

OPTIMAL CONTROL OF SYSTEMS

OPTIMAL CONTROL OF SYSTEMS REPRESENTS A CRITICAL AREA IN ENGINEERING AND APPLIED MATHEMATICS FOCUSED ON DETERMINING CONTROL POLICIES THAT OPTIMIZE THE PERFORMANCE OF DYNAMIC SYSTEMS. THIS FIELD COMBINES ELEMENTS OF SYSTEM THEORY, CALCULUS OF VARIATIONS, AND OPTIMIZATION TO DEVELOP STRATEGIES THAT GUIDE SYSTEMS FROM AN INITIAL STATE TO A DESIRED FINAL STATE WHILE MINIMIZING OR MAXIMIZING A COST FUNCTION. THE APPLICATIONS OF OPTIMAL CONTROL SPAN DIVERSE DOMAINS SUCH AS AEROSPACE, ROBOTICS, ECONOMICS, AND MANUFACTURING, WHERE PRECISION AND EFFICIENCY ARE PARAMOUNT. THIS ARTICLE EXPLORES THE FUNDAMENTAL PRINCIPLES, MATHEMATICAL FORMULATIONS, AND COMPUTATIONAL METHODS INVOLVED IN THE OPTIMAL CONTROL OF SYSTEMS. ADDITIONALLY, IT DISCUSSES PRACTICAL IMPLEMENTATION CHALLENGES AND MODERN ADVANCEMENTS, INCLUDING REAL-TIME CONTROL AND MACHINE LEARNING INTEGRATION. THE FOLLOWING SECTIONS PROVIDE A STRUCTURED OVERVIEW TO FACILITATE A COMPREHENSIVE UNDERSTANDING OF THIS COMPLEX YET VITAL DISCIPLINE.

- FUNDAMENTALS OF OPTIMAL CONTROL OF SYSTEMS
- MATHEMATICAL FORMULATION AND PROBLEM TYPES
- SOLUTION TECHNIQUES AND ALGORITHMS
- APPLICATIONS OF OPTIMAL CONTROL
- CHALLENGES AND FUTURE TRENDS IN OPTIMAL CONTROL

FUNDAMENTALS OF OPTIMAL CONTROL OF SYSTEMS

THE FUNDAMENTALS OF OPTIMAL CONTROL OF SYSTEMS REVOLVE AROUND THE CONCEPTUAL FRAMEWORK THAT MODELS DYNAMIC SYSTEMS AND THE CONTROLS APPLIED TO THEM. A DYNAMIC SYSTEM CAN BE DESCRIBED BY DIFFERENTIAL OR DIFFERENCE EQUATIONS THAT CHARACTERIZE HOW THE SYSTEM STATE EVOLVES OVER TIME UNDER THE INFLUENCE OF CONTROL INPUTS. OPTIMAL CONTROL THEORY SEEKS TO FIND A CONTROL FUNCTION THAT OPTIMIZES A PREDEFINED PERFORMANCE INDEX, OFTEN REFERRED TO AS THE COST OR OBJECTIVE FUNCTIONAL. THIS FUNCTIONAL TYPICALLY INTEGRATES FACTORS SUCH AS ENERGY CONSUMPTION, ERROR MINIMIZATION, OR TIME EFFICIENCY.

KEY CONCEPTS IN OPTIMAL CONTROL

CORE CONCEPTS INCLUDE THE SYSTEM STATE, CONTROL VARIABLES, PERFORMANCE INDEX, CONSTRAINTS, AND THE CONTROL HORIZON. THE STATE REPRESENTS THE SYSTEM'S CURRENT CONDITION, WHILE CONTROLS ARE THE INPUTS INFLUENCING THE SYSTEM'S TRAJECTORY. CONSTRAINTS MAY LIMIT THE RANGE OR RATE OF INPUTS AND STATES, ENSURING PHYSICALLY OR ECONOMICALLY FEASIBLE SOLUTIONS. THE CONTROL HORIZON DEFINES THE TIME INTERVAL OVER WHICH OPTIMIZATION IS PERFORMED, WHICH CAN BE FINITE OR INFINITE.

