

## Model Predictive Control Theory Computation And Design

This book contains 112 papers selected from about 250 submissions to the 6th World Congress on Global Optimization (WCGO 2019) which takes place on July 8–10, 2019 at University of Lorraine, Metz, France. The book covers both theoretical and algorithmic optimization, as well as its applications to modeling and solving decision problems in various domains. It is composed of 10 parts, each of them deals with either the theory and/or methods in a branch of optimization such as Continuous optimization, DC Programming, Optimization & Network optimization, Multiobjective programming, Optimization under uncertainty, or models and optimization methods in a specific application area including Data science, Economics & Finance, Energy & Water management, Engineering systems, Logistics, Resource allocation & Production management. The researchers and practitioners working in Nonconvex Optimization and several application areas can find here many inspiring ideas and useful tools & techniques for their works. This book provides an overview of the nonlinear model predictive control (NMPC) concept for application to innovative combustion engines. Readers can use this book to become more expert in advanced combustion engine control and to develop and implement algorithms to solve challenging control tasks in the field. The significance and relevancy for practice is demonstrated by real-world engine and vehicle application examples. The author provides an overview of fundamental engine control systems for emerging control problems, showing how they can be solved with NMPC. The implementation of NMPC involves various development steps, including: • reduced-order modeling of the process; • analysis of system dynamics; • formulation of the optimization problem; • feasible numerical solution of the optimization problem. Readers will see the entire process of these steps, from the fundamentals to several innovative applications. The application examples highlight the actual difficulties and advantages when implementing NMPC applications. Nonlinear Model Predictive Control of Combustion Engines targets engineers and researchers in academia and industry working in the field of engine control. The book is laid out in a structured and easy-to-read manner, supported by code examples in MATLAB®/Simulink®, thus expanding its readership to students and academics who would like to understand the fundamental concepts of NMPC. Advances in Industrial Control reports and encourages the transfer of technology in control engineering. The rapid development of control technology has an impact on all areas of the control discipline. The series offers an opportunity for researchers to present an extended exposition of new work in all aspects of industrial control.

This volume presents some recent and principal developments related to computational intelligence and optimization methods in control. Theoretical aspects and practical applications of control engineering are covered by 14 self-contained contributions. A detailed discussion of future directions and research perspectives designed to add to the reader's understanding of both the challenges faced in control engineering and the insights into the developing of new techniques. With the knowledge obtained, readers are encouraged to use appropriate control method for specific applications.

This book presents general methods for the design of economic model predictive control (EMPC) systems for broad classes of nonlinear systems that address key theoretical and practical considerations including recursive feasibility, closed-loop stability, closed-loop computational efficiency. Specifically, the book proposes: Lyapunov-based EMPC methods for nonlinear systems: two-tier EMPC architectures that are highly computationally efficient; and EMPC schemes handling explicitly uncertainty, time-varying cost function, and multiple-time-scale dynamics. The proposed methods employ a variety of tools ranging from nonlinear systems analysis, through Lyapunov-based control techniques to nonlinear dynamic optimization. The applicability and performance of the proposed methods are demonstrated through a number of chemical process examples. The book presents state-of-the-art methods for the design of economic model predictive control systems for chemical processes. In addition to being mathematically rigorous, these methods accommodate key practical aspects of direct optimization of process economics, time-varying economic cost functions and computational efficiency. Numerous comments and remarks providing fundamental understanding of the merging of process economics and feedback control into a single framework for control engineer can easily tailor the many detailed examples of industrial relevance given within the text to a specific application. The authors present a rich collection of new research topics and references to significant recent work making Economic Model Predictive Control an important source of information and inspiration for academics and graduate students researching the area and for process engineers interested in applying its ideas.

