

AUTOMATION AND CONTROL ENGINEERING SERIES

# Linear Control Theory

Structure, Robustness,  
and Optimization

Shankar P. Bhattacharyya  
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CRC Press  
Taylor & Francis Group

# Linear Control Theory Linear Control Theory

**Harry L. Trentelman, Anton A.  
Stoorvogel, Malo Hautus**



## **Linear Control Theory Linear Control Theory:**

Control Theory for Linear Systems Harry L. Trentelman, Anton A. Stoorvogel, Malo Hautus, 2012-12-06 Control Theory for Linear Systems deals with the mathematical theory of feedback control of linear systems. It treats a wide range of control synthesis problems for linear state space systems with inputs and outputs. The book provides a treatment of these problems using state space methods, often with a geometric flavour. Its subject matter ranges from controllability and observability, stabilization, disturbance decoupling and tracking and regulation to linear quadratic regulation,  $H_2$  and  $H_\infty$  control and robust stabilization. Each chapter of the book contains a series of exercises intended to increase the reader's understanding of the material. Often these exercises generalize and extend the material treated in the regular text. Linear Control Theory Shankar P. Bhattacharyya, Aniruddha Datta, Lee H. Keel, 2018-10-03 Successfully classroom tested at the graduate level. Linear Control Theory: Structure, Robustness and Optimization covers three major areas of control engineering: PID control, robust control and optimal control. It provides balanced coverage of elegant mathematical theory and useful engineering oriented results. The first part of the book develops results relating to the design of PID and first order controllers for continuous and discrete time linear systems with possible delays. The second section deals with the robust stability and performance of systems under parametric and unstructured uncertainty. This section describes several elegant and sharp results such as Kharitonov's theorem and its extensions, the edge theorem and the mapping theorem. Focusing on the optimal control of linear systems, the third part discusses the standard theories of the linear quadratic regulator,  $H_\infty$  and  $H_1$  optimal control and associated results. Written by recognized leaders in the field, this book explains how control theory can be applied to the design of real world systems. It shows that the techniques of three term controllers along with the results on robust and optimal control are invaluable to developing and solving research problems in many areas of engineering.

*Linear Control Theory* Frederick Walker Fairman, 1998-06-11 Incorporating recent developments in control and systems research, Linear Control Theory provides the fundamental theoretical background needed to fully exploit control system design software. This logically structured text opens with a detailed treatment of the relevant aspects of the state space analysis of linear systems. End of chapter problems facilitate the learning process by encouraging the student to put his or her skills into practice. Features include: The use of an easy to understand matrix variational technique to develop the time invariant quadratic and LQG controllers. A step by step introduction to essential mathematical ideas as they are needed, motivating the reader to venture beyond basic concepts. The examination of linear system theory as it relates to control theory. The use of the PBH test to characterize eigenvalues in the state feedback and observer problems rather than its usual role as a test for controllability or observability. The development of model reduction via balanced realization. The employment of the  $L_2$  gain as a basis for the development of the  $H$  controller for the design of controllers in the presence of plant model uncertainty. Senior undergraduate and postgraduate control engineering students and practicing control engineers will

appreciate the insight this self-contained book offers into the intelligent use of today's control system software tools

**State Functions and Linear Control Systems** Donald G. Schultz, James L. Melsa, 1967

**Linear Control System Analysis and Design with MATLAB** Constantine H. Houptis, Stuart N. Sheldon, 2013-10-30 This book uses numerous in-depth explanations, diagrams, calculations, and tables to provide an intensive overview of modern control theory and control system design. Mathematics is kept to a minimum and engineering applications are stressed throughout. 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.

**Linear Optimal Control Systems** Huibert Kwakernaak, R. Sivan, 1972-11-10 This book attempts to reconcile modern linear control theory with classical control theory. One of the major concerns of this text is to present design methods employing modern techniques for obtaining control systems that stand up to the requirements that have been so well developed in the classical expositions of control theory. Therefore, among other things, an entire chapter is devoted to a description of the analysis of control systems, mostly following the classical lines of thought. In the later chapters of the book, in which modern synthesis methods are developed, the chapter on analysis is recurrently referred to. Furthermore, special attention is paid to subjects that are standard in classical control theory but are frequently overlooked in modern treatments, such as nonzero set point control systems, tracking systems, and control systems that have to cope with constant disturbances. Also, heavy emphasis is placed upon the stochastic nature of control problems because the stochastic aspects are so essential.