SYSTEM DYNAMICS AND MODELING

ACCURATE MODELING OF SYSTEM DYNAMICS IS ESSENTIAL FOR EFFECTIVE OPTIMAL CONTROL. THESE MODELS CAN BE LINEAR OR NONLINEAR AND DETERMINISTIC OR STOCHASTIC. LINEAR MODELS SIMPLIFY ANALYSIS AND SOLUTION METHODS BUT MAY NOT CAPTURE COMPLEX REAL-WORLD BEHAVIORS. NONLINEAR MODELS, THOUGH MORE CHALLENGING, PROVIDE MORE ACCURATE REPRESENTATIONS OF ACTUAL SYSTEMS, SUCH AS ROBOTIC ARMS OR CHEMICAL REACTORS.

MATHEMATICAL FORMULATION AND PROBLEM TYPES

THE MATHEMATICAL FORMULATION OF OPTIMAL CONTROL PROBLEMS INVOLVES DEFINING THE SYSTEM DYNAMICS, PERFORMANCE INDEX, AND CONSTRAINTS IN A PRECISE MATHEMATICAL FRAMEWORK. TYPICALLY, THE SYSTEM IS REPRESENTED BY A SET OF DIFFERENTIAL EQUATIONS, AND THE GOAL IS TO FIND A CONTROL INPUT FUNCTION THAT MINIMIZES OR MAXIMIZES THE COST FUNCTIONAL.

STANDARD OPTIMAL CONTROL PROBLEM

THE STANDARD FORMULATION CAN BE EXPRESSED AS FOLLOWS: MINIMIZE THE INTEGRAL COST FUNCTIONAL $J = \int_0^T L(x(t), u(t), t) dt$ SUBJECT TO THE SYSTEM DYNAMICS $\dot{x}(t) = f(x(t), u(t), t)$, INITIAL CONDITIONS, AND CONSTRAINTS ON STATES AND CONTROLS. HERE, $x(t)$ REPRESENTS THE STATE VECTOR, $u(t)$ THE CONTROL VECTOR, L THE RUNNING COST, AND f THE SYSTEM DYNAMICS FUNCTION.

TYPES OF OPTIMAL CONTROL PROBLEMS

OPTIMAL CONTROL PROBLEMS CAN BE CATEGORIZED BASED ON SEVERAL CRITERIA:

- **TIME HORIZON:** FINITE-TIME VERSUS INFINITE-TIME PROBLEMS.
- **SYSTEM DYNAMICS:** LINEAR VERSUS NONLINEAR SYSTEMS.
- **CONTROL CONSTRAINTS:** UNCONSTRAINED VERSUS CONSTRAINED CONTROLS.
- **DETERMINISTIC VERSUS STOCHASTIC:** WHETHER SYSTEM UNCERTAINTIES ARE CONSIDERED.
- **OPEN-LOOP VERSUS CLOSED-LOOP:** PRECOMPUTED CONTROL TRAJECTORIES VERSUS FEEDBACK CONTROL LAWS.

SOLUTION TECHNIQUES AND ALGORITHMS

SOLVING OPTIMAL CONTROL PROBLEMS INVOLVES ANALYTICAL AND NUMERICAL METHODS TAILORED TO THE PROBLEM'S COMPLEXITY. ANALYTICAL SOLUTIONS ARE AVAILABLE FOR SIMPLE LINEAR-QUADRATIC PROBLEMS, WHILE MORE COMPLEX NONLINEAR OR CONSTRAINED PROBLEMS REQUIRE NUMERICAL APPROACHES.