Encyclopedia of Systems and Control

Receding Horizon Control

Reinforcement Learning and Optimal Control

Model Predictive Control

Optimization of Complex Systems: Theory, Models, Algorithms and Applications

Theory, Formulations and Chemical Process Applications

**This book considers large and challenging multistage decision problems, which can be solved in principle by dynamic programming (DP), but their exact solution is computationally intractable. We discuss solution methods that rely on approximations to produce suboptimal policies with adequate performance. These methods are collectively known by several essentially equivalent names: reinforcement learning, approximate dynamic programming, neuro-dynamic programming. They have been at the forefront of research for the last 25 years, and they underlie, among others, the recent impressive successes of self-learning in the context of games such as chess and Go. Our subject has benefited greatly from the interplay of ideas from optimal control and from artificial intelligence, as it relates to reinforcement learning and simulation-based neural network methods. One of the aims of the book is to explore the common boundary between these two fields and to form a bridge that is accessible by workers with background in either field. Another aim is to organize coherently the broad mosaic of methods that have proved successful in practice while having a solid theoretical and/or logical foundation. This may help researchers and practitioners to find their way through the maze of competing ideas that constitute the current state of the art. This book relates to several of our other books: Neuro-Dynamic Programming (Athena Scientific, 1996), Dynamic Programming and Optimal Control (4th edition, Athena Scientific, 2017), Abstract Dynamic Programming (2nd edition, Athena Scientific, 2018), and Nonlinear Programming (Athena Scientific, 2016). However, the mathematical style of this book is somewhat different. While we provide a rigorous, albeit short, mathematical account of the theory of finite and infinite horizon dynamic programming, and some fundamental approximation methods, we rely more on intuitive explanations and less on proof-based insights. Moreover, our mathematical requirements are quite modest: calculus, a minimal use of matrix-vector algebra, and elementary probability (mathematically complicated arguments involving laws of large numbers and stochastic convergence are bypassed in favor of intuitive explanations). The book illustrates the methodology with many examples and illustrations, and uses a gradual expository approach, which proceeds along four directions: (a) From exact DP to approximate DP: We first discuss exact DP algorithms, explain why they may be difficult to implement, and then use them as the basis for approximations. (b) From finite horizon to infinite horizon problems: We first discuss finite horizon exact and approximate DP methodologies, which are intuitive and mathematically simple, and then progress to infinite horizon problems. (c) From deterministic to stochastic models: We often discuss separately deterministic and stochastic problems, since deterministic problems are simpler and offer special advantages for some of our methods. (d) From model-based to model-free implementations: We first discuss model-based implementations, and then we identify schemes that can be appropriately modified to work with a simulator. The book is related and supplemented by the companion research monograph Rollout, Policy Iteration, and Distributed Reinforcement Learning (Athena Scientific, 2020), which focuses more closely on several topics related to rollout, approximate policy iteration, multiagent problems, discrete and Bayesian optimization, and distributed computation, which are either discussed in less detail or not covered at all in the present book. The author's website contains class notes, and a series of videolectures and slides from a 2021 course at ASU, which address a selection of topics from both books.**

In this original book on model predictive control (MPC) for power electronics, the focus is put on high-power applications with multilevel converters operating at switching frequencies well below 1 kHz, such as medium-voltage drives and modular multi-level converters. Consisting of two main parts, the first offers a detailed review of three-phase power electronics, electrical machines, carrier-based pulse width modulation, optimized pulse patterns, state-of-the-art converter control methods and the principle of MPC. The second part is an in-depth treatment of MPC methods that fully exploit the performance potential of high-power converters. These control methods combine the fast control responses of deadbeat control with the optimal steady-state performance of optimized pulse patterns by resolving the antagonism between the two. MPC is expected to evolve into the control method of choice for power electronic systems operating at low pulse numbers with multiple coupled variables and tight operating constraints. Model Predictive Control of High Power Converters and Industrial Drives will enable the reader to learn how to increase the power capability of the converter, lower the current distortions, reduce the filter size, achieve very fast transient responses and ensure the reliable operation within safe operating area constraints. Targeted at power electronic practitioners working on control-related aspects as well as control engineers, the material is intuitively accessible, and the mathematical formulations are augmented by illustrations, simple examples and a book companion website featuring animations. Readers benefit from a concise and comprehensive treatment of MPC for industrial power electronics, enabling them to understand, implement and advance the field of high-performance MPC schemes.

