
Preface

The extraordinary development of digital computers (microprocessors, microcontrollers) and their extensive use in control systems in all fields of applications has brought about important changes in the design of control systems. Their performance and their low cost make them suitable for use in control systems of various kinds which demand far better capabilities and performances than those provided by analog controllers.

However, in order really to take advantage of the capabilities of microprocessors, it is not enough to reproduce the behavior of analog (PID) controllers. One needs to implement specific and high-performance *model based* control techniques developed for computer-controlled systems (techniques that have been extensively tested in practice). In this context identification of a plant *dynamic model* from data is a fundamental step in the design of the control system.

The book takes into account the fact that the association of books with software and on-line material is radically changing the teaching methods of the control discipline. Despite its interactive character, computer-aided control design software requires the understanding of a number of concepts in order to be used efficiently. The use of software for illustrating the various concepts and algorithms helps understanding and rapidly gives a *feeling* of the various phenomena. Complementary information and material for teaching and applications can be found on the book website:

<http://landau-bookic.lag.ensieg.inpg.fr>

The aim of the book

The aim of this book is to give the necessary knowledge for the comprehension and implementation of digital techniques for system identification and control design. These techniques are applicable to various types of process. The book has been written taking into account the needs of the designer and the user of such systems. Theoretical developments that are not directly relevant to the design have been omitted. The book also takes into account the availability of dedicated control software. A number of useful routines have been developed and they can be freely

downloaded from the book website. Details concerning effective implementation and on-site optimization of the control systems designed have been provided.

An important feature of the book, which makes it different from other books on the subject, is the fact that equal weight has been given to *system identification* and *control design*. This is because both techniques are equally important for design and optimization of a high-performance control system. A control engineer has to possess a balance of knowledge in both subjects since identification cannot be dissociated from control design. The book also emphasizes control robustness aspects and controller complexity reduction, both very important issues in practice.

The object of study

The closed loop control systems studied in this book are characterized by the fact that the control law is implemented on a digital computer (microprocessor, microcontroller). This type of system is sketched in Figure 0.1.

The continuous-time plant to be controlled is formed by the set of actuator, process and sensor. The continuous-time measured output $y(t)$ is converted into a sequence of numbers $\{y(k)\}$ by an analog-to-digital converter (ADC), at sampling instants k defined by the synchronization clock. This sequence is compared with the reference sequence $\{r(k)\}$ and the resulting sequence of errors is processed by the digital computer using a *control algorithm* that will generate a control sequence $\{u(k)\}$. By means of a digital-to-analog converter (DAC), this sequence is converted into an analog signal, which is usually maintained constant between the sampling instants by a zero-order hold (ZOH).

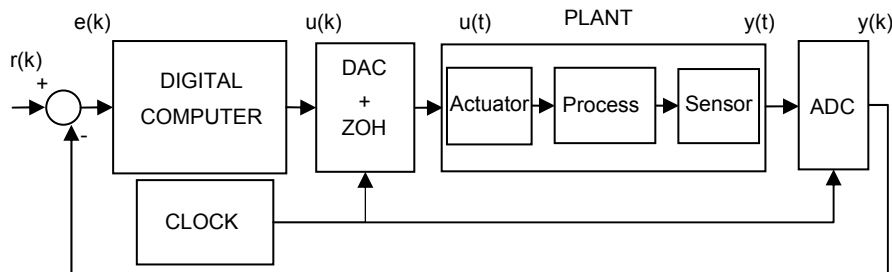


Figure 0.1. Digital control system

The main stream

Figure 0.2 summarizes the general principles for controller design, implementation and validation.