ANALYTICAL METHODS

CLASSICAL METHODS SUCH AS THE PONTRYAGIN'S MAXIMUM PRINCIPLE AND THE HAMILTON-JACOBI-BELLMAN EQUATION PROVIDE NECESSARY AND SUFFICIENT CONDITIONS FOR OPTIMALITY. THESE PRINCIPLES TRANSFORM THE ORIGINAL PROBLEM INTO A BOUNDARY VALUE PROBLEM OR PARTIAL DIFFERENTIAL EQUATION, WHICH CAN SOMETIMES BE SOLVED EXACTLY OR APPROXIMATED.

NUMERICAL METHODS

NUMERICAL TECHNIQUES ARE ESSENTIAL FOR PRACTICAL APPLICATIONS WHERE ANALYTICAL SOLUTIONS ARE NOT FEASIBLE. COMMON METHODS INCLUDE:

1. **DYNAMIC PROGRAMMING:** BREAKS THE PROBLEM INTO SUBPROBLEMS AND SOLVES RECURSIVELY, SUITABLE FOR DISCRETE-TIME SYSTEMS BUT SUFFERS FROM THE "CURSE OF DIMENSIONALITY."

2. **DIRECT METHODS:** CONVERT THE PROBLEM INTO A NONLINEAR PROGRAMMING PROBLEM BY DISCRETIZING THE STATE AND CONTROL TRAJECTORIES.
3. **INDIRECT METHODS:** SOLVE THE NECESSARY OPTIMALITY CONDITIONS DERIVED FROM PONTRYAGIN'S MAXIMUM PRINCIPLE NUMERICALLY.
4. **GRADIENT-BASED OPTIMIZATION:** EMPLOY GRADIENTS OF THE COST FUNCTION TO ITERATIVELY UPDATE CONTROL INPUTS.

APPLICATIONS OF OPTIMAL CONTROL

OPTIMAL CONTROL OF SYSTEMS FINDS EXTENSIVE APPLICATIONS ACROSS VARIOUS INDUSTRIES AND RESEARCH FIELDS. THE ABILITY TO EFFICIENTLY MANAGE COMPLEX DYNAMIC SYSTEMS UNDER CONSTRAINTS MAKES IT INDISPENSABLE IN MODERN TECHNOLOGY.

AEROSPACE AND ROBOTICS

IN AEROSPACE, OPTIMAL CONTROL IS USED FOR TRAJECTORY OPTIMIZATION OF SPACECRAFT AND AIRCRAFT, MINIMIZING FUEL CONSUMPTION AND ENSURING MISSION SUCCESS. ROBOTICS APPLICATIONS INCLUDE MOTION PLANNING AND MANIPULATOR CONTROL TO ACHIEVE PRECISE AND ENERGY-EFFICIENT MOVEMENTS.

ECONOMICS AND FINANCE

OPTIMAL CONTROL MODELS ECONOMIC SYSTEMS FOR RESOURCE ALLOCATION, INVESTMENT STRATEGIES, AND CONSUMPTION PLANNING. IN FINANCE, IT AIDS IN PORTFOLIO OPTIMIZATION AND RISK MANAGEMENT UNDER DYNAMIC MARKET CONDITIONS.

MANUFACTURING AND PROCESS CONTROL

MANUFACTURING SYSTEMS LEVERAGE OPTIMAL CONTROL TO IMPROVE PRODUCTION EFFICIENCY, REDUCE WASTE, AND MAINTAIN QUALITY STANDARDS. PROCESS CONTROL IN CHEMICAL PLANTS USES OPTIMAL CONTROL TO REGULATE TEMPERATURE, PRESSURE, AND CHEMICAL CONCENTRATIONS.

CHALLENGES AND FUTURE TRENDS IN OPTIMAL CONTROL

DESPITE ITS SUCCESSES, OPTIMAL CONTROL OF SYSTEMS FACES SEVERAL CHALLENGES RELATED TO COMPLEXITY, COMPUTATION, AND REAL-WORLD UNCERTAINTIES. ADDRESSING THESE CHALLENGES IS CRUCIAL FOR ADVANCING THE FIELD AND EXPANDING ITS APPLICABILITY.

