

A Primer on Pontryagin's Principle in Optimal Control

Minimize $J(x(t), u(t), t_f) = F(x(t_f), t_f) + \int_0^{t_f} f(x(t), u(t), t) dt$

Subject to

$$\dot{x}(t) = f(x(t), u(t), t)$$

$$x(t_0) = x_0$$

$$t_0 = t_0$$

$$c(x_f, t_f) = 0$$

I. MICHAEL ROSS

A Primer On Pontryagins Principle In Optimal Control

Second Edition

**Andreas Arvanitoyeorgos, George
Kaimakamis**

A Primer On Pontryagins Principle In Optimal Control Second Edition:

A Primer on Pontryagin's Principle in Optimal Control I. Michael Ross,2009 This book introduces a student to Pontryagin's Maximum Principle in a tutorial style How to formulate an optimal control problem and how to apply Pontryagin's theory are the main topics Numerous examples are used to discuss pitfalls in problem formulation Figures are used extensively to complement the ideas An entire chapter is dedicated to solved example problems from the classical Brachistochrone problem to modern space vehicle guidance These examples are also used to show how to obtain optimal nonlinear feedback control Students in engineering and mathematics will find this book to be a useful complement to their lecture notes Table of Contents 1 Problem Formulation 1 1 The Brachistochrone Paradigm 1 1 1 Development of a Problem Formulation 1 1 2 Scaling Equations 1 1 3 Alternative Problem Formulations 1 1 4 The Target Set 1 2 A Fundamental Control Problem 1 2 1 Problem Statement 1 2 2 Trajectory Optimization and Feedback Control 2 Pontryagin's Principle 2 1 A Fundamental Control Problem 2 2 Necessary Conditions 2 3 Minimizing the Hamiltonian 2 3 1 Brief History 2 3 2 KKT Conditions for Problem HMC 2 3 3 Time Varying Control Space 3 Example Problems 3 1 The Brachistochrone Problem Redux 3 2 A Linear Quadratic Problem 3 3 A Time Optimal Control Problem 3 4 A Space Guidance Problem 4 Exercise Problems 4 1 One Dimensional Problems 4 1 1 Linear Quadratic Problems 4 1 2 A Control Constrained Problem 4 2 Double Integrator Problems 4 2 1 L1 Optimal Control 4 2 2 Fuller's Problem 4 3 Orbital Maneuvering Problems 4 3 1 Velocity Steering 4 3 2 Max Energy Orbit Transfer 4 3 3 Min Time Orbit Transfer References Index

A Primer on Pontryagin's Principle in Optimal Control I. Michael Ross,2015-03-03 EDITORIAL REVIEW This book provides a guided tour in introducing optimal control theory from a practitioner's point of view As in the first edition Ross takes the contrarian view that it is not necessary to prove Pontryagin's Principle before using it Using the same philosophy the second edition expands the ideas over four chapters In Chapter 1 basic principles related to problem formulation via a structured approach are introduced What is a state variable What is a control variable What is state space And so on In Chapter 2 Pontryagin's Principle is introduced using intuitive ideas from everyday life Like the process of measuring a sandwich and how it relates to costates A vast number of illustrations are used to explain the concepts without going into the minutia of obscure mathematics Mnemonics are introduced to help a beginner remember the collection of conditions that constitute Pontryagin's Principle In Chapter 3 several examples are worked out in detail to illustrate a step by step process in applying Pontryagin's Principle Included in this example is Kalman's linear quadratic optimal control problem In Chapter 4 a large number of problems from applied mathematics to management science are solved to illustrate how Pontryagin's Principle is used across the disciplines Included in this chapter are test problems and solutions The style of the book is easygoing and engaging The classical calculus of variations is an unnecessary prerequisite for understanding optimal control theory Ross uses original references to weave an entertaining historical account of various events Students particularly beginners will embark on a minimum time

