Preface

Organization of the Book

This book has been conceived to progressively introduce concepts of increasing difficulty and allow learning of theories and control methods in a way which is not too brutal. It contains different levels of reading (Fig. 1). In particular, the majority of the first part can be undertaken by students beginning in control or by technicians and engineers coming from the industrial world, having up to that point only practical contact with control and a desire to improve their knowledge.

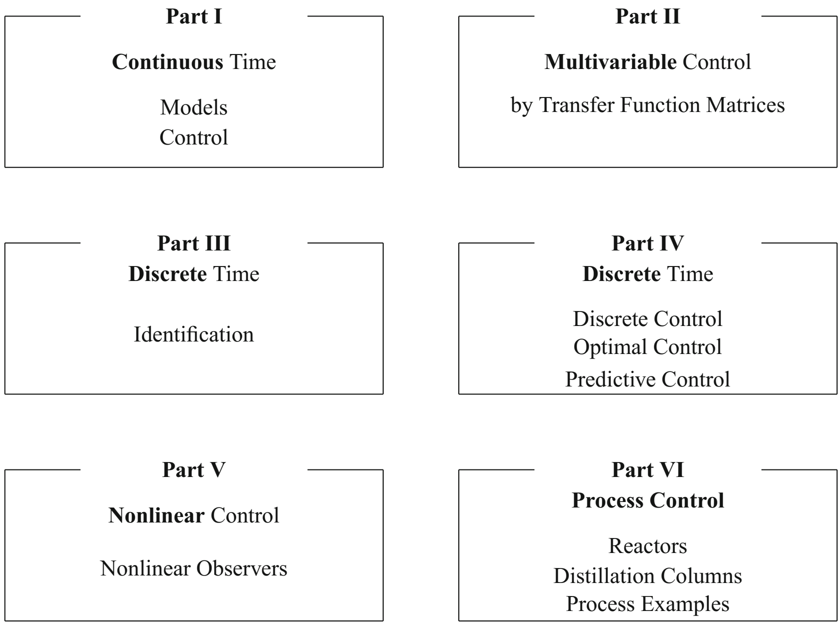

Fig. 1 General organization of the book

The subsequent parts need a minimum previous knowledge in control. They also allow the use of often higher-performance techniques. Without pretending to be exhaustive, this book proposes a wide range of identification and control methods applicable to processes and is accompanied by similar typical examples that provide comparison elements.

This book does not pretend to compete with theoretical control books specialized in one subject or another, e.g. identification, signal processing, multivariable control, robust control or nonlinear control. However, the readers whoever they are, undergraduate or graduate students, engineers, researchers, professors, will find numerous references and statements that enable understanding and application in their own domain of a large number of these concepts, taking their inspiration from the cases treated in the present book (Table 0.1).

Several controls are examined under different angles:

- single-input single-output internal model control in continuous and discrete time and multivariable internal model control in discrete time,
- pole-placement control in continuous and discrete time,
- single-input single-output linear quadratic control by continuous transfer function and multivariable state-space linear quadratic control in continuous and discrete time and
- single-input single-output generalized predictive control and multivariable model predictive control, possibly with observer, linear or nonlinear.

The consideration of the same problem by different approaches thus enables a thorough examination.

Examples are most often taken from the chemical engineering domain and include in general chemical, biological and polymerization reactors, heat exchangers, a catalytic cracking reactor (FCC) and distillation columns. These examples are detailed, even at the numerical level, so that the used reasoning can be verified and taken again by the reader. Simulations have been realized by means of MATLAB® and Fortran77 codes.

Part I concerns single-input single-output continuous-time control. The chosen presentation of single-input single-output feedback linear process control is classical and voluntarily simple for most of the part. It presents the pedagogical advantage of decomposing the approach to a control problem, introduces a given number of important notions and, according to our opinion, facilitates the understanding of discrete-time control, called digital control, and of nonlinear control. Also, it is close, in its conception, to a large part of industrial practice, at least in the domain of chemical engineering. Continuous PID control is abundantly treated, but without exclusivity. The main types of dynamic models met in chemical engineering are commented on, and system models are presented as well in state space as transfer functions (Chap. 1). Control is first simply related to the PID controller (Chap. 2). Stability is presented both for linear and for nonlinear systems. Thus, the stability of a polymerization reactor is detailed by displaying the multiple stationary states in relation to the physical behaviour of the reactor (Chap. 3). The design of

