by identification for the gas mixing systems for the four LHC cryogenics experiments at CERN (the Gas Control System (GCS) project);

– a partnership between ESIEE-Amiens and Schneider Electric involved the computation of the internal model corrector (IMC) to regulate the output temperature of the superheater at an Alstom coal-burning power plant in Algeria;

– the works presented herein about modeling and multi-model control (also known as Takagi-Sugeno Fuzzy Models) are the result of many research projects carried out in the context of projects and theses supported in the past few years. These works relate to Takagi-Sugeno fuzzy control systems, fault-tolerant control systems, fault diagnostic systems and their applications in the automobile domain.

In more general terms, these works aimed to optimize industrial processes by using tools from automation engineering, industrial computing and communications networks. Indeed, in order to improve their product, industrialists have a never-ending need to optimize the regulating parameters of their procedures. Beyond the study of which control laws to use depending on the process to be modeled, it is also a question of providing generic tools which will work on any industrial computing platform (API/SCADA system) to guide the procedure(s), whilst integrating these tools as closely as possible into a clearly-defined development framework. In the particular case of an autonomous machine (area network or building machine), the computer structure is a system such as an embedded PC or microprocessor with a control area network that transmits distributed measurements to the mobile unit. The question then arises of the reliability and rapidity of area network control loops.

In order to study a real system, the following stages are necessary:

– understanding the specifications of the study that is to be carried out (description of a system's operation, constraints, operation point, the problem at hand and the objectives to be achieved);

– modeling the system with an appropriate type of modeling (relevance of the model, accessibility of the physical parameters, implementation of identification techniques and definition of the controllable variables);

– elaborating a strategy for controlling the system;

– calculating and simulating the type of control chosen in relation to the system being modeled;

– choosing the real-time target (industrial computing structure, use of networks) and its environment (real-time system, programming languages, the framework used);

– putting in place the real-time computing platform;

– implementing the control algorithms;

– simulating the whole of the controlled system on the real platform;

– testing and validating the whole system on a test array;

– installing and initializing the real industrial system.

All of this research contributes to the diffusion of modern automation techniques in industrial processes where, due to a lack of tools which make the connection between modeling, identification and implementation on real-time targets, optimization is as yet incomplete. Our work is intended precisely to fill that void, successively integrating new control laws so that the users can fully exploit the power of an engineering science such as automation engineering, to optimize the processes whilst retaining a high degree of maintainability of their installations. Furthermore, in terms of perspectives, on a topic which is of growing importance, such as energy efficiency in the field of sustainable development and construction, this research should be directly applicable, as demonstrated by numerous recent articles.

This manuscript is divided into seven chapters. Following this introductory chapter, the remaining chapters are as follows:

– Chapter 2 – Modeling tools: the aim of this chapter will be to present various techniques for mono- and multi-variable identification (ARX, ARMAX, etc.) for linear systems. The case of nonlinear systems is examined through the lens of the multi-model approach (also known as the multiple model approach or Takagi-Sugeno fuzzy approach). This is an interpolation of different linear models to approximate nonlinear behavior.

– Chapter 3 – Control tools: in this chapter, we examine different linear controllers (TDC, PFC, IMC, etc.). For nonlinear systems, techniques drawn from the domain of “soft computing” are put forward. Indeed, control laws for

Takagi-Sugeno fuzzy systems (also known as multi-model laws) are studied. The advantage to this approach is that it means the numerical tool LMI (Linear Matrix Inequalities) can be used to compute controllers.

– Chapter 4 – Application to cryogenic systems: the objective is thermodynamic modeling and control of a cryogenic exchanger for the NA48 calorimeter at CERN, and the modeling and control of the cryogenics of the ATLAS experiment being run at CERN.

– Chapter 5 – Application to thermal and gas systems: similarly, we shall observe the advanced control of the vapor temperature on output from a superheater at a coal-burning power station, and of gas systems.

