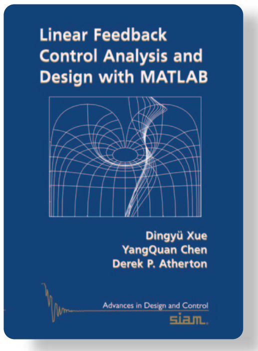

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Linear Feedback Control—Analysis and Design with MATLAB

by DINGYŬ XUE, YANGQUAN CHEN, and DEREK P. ATHERTON

Reviewed by Guoxiang Gu

Because of the complexity of modern physical processes and the mathematical nature of many design methods, it can be difficult, if not impossible, to carry out control system design without the aid of computer analysis and simulation tools. Matlab has emerged as the leader among such tools. More than ten Matlab toolboxes have been developed to aid modeling, simulation, analysis, and synthesis in the design of feedback control systems. These toolboxes greatly facilitate the process of control system design.

Almost all of the textbooks in introductory control courses include Matlab examples and exercises. However, not many have integrated Matlab and the control content well. What is missing in many control textbooks is a natural and smooth flow of illustrative Matlab scripts inserted into the appropriate places in the presentation of the material. There is thus a need for a book that contains not only control theory but also adequate Matlab examples.

I believe that *Linear Feedback Control—Analysis and Design with MATLAB*, which has been written primarily as a reference book, fills this gap. By reducing the mathematics, increasing the number of Matlab-worked examples, and inserting short scripts and plots within the text, the authors have created a book for a wide range of users, including beginners in the field, students who wish to bridge the gap between control theory and the use of Matlab in the analysis and design of control systems, and practicing engineers.

CONTENTS

The book is organized into eight chapters, which cover modeling, analysis, simulation, and controller design. Each chapter contains Matlab examples with short scripts and plots inserted within the text. In addition, each chapter provides a large number of exercises that require the use of various Matlab commands or Matlab programming.

Chapter 1 introduces the concept and structure of feedback control systems and offers a brief but interesting historical account of control systems. In addition, this chapter describes the organization of the book and provides a short tutorial on the basic elements of Matlab.

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Mathematical models for feedback control systems are developed in Chapter 2. The chapter begins with an electric circuit before introducing the Laplace transform. Transfer function models with Matlab representations are presented subsequently, covering both continuous-time and discrete-time systems, including multi-input/multi-output (MIMO) systems. State-space models with Matlab illustrations are also covered together with realization theory. Interconnections within a linear system as well as conversion between different mathematical models and between Matlab representations are described in detail. The chapter ends with a brief introduction to system identification, which is more involved mathematically.

Chapter 3 focuses on the analysis of linear control systems. Various system properties, such as stability, controllability, observability, and Kalman decomposition, are studied and analyzed. This material is followed by time-domain analysis that includes norm measures of signals and systems as well as responses of state-space systems. Many Matlab scripts are used to illustrate the use of relevant Matlab commands. Numerical simulation of linear systems is presented with emphasis on the step response of a second-order prototype system. Both qualitative specifications of the step response and the evaluation of the step response with Matlab are discussed. Root locus is introduced not only as a stability analysis tool but also as a controller design procedure, both illustrated with Matlab examples. An equally important design tool is the frequency-domain analysis that introduces the notion of gain and phase margins crucial to both performance analysis and controller design. The last topic of the chapter is model reduction, which echoes the identification section of the previous chapter.

Simulation analysis of nonlinear systems is covered in Chapter 4. This chapter is the shortest one but involves the most sophisticated aspects of mathematics and the Matlab toolbox. Simulink becomes the main tool for modeling and simulating nonlinear systems. The authors introduce Simulink first and then provide guidelines for Simulink modeling. Nonlinear modeling is illustrated by examples, using elements such as relay loop and double-valued nonlinearities. These examples help the reader to understand both the mathematical aspects of nonlinear systems and the programming side of Simulink. Linearization is treated at the end of the chapter.

