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Taking a different approach from standard thousand-page reference-style control textbooks, Fundamentals of Linear Control provides a concise yet comprehensive introduction to the analysis and design of feedback control systems in fewer than 400 pages. The text focuses on classical methods for dynamic linear systems in the frequency domain. The treatment is, however, modern and the reader is kept aware of contemporary tools and techniques, such as state space methods and robust and nonlinear control. Featuring fully worked design examples, richly illustrated chapters, and an extensive set of homework problems and examples spanning across the text for gradual challenge and perspective, this textbook is an excellent choice for senior-level courses in systems and control or as a complementary reference in introductory graduate level courses. The text is designed to appeal to a broad audience of engineers and scientists interested in learning the main ideas behind feedback control theory.

Praise for Previous Volumes "This book will be a useful reference to control engineers and researchers. The papers contained cover well the recent

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advances in the field of modern control theory." -IEEE GROUP

CORRESPONDENCE "This book will help all those researchers who valiantly try to keep abreast of what is new in the theory and practice of optimal control."

-CONTROL

Based largely on state space models, this text/reference utilizes fundamental linear algebra and operator techniques to develop classical and modern results in linear systems analysis and control design. It presents stability and performance results for linear systems, provides a geometric perspective on controllability and observability, and develops state space realizations of transfer functions. It also studies stabilizability and detectability, constructs state feedback controllers and asymptotic state estimators, covers the linear quadratic regulator problem in detail, introduces H-infinity control, and presents results on Hamiltonian matrices and Riccati equations.

Introduction to Linear Control Systems is designed as a standard introduction to linear control systems for all those who one way or another deal with control systems. It can be used as a comprehensive up-to-date textbook for a one-semester 3-credit undergraduate course on linear control systems as the first course on this topic at university. This includes the faculties of electrical engineering, mechanical engineering, aerospace engineering, chemical and

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petroleum engineering, industrial engineering, civil engineering, bio-engineering, economics, mathematics, physics, management and social sciences, etc. The book covers foundations of linear control systems, their raison detre, different types, modelling, representations, computations, stability concepts, tools for time-domain and frequency-domain analysis and synthesis, and fundamental limitations, with an emphasis on frequency-domain methods. Every chapter includes a part on further readings where more advanced topics and pertinent references are introduced for further studies. The presentation is theoretically firm, contemporary, and self-contained. Appendices cover Laplace transform and differential equations, dynamics, MATLAB and SIMULINK, treatise on stability concepts and tools, treatise on Routh-Hurwitz method, random optimization techniques as well as convex and non-convex problems, and sample midterm and endterm exams. The book is divided to the sequel 3 parts plus appendices. PART I: In this part of the book, chapters 1-5, we present foundations of linear control systems. This includes: the introduction to control systems, their raison detre, their different types, modelling of control systems, different methods for their representation and fundamental computations, basic stability concepts and tools for both analysis and design, basic time domain analysis and design details, and the root locus as a stability analysis and synthesis tool. PART II: In this part

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of the book, Chapters 6-9, we present what is generally referred to as the frequency domain methods. This refers to the experiment of applying a sinusoidal input to the system and studying its output. There are basically three different methods for representation and studying of the data of the aforementioned frequency response experiment: these are the Nyquist plot, the Bode diagram, and the Krohn-Manger-Nichols chart. We study these methods in details. We learn that the output is also a sinusoid with the same frequency but generally with different phase and magnitude. By dividing the output by the input we obtain the so-called sinusoidal or frequency transfer function of the system which is the same as the transfer function when the Laplace variable  $s$  is substituted with  $j\omega$ . Finally we use the Bode diagram for the design process. PART III: In this part, Chapter 10, we introduce some miscellaneous advanced topics under the theme fundamental limitations which should be included in this undergraduate course at least in an introductory level. We make bridges between some seemingly disparate aspects of a control system and theoretically complement the previously studied subjects. Appendices: The book contains seven appendices. Appendix A is on the Laplace transform and differential equations. Appendix B is an introduction to dynamics. Appendix C is an introduction to MATLAB, including SIMULINK. Appendix D is a survey on stability concepts and tools. A glossary

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and road map of the available stability concepts and tests is provided which is missing even in the research literature. Appendix E is a survey on the Routh-Hurwitz method, also missing in the literature. Appendix F is an introduction to random optimization techniques and convex and non-convex problems. Finally, appendix G presents sample midterm and endterm exams, which are class-tested several times.

