

Modeling, Analysis, and Control of Dynamic Systems

Second Edition

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*To Mary Louise.
For Aileene, Bill, and Andrew.*

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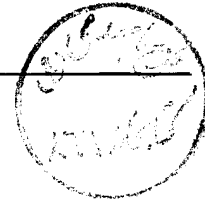
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Preface



This text is an introduction to modeling and analysis of dynamic systems, and to the design of controllers for such systems. It is assumed that the student has a background in calculus and college physics (mechanics, thermodynamics, and electrical circuits). Any other required material in physics and mathematics (e.g., differential equations, transforms, and matrices) is developed in the text.

Teaching, and therefore, writing a text in the area of dynamic systems and control present a great challenge for several reasons. The systems engineer can be called on to develop mathematical models for a variety of applications involving hydraulic, pneumatic, thermal, mechanical, and electrical systems, and must be familiar with the modeling techniques appropriate to each area. The challenge is to develop the student's ability to create a model that is sufficiently detailed to capture the dominant dynamic characteristics of the system, yet simple enough to be useful for design purposes.

Technological developments in the field have been rapid, as evidenced by the increasing use of digital computers as controllers, and by the now widespread use of computer packages such as **MATLAB** for analysis, simulation, and design. In addition to hardware and software developments, the field has seen the rapid development of analytical techniques collectively known as "modern" systems and control theory. Matrix formulations using the state-space approach provide a good basis for developing general algorithms that are well suited for computer-aided design purposes. On the other hand, the methods of "classical" systems theory are still widely used and have significant advantages over the modern methods in many applications. Today's engineer must be familiar with the classical and modern approaches, and a balanced treatment of these topics is needed.

Here an attempt to satisfy these needs has been made by introducing the required concepts and methods in a balanced and gradual way. Examples from different fields are given to show the student how to develop relatively low-order models that are adequate for many applications. Most system-dynamics concepts can be explained with first- and second-order models. Extensions to higher order models are gradually introduced along with any required mathematical tools. In this way, students can appreciate the need for such tools and can better understand their use. Because of this approach, there are no separate chapters devoted to **Laplace** transform methods, stability analysis, nonlinear systems, or state-space methods. Instead, students are led to apply any of these methods whenever appropriate.

MATLAB

Readers familiar with the first edition will notice a great many additions and deletions, as well as a substantial rearrangement of the material. This was done because of an increased interest in modeling and because of the now widespread use of **MATLAB**.

This text uses **MATLAB** to illustrate how modern computer tools can be applied in dynamic systems and control because surveys have shown that **MATLAB** is the most widely used computer package in such courses. However, it is not necessary

to cover **MATLAB** in order to use the text. All **MATLAB** material has been placed in separate sections at the end of each chapter. If **MATLAB** is not used in the course, these sections can be skipped without affecting the students' understanding of the rest of the material.

An innovative feature of the text is the coverage of sampled-data system analysis and digital control without the use of the z-transform. This approach uses the capabilities of **MATLAB** to avoid the time-consuming theoretical development of the z-transform and the derivation of pulse transfer functions for systems containing a zero-order hold. Students thus become comfortable with the analysis of sampled-data systems and digital control faster and easier than was formerly possible.

Chapter Structure

There are eleven chapters. The first six deal with dynamic systems; the last five cover control systems.

Each chapter has a similar structure designed to maximize flexibility of use. Each chapter has some optional material that can be omitted without impeding understanding of the subsequent chapters. All optional material has been placed in sections near the end of the chapter. This optional material includes:

1. All material dealing with **MATLAB**.
2. Material on linearization and nonlinear systems in Chapter 2.
3. Numerical solution of differential equations in Chapter 2.
4. Three case studies in Chapter 4.
5. Curve fitting and regression in Chapter 5.
6. Analog controller hardware in Chapter 7.
7. Discrete-time systems, sampled-data systems, and digital control in Chapter 8.
8. Design of digital controllers using **MATLAB**, in Chapter 9.
9. Dead-time elements in Chapter 10.
- 10.** Linear-quadratic regulator design in Chapter 11.

Design Applications

Since the publication of the first edition, changing accreditation criteria has resulted in increased demand for design coverage. A determined effort has been made throughout the text to justify and to illustrate the analytical methods in terms of their practical applications. Book length restrictions always prevent the treatment of design problems at the level of fine detail needed in practice, and some design considerations such as economics and reliability are difficult to treat within the scope of this study. Nevertheless, the discussion and examples should give students as much of a feel for the design process as is possible in an academic environment. To this end, a number of case studies and extended examples have been added. In addition, each chapter has a set of problems that have a design emphasis. Many of these can be done with a computer package such as **MATLAB**.

Chapter Problems

The number of problems at the end of each chapter has been greatly increased, and they are keyed to the appropriate section of the chapter. At the end of each

problem set there are a number of problems designated as **Design Problems** or **Computer Problems**. Many of the design problems are best done with a computer. The computer problems can be done with **MATLAB** or with another package.

Courses in Dynamic Systems and Control

It is my view that an undergraduate dynamic systems course should introduce the terminology and the basic principles of modeling and analysis, with emphasis on applications in vibrations and elementary feedback control systems. A general understanding of these topics is important even for graduates who will not be actively involved in designing dynamic systems, because such systems are encountered in many applications and their characteristics should be understood. This introduction should also prepare students for continuing their education in the vibrations or controls area, either with self-study by reading the literature or attending short courses or graduate school.

There is great variability among schools in how dynamic systems and control are handled in the curriculum, and this text has been designed to accommodate a number of variations. The only chapters that must be covered are Chapters 1 through 4. These chapters cover the basic modeling and analysis topics. Chapters 5 through 11 can be selected to provide the desired emphasis.

The national trend is toward requiring a dynamic systems course that includes some vibration and an introduction to control systems. Chapters 1 through 7 are designed for such a course. At the author's institution, the required junior course in dynamic systems covers the first seven chapters. No formal laboratory accompanies the course. However, if one is available, the text contains enough information on hardware to serve as a reference for the laboratory sessions. A senior elective course in control systems covers Chapters 8 through 11.

Some schools omit fluid and thermal systems from the dynamic systems course. If this is desired, Chapter 5 can be skipped without affecting understanding of the subsequent chapters. Students should have had elementary thermodynamics before covering the pneumatics material in this chapter, but previous exposure to fluid mechanics or heat transfer is not required.

Chapters 8 through 11 were designed to enable more extensive coverage of control systems in several ways. For example,

1. Coverage of Chapter 8 is recommended because it deals with the important practical topics of tuning, compensation, actuator saturation, reset wind-up, and digital control.
2. For treatment of classical design methods, cover Chapters 9 and 10. These deal with design applications of the root locus and frequency response plots.
3. For treatment of modern control methods based on state variable and matrix methods, cover Chapter 11. Note that Chapter 11 does not require coverage of Chapters 8, 9, or 10.

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William J. Palm III

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