Easy-to-follow Learning structure makes absorption of advanced material as pain-free as possible Introduces complete theories for stability and cost monotonicity for constrained and non-linear systems as well as for linear systems In co-ordination with MATLAB® files available from springeronline.com, exercises and examples give the student more practice in the predictive control and filtering techniques presented

This open access Brief introduces the basic principles of control theory in a concise self-study guide. It complements the classic texts by emphasizing the simple conceptual unity of the subject. A novice can quickly see how and why the different parts fit together. The concepts build slowly and naturally one after another, until the reader soon has a view of the whole. Each concept is illustrated by detailed examples and graphics. The full software code for each example is available, providing the basis for experimenting with various assumptions, learning how to write programs for control analysis, and setting the stage for future research projects. The topics focus on robustness, design trade-offs, and optimality. Most of the book develops classical linear theory. The last part of the book considers robustness with respect to nonlinearity and explicitly nonlinear extensions, as well as advanced topics such as adaptive control and model predictive control. New students, as well as scientists from other backgrounds who want a concise and easy-to-grasp coverage of control theory, will benefit from the emphasis on concepts and broad understanding of the various approaches.

New Directions on Model Predictive Control

Model-Based Predictive Control of Electric Drives

Assessment and Future Directions of Nonlinear Model Predictive Control

From Fundamentals to Applications

Model Predictive Control in the Process Industry

A Practical Approach

*Controlling a system with control and state constraints is one of the most important problems in control theory, but also one of the most challenging. Another important but just as demanding topic is robustness against uncertainties in a controlled system. One of the most successful approaches, both in theory and practice, to control constrained systems is model predictive control (MPC). The basic idea in MPC is to repeatedly solve optimization problems on-line to find an optimal input to the controlled system. In recent years, much effort has been spent to incorporate the robustness problem into this framework. The main part of the thesis revolves around minimax formulations of MPC for uncertain constrained linear discrete-time systems. A minimax strategy in MPC means that worst-case performance with respect to uncertainties is optimized. Unfortunately, many minimax MPC formulations yield intractable optimization problems with exponential complexity. Minimax algorithms for a number of uncertainty models are derived in the thesis. These include systems with bounded external additive disturbances, systems with uncertain gain, and systems described with linear fractional transformations. The central theme in the different algorithms is semidefinite relaxations. This means that the minimax problems are written as uncertain semidefinite programs, and then conservatively approximated using robust optimization theory. The result is an optimization problem with polynomial complexity. The use of semidefinite relaxations enables a framework that allows extensions of the basic algorithms, such as joint minimax control and estimation, and approximation of closed-loop minimax MPC using a convex programming framework. Additional topics include development of an efficient optimization algorithm to solve the resulting semidefinite programs and connections between deterministic minimax MPC and stochastic risk-sensitive control. The remaining part of the thesis is devoted to stability issues in MPC for continuous-time nonlinear unconstrained systems. While stability of MPC for un-constrained linear systems essentially is solved with the linear quadratic controller, no such simple solution exists in the nonlinear case. It is shown how tools from modern nonlinear control theory can be used to synthesize finite horizon MPC controllers with guaranteed stability, and more importantly, how some of the technical assumptions in the literature can be dispensed with by using a slightly more complex controller.*

*For more than 20 years, the so-called field-oriented control is standard for controlled electric drive systems. Until now, the strategies based on this method fulfill completely the requirements of drive technology. However, due to the system characteristics, an arbitrary improvement of the controller properties is not possible. Predictive or precalculating control methods which need no controller cascade are an alternative. Main focus of this work is to examine model-based predictive controllers for their applicability in drive technology. These methods with their high prediction horizon are well-known from classic control theory and in process engineering they are applied with great success. Several strategies are presented, explained and evaluated, whereas, at the same time, the interested reader gets advice for the implementation of these methods. Since model-based predictive control is, until now, not very common in drive technology, this work also includes detailed derivations of the control algorithms.*