Introduction to state-space methods covers feedback control; state-space representation of dynamic systems and dynamics of linear systems; frequency-domain analysis; controllability and observability; shaping the dynamic response; more. 1986 edition.

Linear Stochastic Control Systems presents a thorough description of the mathematical theory and fundamental principles of linear stochastic control systems. Both continuous-time and discrete-time systems are thoroughly covered. Reviews of the modern probability and random processes theories and the Itô stochastic differential equations are provided. Discrete-time stochastic systems theory, optimal estimation and Kalman filtering, and optimal stochastic control theory are studied in detail. A modern treatment of these same topics for continuous-time stochastic control systems is included. The text is written in an easy-to-understand style, and the reader needs only to have a background of

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elementary real analysis and linear deterministic systems theory to comprehend the subject matter. This graduate textbook is also suitable for self-study, professional training, and as a handy research reference. Linear Stochastic Control Systems is self-contained and provides a step-by-step development of the theory, with many illustrative examples, exercises, and engineering applications.

Anyone seeking a gentle introduction to the methods of modern control theory and engineering, written at the level of a first-year graduate course, should consider this book seriously. It contains: A generous historical overview of automatic control, from Ancient Greece to the 1970s, when this discipline matured into an essential field for electrical, mechanical, aerospace, chemical, and biomedical engineers, as well as mathematicians, and more recently, computer scientists; A balanced presentation of the relevant theory: the main state-space methods for description, analysis, and design of linear control systems are derived, without overwhelming theoretical arguments; Over 250 solved and exercise problems for both continuous- and discrete-time systems, often including MATLAB simulations; and Appendixes on MATLAB, advanced matrix theory, and the history of mathematical tools such as differential calculus, transform methods, and linear algebra. Another noteworthy feature is the

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frequent use of an inverted pendulum on a cart to illustrate the most important concepts of automatic control, such as: Linearization and discretization; Stability, controllability, and observability; State feedback, controller design, and optimal control; and Observer design, reduced order observers, and Kalman filtering. Most of the problems are given with solutions or MATLAB simulations. Whether the book is used as a textbook or as a self-study guide, the knowledge gained from it will be an excellent platform for students and practising engineers to explore further the recent developments and applications of control theory. This book provides an introduction to the analysis and control of Linear Parameter-Varying Systems and Time-Delay Systems and their interactions. The purpose is to give the readers some fundamental theoretical background on these topics and to give more insights on the possible applications of these theories. This self-contained monograph is written in an accessible way for readers ranging from undergraduate/PhD students to engineers and researchers willing to know more about the fields of time-delay systems, parameter-varying systems, robust analysis, robust control, gain-scheduling techniques in the LPV fashion and LMI based approaches. The only prerequisites are basic knowledge in linear algebra, ordinary differential equations and (linear) dynamical systems. Most of the results are proved unless the proof is too complex or not necessary for a good understanding of the results. In the latter cases,

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suitable references are systematically provided. The first part pertains on the representation, analysis and control of LPV systems along with a reminder on robust analysis and control techniques. The second part is concerned with the representation and analysis of time-delay systems using various time-domain techniques. The third and last part is devoted to the representation, analysis, observation, filtering and control of LPV time-delay systems. The book also presents many important basic and advanced results on the manipulation of LMIs.

