CCES

M. S. Mahmoud · M. G. Singh

Discrete Systems

Analysis, Control and Optimization

Springer-Verlag
Berlin Heidelberg New York Tokyo

M. S. Mahmoud · M. G. Singh

Discrete Systems

Analysis, Control and Optimization

With 87 Figures

Springer-Verlag
Berlin Heidelberg New York Tokyo 1984

MAGDI S. MAHMOUD
Professor, Electrical and Computer Engineering Dept.
Kuwait University - Kuwait

MADAN G. SINGH
Professor of Control Engineering at U.M.I.S.T.
Manchester, U.K.

ISBN 3-540-13645-2 Springer-Verlag Berlin Heidelberg New York Tokyo
ISBN 0-387-13645-2 Springer-Verlag New York Heidelberg Berlin Tokyo

Library of Congress Cataloging in Publication Data
Mahmoud, Magdi S. Discrete systems, analysis, control, and optimization.
(Communications and control engineering series)
Bibliography: p. 1. Discrete-time systems. 2. Control theory. 3. Mathematical optimization.
I. Singh, Madan G. III. Series. QA 402.M29 1984 621.38 84-13915

Offsetprinting: Mercedes-Druck, Berlin. Bookbinding: Lüderitz & Bauer, Berlin
2061/3020-543210

Dedicated to

Medhat, Monda and Salwa
(M.S. MAHMOUD)

Alexandre and Anne-Marie
(M. G. SINGH)

Preface

More and more digital devices are being used for information processing and control purposes in a variety of systems applications, including industrial processes, power networks, biological systems and communication networks. This trend has been helped by the advent of microprocessors and the consequent availability of cheap distributed computing power. For those applications, where digital devices are used, it is reasonable to model the system in discrete-time. In addition there are other application areas, e.g. econometric systems, business systems, certain command and control systems, environmental systems, where the underlying models are in discrete-time and here discrete-time approaches to analysis and control are the most appropriate.

In order to deal with these two situations, there has been a lot of interest in developing techniques which allow us to do analysis, design and control of discrete-time systems.

This book provides a comprehensive treatment of discrete-time dynamical systems. It covers the topics of modelling, optimization techniques and control design. The book is designed to serve as a text for teaching at the first year graduate level.

The material included is organized into eight chapters. In the first chapter, a number of discrete-time models taken from various fields are given to motivate the reader. The rest of the book (seven chapters) is split into three parts: *Analysis* (part I), *Control* (part II) and *Optimization* (part III).

Analysis of discrete-time systems is covered in Chapters 2 and 3. Chapter 2 deals with the representation of discrete dynamical systems using transfer functions, difference equations, discrete state equations and modal decomposition. The simplification of high-order transfer functions is also presented using continued fraction expansions. In Chapter 3, we examine the structural properties of discrete control systems such as controllability (reachability), observability (determinability) and stability. By considering the system modes, other properties are then introduced. Following that, we present Lyapunov analysis of stability and give suitable computational algorithms for solving Lyapunov equations.

Part II on control comprises Chapters 4 and 5. In Chapter 4, we consider the design of feedback controllers for discrete systems using state feedback (based on eigenvalue and eigenstructure assignment algorithms) and output feedback. Feedback control schemes are developed for both low-order systems as well as large-scale systems. In Chapter 5, we undertake parallel developments for systems with some inaccessible states.

Part III on optimization comprises three chapters (6 to 8). State and parameter estimation techniques are considered in Chapter 6. In Chapter 7, we examine adaptive control systems via model reference and self-tuning approaches. The final chapter (8) is concerned with dynamic optimization techniques for discrete dynamical systems. Here again, both the standard techniques as well as their extension to large systems are examined.

Throughout the book many worked examples are provided to illustrate various concepts and methods. We also give problems at the end of each chapter with the exception of Chapter 1. The material presented in the book should prove useful for teaching and research to engineers and practitioners.

We are grateful to Mrs. Vera Butterworth and Mrs. Liz Tongue for typing the final version of this book, to Mr. S. Grace for doing the artwork, and Mrs. Beryl Hooley for preparing the index.

Contents

Chapter 1

Discrete Models in Systems Engineering

1.1 Introduction

In studying physical and engineering systems, one usually starts with a mathematical model which is obtained by considering some physical laws and/or empirical formulae. The behaviour of the system is then described by the evolution of appropriate variables (dependent variables) over time or over frequencies (the independent variable). For a broad class of systems, the values of the dependent variables are only known, or can only be defined, at discrete time instants. Typical examples of this are found in the fields of information processing, digital filters, managerial systems, environmental systems, certain command and control systems, socioeconomic systems, to name but a few. In addition, the rapid growth in computing capabilities and the improved technology of microprocessors has attracted systems analysts and modellers to utilise digital computers extensively in solving their problems. This is the case with many industrial processes where digital devices are often used. In such industrial applications, we have batch information processing in contrast to the continuous information processing which was required when traditional analog equipment was used.

For both categories of systems, it is convenient and meaningful to represent their dynamic models by discrete mathematical structures i.e. by using Z-transform theory or difference equations. The resulting models are commonly termed discrete-time dynamical models.

This book is devoted to the analysis, control and optimisation of discrete-time dynamical systems. Although the analytical development is focused on time-domain characterisations, a modest coverage of the frequency-domain representation methods is also given.

We now start with some illustrative examples drawn from different fields to motivate the reader. It should be pointed out that most of the definitions and concepts are stated in simple terms, leaving all rigorous treatment to subsequent chapters.

1.2 Some illustrative Examples

Our purpose in this section is to provide the reader with some feel about the importance of discrete models and discrete-time dynamical systems. This will be done by presenting some illustrative examples. Each example will be described and analysed in a simple way to stress the main features.

1.2.1 *DIRECT DIGITAL CONTROL OF A THERMAL PROCESS*

A schematic diagram of a typical environmental test chamber is shown in Fig. 1.1. The object to be tested is placed inside the chamber and its temperature is measured with a thermocouple (transducer). Since the electrical signal obtained by the temperature transducer usually has a low voltage level, an amplifier-filter unit is used to raise its level and remove any noise components [1]. The resulting signal is then fed into a digital control system consisting of an A/D (analog-to-digital) converter, a processor unit, and a D/A (digital-to-analog) converter. This system performs the following functions

a) sampling and coding of the electrical analog signal into binary format

b) implementation of a suitable algorithm to generate the discrete control signal

c) conversion of the digital signal back into an electrical voltage