trajectory to applying Pontryagin's Principle [Optimal Control of a Double Integrator](#) Arturo Locatelli,2016-07-26 This book provides an introductory yet rigorous treatment of Pontryagin's Maximum Principle and its application to optimal control problems when simple and complex constraints act on state and control variables the two classes of variable in such problems The achievements resulting from first order variational methods are illustrated with reference to a large number of problems that almost universally relate to a particular second order linear and time invariant dynamical system referred to as the double integrator The book is ideal for students who have some knowledge of the basics of system and control theory and possess the calculus background typically taught in undergraduate curricula in engineering Optimal control theory of which the Maximum Principle must be considered a cornerstone has been very popular ever since the late 1950s However the possibly excessive initial enthusiasm engendered by its perceived capability to solve any kind of problem gave way to its equally unjustified rejection when it came to be considered as a purely abstract concept with no real utility In recent years it has been recognized that the truth lies somewhere between these two extremes and optimal control has found its appropriate yet limited place within any curriculum in which system and control theory plays a significant role **Proceedings of the 44th Annual American Astronautical Society Guidance, Navigation, and Control Conference, 2022** Matt

Sandnas,David B. Spencer,2024-03-30 This conference attracts GN C specialists from across the globe The 2022 Conference was the 44th Annual GN C conference with more than 230 attendees from six different countries with 44 companies and 28 universities represented The conference presented more than 100 presentations and 16 posters across 18 topics This year the planning committee wanted to continue a focus on networking and collaboration hoping to inspire innovation through the intersection of diverse ideas These proceedings present the relevant topics of the day while keeping our more popular and well attended sessions as cornerstones from year to year Several new topics including Autonomous Control of Multiple Vehicles and Results and Experiences from OSIRIS REx were directly influenced by advancements in our industry In the end the 44th Annual GN C conference became a timely reflection of the current state of the GN C in the space industry The annual American Astronautical Society Rocky Mountain Guidance Navigation and Control GN C Conference began 1977 as an informal exchange of ideas and reports of achievements among guidance and control specialists local to the Colorado area Bud Gates Don Parsons and Bob Culp organized the first conference and began the annual series of meetings the following winter In March 1978 the First Annual Rocky Mountain Guidance and Control Conference met at Keystone Colorado It met there for eighteen years moving to Breckenridge in 1996 where it has been for over 25 years [The Sequential Quadratic Hamiltonian Method](#) Alfio Borzì,2023-05-26 The sequential quadratic hamiltonian SQH method is a novel numerical optimization procedure for solving optimal control problems governed by differential models It is based on the characterisation of optimal controls in the framework of the Pontryagin maximum principle PMP The SQH method is a powerful computational methodology that is capable of development in many directions The Sequential Quadratic

Hamiltonian Method Solving Optimal Control Problems discusses its analysis and use in solving nonsmooth ODE control problems relaxed ODE control problems stochastic control problems mixed integer control problems PDE control problems inverse PDE problems differential Nash game problems and problems related to residual neural networks This book may serve as a textbook for undergraduate and graduate students and as an introduction for researchers in sciences and engineering who intend to further develop the SQH method or wish to use it as a numerical tool for solving challenging optimal control problems and for investigating the Pontryagin maximum principle on new optimisation problems Features Provides insight into mathematical and computational issues concerning optimal control problems while discussing many differential models of interest in different disciplines Suitable for undergraduate and graduate students and as an introduction for researchers in sciences and engineering Accompanied by codes which allow the reader to apply the SQH method to solve many different optimal control and optimisation problems

Mathematical Modeling for Environmental

Management Sajib Mandal,Md Haider Ali Biswas,Md Sirajul Islam,2025-01-16 This book investigates the potential impacts of global warming and rapid GHG emissions from artificial sources on coastal and marine ecosystems and introduces effective strategies to improve coastal and marine ecosystems by mitigating GHG emissions and concentrations Therefore this book develops four novel mathematical models to investigate the potential impacts on coastal and marine ecosystems and two novel optimal control problems to mitigate the potential impacts and improve coastal and marine ecosystems by reducing GHG emissions and concentrations All models are extensively validated by theoretical analysis and numerical simulations The main objective of this book is to be aware of the adverse effects of rapid GHG emissions and global warming on the environment and all life on earth to reveal how to maintain a healthy environment for all life and to save our beautiful planet from ecological deserts The book discloses applications of mathematical modeling for environmental management in environmental science and applied mathematics It provides new concepts and methods for scientists who study and develop mathematical modeling and environmental science and researchers who apply them to solve real life problems

Optimal Control with Aerospace Applications James M Longuski,José J. Guzmán,John E. Prussing,2013-11-04