Thoroughly classroom-tested and proven to be a valuable self-study companion, Linear Control System Analysis and Design: Sixth Edition provides an intensive overview of modern control theory and conventional control system design using in-depth explanations, diagrams, calculations, and tables. Keeping mathematics to a minimum, the book is designed with the undergraduate in mind, first building a foundation, then bridging the gap between control theory and its real-world application. Computer-aided design accuracy checks (CADAC) are used throughout the text to enhance computer literacy. Each CADAC uses fundamental concepts to ensure the viability of a computer solution. Completely updated and packed with student-friendly features, the sixth edition presents a range of updated examples using MATLAB®, as well as an appendix listing MATLAB functions for optimizing control system analysis and design. Over 75 percent of the problems presented in the previous edition have been revised or replaced.



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This book discusses analysis and design techniques for linear feedback control systems using MATLAB® software. By reducing the mathematics, increasing MATLAB working examples, and inserting short scripts and plots within the text, the authors have created a resource suitable for almost any type of user. The book begins with a summary of the properties of linear systems and addresses modeling and model reduction issues. In the subsequent chapters on analysis, the authors introduce time domain, complex plane, and frequency domain techniques. Their coverage of design includes discussions on model-based controller designs, PID controllers, and robust control designs. A unique aspect of the book is its inclusion of a chapter on fractional-order controllers, which are useful in control engineering practice.

An introduction to analysis techniques used in the design of linear feedback control systems with emphasis on both classical and matrix methods. This text presents all design methods in a building-block sequence, including a thorough analysis of first- and second-order systems as well as general state space systems.

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This revised edition emphasizes undergraduate topics and the use of CAD programs, while providing a rigorous treatment of advanced topics and derivation techniques. Organized logically and for maximum teaching flexibility, it instills the basic principles of feedback control essential to all specialty areas of engineering.

An excellent introduction to feedback control system design, this book offers a theoretical approach that captures the essential issues and can be applied to a wide range of practical problems. Its explorations of recent developments in the field emphasize the relationship of new procedures to classical control theory, with a focus on single input and output systems that keeps concepts accessible to students with limited backgrounds. The text is geared toward a single-semester senior course or a graduate-level class for students of electrical engineering. The opening chapters constitute a basic treatment of feedback design. Topics include a detailed formulation of the control design program, the fundamental issue of performance/stability robustness tradeoff, and the graphical design technique of loopshaping. Subsequent chapters extend the discussion of the loopshaping technique and connect it with notions of optimality. Concluding chapters examine controller design via optimization, offering a mathematical approach that is useful for multivariable systems.

Dynamics systems (living organisms, electromechanical and industrial systems, chemical and technological processes, market and ecology, and so forth) can be considered and analyzed using information and systems theories. For example,

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adaptive human behavior can be studied using automatic feedback control. As an illustrative example, the driver controls a car changing the speed and steering wheels using incoming information, such as traffic and road conditions. This book focuses on the most important and manageable topics in applied multivariable control with application to a wide class of electromechanical dynamic systems. A large spectrum of systems, familiar to electrical, mechanical, and aerospace students, engineers, and scholars, are thoroughly studied to build the bridge between theory and practice as well as to illustrate the practical application of control theory through illustrative examples. It is the author's goal to write a book that can be used to teach undergraduate and graduate classes in automatic control and nonlinear control at electrical, mechanical, and aerospace engineering departments. The book is also addressed to engineers and scholars, and the examples considered allow one to implement the theory in a great variety of industrial systems. The main purpose of this book is to help the reader grasp the nature and significance of multivariable control.

Thoroughly classroom-tested and proven to be a valuable self-study companion, *Linear Control System Analysis and Design: Fifth Edition* uses in-depth explanations, diagrams, calculations, and tables, to provide an intensive overview of modern control theory and conventional control system design. The authors

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keep the mathematics to a minimum while stressing real-world engineering challenges. Completely updated and packed with student-friendly features, the Fifth Edition presents a wide range of examples using MATLAB® and TOTAL-PC, as well as an appendix listing MATLAB functions for optimizing control system analysis and design. Eighty percent of the problems presented in the previous edition have been revised to further reinforce concepts necessary for current electrical, aeronautical, astronautical, and mechanical applications.