COMPUTATIONAL COMPLEXITY AND SCALABILITY

HIGH-DIMENSIONAL SYSTEMS AND NONLINEAR DYNAMICS OFTEN RESULT IN COMPUTATIONALLY INTENSIVE PROBLEMS. DEVELOPING SCALABLE ALGORITHMS THAT CAN HANDLE LARGE-SCALE SYSTEMS IN REAL TIME REMAINS A SIGNIFICANT RESEARCH FOCUS.

ROBUSTNESS AND UNCERTAINTY

REAL-WORLD SYSTEMS ARE SUBJECT TO UNCERTAINTIES IN MODELING, MEASUREMENTS, AND EXTERNAL DISTURBANCES. ROBUST

OPTIMAL CONTROL STRATEGIES AIM TO MAINTAIN PERFORMANCE DESPITE THESE UNCERTAINTIES, INCORPORATING STOCHASTIC MODELS AND ADAPTIVE MECHANISMS.

INTEGRATION WITH MACHINE LEARNING

RECENT ADVANCES COMBINE OPTIMAL CONTROL WITH MACHINE LEARNING TO ENHANCE PREDICTIVE CAPABILITIES AND ADAPT CONTROL POLICIES BASED ON DATA-DRIVEN INSIGHTS. REINFORCEMENT LEARNING, IN PARTICULAR, OFFERS PROMISING APPROACHES TO APPROXIMATE OPTIMAL CONTROL LAWS IN COMPLEX ENVIRONMENTS.

FREQUENTLY ASKED QUESTIONS

WHAT IS OPTIMAL CONTROL OF SYSTEMS?

OPTIMAL CONTROL OF SYSTEMS IS A MATHEMATICAL OPTIMIZATION APPROACH TO DESIGNING CONTROL POLICIES THAT RESULT IN THE BEST POSSIBLE SYSTEM PERFORMANCE ACCORDING TO A DEFINED CRITERION, SUCH AS MINIMIZING ENERGY USE OR MAXIMIZING EFFICIENCY.

WHAT ARE THE MAIN METHODS USED IN OPTIMAL CONTROL?

THE MAIN METHODS INCLUDE PONTRYAGIN'S MAXIMUM PRINCIPLE, DYNAMIC PROGRAMMING, LINEAR QUADRATIC REGULATOR (LQR), AND MODEL PREDICTIVE CONTROL (MPC), EACH SUITED TO DIFFERENT TYPES OF SYSTEMS AND CONTROL OBJECTIVES.

HOW DOES MODEL PREDICTIVE CONTROL (MPC) RELATE TO OPTIMAL CONTROL?

MPC IS A TYPE OF OPTIMAL CONTROL STRATEGY THAT SOLVES AN OPTIMIZATION PROBLEM AT EACH TIME STEP TO DETERMINE THE CONTROL ACTION, USING A MODEL OF THE SYSTEM TO PREDICT FUTURE BEHAVIOR AND OPTIMIZE PERFORMANCE OVER A MOVING HORIZON.

WHAT ARE COMMON CHALLENGES IN IMPLEMENTING OPTIMAL CONTROL IN REAL-WORLD SYSTEMS?

CHALLENGES INCLUDE MODEL INACCURACIES, COMPUTATIONAL COMPLEXITY, REAL-TIME CONSTRAINTS, SYSTEM NONLINEARITIES, AND HANDLING UNCERTAINTIES OR DISTURBANCES EFFECTIVELY.

HOW DOES OPTIMAL CONTROL HANDLE SYSTEM CONSTRAINTS?

OPTIMAL CONTROL FRAMEWORKS CAN INCORPORATE CONSTRAINTS ON STATES AND CONTROL INPUTS DIRECTLY INTO THE OPTIMIZATION PROBLEM, ENSURING THAT SOLUTIONS RESPECT PHYSICAL AND OPERATIONAL LIMITS OF THE SYSTEM.

WHAT ROLE DOES THE COST FUNCTION PLAY IN OPTIMAL CONTROL?

