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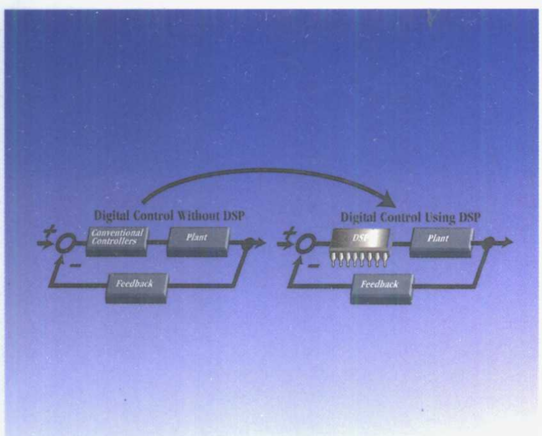
Digital Control Using Digital Signal Processing

（英文影印版）



Farzad Nekoogar　Gene Moriarty　著

科学出版社
Pearson Education
Prentice Hall
培生教育出版集团

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2002

内 容 简 介

本书为国外高校电子信息类优秀教材（英文影印版）之一。

本书介绍了数字控制系统及如何分析和设计这些系统。它展示了如何利用数字信号处理（DSP）技术并结合经典的频域技术和现代的状态参数法共同设计控制器。计算机辅助分析和设计工具如 MATLAB 的使用贯穿全书，并在开始部分给出了数字控制系统的基本数学知识，从而为读者解决实际问题打下了基础。此外，本书还介绍了补偿器的经典设计技巧，并对模糊逻辑设计进行了简要的讨论。

本书适用于高等院校电气工程、自动化专业本科生，也可供一般工程技术人员参考。

图字：01-2002-2772

图书在版编目(CIP)数据

应用数字信号处理进行数字控制/(美)尼库加(Nekoogar, F.)等著.—影印本.—北京：科学出版社，2002
(国外高校电子信息类优秀教材)
ISBN 7-03-010603-2

Ⅰ.应… Ⅱ.尼… Ⅲ.数字信号-信号处理-应用-数字控制-高等学校-教材-英文 Ⅳ.TP273

中国版本图书馆 CIP 数据核字(2002)第 046824 号

科学出版社 出版
北京东黄城根北街16号
邮政编码：100717
http://www.sciencep.com
源海印刷厂 印刷
科学出版社发行 各地新华书店经销

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2002年6月第 一 版 开本：787×1092 1/16
2002年6月第一次印刷 印张：28 1/4
印数：1—3 000 字数：700 000

定价：38.00 元

（如有印装质量问题，我社负责调换〈环伟〉）

国外高校电子信息类优秀教材(英文影印版)

丛书编委会

(按姓氏笔画排序)

We dedicate this book

To my parents
—Farzad

To Frances, Avelina, and Martin
—Gene

Preface

This book describes digital control using digital signal processors (DSPs). Most textbooks on digital control contain much control system theory but little information on using DSPs in control systems. Textbooks on DSP cover digital signal processing well but do not show how to use DSPs in control systems. This book covers fundamental digital control theory, as well as DSPs and how to use DSPs in control systems.

This book can be used as part of a first course in digital control systems. It is based on material taught to practicing engineers at the University of California at Berkeley Extension, and on material presented in several controls courses taught to graduate and undergraduate electrical engineering students at San Jose State University. Its level is appropriate for seniors or graduate students in engineering and practicing engineers for self-study. This book requires some background in linear systems theory and some understanding of linear algebra. The first courses in these areas would more than suffice.

The first half of the book (Chapters 1 through 4) covers the basic analysis and design of digital control systems. The second half (Chapters 5 and 6) covers the fundamentals of DSPs as well as modern techniques of digital control system design and compensation using DSPs as discrete controllers.

In Chapter 1 we introduce digital control and contrast it with analog control. There is a brief discussion of the difference between classical control theory and modern control theory. We also present an overview of the design process and the role of DSPs in the design of control systems. The capabilities of CAE packages and their role in the analysis and design of digital control systems are covered. The MATLAB and MATRIX_x software packages, discussed in Appendix A, are tools found to be most useful in the analysis and design of the digital control systems that are at issue in the following chapters.