"Uncertainty is inherent in control systems. Consider the following example: as an aircraft flies, it consumes fuel, which causes its mass to decrease. In order to maintain stability, the autopilot mechanism must adapt to this (a priori unknown) change in mass. Delays also pose a challenge in control systems. If you have tried to maintain a comfortable water temperature while showering in a building with outdated plumbing, you will understand the difficulties that arise when a control system has significant delays: the controller (you) is forced to make decisions based on "old" information. The intersection of these two problems (estimating unknown parameters when a system has delays) poses a significant mathematical challenge. Delay-Adaptive Linear Control presents new mathematical techniques to handle the intersection of the two distinct types of uncertainty described above: adaptive constraints, and uncertainties caused by

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delays. Traditionally, the problems of adaption and delays have been treated separately. This book considers the intersection of these two problems, developing new techniques for addressing different combinations of uncertainty- all within a single, unified framework. This work has applications in electrical and mechanical engineering (unmanned aerial vehicles, robotic manipulators), biomedical engineering (3D printing, neuromuscular electrical stimulation), and management and traffic science (supply chains, traffic flow), among others. Beyond its practical importance, this work is also of significant theoretical interest, as it addresses mathematical challenges involved in the analysis and design of these systems"--

The design of control systems is at the very core of engineering. Feedback controls are ubiquitous, ranging from simple room thermostats to airplane engine control. Helping to make sense of this wide-ranging field, this book provides a new approach by keeping a tight focus on the essentials with a limited, yet consistent set of examples. Analysis and design methods are explained in terms of theory and practice. The book covers classical, linear feedback controls, and linear approximations are used when needed. In parallel, the book covers time-discrete (digital) control systems and juxtaposes time-continuous and time-discrete treatment when needed. One chapter covers the industry-standard PID

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control, and one chapter provides several design examples with proposed solutions to commonly encountered design problems. The book is ideal for upper level students in electrical engineering, mechanical engineering, biological/biomedical engineering, chemical engineering and agricultural and environmental engineering and provides a helpful refresher or introduction for graduate students and professionals Focuses on the essentials of control fundamentals, system analysis, mathematical description and modeling, and control design to guide the reader Illustrates the theory and practical application for each point using real-world examples Strands weave throughout the book, allowing the reader to understand clearly the use and limits of different analysis and design tools

Originally published: London; New York: Academic Press, 1980, in series: Mathematics in science and engineering; v. 156.

For more than forty years, the equation  $y'(t) = Ay(t) + u(t)$  in Banach spaces has been used as model for optimal control processes described by partial differential equations, in particular heat and diffusion processes. Many of the outstanding open problems, however, have remained open until recently, and some have never been solved. This book is a survey of all results know to the author, with emphasis on very recent results (1999 to date). The book is restricted to linear

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equations and two particular problems (the time optimal problem, the norm optimal problem) which results in a more focused and concrete treatment. As experience shows, results on linear equations are the basis for the treatment of their semilinear counterparts, and techniques for the time and norm optimal problems can often be generalized to more general cost functionals. The main object of this book is to be a state-of-the-art monograph on the theory of the time and norm optimal controls for  $y'(t) = Ay(t) + u(t)$  that ends at the very latest frontier of research, with open problems and indications for future research. Key features:

- Applications to optimal diffusion processes.
- Applications to optimal heat propagation processes.
- Modelling of optimal processes governed by partial differential equations.
- Complete bibliography.
- Includes the latest research on the subject.
- Does not assume anything from the reader except basic functional analysis.
- Accessible to researchers and advanced graduate students alike

Applications to optimal diffusion processes. · Applications to optimal heat propagation processes. · Modelling of optimal processes governed by partial differential equations. · Complete bibliography. · Includes the latest research on the subject. · Does not assume anything from the reader except basic functional analysis. · Accessible to researchers and advanced graduate students alike

The book blends readability and accessibility common to undergraduate control



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systems texts with the mathematical rigor necessary to form a solid theoretical foundation. Appendices cover linear algebra and provide a Matlab overview and files. The reviewers pointed out that this is an ambitious project but one that will pay off because of the lack of good up-to-date textbooks in the area.