For design and tuning of a good controller one needs:

1. To specify the desired control loop performance and robustness
2. To know the dynamic model of the plant to be controlled
3. To possess a suitable controller design method making it possible to achieve the desired performance and robustness specifications for the corresponding plant model

4. To implement the resulting controller taking into account practical constraints
5. To validate the controller performance on site and, if necessary, to re-tune it

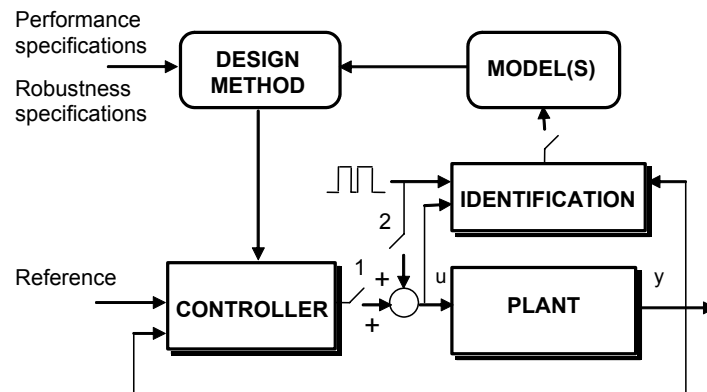


Figure 0.2. Principle of controller design and validation

In order to obtain a relevant dynamic plant model for design, system identification techniques using input/output measurements (switch 1 is off, switch 2 is on) should be considered. The methodology for system identification is presented in the book together with dedicated algorithms implemented as software tools.

Once the system model is available, the book provides a set of methods (and the corresponding software tools) for the design of an appropriate controller.

The implementation of the controller should take into account aspects related to data acquisition, switching from open loop to closed loop, and saturation of the actuator as well as constraints on the complexity of the controller. These aspects are examined in detail in the book.

Expected audience

The book represents a course reference for Universities and Engineering Schools offering courses on applied computer-controlled systems and system identification.

In addition to its academic audience, *Digital Control Systems* is aimed at practising engineers wishing to acquire the concepts and techniques of system identification, control design and implementation using a digital computer. The industrial references for the techniques presented in the book and the various applications described provide useful information for those directly involved in the real-world uses of control.

Readers who are already familiar with the basics of computer-controlled systems will find in this book a clear, application oriented, methodology for system identification and the design of various types of controllers for single-input, single-output (SISO) systems.

The content

Chapter 1 briefly reviews the continuous-time control techniques which will be used later on as a reference for the introduction of basic concepts for computer control.

Chapter 2 provides a concise overview of computer-controlled systems: the structure of these systems, the sampling process, discrete-time dynamic models, the principles of design of discrete-time two-degrees-of-freedom controllers (RST), and robustness analysis of the control loops.

Chapter 3 presents several pertinent model-based design methods for discrete-time controllers operating in a deterministic environment. After the design of digital PID controllers, more general design methods allowing systems of any order, with or without delay, to be controlled are presented. The *robustness* of the closed loop with respect to plant model uncertainties or variations is examined in detail and appropriate control design methods that take into account robustness specifications are provided.

The design of discrete-time controllers operating in the presence of random disturbances is discussed in Chapter 4. The chapter begins with a review of random disturbances and of models and predictors for random disturbances. Connections with design in deterministic environments are emphasized.

The basics of system identification using a digital computer are presented in Chapter 5. Methods that are used for the identification of discrete-time models, and model validation techniques as well as techniques for order estimation from input/output data are described in Chapter 6.

Chapter 7 discusses the practical aspects of system identification using data from several applications: air heater, distillation column, DC motor, and flexible transmission.

The main goal of this work, the use of control design methods and system identification techniques in the implementation of a digital controller for a specific application, is discussed in Chapter 8. Implementation aspects are reviewed and several applications presented (air heater, speed and position control of a DC motor, flexible transmission, flexible arm, and hot-dip galvanizing).

For on-site optimization and controller re-tuning a plant model should be obtained by identification in closed loop (switches 1 and 2 are on in Figure 0.2). The techniques for identification in closed loop are presented in Chapter 9.

In many situations constraints on the complexity of the controller are imposed so Chapter 10 presents techniques for controller order reduction.

