Optimal Control of Systems

Given a system: $\dot{x} = f(x, u, n)$; $x \in \mathbb{R}^n$, $u \in \Omega \subset \mathbb{R}^p$; $x(0) = x_0$

Find the control u(t) for $t \Rightarrow$ [0,T] such that

Instantaneous (Stage) Cost

Terminal Cost

$$u = \arg \lim_{u \in \Omega} \int_0^T \underbrace{L(x, u)dt}_{} + \underbrace{V(x(T), u(T))}_{}$$

$$\underbrace{\hspace{5cm}}_{J(x, u)}$$

- Can include constraints on control u and state x
  - (along trajectory or at final time):
- Final time *T* may or may not be free (we'll first derive fixed *T* case)

Optimal Control Systems

Jason L. Speyer,David H. Jacobson

Optimal Control Systems:

Nonlinear and Optimal Control Systems Thomas L. Vincent,Walter J. Grantham,1997-06-23 Designed for one semester introductory senior or graduate level course the authors provide the student with an introduction of analysis techniques used in the design of nonlinear and optimal feedback control systems There is special emphasis on the fundamental topics of stability controllability and optimality and on the corresponding geometry associated with these topics Each chapter contains several examples and a variety of exercises **Optimal Control Systems** D. Subbaram Naidu,2018-10-03 The theory of optimal control systems has grown and flourished since the 1960 s Many texts written on varying levels of sophistication have been published on the subject Yet even those purportedly designed for beginners in the field are often riddled with complex theorems and many treatments fail to include topics that are essential to a thorough grounding in the various aspects of and approaches to optimal control Optimal Control Systems provides a comprehensive but accessible treatment of the subject with just the right degree of mathematical rigor to be complete but practical It provides a solid bridge between traditional optimization using the calculus of variations and what is called modern optimal control It also treats both continuous time and discrete time optimal control systems giving students a firm grasp on both methods Among this book s most outstanding features is a summary table that accompanies each topic or problem and includes a statement of the problem with a step by step solution Students will also gain valuable experience in using industry standard MATLAB and SIMULINK software including the Control System and Symbolic Math Toolboxes Diverse applications across fields from power engineering to medicine make a foundation in optimal control systems an essential part of an engineer s background This clear streamlined presentation is ideal for a graduate level course on control systems and as a quick reference for working engineers **Linear Optimal Control Systems** Huibert Kwakernaak,1969 **Industrial Control Systems Design** Michael J. Grimble,2001-03-30 Bridging the gap between research and industry this volume systematically and comprehensively presents the latest advances in control and estimation With emphasis on applications industrial problems illustrate the use of transfer function and state space methods for modelling and design Combining theroy with practice Industrial Control Systems Design will appeal to practising engineers and academic researchers in control engineering This unique reference spans fundamental state space and polynomial systems theory and introduces quantitative feedback theory Includes design case studies with illustrative problem descriptions and analysis from the steel marine process control aerospace and power generation sectors Focuses on the challenges in predictive optimal control now an indispensable method in advanced control applications Provides an introduction to safety critical control systems design and combined fault monitoring and control techniques Discusses the design of LQG and H controllers with several degrees of freedom including feedback tracking and feedforward functions **Optimum Systems Control** Andrew P. Sage,1968 Structurally the text is divided into three areas although overlap certainly exists These are 1 Optimal control with deterministic inputs 2 State

estimation and combined estimation and control and 3 Sensitivity and computational techniques in systems control Preface