Automation of linear systems is a fundamental and essential theory. This book deals with the theory of continuous-state automated systems.

A guide to common control principles and how they are used to characterize a variety of physiological mechanisms The second edition of Physiological Control Systems offers an updated and comprehensive resource that reviews the fundamental concepts of classical control theory and how engineering methodology can be applied to obtain a quantitative understanding of physiological systems. The revised text also contains more advanced topics that feature applications to physiology of nonlinear dynamics, parameter estimation methods, and adaptive estimation and control. The author—a noted expert in the field—includes a wealth of worked examples that illustrate key concepts and methodology and offers in-depth analyses of selected physiological control models that highlight the topics presented. The author discusses the most noteworthy developments in system identification, optimal control, and nonlinear dynamical analysis and targets recent bioengineering advances. Designed to be

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a practical resource, the text includes guided experiments with simulation models (using Simulink/Matlab). Physiological Control Systems focuses on common control principles that can be used to characterize a broad variety of physiological mechanisms. This revised resource: Offers new sections that explore identification of nonlinear and time-varying systems, and provide the background for understanding the link between continuous-time and discrete-time dynamic models Presents helpful, hands-on experimentation with computer simulation models Contains fully updated problems and exercises at the end of each chapter Written for biomedical engineering students and biomedical scientists, Physiological Control Systems, offers an updated edition of this key resource for understanding classical control theory and its application to physiological systems. It also contains contemporary topics and methodologies that shape bioengineering research today.

Numerical Methods for Linear Control Systems Design and Analysis is an interdisciplinary textbook aimed at systematic descriptions and implementations of numerically-viable algorithms based on well-established, efficient and stable modern numerical linear techniques for mathematical problems arising in the design and analysis of linear control systems both for the first- and second-order models. Unique coverage of modern mathematical concepts such as parallel

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computations, second-order systems, and large-scale solutions Background material in linear algebra, numerical linear algebra, and control theory included in text Step-by-step explanations of the algorithms and examples

A comprehensive treatment of model-based fuzzy control systems This volume offers full coverage of the systematic framework for the stability and design of nonlinear fuzzy control systems. Building on the Takagi-Sugeno fuzzy model, authors Tanaka and Wang address a number of important issues in fuzzy control systems, including stability analysis, systematic design procedures, incorporation of performance specifications, numerical implementations, and practical applications. Issues that have not been fully treated in existing texts, such as stability analysis, systematic design, and performance analysis, are crucial to the validity and applicability of fuzzy control methodology. Fuzzy Control Systems Design and Analysis addresses these issues in the framework of parallel distributed compensation, a controller structure devised in accordance with the fuzzy model. This balanced treatment features an overview of fuzzy control, modeling, and stability analysis, as well as a section on the use of linear matrix inequalities (LMI) as an approach to fuzzy design and control. It also covers advanced topics in model-based fuzzy control systems, including modeling and control of chaotic systems. Later sections offer practical examples in the form

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of detailed theoretical and experimental studies of fuzzy control in robotics systems and a discussion of future directions in the field. Fuzzy Control Systems Design and Analysis offers an advanced treatment of fuzzy control that makes a useful reference for researchers and a reliable text for advanced graduate students in the field.

After motivating examples, this monograph gives substantial new results on the analysis and control of linear repetitive processes. These include further applications of the abstract model based stability theory which, in particular, shows the critical importance to the dynamics developed of the structure of the initial conditions at the start of each new pass, the development of stability tests and performance bounds in terms of so-called 1D and 2D Lyapunov equations. It presents the development of a major bank of results on the structure and design of control laws, including the case when there is uncertainty in the process model description, together with numerically reliable computational algorithms. Finally, the application of some of these results in the area of iterative learning control is treated --- including experimental results from a chain conveyor system and a gantry robot system.