THE COST FUNCTION DEFINES THE PERFORMANCE CRITERION TO BE MINIMIZED OR MAXIMIZED, SUCH AS ENERGY CONSUMPTION, TIME, OR DEVIATION FROM A DESIRED TRAJECTORY, GUIDING THE CONTROL STRATEGY TO ACHIEVE OPTIMAL RESULTS.

CAN OPTIMAL CONTROL BE APPLIED TO NONLINEAR SYSTEMS?

YES, OPTIMAL CONTROL CAN BE APPLIED TO NONLINEAR SYSTEMS, BUT THE PROBLEM BECOMES MORE COMPLEX. TECHNIQUES LIKE NONLINEAR MPC, ITERATIVE METHODS, AND APPROXIMATE DYNAMIC PROGRAMMING ARE COMMONLY USED.

WHAT INDUSTRIES BENEFIT MOST FROM OPTIMAL CONTROL OF SYSTEMS?

INDUSTRIES SUCH AS AEROSPACE, AUTOMOTIVE, ROBOTICS, ENERGY MANAGEMENT, MANUFACTURING, AND PROCESS CONTROL EXTENSIVELY BENEFIT FROM OPTIMAL CONTROL TO ENHANCE EFFICIENCY, SAFETY, AND PERFORMANCE.

ADDITIONAL RESOURCES

1. *OPTIMAL CONTROL THEORY: AN INTRODUCTION*

THIS BOOK PROVIDES A COMPREHENSIVE INTRODUCTION TO THE PRINCIPLES AND METHODS OF OPTIMAL CONTROL THEORY. IT COVERS THE FORMULATION OF CONTROL PROBLEMS, THE CALCULUS OF VARIATIONS, AND PONTRYAGIN'S MAXIMUM PRINCIPLE. THE TEXT IS WELL-SUITED FOR GRADUATE STUDENTS AND ENGINEERS LOOKING TO UNDERSTAND THE MATHEMATICAL FOUNDATIONS AND PRACTICAL APPLICATIONS OF OPTIMAL CONTROL.

2. *APPLIED OPTIMAL CONTROL: OPTIMIZATION, ESTIMATION AND CONTROL*

FOCUSED ON PRACTICAL APPLICATIONS, THIS BOOK BRIDGES THEORY AND REAL-WORLD CONTROL PROBLEMS. IT INCLUDES DETAILED DISCUSSIONS ON NUMERICAL METHODS, DYNAMIC PROGRAMMING, AND STOCHASTIC CONTROL. READERS WILL FIND A VARIETY OF EXAMPLES FROM AEROSPACE, ROBOTICS, AND ECONOMICS.

3. *OPTIMAL CONTROL AND ESTIMATION*

THIS TEXT EXPLORES BOTH OPTIMAL CONTROL AND STATE ESTIMATION IN A UNIFIED FRAMEWORK. IT HIGHLIGHTS THE CONNECTIONS BETWEEN CONTROL THEORY AND ESTIMATION TECHNIQUES SUCH AS THE KALMAN FILTER. THE BOOK IS IDEAL FOR THOSE INTERESTED IN CONTROL SYSTEM DESIGN AND SIGNAL PROCESSING.

4. *DYNAMIC PROGRAMMING AND OPTIMAL CONTROL*

A TWO-VOLUME SERIES THAT PRESENTS THE THEORY AND APPLICATIONS OF DYNAMIC PROGRAMMING IN OPTIMAL CONTROL PROBLEMS. IT COVERS DISCRETE AND CONTINUOUS-TIME SYSTEMS, OFFERING RIGOROUS MATHEMATICAL TREATMENT ALONGSIDE PRACTICAL ALGORITHMS. THIS WORK IS ESSENTIAL FOR RESEARCHERS AND PRACTITIONERS WORKING WITH COMPLEX DECISION-MAKING SYSTEMS.