Table 0.1 Contents of the chapters

Part I	
Dynamic Modelling, Open-Loop Dynamics	Chapter 1
PID Linear Feedback Control	Chapter 2
Linear and Nonlinear Stability Analysis	Chapter 3
Design of Feedback PID Controllers, Pole-Placement	Chapter 4
Linear Quadratic Control, Internal Model Control Frequency Analysis, Robustness	Chapter 5
Improved Controllers, Smith Predictor Cascade, Feedforward Control	Chapter 6
State Representation, Controllability, Observability Realizations and Model Reduction	Chapter 7
Part II	
Multivariable Control by Transfer Function Matrices	Chapter 8
Part III	
Discrete-Time Generalities Signal Processing	Chapter 9
Identification Principles	Chapter 10
Identification Models	Chapter 11
Identification Algorithms	Chapter 12
Part IV	
Discrete Pole-Placement Discrete PID	Chapter 13
Discrete Internal Model Control Optimal Control	Chapter 14
Continuous LQ and LQG Control Discrete LQ and LQG Control SISO Generalized Predictive Control	Chapter 15
MIMO Model Based Predictive Control	Chapter 16
Part V	
Nonlinear Control	Chapter 17
Nonlinear Observers, Statistical Estimators	Chapter 18
Part VI	
Reactors	Chapter 19
Distillation Columns	Chapter 20
Process Examples, Benchmarks	Chapter 21

controllers first deals with PID and then is broadened to internal model control, which is very important industrially, pole-placement control and linear quadratic control by means of continuous transfer functions (Chap. 4). Frequency analysis begins classically by the analysis in Bode and Nyquist representations, but is then extended to robustness and sensitivity functions (Chap. 5). The improvements of controllers including time delay compensation, cascade control and feedforward control are reviewed with application examples in industrial processes (Chap. 6).

The first part finishes with the concepts of state representation for linear systems, controllability and observability (Chap. 7). Some more difficult parts of different chapters such as robustness, pole-placement control or linear quadratic control can be tackled in a subsequent reading.

Part II consists of only one chapter which deals with multivariable control by either continuous or discrete transfer function matrix. This choice was made because of the relatively common practice of system representation chosen in process control. The chapter essentially presents general concepts for the design of a multivariable control system. Other types of multivariable control are treated in specific chapters in other parts of the book: linear quadratic control and Gaussian linear quadratic control in Chap. 14, model predictive control in Chap. 16 and nonlinear multivariable control in Chap. 17. In fact, Part III can be studied before Part II.

Part III begins by considering signal processing whose general concepts are necessary in identification and control. Then, the general aspects of digital control and sampling are treated, and discrete transfer functions are introduced (Chap. 9). The remainder of Part III is devoted to discrete-time identification. First, different model types are presented and the principles of identification are explained (Chap. 10), and then, different types of models are presented (Chap. 11). Lastly, the main algorithms of parametric identification are detailed with many indications on usage precautions (Chap. 12). The parametric identification of a chemical reactor is presented. Identification is treated as single-input single-output except with respect to the Kalman filter, which can be applied to multi-input multi-output systems.

In Part IV, several classical types of digital control are studied. Chapter 13 describes pole-placement, digital PID and discrete internal model control as single-input single-output control with application to the same chemical reactor. In Chap. 14, optimal control is considered in the general framework of dynamic optimization applicable to nonlinear continuous or discrete systems; it includes general methods such as variational methods, Euler, Hamilton–Jacobi, Pontryagin and dynamic programming. Linear quadratic control and linear quadratic Gaussian control are presented in direct relation to optimal control both for continuous and for discrete state-space system descriptions. An application of multivariable linear quadratic Gaussian control to an extractive distillation column with two inputs and two outputs is presented. Two types of predictive control are studied. Chapter 15 concerns generalized predictive control for single-input single-output systems represented by their discrete transfer function with application to the previously mentioned chemical reactor. Chapter 16 is devoted to model predictive control applicable to large multivariable systems known by transfer functions or state-space models. Furthermore, model predictive control is popular in industry as it allows constraints to be taken into account. Two multivariable applications for a catalytic cracking reactor (FCC) are shown.

Part V concerns nonlinear control presented through differential geometry (Chap. 17) and state observers (Chap. 18). These are recent developments in control and are potentially very powerful. To facilitate its approach, several concepts are analysed from a linear point of view, and then, nonlinear control for a single-input single-output system is studied with input-state and input-output linearization.

Nonlinear multivariable control is just outlined. State estimation is necessary in nonlinear control. Chapter 18 on observers does not concern the linear Kalman filter described in Part III, but considers nonlinear observers including the extended Kalman filter and the high-gain observer, as well as statistical estimators.

Part VI considers two important classes of chemical processes: reactors and distillation columns. In the previous parts, linear identification and linear control are applied to the chemical reactor described in detail in Chap. 19. In this first chapter of Part VI, the use of geometric nonlinear control, based on the knowledge model of the process or coupled with a state observer, is explained for a chemical reactor and a biological reactor. It must be noticed that this is the same simulated chemical reactor that was used for identification of a linear model and several discrete linear control methods. Chapter 20 sweeps the control methods used in distillation since the 1970s until our epoch that is marked by the extensive use of model predictive control and the start of industrial use of nonlinear control. Chapter 21 describes different processes and benchmarks that can be used as more or less complicated examples to test various control strategies.

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