Chapter 2 covers the basic mathematics of discrete systems: difference equations, the unit pulse response, discrete convolution, z-transforms, the discrete system transfer function, frequency response, Fourier transforms, and mappings from s to z domains. Appendices C and D, on transform pairs and partial-fraction expansions, should be used in conjunction with this chapter.

In Chapter 3 we use discussions of sampled-data systems, state-variable methods, nonlinear systems issues, stability, and sensitivity analysis to give the reader the basic knowledge needed to analyze digital control systems. Appendix E, on matrix algebra, should be reviewed before reading this chapter.

In Chapter 4 we discuss methods used to design control systems and, specifically, controllers used in control systems. We review design parameters from classical control in its discussion of steady-state response and cover conventional classical design methods, such as Bode plots and root locus, and discuss compensation techniques.

Chapter 5 covers the fundamentals of DSPs and shows a general guideline for selecting DSP chips for specific control system applications. The basics of computer architecture as necessary DSP background are provided in Appendix H. We compare analog and digital signal-processing methods and discuss generic DSPs and their architectures. Software and hardware support tools for commercial DSPs are discussed. We include examples of the application of DSPs in control systems.

In Chapter 6 we present the fundamentals of modern control systems design, emphasizing techniques such as state controllability, observability, and pole placement. There is also a brief discussion of the linear quadratic optimal design methodology. The implementation of designs as DSPs is stressed. A detailed example from the area of motion control is included to illustrate these modern design techniques. In addition, the basic ideas of fuzzy logic control are discussed.

In Appendix A we describe the CAE design and analysis packages $MATRIX_X$ and MATLAB, and in Appendix B we describe tools from dSPACE which are used in the implementation of DSP technology in control systems. Appendices C, D, and E provide tables of z-transforms and Laplace transforms, a description of the partial-fraction expansion method, and a description of matrix analysis, respectively. Appendix F contains a functional description of some of the most popular motion controller boards. In Appendix G we give examples of some DSP programs written for control system applications. Appendix H covers the basics of computer architecture.

Undergraduate students should find that the first half of the book, together with selected topics from the final two chapters, provides an adequate introduction to the business of digital control systems, an increasingly important topic of concern in the unfolding of the Information Era. As the century comes to a close, the Age of Energy is shifting into the Age of Information. That disciplines, such as control systems, focused for so long in the analog world, are more and more favoring digital representations and implementations comes as no surprise to most people today. Students, in particular, seem to have no reluctance toward embracing the digitalness of contemporary reality. Graduate students should find sufficient material in the six chapters of the text for a first-year grad course in digital controls using DSPs. They might find that the first three chapters need only be reviewed because most of the material therein has probably been encountered in undergraduate courses.

Instructors might want to skip some material, such as the discussion of discrete equation solutions in the early part of Chapter 2, or they may want to supplement the material in various places, such as the classical frequency-domain topics in Chapter 3, which consider Bode and root-locus analysis but not Nyquist analysis. If students already have a good digital controls background, Chapter 5 on DSP material can be studied independently. Then if the instructor supplements the material with topics from the controls literature, Chapter 5 coupled with Chapter 6 on modern design techniques using DSPs should make a good graduate course at a more advanced level.

If the reader is already a practicing engineer, the book can serve as a reference for digital controls using DSPs, in particular, a theoretical framework for digital controls, the practical aspects with which the reader may be conversant. The use of computer-assisted engineering (CAE) tools should be of special interest to the practicing engineer, who generally needs to handle higher-order systems than most texts deal with.

Acknowledgments

- We are indebted to Dr. Herbert Hanselmann, Chief Executive of dSPACE GmbH, for his suggestions on the book's content.
- We are also indebted to Jack Borninski, of Texas Instruments, Inc., for his detailed review of the manuscript, constructive criticism, suggestions on information to be added, and for his contribution of an important example that we use in the text.
- We also extend our thanks to J. Chris Harvey, our editor, for his editing work, advice on format and writing style, and general knowledge of the publication process.
- We would like to thank the staff of Prentice Hall, Inc., especially Bernard Goodwin and Jane Bonnell, for their support of this project.
- We are also grateful for the fine editing skills of former professor John Lamandella, who helped us gather together many far-flung thoughts.
- Finally, we would like to acknowledge Dave Aiken for his technical input to the book, his computer expertise which was required to pull the book together, and his determination and stamina which were required to complete this project.