Want to know not just what makes rockets go up but how to do it optimally Optimal control theory has become such an important field in aerospace engineering that no graduate student or practicing engineer can afford to be without a working knowledge of it This is the first book that begins from scratch to teach the reader the basic principles of the calculus of variations develop the necessary conditions step by step and introduce the elementary computational techniques of optimal control This book with problems and an online solution manual provides the graduate level reader with enough introductory knowledge so that he or she can not only read the literature and study the next level textbook but can also apply the theory to find optimal solutions in practice No more is needed than the usual background of an undergraduate engineering science or mathematics program namely calculus differential equations and numerical integration Although finding optimal solutions for these problems is a

complex process involving the calculus of variations the authors carefully lay out step by step the most important theorems and concepts Numerous examples are worked to demonstrate how to apply the theories to everything from classical problems e g crossing a river in minimum time to engineering problems e g minimum fuel launch of a satellite Throughout the book use is made of the time optimal launch of a satellite into orbit as an important case study with detailed analysis of two examples launch from the Moon and launch from Earth For launching into the field of optimal solutions look no further

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

Geometry of Submanifolds and Homogeneous Spaces Andreas Arvanitoyeorgos,George Kaimakamis,2020-01-03 The present Special Issue of

Symmetry is devoted to two important areas of global Riemannian geometry namely submanifold theory and the geometry of Lie groups and homogeneous spaces Submanifold theory originated from the classical geometry of curves and surfaces

Homogeneous spaces are manifolds that admit a transitive Lie group action historically related to F Klein's Erlangen

Program and S Lie's idea to use continuous symmetries in studying differential equations In this Special Issue we provide a collection of papers that not only reflect some of the latest advancements in both areas but also highlight relations between them and the use of common techniques Applications to other areas of mathematics are also considered

Fast Solar Sailing Giovanni Vulpetti,2012-08-10 The range of solar sailing is very vast it is a fully in space means of propulsion that should allow us to accomplish various mission classes that are literally impossible using rocket propulsion no matter if nuclear or electric Fast and very fast solar sailings are special classes of sailcraft missions initially developed only in the first half of the 1990s and still evolving especially after the latest advances in nanotechnology This book describes how to plan compute and optimize the trajectories of sailcraft with speeds considerably higher than 100 km/s such sailcraft would be able to explore the outer heliosphere the near interstellar medium and the solar gravitational lens 550 800 astronomical units in times significantly shorter than the span of an average career 35 years just to cite a few examples The scientific interest in this type of exploration is huge

Advanced Trajectory Optimization, Guidance and Control Strategies for Aerospace Vehicles Runqi Chai,Kaiyuan Chen,Lingguo Cui,Senchun Chai,Gokhan Inalhan,Antonios Tsourdos,2023-09-27 This book focuses on the design and application of advanced trajectory optimization and guidance and control G C techniques for aerospace vehicles Part I of the book focuses on the introduction of constrained aerospace vehicle trajectory optimization problems with particular emphasis on the design of high fidelity trajectory optimization methods heuristic optimization based strategies and fast convexification based algorithms In Part II various optimization theory artificial intelligence AI based methods are constructed and presented including dynamic programming based methods model predictive control based methods and deep neural network based algorithms Key aspects of the application of these approaches such as their main advantages and inherent challenges are detailed and discussed Some practical implementation considerations are then

summarized together with a number of future research topics The comprehensive and systematic treatment of practical issues in aerospace trajectory optimization and guidance and control problems is one of the main features of the book which is particularly suitable for readers interested in learning practical solutions in aerospace trajectory optimization and guidance and control The book is useful to researchers engineers and graduate students in the fields of G C systems engineering optimization applied optimal control theory etc [Spaceflight Mechanics 2005](#) David A. Vallado,Michael J. Gabor,Prasun N. Desai,2005

Optimal Control Leslie M. Hocking,1991 Systems that evolve with time occur frequently in nature and modelling the behaviour of such systems provides an important application of mathematics These systems can be completely deterministic but it may be possible too to control their behaviour by intervention through controls The theory of optimal control is concerned with determining such controls which at minimum cost either direct the system along a given trajectory or enable it to reach a given point in its state space This textbook is a straightforward introduction to the theory of optimal control with an emphasis on presenting many different applications Professor Hocking has taken pains to ensure that the theory is developed to display the main themes of the arguments but without using sophisticated mathematical tools Problems in this setting can arise across a wide range of subjects and there are illustrative examples of systems from as diverse fields as dynamics economics population control and medicine Throughout there are many worked examples and numerous exercises with solutions are provided