Mathematical Theory of Control Systems Design V.N. Afanasiev,V. Kolmanovskii,V.R. Nosov,2013-04-17 Give and it shall be given unto you ST LUKE VI 38 The book is based on several courses of lectures on control theory and appli cations which were delivered by the authors for a number of years at Moscow Electronics and Mathematics University The book originally written in Rus sian was first published by Vysshaya Shkola Higher School Publishing House in Moscow in 1989 In preparing a new edition of the book we planned to make only minor changes in the text However we soon realized that we like many scholars working in control theory had learned many new things and had had many new insights into control theory and its applications since the book was first published Therefore we rewrote the book especially for the English edition So this is substantially a new book with many new topics The book consists of an introduction and four parts Part One deals with the fundamentals of modern stability theory general results concerning stability and instability sufficient conditions for the stability of linear systems methods for determining the stability or instability of systems of various type theorems on stability under random disturbances **Optimal Adaptive Control Systems by David Sworder** ,1966-01-01 In this book we study theoretical and practical aspects of computing methods for mathematical modelling of nonlinear systems A number of computing techniques are considered such as methods of operator approximation with any given accuracy operator interpolation techniques including a non Lagrange interpolation methods of system representation subject to constraints associated with concepts of causality memory and stationarity methods of system representation with an accuracy that is the best within a given class of models methods of covariance matrix estimation methods for low rank matrix approximations hybrid methods based on a combination of iterative procedures and best operator approximation andmethods for information compression and filtering under condition that a filter model should satisfy restrictions associated with causality and different types of memory As a result the book represents a blend of new methods in general computational analysis and specific but also generic techniques for study of systems theory ant its particularbranches such as optimal filtering and information compression Best operator approximation Non Lagrange interpolation Generic Karhunen Loeve transform Generalised low rank matrix approximation Optimal data compression Optimal nonlinear filtering *Optimal Control* Michael Athans,Peter L. Falb,2007-01-01 Geared toward advanced undergraduate and graduate engineering students this text introduces the theory and applications of optimal control It serves as a bridge to the technical literature enabling students to evaluate the implications of theoretical control work and to judge the merits of papers on the subject Rather than presenting an exhaustive treatise Optimal Control offers a detailed introduction that fosters careful thinking and disciplined intuition It develops the basic mathematical background with a coherent formulation of the control problem and discussions of the necessary conditions for optimality based on the maximum principle of Pontryagin In depth examinations cover applications of the theory to minimum time minimum fuel and to quadratic criteria problems The structure properties

and engineering realizations of several optimal feedback control systems also receive attention Special features include numerous specific problems carried through to engineering realization in block diagram form The text treats almost all current examples of control problems that permit analytic solutions and its unified approach makes frequent use of geometric ideas to encourage students intuition   Constrained Optimal Control of Linear and Hybrid Systems Francesco Borrelli,2003-09-04 Many practical control problems are dominated by characteristics such as state input and operational constraints alternations between different operating regimes and the interaction of continuous time and discrete event systems At present no methodology is available to design controllers in a systematic manner for such systems This book introduces a new design theory for controllers for such constrained and switching dynamical systems and leads to algorithms that systematically solve control synthesis problems The first part is a self contained introduction to multiparametric programming which is the main technique used to study and compute state feedback optimal control laws The book s main objective is to derive properties of the state feedback solution as well as to obtain algorithms to compute it efficiently The focus is on constrained linear systems and constrained linear hybrid systems The applicability of the theory is demonstrated through two experimental case studies a mechanical laboratory process and a traction control system developed jointly with the Ford Motor Company in Michigan   **Optimal Sampled-Data Control Systems** Tongwen Chen,Bruce A. Francis,2012-12-06 Among the many techniques for designing linear multivariable analogue controllers the two most popular optimal ones are H2 and H infinity optimization The fact that most new industrial controllers are digital provides strong motivation for adapting or extending these techniques to digital control systems This book now available as a corrected reprint attempts to do so Part I presents two indirect methods of sampled data controller design These approaches include approximations to a real problem which involves an analogue plant continuous time performance specifications and a sampled data controller Part II proposes a direct attack in the continuous time domain where sampled data systems are time varying The findings are presented in forms that can readily be programmed in e g MATLAB   *Linear Systems* Alok Sinha,2007-01-31 Balancing rigorous theory with practical applications Linear Systems Optimal and Robust Control explains the concepts behind linear systems optimal control and robust control and illustrates these concepts with concrete examples and problems Developed as a two course book this self contained text first discusses linear systems incl   **Optimal Control** Zoran Gajic,Myo-Taeg Lim,Dobrila Skataric,Wu-Chung Su,Vojislav Kecman,2018-10-03 Unique in scope Optimal Control Weakly Coupled Systems and Applications provides complete coverage of modern linear bilinear and nonlinear optimal control algorithms for both continuous time and discrete time weakly coupled systems using deterministic as well as stochastic formulations This book presents numerous applications to real world systems from various industries including aerospace and discusses the design of subsystem level optimal filters Organized into independent chapters for easy access to the material this text also contains several case studies examples exercises computer assignments and formulations of