– Chapter 6 – Application to vehicles: the aim in this chapter is to present two main domains: that of automobiles and that of excavator-loaders. Multi-controller-based techniques are applied to the dynamics of automobiles with a view to improving stability and safety. Driver assistance systems for an excavator-loader in a critical situation, kinematic modeling of the excavator-loader and control of the articulated arm are also subjects touched upon in this chapter.

– Chapter 7 – Real-time implementation (UNICOS, onboard systems): examples of distributed real-time architectures on a PLC-SCADA structure are examined. We also present the example of a universal controller: multi-controller, study of the reliability and rapidity of a CAN (Control Area Network)-based distributed architecture for an excavator-loader test array.

Chapter 2

Modeling Tools

2.1. Introduction

The literature about system modeling and identification goes back as far as does the literature about control. The first major papers to appear in the 1930s–1940s by Nyquist and Bode about frequency responses demonstrate this early interest. Ziegler and Nyquist's identifying work on the study of indicial responses dates from the 1940s. In addition, the progress made in terms of adaptive identification in the 1960s greatly contributed to the development of research in this domain. The research effort became organized, and in 1967, IFAC launched the first symposium on Identification and System Parameter Estimation. This and the series of symposiums which followed would produce a considerable number of articles about the aspects and problems surrounding system identification. Today, many books and articles dealing with modeling and identification are available, which give practical indications (for instance, see [BOR 01; EYK 74; LAN 02]).

Before speaking of models and identification, we shall quite deliberately discuss systems. L. Ljung [LJU 87] explains that if we wish to explicitly define the term "system", we could define it as being an object from which different interactions produce observable reactions. He adds that the determination of models by observation and study of the properties peculiar to a system is the very essence of science itself. It is indeed noteworthy that the goal of most scientific research projects since time began was merely to find representative models sufficiently accurate to describe natural phenomena. The view of a model as being unerringly true is therefore false in view of an (arbitrary) approach which defines a model for

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Chapter written by Sébastien CABARET and Mohammed CHADLI.

any system. These philosophical considerations highlight the relative principle of a model and its relevance as regards a real system. All the approaches discussed in this chapter will take account of these hypotheses.

At the level of a control/command framework, the determination of a model is developed with a view to creating the control system [FLA 94]. In practice, a model is constructed on the basis of knowledge and observation of the data of the system subjected to stimuli (inputs) and its reactions (outputs). Experience is also a crucial factor in this process. The model, in industrial automation engineering, is intended to describe a system's behavior in order to assist the design and practical implementation of a control mechanism [BOR 01]. For this purpose, identification aims to determine the characteristics of a model, which essentially means producing a mathematical description of a system's dynamic and stationary behavior (if possible). Identification can therefore be summarized as the study and mathematical design of a model on the basis of observation, knowledge and the experience gained about the system.

System identification can be performed by way of six different treatments [GRA 76]:

– the distinction between a linear and a nonlinear system: all systems are naturally strictly nonlinear. Thus, a system is linear if for an area of its operation, its behavior is considered to be quasi-linear. In a linear regime, the principles of superposition are applicable, which makes system identification relatively simple;

– the difference between a stationary and a non-stationary system: non-stationarity must not be confused with nonlinearity. A stationary system is a system whose parameters do not vary under the same physio-chemical conditions within a given range of operation. This property is of fundamental importance in modeling and therefore in identification. Put more simply, we consider a system to be stationary if over the time taken to gather the data needed for the purpose of identification, the state of that system does not change;

– continuous or discrete systems: this aspect of the problem is rarely paid enough attention. Although it is not difficult to switch from a continuous to a discrete formulation, the implications for data processing and for the design of the control mechanism are great. The treatment regarding stability and robustness of the corrected systems is different depending on whether or not we are moving into a strictly continuous environment (programmable industrial robots can work in discrete mode);

– mono- or multi-variable treatment: the theoretical treatment of a mono- or multi-variable problem may be similar under certain conditions. The problem with multi-variable systems (or MIMO, for multiple input, multiple output) lies in the techniques for performing identification in concrete terms (complex algorithms and

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