Optimal Control and Some Applications of Pontryagin's Maximum Principle George Ivan Boyadjieff,1963 [Infinite-Horizon Optimal Control in the Discrete-Time Framework](#) Joël Blot,Naila Hayek,2013-11-08

In this book the authors take a rigorous look at the infinite horizon discrete time optimal control theory from the viewpoint of Pontryagin s principles Several Pontryagin principles are described which govern systems and various criteria which define the notions of optimality along with a detailed analysis of how each Pontryagin principle relate to each other The Pontryagin principle is examined in a stochastic setting and results are given which generalize Pontryagin s principles to multi criteria problems Infinite Horizon Optimal Control in the Discrete Time Framework is aimed toward researchers and PhD students in various scientific fields such as mathematics applied mathematics economics management sustainable development such as of fisheries and of forests and Bio medical sciences who are drawn to infinite horizon discrete time optimal control problems

[A Primer on the Calculus of Variations and Optimal Control Theory](#) Mike Mesterton-Gibbons,2009-01-01 The Brachistochrone The fundamental problem Extremals The insufficiency of extremality Important first integrals The du Bois Reymond equation The corner conditions Legendre s necessary condition Jacobi s necessary condition Weak versus strong variations Weierstrass s necessary condition The transversality conditions Hilbert s invariant integral The fundamental sufficient condition Jacobi s condition revisited Isoperimetrical problems Optimal control problems Necessary conditions for optimality Time optional control A singular control problem A biological control problem Optimal control to a general target Navigational control problems State variable restrictions Optimal harvesting Afterword

Solutions or hints for selected exercises Bibliography Index

U.S. Government Research and Development Reports

,1967 Optimal Control with Engineering Applications Hans P. Geering,2007-03-23 This book introduces a variety of problem statements in classical optimal control in optimal estimation and filtering and in optimal control problems with non scalar valued performance criteria Many example problems are solved completely in the body of the text All chapter end exercises are sketched in the appendix The theoretical part of the book is based on the calculus of variations so the exposition is very transparent and requires little mathematical rigor

Optimal Control Leonid T. Ashchepkov,Dmitriy V.

Dolgy,Taekyun Kim,Ravi P. Agarwal,2022-02-10 This textbook now in its second edition results from lectures practical problems and workshops on Optimal Control given by the authors at Irkutsk State University Far Eastern Federal University both in Vladivostok Russia and Kwangwoon University Seoul South Korea In this work the authors cover the theory of linear and nonlinear systems touching on the basic problem of establishing the necessary and sufficient conditions of optimal processes Readers will find two new chapters with results of potential interest to researchers with a focus on the theory of optimal control as well as to those interested in applications in Engineering and related sciences In addition several improvements have been made through the text This book is structured in three parts Part I starts with a gentle introduction to the basic concepts in Optimal Control In Part II 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 reachability set in the class of piecewise continuous controls and touch on the problems of controllability observability identification performance and terminal control Part III in its turn 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 Problem sets at the end of chapters and a list of additional tasks provided in the appendix are offered for students seeking to master the subject The exercises have been chosen not only as a way to assimilate the theory but also as to induct the application of such knowledge in more advanced problems

An Introduction to Optimal Control Theory

Aaron Strauss,2012-12-06 This paper is intended for the beginner It is not a state of the art paper for research workers in the field of control theory Its purpose is to introduce the reader to some of the problems and results in control theory to illustrate the application of these results and to provide a guide for his further reading on this subject I have tried to motivate the results with examples especially with one canonical simple example described in 3 Many results such as the maximum principle have long and difficult proofs I have omitted these proofs In general I have included only the proofs which are either 1 not too difficult or 2 fairly enlightening as to the nature of the result I have however usually attempted to draw the strongest conclusion from a given proof For example many existing proofs in control theory for compact targets and uniqueness of solutions also hold for closed targets and non uniqueness Finally at the end of each section I have given references to generalizations and origins of the results discussed in that section I make no claim of completeness in the

references however as I have often been content merely to refer the reader either to an exposition or to a paper which has an extensive bibliography IV These lecture notes are revisions of notes I used for a series of nine lectures on control theory at the International Summer School on Mathematical Systems and Economics held in Varenna Italy June 1967

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