In addition, we'd like to thank the following people and companies:

- Mr. Paul Schmidt, of Integrated Systems Technology, Inc., for his assistance.
- Ms. Christina Palumbo, of the MathWorks, Inc.
- F.N.'s students at the University of California at Berkeley Extension, who contributed to the development of the course Digital Control Using Digital Signal Processing and who gave suggestions on this book's content.

- G.M.'s students at San Jose State University, who, during his 20 years of teaching, have contributed directly and indirectly to his understanding of control theory.
- F.N.'s sister, Faranak, and brother, Farhad, for their assistance and support.

F. N.
G. M.

Contents

CHAPTER 1

Introduction to Digital Control Using Digital Signal Processing

1.1 BACKGROUND

In this book we introduce the reader to the challenging process of implementing discrete system design concepts by programming digital signal processors (DSPs) to function as controllers in digital control systems. Fig. 1.1 indicates a standard feedback control system configuration. The plant is the process to be controlled. The feedback element is typically a sensor that feeds the plant output back to the input side of the system. The essential task of the designer is to determine the structure of the controller, which is driven by the difference between the input and fed-back output signals.

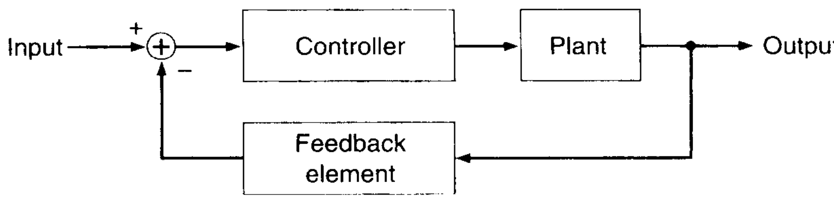

Figure 1.1 Block diagram of a standard feedback control system.

Traditionally, control systems have been designed and analyzed using analog techniques, and their controllers have been implemented with analog components, such as resistors, capacitors, and operational amplifiers. But today, because of the explosive growth and expanding efficiency of digital technology, controllers are typically implemented as programmable digital hardware or as programs on digital computers. The concepts and techniques for analysis and design of digital controllers, implemented as DSPs, are central concerns of this book.

To be useable by digital computers, analog signals need to be sampled and converted to digital form by an analog-to-digital (A/D) converter (also known as an ADC). After being processed by the digital computer, the digital signals need to be converted back to analog form by a digital-to-analog (D/A) converter (DAC). Such a configuration of ADCs, DACs, analog systems to be controlled, sensors, and digital computers functioning as controllers is called a *sampled-data system*. Fig. 1.2 indicates a standard sampled-data digital feedback control system configuration.

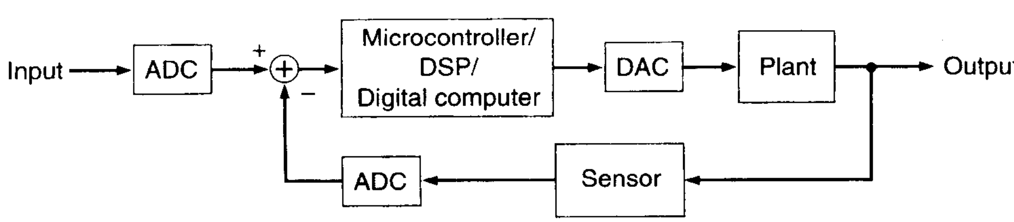

Figure 1.2 Block diagram of a standard digital control system.

Although the expression *digital control system* refers to a control system some part of which is in digital form (and that generally means a sampled-data control system), occasionally we may have a plant completely described by digital mathematics, and when this plant is combined with a digital controller, the system is entirely digital.