research problems to help instructors and students *Optimal Control* Leonid T. Aschepkov,Dmitriy V. Dolgy,Taekyun Kim,Ravi P. Agarwal,2017-01-11 This book is based on lectures from a one year course at the Far Eastern Federal University Vladivostok Russia as well as on workshops on optimal control offered to students at various mathematical departments at the university level The main themes of the theory of linear and nonlinear systems are considered including the basic problem of establishing the necessary and sufficient conditions of optimal processes In the first part of the course the theory of linear control systems is constructed on the basis of the separation theorem and the concept of a reachability set The authors prove the closure of a reachability set in the class of piecewise continuous controls and the problems of controllability observability identification performance and terminal control are also considered The second part of the course is devoted to nonlinear control systems Using the method of variations and the Lagrange multipliers rule of nonlinear problems the authors prove the Pontryagin maximum principle for problems with mobile ends of trajectories Further exercises and a large number of additional tasks are provided for use as practical training in order for the reader to consolidate the theoretical material Optimal Control and Estimation Robert F. Stengel,1994-09-20 An excellent introduction to optimal control and estimation theory and its relationship with LQG design invaluable as a reference for those already familiar with the subject Automatica This highly regarded graduate level text provides a comprehensive introduction to optimal control theory for stochastic systems emphasizing application of its basic concepts to real problems The first two chapters introduce optimal control and review the mathematics of control and estimation Chapter 3 addresses optimal control of systems that may be nonlinear and time varying but whose inputs and parameters are known without error Chapter 4 of the book presents methods for estimating the dynamic states of a system that is driven by uncertain forces and is observed with random measurement error Chapter 5 discusses the general problem of stochastic optimal control and the concluding chapter covers linear time invariant systems Robert F Stengel is Professor of Mechanical and Aerospace Engineering at Princeton University where he directs the Topical Program on Robotics and Intelligent Systems and the Laboratory for Control and Automation He was a principal designer of the Project Apollo Lunar Module control system An excellent teaching book with many examples and worked problems which would be ideal for self study or for use in the classroom The book also has a practical orientation and would be of considerable use to people applying these techniques in practice Short Book Reviews Publication of the International Statistical Institute An excellent book which guides the reader through most of the important concepts and techniques A useful book for students and their teachers and for those practicing engineers who require a comprehensive reference to the subject Library Reviews The Royal Aeronautical Society *Primer on Optimal Control Theory* Jason L. Speyer,David H. Jacobson,2010-05-13 A rigorous introduction to optimal control theory which will enable engineers and scientists to put the theory into practice **Optimal Networked Control Systems with MATLAB** Jagannathan Sarangapani,Hao Xu,2018-09-03 Optimal Networked Control Systems with MATLAB discusses

optimal controller design in discrete time for networked control systems NCS The authors apply several powerful modern control techniques in discrete time to the design of intelligent controllers for such NCS Detailed derivations rigorous stability proofs computer simulation examples and downloadable MATLAB codes are included for each case The book begins by providing background on NCS networked imperfections dynamical systems stability theory and stochastic optimal adaptive controllers in discrete time for linear and nonlinear systems It lays the foundation for reinforcement learning based optimal adaptive controller use for finite and infinite horizons The text then Introduces quantization effects for linear and nonlinear NCS describing the design of stochastic adaptive controllers for a class of linear and nonlinear systems Presents two player zero sum game theoretic formulation for linear systems in input output form enclosed by a communication network Addresses the stochastic optimal control of nonlinear NCS by using neuro dynamic programming Explores stochastic optimal design for nonlinear two player zero sum games under communication constraints Treats an event sampled distributed NCS to minimize transmission of state and control signals within the feedback loop via the communication network Covers distributed joint optimal network scheduling and control design for wireless NCS as well as the effect of network protocols on the wireless NCS controller design An ideal reference for graduate students university researchers and practicing engineers Optimal Networked Control Systems with MATLAB instills a solid understanding of neural network controllers and how to build them   Optimal Control Systems by AA Fel'Dbaum ,1966-01-01 In this book we study theoretical and practical aspects of computing methods for mathematical modelling of nonlinear systems A number of computing techniques are considered such as methods of operator approximation with any given accuracy operator interpolation techniques including a non Lagrange interpolation methods of system representation subject to constraints associated with concepts of causality memory and stationarity methods of system representation with an accuracy that is the best within a given class of models methods of covariance matrix estimation methods for low rank matrix approximations hybrid methods based on a combination of iterative procedures and best operator approximation andmethods for information compression and filtering under condition that a filter model should satisfy restrictions associated with causality and different types of memory As a result the book represents a blend of new methods in general computational analysis and specific but also generic techniques for study of systems theory ant its particularbranches such as optimal filtering and information compression Best operator approximation Non Lagrange interpolation Generic Karhunen Loeve transform Generalised low rank matrix approximation Optimal data compression Optimal nonlinear filtering   **Control Systems** Jitendra R. Raol,Ramakalyan Ayyagari,2019-07-12 Control Systems Classical Modern and AI Based Approaches provides a broad and comprehensive study of the principles mathematics and applications for those studying basic control in mechanical electrical aerospace and other engineering disciplines The text builds a strong mathematical foundation of control theory of linear nonlinear optimal model predictive robust digital and adaptive control systems and it addresses applications in several emerging areas such as