**Linear Algebra for Control Theory** Paul Van Dooren, Bostwick Wyman, 2012-12-06 During the past decade, the interaction between control theory and linear algebra has been ever increasing, giving rise to new results in both areas. As a natural outflow of this research, this book presents information on this interdisciplinary area. The cross-fertilization between control and linear algebra can be found in subfields such as Numerical Linear Algebra, Canonical Forms, Ring-theoretic Methods, Matrix Theory, and Robust Control. This book's editors were challenged to present the latest results in these areas and to find points of common interest. This volume reflects very nicely the interaction; the range of topics seems very wide, indeed, but the basic problems and techniques are always closely connected. And the common denominator in all of this is, of course, linear algebra. This book is suitable for both mathematicians and students.

**Linear State-Space Control Systems** Robert L. Williams, II, Douglas A. Lawrence, 2007-02-09 The book blends readability and accessibility common to undergraduate control 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.

[Introduction to Linear Control Systems](#) Yazdan Bavafa-Toosi, 2017-09-19

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 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 d'être 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 into 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 d'être 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 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 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

### **Functional Analysis and Linear Control Theory** J. R.

Leigh, 2007-03-16 Originally published London New York Academic Press 1980 in series Mathematics in science and engineering v 156

Linear Control Theory Shankar P. Bhattacharyya, Aniruddha Datta, Lee H. Keel, 2018-10-03 Successfully classroom tested at the graduate level Linear Control Theory Structure Robustness and Optimization covers three major areas of control engineering PID control robust control and optimal control It provides balanced coverage of elegant mathematical theory and useful engineering oriented results The first part of the book develops results relating to the design of PID and first order controllers for continuous and discrete time linear systems with possible delays The second section deals with the robust stability and performance of systems under parametric and unstructured uncertainty This section describes several elegant and sharp results such as Kharitonov's theorem and its extensions the edge theorem and the mapping theorem Focusing on the optimal control of linear systems the third part discusses the standard theories of the linear quadratic regulator  $H_\infty$  and  $H_1$  optimal control and associated results Written by recognized leaders in the field this book explains how control theory can be applied to the design of real world systems It shows that the techniques of three term controllers along with the results on robust and optimal control are invaluable to developing and solving research problems in many areas of engineering

### Linear Control System Analysis and Design

Constantine H. Houpis, Stuart N. Sheldon, John J. D'Azzo, 2003-08-14 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 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

*Computational Aspects of Linear Control* Claude Brezinski, 2013-12-01 Many devices we say dynamical systems or simply systems behave like black boxes they receive an input this input is transformed following some laws usually a differential equation and an output is observed The problem is to regulate the input in order to control the output that is for obtaining a desired output Such a mechanism where the input is modified according to the output measured is called feedback The study and design of such automatic processes is called control theory As we will see the term system embraces any device and control theory has a wide variety of applications in the real world Control theory is an interdisciplinary domain at the junction of differential and difference equations system theory and statistics Moreover the solution of a control problem involves many topics of numerical analysis and leads to many interesting computational problems linear algebra QR SVD projections Schur complement structured matrices localization of eigenvalues computation of the rank

Jordan normal form Sylvester and other equations systems of linear equations regularization etc root localization for polynomials inversion of the Laplace transform computation of the matrix exponential approximation theory orthogonal polynomials Padé approximation continued fractions and linear fractional transformations optimization least squares dynamic programming etc So control theory is also a good excuse for presenting various sometimes unrelated issues of numerical analysis and the procedures for their solution This book is not a book on control

**Introduction to Control Theory, Including Optimal Control** David N. Burghes, Alexander Graham, 1980

**Tracking Control of Linear Systems** Lyubomir T. Gruyitch, 2013-05-29 The primary purpose of control is to force desired behavior in an unpredictable environment under the actions of unknown possibly unmeasurable disturbances and unpredictable and therefore probably nonzero initial conditions This means that tracking and tracking control synthesis are fundamental control issues Surprisingly however tracking theory has not been well developed and stability theory has dominated Tracking Control of Linear Systems presents the fundamentals of tracking theory for control systems The book introduces the full transfer function matrix  $F(s)$  which substantially changes the theory of linear dynamical and control systems and enables a novel synthesis of tracking control that works more effectively in real environments An Introduction to the New Fundamentals of the Theory of Linear Control Systems The book begins by re-examining classic linear control systems theory It then defines and determines the system full complete transfer function matrix  $F(s)$  for two classes of systems input output IO control systems and input state output ISO control systems The book also discusses the fundamentals of tracking and trackability It presents new Lyapunov tracking control algorithms and natural tracking control NTC algorithms which ensure the quality of the tracking under arbitrary disturbances and initial conditions This natural tracking control is robust adaptable and simple to implement Advances in Linear Control Systems Theory Tracking and Trackability This book familiarizes readers with novel sophisticated approaches and methods for tracking control design in real conditions Contributing to the advancement of linear control systems theory this work opens new directions for research in time invariant continuous time linear control systems It builds on previous works in the field extending treatment of the system transfer functions stability issues the plant control relationship and control synthesis