This advanced textbook introduces the main concepts and advances in systems and control theory, and highlights the importance of geometric ideas in the

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context of possible extensions to the more recent developments in nonlinear systems theory. Although inspired by engineering applications, the content is presented within a strong theoretical framework and with a solid mathematical background, and the reference models are always finite dimensional, time-invariant multivariable linear systems. The book focuses on the time domain approach, but also considers the frequency domain approach, discussing the relationship between the two approaches, especially for single-input-single-output systems. It includes topics not usually addressed in similar books, such as a comparison between the frequency domain and the time domain approaches, bounded input bounded output stability (including a characterization in terms of canonical decomposition), and static output feedback stabilization for which a simple and original criterion in terms of generalized inverse matrices is proposed. The book is an ideal learning resource for graduate students of control theory and automatic control courses in engineering and mathematics, as well as a reference or self-study guide for engineers and applied mathematicians.

Linear Control System Analysis and Design with MATLAB®, Sixth Edition  
CRC Press

An integrated treatment of linear control system modeling, analysis and design, geared for advanced undergraduates in electrical engineering. The book examines both component and

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system models; time response, root locus and frequency response methods using Bode diagrams and the Nyquist criterion; and classical design by series compensation and state variable design using introductory concepts from optimal control theory. Over 200 problems are contained in the book with detailed worked-out examples, and numerous photographs. Digital controllers are part of nearly all modern personal, industrial, and transportation systems. Every senior or graduate student of electrical, chemical or mechanical engineering should therefore be familiar with the basic theory of digital controllers. This new text covers the fundamental principles and applications of digital control engineering, with emphasis on engineering design. Fadali and Visioli cover analysis and design of digitally controlled systems and describe applications of digital controls in a wide range of fields. With worked examples and Matlab applications in every chapter and many end-of-chapter assignments, this text provides both theory and practice for those coming to digital control engineering for the first time, whether as a student or practicing engineer. Extensive Use of computational tools: Matlab sections at end of each chapter show how to implement concepts from the chapter Frees the student from the drudgery of mundane calculations and allows him to consider more subtle aspects of control system analysis and design An engineering approach to digital controls: emphasis throughout the book is on design of control systems. Mathematics is used to help explain concepts, but throughout the text discussion is tied to design and implementation. For example coverage of analog controls in chapter 5 is not simply a review, but is used to show how analog control systems map to digital control systems Review of Background Material: contains review material to aid understanding of digital control analysis and design. Examples include discussion of discrete-time systems in time domain and

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frequency domain (reviewed from linear systems course) and root locus design in s-domain and z-domain (reviewed from feedback control course) Inclusion of Advanced Topics In addition to the basic topics required for a one semester senior/graduate class, the text includes some advanced material to make it suitable for an introductory graduate level class or for two quarters at the senior/graduate level. Examples of optional topics are state-space methods, which may receive brief coverage in a one semester course, and nonlinear discrete-time systems Minimal Mathematics Prerequisites The mathematics background required for understanding most of the book is based on what can be reasonably expected from the average electrical, chemical or mechanical engineering senior. This background includes three semesters of calculus, differential equations and basic linear algebra. Some texts on digital control require more

This textbook is intended to provide a clear, understandable, and motivated account of the subject which spans both conventional and modern control theory. The authors have tried to exert meticulous care with explanations, diagrams, calculations, tables, and symbols. They have tried to ensure that the student is made aware that rigor is necessary for advanced control work. Also stressed is the importance of clearly understanding the concepts which provide the rigorous foundations of modern control theory. The text provides a strong, comprehensive, and illuminating account of those elements of conventional control theory which have relevance in the design and analysis of control systems. The presentation of a variety of different techniques contributes to the development of the student's working understanding of what A.T. Fuller has called "the enigmatic control system." To provide a coherent development of the subject, an attempt is made to eschew formal proofs and lemmas

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with an organization that draws the perceptive student steadily and surely onto the demanding theory of multi-variable control systems. It is the opinion of the authors that a student who has reached this point is fully equipped to undertake with confidence the challenges presented by more advanced control theories as typified by chapters 18 through 22. The importance and necessity of making extensive use of computers is emphasized by references to comprehensive computer-aided-design (CAD) programs. - Preface.

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