aircraft electro mechanical and some nonengineering systems DC motor control steel beam thickness control drum boiler motional control system chemical reactor head disk assembly pitch control of an aircraft yaw damper control helicopter control and tidal power control Decentralized control game theoretic control and control of hybrid systems are discussed Also control systems based on artificial neural networks fuzzy logic and genetic algorithms termed as AI based systems are studied and analyzed with applications such as auto landing aircraft industrial process control active suspension system fuzzy gain scheduling PID control and adaptive neuro control Numerical coverage with MATLAB is integrated and numerous examples and exercises are included for each chapter Associated MATLAB code will be made available _Robust and Optimal Control_ Mi-Ching Tsai,Da-Wei Gu,2014-01-07 A Two port Framework for Robust and Optimal Control introduces an alternative approach to robust and optimal controller synthesis procedures for linear time invariant systems based on the two port system widespread in electrical engineering The novel use of the two port system in this context allows straightforward engineering oriented solution finding procedures to be developed requiring no mathematics beyond linear algebra A chain scattering description provides a unified framework for constructing the stabilizing controller set and for synthesizing H2 optimal and H sub optimal controllers Simple yet illustrative examples explain each step A Two port Framework for Robust and Optimal Control features a hands on tutorial style presentation giving the reader the opportunity to repeat the designs presented and easily to modify them for their own programs an abundance of examples illustrating the most important steps in robust and optimal design and end of chapter exercises To further demonstrate the proposed approaches in the last chapter an application case study is presented which demonstrates the use of the framework in a real world control system design and helps the reader quickly move on with their own challenges MATLAB codes used in examples throughout the book and solutions to selected exercise questions are available for download The text will have particular resonance for researchers in control with an electrical engineering background who wish to avoid spending excessive time in learning complex mathematical theoretical developments but need to know how to deal with robust and optimal control synthesis problems Please see http km emotors ncku edu tw class hw1 html for solutions to the exercises provided in this book

Nonlinear Industrial Control Systems Michael J. Grimble,Paweł Majecki,2020-05-19 Nonlinear Industrial Control Systems presents a range of mostly optimisation based methods for severely nonlinear systems it discusses feedforward and feedback control and tracking control systems design The plant models and design algorithms are provided in a MATLAB toolbox that enable both academic examples and industrial application studies to be repeated and evaluated taking into account practical application and implementation problems The text makes nonlinear control theory accessible to readers having only a background in linear systems and concentrates on real applications of nonlinear control It covers different ways of modelling nonlinear systems including state space polynomial based linear parameter varying state dependent and hybrid design techniques for nonlinear optimal control including generalised minimum variance model predictive control

quadratic Gaussian factorised and H design methods design philosophies that are suitable for aerospace automotive marine process control energy systems robotics servo systems and manufacturing steps in design procedures that are illustrated in design studies to define cost functions and cope with problems such as disturbance rejection uncertainties and integral wind up and baseline non optimal control techniques such as nonlinear Smith predictors feedback linearization sliding mode control and nonlinear PID Nonlinear Industrial Control Systems is valuable to engineers in industry dealing with actual nonlinear systems It provides students with a comprehensive range of techniques and examples for solving real nonlinear control design problems

Optimal Control Systems Book Review: Unveiling the Power of Words

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