Nonlinear Control Systems II Alberto Isidori, 1999-09-22 This eagerly awaited follow up to Nonlinear Control Systems incorporates recent advances in the design of feedback laws for the purpose of globally stabilizing nonlinear systems via state or output feedback The author is one of the most prominent researchers in the field

*Introduction to Mathematical Systems Theory* C. Heij, Christiaan Heij, André C.M. Ran, F. van Schagen, 2007 This book provides an introduction to the theory of linear systems and control for students in business mathematics econometrics computer science and engineering The focus is on discrete time systems which are the most relevant in business applications as opposed to continuous time systems requiring less mathematical preliminaries The subjects treated are among the central topics of deterministic linear system theory controllability observability realization theory stability and stabilization by

feedback LQ optimal control theory Kalman filtering and LQC control of stochastic systems are also discussed as are modeling time series analysis and model specification along with model validation *Linear Control Systems* Branislav Kisić, Gyan C. Agarwal, 2012-12-06 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 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 **Functional Analysis and Control Theory** Stefan Rolewicz, 1987

**Linear Systems Control** Elbert Hendricks, Ole Jannerup, Paul Haase Sørensen, 2008-10-13 Modern control theory and in particular state space or state variable methods can be adapted to the description of many different systems because it depends strongly on physical modeling and physical intuition The laws of physics are in the form of differential equations and for this reason this book concentrates on system descriptions in this form This means coupled systems of linear or nonlinear differential equations The physical approach is emphasized in this book because it is most natural for complex systems It also makes what would ordinarily be a difficult mathematical subject into one which can straightforwardly be understood intuitively and which deals with concepts which engineering and science students are already familiar In this way it is easy to immediately apply the theory to the understanding and control of ordinary systems Application engineers working in industry will also find this book interesting and useful for this reason In line with the approach set forth above the book first deals with the modeling of systems in state space form Both transfer function and differential equation modeling methods are treated with many examples Linearization is treated and explained first for very simple nonlinear systems and then more complex systems Because computer control is so fundamental to modern applications discrete time modeling of systems as difference equations is introduced immediately after the more intuitive differential equation models The conversion of differential equation models to difference equations is also discussed at length including transfer function formulations A

vital problem in modern control is how to treat noise in control systems Nevertheless this question is rarely treated in many control system textbooks because it is considered to be too mathematical and too difficult in a second course on controls In this textbook a simple physical approach is made to the description of noise and stochastic disturbances which is easy to understand and apply to common systems This requires only a few fundamental statistical concepts which are given in a simple introduction which lead naturally to the fundamental noise propagation equation for dynamic systems the Lyapunov equation This equation is given and exemplified both in its continuous and discrete time versions With the Lyapunov equation available to describe state noise propagation it is a very small step to add the effect of measurements and measurement noise This gives immediately the Riccati equation for optimal state estimators or Kalman filters These important observers are derived and illustrated using simulations in terms which make them easy to understand and easy to apply to real systems The use of LQR regulators with Kalman filters give LQG Linear Quadratic Gaussian regulators which are introduced at the end of the book Another important subject which is introduced is the use of Kalman filters as parameter estimations for unknown parameters The textbook is divided into 7 chapters 5 appendices a table of contents a table of examples extensive index and extensive list of references Each chapter is provided with a summary of the main points covered and a set of problems relevant to the material in that chapter Moreover each of the more advanced chapters 3 7 are provided with notes describing the history of the mathematical and technical problems which lead to the control theory presented in that chapter Continuous time methods are the main focus in the book because these provide the most direct connection to physics This physical foundation allows a logical presentation and gives a good intuitive feel for control system construction Nevertheless strong attention is also given to discrete time systems Very few proofs are included in the book but most of the important results are derived This method of presentation makes the text very readable and gives a good foundation for reading more rigorous texts A complete set of solutions is available for all of the problems in the text In addition a set of longer exercises is available for use as Matlab Simulink laboratory exercises in connection with lectures There is material of this kind for 12 such exercises and each exercise requires about 3 hours for its solution Full written solutions of all these exercises are available

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## Linear Control Theory Linear Control Theory Introduction

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