5. *OPTIMAL CONTROL OF NONLINEAR PROCESSES: WITH APPLICATIONS IN DRUGS, CORRUPTION, AND TERROR*

THIS UNIQUE BOOK APPLIES OPTIMAL CONTROL PRINCIPLES TO SOCIETAL AND BIOLOGICAL SYSTEMS. IT ADDRESSES NONLINEAR DYNAMICS AND CONSTRAINTS, DEMONSTRATING HOW CONTROL THEORY CAN MANAGE COMPLEX REAL-WORLD CHALLENGES. THE INTERDISCIPLINARY APPROACH MAKES IT VALUABLE FOR APPLIED MATHEMATICIANS AND SOCIAL SCIENTISTS.

6. *OPTIMAL CONTROL: LINEAR QUADRATIC METHODS*

FOCUSED ON LINEAR SYSTEMS, THIS BOOK DELVES INTO LINEAR QUADRATIC REGULATOR (LQR) THEORY AND ITS APPLICATIONS. IT COVERS RICCATI EQUATIONS, STABILITY ANALYSIS, AND ROBUSTNESS IN CONTROL DESIGN. THE CLEAR PRESENTATION MAKES IT A STAPLE REFERENCE FOR ENGINEERS AND CONTROL THEORISTS.

7. *OPTIMAL CONTROL AND THE CALCULUS OF VARIATIONS*

OFFERING A RIGOROUS MATHEMATICAL APPROACH, THIS TEXT LINKS OPTIMAL CONTROL PROBLEMS WITH THE CALCULUS OF VARIATIONS. IT DISCUSSES EXISTENCE THEOREMS, NECESSARY CONDITIONS, AND NUMERICAL TECHNIQUES. ADVANCED STUDENTS AND RESEARCHERS WILL APPRECIATE ITS IN-DEPTH THEORETICAL INSIGHTS.

8. *NUMERICAL METHODS FOR OPTIMAL CONTROL PROBLEMS*

THIS BOOK FOCUSES ON COMPUTATIONAL TECHNIQUES FOR SOLVING OPTIMAL CONTROL PROBLEMS. IT COVERS DIRECT AND INDIRECT METHODS, DISCRETIZATION STRATEGIES, AND SOFTWARE TOOLS. PRACTITIONERS DEALING WITH COMPLEX MODELS WILL FIND PRACTICAL GUIDANCE FOR IMPLEMENTING OPTIMAL CONTROL ALGORITHMS.

9. *ROBUST AND ADAPTIVE CONTROL: WITH AEROSPACE APPLICATIONS*

WHILE EMPHASIZING ROBUSTNESS AND ADAPTABILITY, THIS BOOK INTEGRATES OPTIMAL CONTROL CONCEPTS TO HANDLE UNCERTAINTIES IN DYNAMIC SYSTEMS. AEROSPACE EXAMPLES ILLUSTRATE THEORETICAL DEVELOPMENTS AND CONTROLLER DESIGN METHODS. IT IS A VITAL RESOURCE FOR ENGINEERS WORKING ON ADVANCED CONTROL SYSTEMS IN UNCERTAIN ENVIRONMENTS.

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optimal control of systems: Linear Optimal Control Systems Huibert Kwakernaak, Raphel 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. --Preface.

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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.

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. . . 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.

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(sub-classes) of general hybrid and switched systems. It contains all mathematical tools necessary for an adequate understanding and using of the sophisticated relaxation techniques. In addition, readers will find many practically oriented optimal control problems related to the new class of dynamic systems. All in all, the book follows engineering and numerical concepts. However, it can also be considered as a mathematical compendium that contains the necessary formal results and important algorithms related to the modern relaxation theory. - Illustrates the use of the relaxation approaches in engineering optimization - Presents application of the relaxation methods in computational schemes for a numerical treatment of the sophisticated hybrid/switched optimal control problems - Offers a rigorous and self-contained mathematical tool for an adequate understanding and practical use of the relaxation techniques - Presents an extension of the relaxation methodology to the new class of applied dynamic systems, namely, to hybrid and switched control systems

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