Readers may be familiar with the basic ideas of analog control systems analysis and design. Many of the ideas of digital analysis and design transfer over directly from the analog world. Those that do not, of course, require more elaboration. For example, the use of digital computers and microcontrollers such as DSPs *in the loop* for controlling systems is a very different procedure than using computers *outside the loop*, as is common in the analysis and design of both analog and digital controllers. Within the closed loop of a feedback system, a DSP functions as an information-processing device. Similar to the way in which philosopher of technology Albert Borgmann distinguishes between information *about* reality and information *for* reality [1], we might say that a computer in the loop (e.g., a DSP) provides information for the system, whereas a computer outside the loop only provides information about the system.

Although the DSP is an information transformation device, the systems to be controlled, systems such as airplanes or robots or air conditioners, are primarily energy-based devices. But the notions of energy and information are hard to separate. Energy-based systems typically include their information-based controllers, and these controllers, in turn, inform the energy-based systems of which they are a part. At the close of the twentieth century, we are witnessing the rapid proliferation of information-based technology and the gradual diminution of energy-based technology: the postindustrial era is shaping up as the age of information. Yet it seems unlikely that information will totally supplant energy– that virtual reality will totally replace actual reality. The physical, mechanical, and energy aspects of control systems will be essential components for some time to come, because a control system generally seeks to provide or prevent a physical displacement or motion of some kind, and displacement and movement are classical energy notions. Although the hardware or mechanical aspects of energy-based systems tend to become less obtrusive and less obvious to the user, such aspects continue to be of concern to control systems engineers. Despite the recent shift in emphasis between the two, energy and information both play important roles in the control systems of today.

1.2 Digital Control versus Analog Control

Fig. 1.3 (elaborated from Fig. 1.1) shows a block diagram representation of a typical analog control system. The basic components of the loop in Fig. 1.3 are the controller, the plant, and the feedback blocks, represented, respectively, by the transfer functions $G_c(s)$, $G_p(s)$, and H(s). Controllers or compensators are usually filters used to compensate or change the frequency response of the system. R(s) is the Laplace transform of the input and C(s) is the Laplace transform of the output.

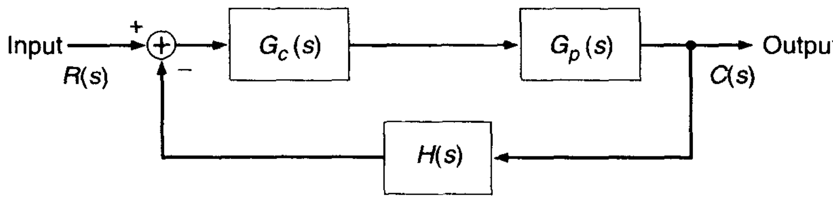

Figure 1.3 Block diagram of an analog control system.

If the output of thc summing device is E(s), then

$$\frac{C(s)}{R(s)} = M(s) = \frac{G_c(s)G_p(s)}{1 + G_c(s)G_p(s)H(s)} \tag{1.1}$$

and

$$G_c(s)G_p(s)E(s) = C(s) \tag{1.2}$$

from which

$$\frac{C(s)}{R(s)} = M(s) = \frac{G_c(s)G_p(s)}{1 + G_c(s)G_p(s)H(s)} \tag{1.3}$$

M(s) is called the *closed-loop transfer function*. (We assume that readers are familiar with the Laplace transform and the concept of transfer function as the ratio of Laplace transform of output to Laplace transform of input.)

Fig. 1.4 (elaborated from Fig. 1.2) shows a block diagram of a basic digital control system.

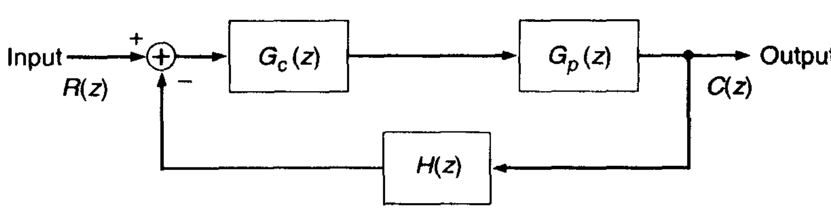

Figure 1.4 Digital control system block diagram.