*Model Predictive Control is an important technique used in the process control industries. It has developed considerably in the last few years, because it is the most general way of posing the process control problem in the time domain. The Model Predictive Control formulation integrates optimal control, stochastic control, control of processes with dead time, multivariable control and future references. The finite control horizon makes it possible to handle constraints and non linear processes in general which are frequently found in industry. Focusing on implementation issues for Model Predictive Controllers in industry, it fills the gap between the empirical way practitioners use control algorithms and the sometimes abstractly formulated techniques developed by researchers. The text is firmly based on material from lectures given to senior undergraduate and graduate students and articles written by the authors.*

*This book focuses on distributed and economic Model Predictive Control (MPC) with applications in different fields. MPC is one of the most successful advanced control methodologies due to the simplicity of the basic idea (measure the current state, predict and optimize the future behavior of the plant to determine an input signal, and repeat this procedure ad infinitum) and its capability to deal with constrained nonlinear multi-input multi-output systems. While the basic idea is simple, the rigorous analysis of the MPC closed loop can be quite involved. Here, distributed means that either the computation is distributed to meet real-time requirements for (very) large-scale systems or that distributed agents act autonomously while being coupled via the constraints and/or the control objective. In the latter case, communication is necessary to maintain feasibility or to recover system-wide optimal performance. The term economic refers to general control tasks and, thus, goes beyond the typically predominant control objective of set-point stabilization. Here, recently developed concepts like (strict) dissipativity of optimal control problems or turnpike properties play a crucial role. The book collects research and survey articles on recent ideas and it provides perspectives on current trends in nonlinear model predictive control. Indeed, the book is the outcome of a series of six workshops funded by the German Research Foundation (DFG) involving early-stage career scientists from different countries and from leading European industry stakeholders.*

MPC for MATLAB® and Simulink® Users

Model Predictive Control of High Power Converters and Industrial Drives

Recent Advances in Model Predictive Control

Control Theory Tutorial

Explicit Nonlinear Model Predictive Control

Computational Intelligence and Optimization Methods for Control Engineering

**The Encyclopedia of Systems and Control collects a broad range of short expository articles that describe the current state of the art in the central topics of control and systems engineering as well as in many of the related fields in which control is an enabling technology. The editors have assembled the most comprehensive reference possible, and this has been greatly facilitated by the publisher's commitment continuously to publish updates to the articles as they become available in the future. Although control engineering is now a mature discipline, it remains an area in which there is a great deal of research activity, and as new developments in both theory and applications become available, they will be included in the online version of the encyclopedia. A carefully chosen team of leading authorities in the field has written the well over 250 articles that comprise the work. The topics range from basic principles of feedback in servomechanisms to advanced topics such as the control of Boolean networks and evolutionary game theory. Because the content has been selected to reflect both foundational importance as well as subjects that are of current interest to the research and practitioner communities, a broad readership that includes students, application engineers, and research scientists will find material that is of interest.**

**A comprehensive examination of DMPC theory and its technological applications • A comprehensive examination of DMPC theory and its technological applications from basic through to advanced level • A systematic introduction to DMPC technology providing classic DMPC coordination strategies, analysis of their performance, and design methods for both unconstrained and constraint systems • Includes the system partition methods, coordination strategies, the performance analysis and how to design stabilized DMPC under different coordination strategies • Presents useful theories and technologies which can be used in many different industrial fields, such as the metallurgical process and high speed transport, helping readers to grasp the procedure of using the DMPC • Reflects the authors' combined research in the area, providing a wealth of and current and background information**

**For the first time, a textbook that brings together classical predictive control with treatment of up-to-date robust and stochastic techniques. Model Predictive Control describes the development of tractable algorithms for uncertain, stochastic, constrained systems. The starting point is classical predictive control and the appropriate formulation of performance objectives and constraints to provide guarantees of closed-loop stability and performance. Moving on to robust predictive control, the text explains how similar guarantees may be obtained for cases in which the model describing the system dynamics is subject to additive disturbances and parametric uncertainties. Open- and closed-loop optimization are considered and the state of the art in computationally tractable methods based on uncertainty tubes presented for systems with additive model uncertainty. Finally, the tube framework is also applied to model predictive control problems involving hard or probabilistic constraints for the cases of multiplicative and stochastic model uncertainty. The book provides: extensive use of illustrative examples; sample problems; and discussion of novel control applications such as resource allocation for sustainable development and turbine-blade control for maximized power capture with simultaneously reduced risk of turbulence-induced damage. Graduate students pursuing courses in model predictive control or more generally in advanced or process control and senior undergraduates in need of a specialized treatment will find Model Predictive Control an invaluable guide to the state of the art in this important subject. For the instructor it provides an authoritative resource for the construction of courses.**

