Preface

This book represents a modern treatment of classical control theory and its applications. Theoretically, *it is based on the state space approach*, where the main control theory concepts are derived by using only elementary knowledge from sophomore/junior level courses in differential equations and linear algebra. Practically, it is based on the MATLAB®[1] package for computer-aided control system design, so that presentation of design techniques is simplified. The inclusion of MATLAB allows deeper insight into dynamical behavior of real physical control systems, which are quite often of high dimensions. The book treats simultaneously continuous- and discrete-time control systems with emphasis on continuous-time systems.

Our motivation for writing this book is twofold: (1) Undergraduate students usually take only one control systems course, studying first of all design techniques (mostly in the frequency domain). Students are very often left without full understanding of the standard control theory concepts such as state space, controllability, observability, and system stability. Most of nowadays control system textbooks originated in the sixties or kept the structure of the books written in the sixties. Namely, they emphasize the frequency domain approach and the corresponding design methods. With inclusion of MATLAB, which simplifies design techniques, we are able to spend more time explaining theoretical concepts. (2) Undergraduate laboratories are increasingly software oriented. This book provides at the same time the *laboratory manual*. After each chapter, the corresponding MATLAB laboratory experiments are formulated. Since there is no control systems laboratory manual in the literature, course instructors are faced with the problem of designing laboratory experiments. The appearance of MATLAB, a

[1] MATLAB is a registered trademark of The MathWorks, Inc.

broadly accepted software package at almost all universities around the world, allows development of a unified control systems laboratory manual. The MATLAB laboratory experiments developed present clearly considered theoretical issues in view of numerous control system applications.

The book contains a lot of examples, case studies, and problems. Most of these are of analytical nature. Some of them, especially those referring to high-order systems, are done (or ought to be performed) by the MATLAB package. Real world examples and problems are given in state space forms (system, input, and output matrices). In several cases we explain also the physics of the control systems under consideration and outline the corresponding mathematical modeling. Since this book is intended for students in all engineering fields (electrical, mechanical, aerospace, systems, chemical, industrial, and general engineering), we have presented real world examples for most of these areas. Many of the real-world control problems presented in the book are also perfectly suited for fast and easy analysis by another modern computer package for simulation of dynamic systems known as SIMULINK®[2].

Outstanding features that distinguish this book from other undergraduate control system books treating the same subjects are: (a) Chapter 5 on controllability and observability, where these fundamental control theory concepts are completely derived and explained by using only elementary knowledge about systems of linear algebraic equations; (b) inclusion of MATLAB laboratory experiments, designed after each chapter, to be used either in an associated control system laboratory or as supplements for instructions; (c) MATLAB case studies, examples, and problems are given in each chapter; (d) an extensive chapter on the state space approach based only on sophomore/junior level courses in differential equations and linear algebra; (e) the stability concept is thoroughly explained through the notion of the system minimal polynomial so that the unstable nature of the multiple poles (system eigenvalues) on the imaginary axis is completely clarified; (f) complete proofs of all rules for the root locus technique (Chapter 7) using only elementary mathematics; (g) complete set of controller design techniques based solely on the root locus method, which have much simpler forms than those based on the Bode diagrams; and (h) Chapter 10, entitled "Control System Theory Overview," which gives to students better insight into this extremely broad and multi-disciplinary engineering area.

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This book is intended for senior students in engineering. *Prerequisites for this course are either undergraduate sophomore/junior level courses in differential equations and linear algebra or linear systems course* (taught to juniors majoring in electrical engineering). In some schools, without undergraduate control courses, this book can be used as the first year graduate control theory text. In addition, the theoretical concepts presented in Chapters 1–5 and 10 are very helpful for graduate students interested in control system theory since they represent the required background for other graduate control theory courses and can be used for preparing master comprehensive and Ph.D. qualifying examinations. Chapters 6–9 are useful for practicing engineers who are applying control system design techniques to real physical systems.

The material presented in this book has been class-tested during several semesters at Rutgers University, Department of Electrical and Computer Engineering in the required senior level course on Automatic Control. The book includes a teacher's solution manual for problems and laboratory experiments and a computer disk with all MATLAB programs, laboratory experiments, and numerical data for vectors and matrices necessary to run MATLAB examples, problems, and laboratory experiments. The computer disk is available at no cost through The MathWorks Inc. The interested reader should fill in the card at the back of this book and send it to the address given. The software may also be retrieved from the MathWorks anonymous `FTP` server at `ftp.mathworks.com` in `pub/books/gajic/`. In addition, the MATLAB programs and numerical data used in this book may be obtained via anonymous `FTP` from the Internet site `ece.rutgers.edu` in the directory `/pub/gajic` or by pointing a Web browser to the book's `WWW` homepage on `http://www.ece.rutgers.edu/~gajic/control.html`.

Finally, we would like to clarify why the book is titled *Modern Control Systems Engineering*. This book is structured to cover thoroughly the fundamental control theory concepts (state space, controllability, observability, stability) deeper than any other undergraduate textbook through the use of only elementary mathematics. These concepts are used nowadays and will be used in the future not just in control engineering, but in many other engineering and scientific disciplines, like aerospace, motor industry, robotics, communications, signal processing, power systems, hydrology, computer science, bioengineering, chemical processes, economics, etc. In addition, showing how to use MATLAB extensively

for "quick" control system design purposes makes the techniques presented in this book efficient design tools for modern control system practitioners.

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