Appendix A reviews some basic concepts.

Appendix B offers an alternative time-domain approach to the design of RST digital controllers using one-step-ahead and long-range-predictive control strategies. Links and equivalence with the design methods presented in Chapter 3 are emphasized.

Appendix C presents a state space approach to the design of RST digital controllers. The equivalence with the design approach presented in Chapter 3 is emphasized. The linear quadratic control is also discussed.

Appendix D presents some important concepts in robustness.

Appendix E demonstrates the Youla–Kucera parametrization of digital controllers which is useful for a number of developments.

Appendix F describes a numerically robust algorithm for recursive identification.

Appendix G is dedicated to the presentation of suggested laboratory sessions that use data files and functions which can be downloaded from the book website.

Appendix H gives a list and a brief description of the MATLAB[®]- and Scilab-based functions and C⁺⁺ programs implementing algorithms presented in the book. These functions and programs can also be downloaded from the book website.

The book website gives access, to the various functions and programs as well as to data files. It contains descriptions of additional laboratory sessions and slides for a number of chapters, tutorials and courses related to the material included in the book that can be downloaded; all the MATLAB[®] files used for generating the examples and figures in the text can also be found on the website.

How to read the book

The book can be read in different ways after the basic control concepts presented in Chapters 1 and 2 have been assimilated. If the reader is mainly interested in control algorithms, it would be useful for him/her to read Chapters 3 and 4 and then Chapters 5, 6, 7 and 8. If the reader is mainly interested in identification techniques, he or she can jump straight to Chapters 5, 6 and 7 and then return to Chapters 3, 4 and 8. Those who are familiar with the basics of computer-controlled systems can even start with Section 2.5. Chapters 9 and 10 follow dependently from Chapter 8. Figure 0.3 shows the interdependence between the various chapters.

Course configurations

A complete basic course on digital control should cover most of the material presented in Chapters 2, 3, 5, 8 and Section 4.1. For an advanced course, all chapters might be included. For an introductory course in digital control one can use Chapters 2, 3 and 8. For an introductory course on system identification one can use Chapters 5, 6 and 7.

Why this book?

The book reflects the first author's more than twenty-five years of experience in teaching, design and implementation of digital control systems. Involvement in many industrial projects and feedback from an industrial and academic audience from various countries in Europe, North and South America and Asia have played a major role in the selection, organization and presentation of the material. Experience from writing the book *System Identification and Control Design*, Prentice Hall, 1990¹ (Information and System Sciences Series) has been also very useful.

The present book is a revised translation of a book (*Commande des systèmes – conception, identification et mise en oeuvre*) published in 2002 by Hermes-Lavoisier, Paris.

¹ Revised taranlation of a book published by Hermes Paris, 1988 (second edition 1993).

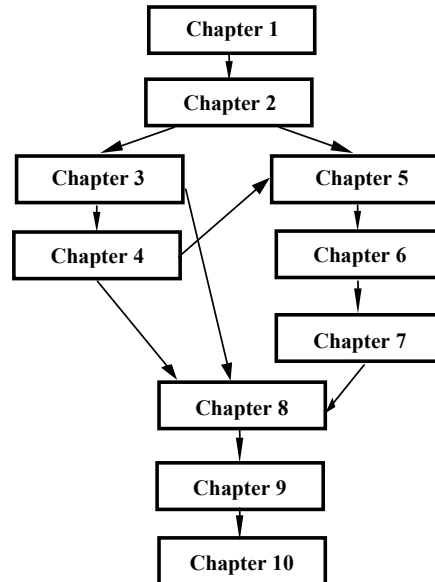


Figure 0.3. Logical dependence of the various chapters

The most recent academic courses based on the material in the present book include PhD courses delivered in 2004 at Universita Technologica de Valencia, Spain (robust discrete time controller design) and Escuela Superior de Ingenieros de Sevilla, Spain (system identification in open and closed loop).

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