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COMPUTER CONTROLLED SYSTEMS

Theory and Design

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the new theory produced except in a few exotic cases—mostly in aerospace or advanced process control. However, due to the revolutionary development of microelectronics, advanced regulators can be implemented even for basic applications. It is also possible to do analysis and design at a reasonable cost with the interactive design tools that are becoming increasingly available.

The purpose of this book is to present control theory that is relevant to the analysis and design of computer-controlled systems, with an emphasis on basic concepts and ideas. It is assumed that a digital computer with a reasonable software is available for computations and simulations so that many tedious details can be left to the computer. The control-system design is also carried out up to the stage of implementation in the form of computer programs in a high-level language.

The book is organized as follows: An overview of the development of computer control is given in Chapter 1. A survey of the development of the theory is also given in order to provide some perspective. (Those who do not know history are bound to repeat it.)

Sampling, which is a fundamental property of computer-controlled systems, is discussed in Chapter 2. The basic mathematical models needed are given in Chapters 3, 4, and 6. Chapter 3 gives the models as seen from the computer, while Chapter 4 treats the models as seen from the process. Without disturbances there are no control problems; it is therefore important to find suitable ways to characterize disturbances, which is done in Chapter 6.

In Chapter 5 the major tools for analysis and simulation are given. Simulation plays an important role because there are many detailed questions that are very hard to answer through analysis alone. Simnon, an interactive simulation language that is used throughout the book, is presented in an appendix. It is not very difficult to translate the programs into other simulation languages. The fact that a powerful simulation tool is available makes a drastic change in attitudes and techniques. It is very important that the simulations be accompanied by analysis that can give order-of-magnitude estimates to ensure that the simulation results are reasonable. At the same time it is not necessary to provide tools for very accurate calculations because these can easily be done by the computer. Chapters 7 through 12 are devoted to the design problem. An overview is given in Chapter 7. Translation of analog design methods is discussed in Chapter 8. State-space design techniques for deterministic systems based on pole assignment are discussed in Chapter 9. The same problem is discussed in Chapter 10 using input-output models. Optimal design methods based on Kalman filters, linear quadratic, and linear quadratic Gaussian control are treated in Chapter 11 based on state-space models and in Chapter 12 using input-output models.

A characteristic feature of many of the new design methods is that a model of the process and its disturbances is needed. Chapter 13 discusses how such models can be obtained. A brief treatment of parameter-adaptive control systems is given in Chapter 14. This may be viewed as a combination of the design methods in Chapters 9 to 12 with the recursive identification methods in Chapter 14. Chapter 15 discusses different aspects of implementation of computer-control algorithms.

The theory is organized in such a way that all models and specifications are given in continuous time. This makes applications easier because of the close connections with physics. Multivariable systems are covered whenever state-space techniques are used; however, the treatment of input-output models using the polynomial approach is limited to the single-input–single-output case. Both deterministic and stochastic aspects of the analysis and the design problem are given.

When designing a system it is often advantageous to see a problem from several viewpoints. Since the goal of the book is to give a good foundation for design of computer-controlled systems, it is necessary to cover a wide range of topics. A reasonable balance between detail and overview has been achieved; however, Chapters 6, 11, 12, 13, and 14 require complete books to cover each topic fully.

In sampled-data theory it has been the custom to let the same symbol z denote both a complex variable and a forward-shift operator. We have found this practice confusing for the students and have therefore introduced the symbol q to denote the forward-shift operator. This is analogous to the use of s as a complex variable and $p = d/dt$ as a differential operator for continuous-time systems. The notation q^{-1} is used to denote the backward-shift operator.

This book can be used in many different ways. Chapters 2, 3, 5, 7, 8, 9, 10, and 15 and Sections 6.1–6.3 are suited for an undergraduate course in sampled data systems. A detailed treatment of Chapters 4, 6, 7, and 9 through 15 can form the core of a graduate course in design of computer-controlled systems. We have given courses to industrial audiences based on Chapters 3, 4, 5, 8, 9, 10, 13, 14, and 15. In all cases we have found it very advantageous to have access to computer simulation and to supplement lectures and exercises with laboratory experiments. Some suggestions for this are given in the solutions manual.

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1 COMPUTER CONTROL

GOAL *To Introduce the Subject and to Give Some Historical Background on the Development of Computer-Control Technology and Theory.*

1.1 Introduction

Digital computers are increasingly being used to implement control systems. It is therefore important to understand computer-controlled systems well. One can view computer-controlled systems as approximations of analog-control systems, but this is a poor approach because the full potential of computer control is not used. At best the results are only as good as those obtained with analog control. Alternatively, one can learn about computer-controlled systems, so that the full potential of computer control is used. The main goal of this book is to provide the required background.

A computer-controlled system can be schematically described as in Fig. 1.1. The

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