The remaining four chapters are concerned with controller design. Chapter 5 focuses on model-based controller design. Strictly speaking the other chapters on controller design are also model based. The difference lies in that the design techniques in Chapter 5 are solely based on differential or difference equation models. The material in this chapter is rich and includes lead-lag synthesis based on the transfer function method and Bode plots with phase margin as the performance measure, for which SISOTool

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from Matlab is a convenient and effective design tool; linear-quadratic optimal control based on the state-space method for synthesizing observer-based controllers to minimize a linear-quadratic performance index; pole placement design, which combines state feedback and observation to form an observer-based controller and covers a variety of effective algorithms; and decoupling of multivariable systems, which is a less significant part of the chapter.

Chapter 6 covers traditional proportional-integral-differential (PID) control. Several PID design techniques are presented. The chapter begins with discussions on the action of proportional, differential, and integral controls, followed by the Ziegler-Nichols tuning formula and other PID controller tuning algorithms. Again, Matlab tools are used to work out many examples in this chapter. This approach helps the reader to understand the basics of PID control and its tuning formulas. Applications to other types of plants are also covered, including tuning formulas for various types of plant models. The chapter includes anti-windup PID controllers and automatic tuning of PID controllers. In addition, solutions to constrained and unconstrained optimization problems are presented with application to optimal controller design in which a Matlab interface is used.

Chapter 7 focuses on optimal robust control system design. This chapter starts with linear-quadratic-Gaussian control and loop transfer recovery in addressing the stability margin problem, which are followed by the small gain theorem and uncertainty descriptions in the frequency domain. These materials are solid preparation for introducing $\mathcal{H}_\infty$-based robust control. However, the presentation of $\mathcal{H}_\infty$ is too brief to include the complete design formulae for the general case, even though frequency weighting functions are discussed with weighted sensitivity minimization as an illustrative example. This problem is less severe in the case of $\mathcal{H}_2$ control, which is also covered in the chapter.

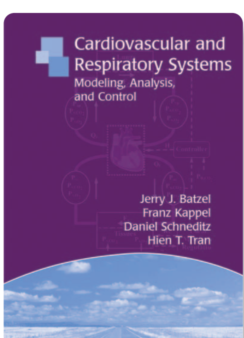
The final chapter on controller design, Chapter 8, focuses on fractional-order controllers. Because of Matlab, analysis and synthesis of these feedback controllers is feasible. The chapter covers computations, analysis, modeling, reduction, and controller design.

CONCLUSIONS

This book is an excellent addition to the existing literature on control. The book is easy to read, although mathematical details are mostly omitted. Many Matlab examples are used to illustrate the material covered. All example scripts within the book, as well as the CtrlLAB package developed by the authors, are freely downloadable from Matlab Central. I recommend that every control instructor obtain a copy of the package in which many Matlab examples can be taught to complement the textbook and to meet students' needs in learning Matlab. I also encourage practicing control engineers to obtain a copy of the book, which will provide them with a valuable source of information and a handy reference in control.

REVIEWER INFORMATION

Guoxiang Gu received his Ph.D. degree in electrical engineering from the University of Minnesota in 1988. From 1988 to 1990, he was with the Department of Electrical Engineering, Wright State University, Dayton, Ohio, as a visiting assistant professor. Since 1990, he has taught at Louisiana State University, where he is currently a professor. His research interests include control, system identification, and digital signal processing. He is an associate editor for *Automatica* and *SIAM Journal on Control and Optimization*.



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Cardiovascular and Respiratory Systems: Modeling, Analysis, and Control

by JERRY J. BATZEL, FRANZ KAPPEL, DANIEL SCHNEDITZ, and HIEN T. TRAN

Reviewed by Yih-Choung Yu

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Mathematical modeling of physiological systems is an interdisciplinary field that applies fundamental laws in mathematics, physics, chemistry, and engineering to characterize the interactions among physiological subsystems. These models are useful tools in various applications in medicine by supporting experimental design and facilitating better understanding of the functions underlying physiology [1], [2]. In addition, physiological models provide a convenient and cost-effective tool for medical training and education [3], and they assist clinical diagnosis, treatment, and medical device development [4], [5].

For example, the cardiovascular system consists of the heart, blood vessels, blood, and nerves. The heart pumps the blood into the blood vessels to circulate throughout the body and perfuse the organs. The nervous system controls the heart's pumping action (heart rate and cardiac