**This book is a printed edition of the Special Issue "New Directions on Model Predictive Control" that was published in Mathematics**

**Nonlinear Model Predictive Control of Combustion Engines**

**Towards New Challenging Applications**

**Concepts, Algorithms, and Applications to Chemical Processes**

**Lessons from AlphaZero for Optimal, Model Predictive, and Adaptive Control**

**Economic Model Predictive Control Theory: Computational Efficiency and Application to Smart Manufacturing**

**Economic Model Predictive Control**

The chemical industry is a vital sector of the US economy. Maintaining optimal chemical process operation is critical to the future success of the US chemical industry on a global market. Traditionally, economic optimization of chemical processes has been an architecture. In the upper layer, real-time optimization carries out economic process optimization by computing optimal process operation set-points using detailed nonlinear steady-state process models. These set-points are used by the lower layer feedback control to operate on these set-points. While this paradigm has been successful, we are witnessing an increasing need for dynamic market and demand-driven operations for more efficient process operation, increasing response capability to changing customer demand management. To enable next-generation market-driven operation, economic model predictive control (EMPC), which is an model predictive control scheme formulated with a stage cost that represents the process economics, has been proposed to integrate the upper and lower layers. Motivated by these considerations, novel theory and methods needed for the design of computationally tractable economic model predictive control systems for nonlinear processes are developed in this dissertation. Specifically, we address: a) EMPC structures for nonlinear systems which address: infinite-time and finite-time closed-loop economic performance and time-varying economic considerations such as changing energy pricing; b) two-layer (hierarchical) dynamic economic process control frameworks that incorporate EMPC with other control strategies allowing for computational efficiency; and c) EMPC schemes that account for real-time computation requirements. The EMPC schemes and methodologies are applied to chemical processes.

studies demonstrate the effectiveness of the EMPC schemes to maintain process stability and improve economic performance under dynamic operation as well as to increase efficiency, reliability and profitability of processes, thereby contributing to the vision of Practical Design and Application of Model Predictive Control is a self-learning resource on how to design, tune and deploy an MPC using MATLAB® and Simulink®. This reference is one of the most detailed publications on how to design and tune MPC control from double-Mass spring system, ship heading and speed control, robustness analysis through Monte-Carlo simulations, photovoltaic optimal control, and energy management of power-split and air-handling control. Readers will also learn how to embed the control platform such as Arduino®. The selected problems are nonlinear and challenging, and thus serve as an excellent experimental, dynamic system to show the reader the capability of MPC. The step-by-step solutions of the problems are thoroughly documented with the results. Furthermore, the MATLAB® and Simulink® codes for the solutions are available for free download. Readers can connect with the authors through the dedicated website which includes additional free resources at [www.practicalmpc.com](http://www.practicalmpc.com). Illustrates MPC for projects in a quick manner Demonstrates a variety of applications that are solved using MATLAB® and Simulink® Bridges the gap in providing a number of realistic problems with very hands-on training Provides MATLAB® and Simulink® code solution models that the reader can use for other projects and research work Presents application problems with solutions to help reinforce the information learned

The purpose of this book is to propose and develop a new conceptual framework for approximate Dynamic Programming (DP) and Reinforcement Learning (RL). This framework centers around two algorithms, which are designed largely independently of each other through the powerful mechanism of Newton's method. We call these the off-line training and the on-line play algorithms: the names are borrowed from some of the major successes of RL involving games. Primary examples are the recent (2017) AlphaZero program, which is similarly structured and earlier (1990s) TD-Gammon program (which plays backgammon). In these game contexts, the off-line training algorithm is the method used to teach the program how to evaluate positions and to generate good moves at any given position. The on-line play is the method used to play in real time against human or computer opponents. Both AlphaZero and TD-Gammon were trained off-line extensively using neural networks and an approximate version of the fundamental DP algorithm of policy iteration. Yet the AlphaZero off-line is not used directly during on-line play (it is too inaccurate due to approximation errors that are inherent in off-line neural network training). Instead a separate on-line player is used to select moves, based on multistep lookahead minimization and a trained using experience with the off-line player. The on-line player performs a form of policy improvement, which is not degraded by neural network approximations. As a result, it greatly improves the performance of the off-line player. Similarly, TD-Gammon performs a policy improvement step using one-step or two-step lookahead minimization, which is not degraded by neural network approximations. To this end it uses an off-line neural network-trained terminal position evaluator, and importantly it also extends its on-line lookahead player that is based on the position evaluator). Significantly, the synergy between off-line training and on-line play also underlies Model Predictive Control (MPC), a major control system design methodology that has been extensively developed and understood in terms of abstract models of infinite horizon DP and simple geometrical constructions, and helps to explain the all-important stability issues within the MPC context. An additional benefit of policy improvement by approximation in value space (which have stable rules and environment), is that it works well with changing problem parameters and on-line replanning, similar to indirect adaptive control. Here the Bellman equation is perturbed due to the parameter changes, but approximation in value space is an essential requirement here is that a system model is estimated on-line through some identification method, and is used during the one-step or multistep lookahead minimization process. In this monograph we aim to provide insights (often based on visual effects of on-line decision making on top of off-line training. In the process, we will bring out the strong connections between the artificial intelligence view of RL, and the control theory views of MPC and adaptive control. Moreover, we will show that in an appropriate conceptual framework can be effectively integrated with other important methodologies such as multiagent systems and decentralized control, discrete and Bayesian optimization, and heuristic algorithms for discrete optimization. One of our principal aims is to extend Newton's method and the unifying principles of abstract DP, that the AlphaZero/TD-Gammon methodology of approximation in value space and rollout applies very broadly to deterministic and stochastic optimal control problems. Newton's method here is the equation, an operator equation that applies universally within DP with both discrete and continuous state and control spaces, as well as finite and infinite horizon.

Model Predictive Control Theory, Computation, and Design  
 Model Predictive Control Theory and Design  
 Nonlinear Model Predictive Control Theory and Algorithms  
 Handbook on Planning, Design, Development, and Regulation  
 Theory and Algorithms  
 Networked Control Systems  
 Model Predictive Control for State Models  
 Model-Based Predictive Control

The past three decades have seen rapid development in the area of model predictive control with respect to both theoretical and application aspects. Over these 30 years, model predictive control for linear systems has been widely applied, especially in the area of process control. However, today's applications often require driving the process over a wide region and close to the boundaries of operability, while satisfying constraints and achieving near-optimal performance. Consequently, the application of linear control methods does not always lead to satisfactory performance, and here nonlinear methods must be employed. This is one of the reasons why nonlinear model predictive control (NMPC) has enjoyed significant attention over the past years, with a number of recent advances on both the theoretical and application frontier. Additionally, the widespread availability and steadily increasing power of today's computers, as well as the development of specially tailored numerical solution methods for NMPC, bring the practical applicability of NMPC within reach even for very fast systems. This has led to a series of new, exciting developments, along with new challenges in the area of NMPC. Nonlinear Model Predictive Control (NMPC) has become the accepted methodology to solve complex control problems related to process industries. The main motivation behind explicit NMPC is that an explicit state feedback law avoids the need for executing a numerical optimization algorithm in real time. The benefits of an explicit solution, in addition to the efficient on-line computations, include also verifiability of the implementation and the possibility to design embedded control systems with low software and hardware complexity. This book considers the multi-parametric Nonlinear Programming (mp-NLP) approaches to explicit approximate NMPC of constrained nonlinear systems, developed by the authors, as well as their applications to various NMPC problem formulations and several case studies. The following types of nonlinear systems are considered, resulting in different NMPC problem formulations: Nonlinear systems described by first-principles models and nonlinear systems described by black-box models; Nonlinear systems with continuous control inputs and nonlinear systems with quantized control inputs; Nonlinear systems without uncertainty and nonlinear systems with uncertainties (polyhedral description of uncertainty and stochastic description of uncertainty); Nonlinear systems, consisting of interconnected nonlinear sub-systems. The proposed mp-NLP approaches are illustrated with applications to several case studies, which are taken from diverse areas such as automotive mechatronics, compressor control, combustion plant control, reactor control, pH maintaining system control, cart and spring system control, and diving computers.

This brief addresses the design of model predictive control algorithms for performing space rendezvous manoeuvres. It consolidates developments within guidance and control algorithms, with the aim of improving the efficiency, safety, and autonomy of these manoeuvres. The brief presents several applications of model predictive control to rendezvous manoeuvres, including Ankersen zero-order-hold particular solution1, which provides a realistic thrust profile. It offers new approaches for rendezvous manoeuvres in elliptical orbits, formulating obstacle avoidance constraints, passive safety constraints, and robustness techniques. It also compares finite-horizon and variable-horizon formulations for model predictive control in the context of performance and computational complexity. Predictive Control for Spacecraft Rendezvous is accessible to academics and students new to the topics of orbital rendezvous and model predictive control, but also presents compelling subject matter for researchers and professionals in the aerospace industry.

The rapid evolution of computer science, communication, and information technology has enabled the application of control techniques to systems beyond the possibilities of control theory just a decade ago. Critical infrastructures such as electricity, water, traffic and intermodal transport networks are now in the scope of control engineers. The sheer size of such large-scale systems requires the adoption of advanced distributed control approaches. Distributed model predictive control (MPC) is one of the promising control methodologies for control of such systems. This book provides a state-of-the-art overview of distributed MPC approaches, while at the same time making clear directions of research that deserve more attention. The core and rationale of 35 approaches are carefully explained. Moreover, detailed step-by-step algorithmic descriptions of each approach are provided. These features make the book a comprehensive guide both for those seeking an introduction to distributed MPC as well as for those who want to gain a deeper insight in the wide range of distributed MPC techniques available.

Basic Concepts Illustrated by Software Examples  
 Theory, Computation, and Design  
 Distributed Model Predictive Control for Plant-Wide Systems  
 Model Predictive Control System Design and Implementation Using MATLAB®  
 Practical Design and Application of Model Predictive Control  
 Process Control

Solving Urban Infrastructure Problems Using Smart City Technologies is the most complete guide for integrating next generation smart city technologies into the very foundation of urban areas worldwide, showing how to make urban areas more efficient, more sustainable, and safer. Smart cities are complex systems of systems that encompass all aspects of modern urban life. A key component of their success is creating an ecosystem of smart infrastructures that can work together to enable dynamic, real-time interactions between urban subsystems such as transportation, energy, healthcare, housing, food, entertainment, work, social interactions, and governance. Solving Urban Infrastructure Problems Using Smart City Technologies is a complete reference for building a holistic, system-level perspective on smart and sustainable cities, leveraging big data analytics and strategies for planning, zoning, and public policy. It offers in-depth coverage and practical solutions for how smart cities can utilize resident's intellectual and social capital, press environmental sustainability, increase personalization, mobility, and higher quality of life. Brings together experts from academia, government and industry to offer state-of-the-art solutions for urban system problems, showing how smart technologies can be used to improve the lives of the billions of people living in cities across the globe Demonstrates practical implementation solutions through real-life case studies Enhances reader comprehension with learning aid such as hands-on exercises, questions and answers, checklists, chapter summaries, chapter review questions, exercise problems, and more

With a simple approach that includes real-time applications and algorithms, this book covers the theory of model predictive control (MPC).

"In the research Model Predictive Control on Open Water Systems, the relatively new control methodology Model Predictive Control is configured for application of water quantity control on open water systems, especially on irrigation canals and large drainage systems. The methodology applies an internal model of the open water system, by which optimal control actions are calculated over a prediction horizon. As internal model, two simplified models are used, the Integrator Delay model and the Saint Venant model. Kalman filtering is applied to initialize the internal models. The optimization uses an objective function in which conflicting objectives can be weighed. In most of the cases, these conflicting objectives are keeping the water levels at different locations in the water system within a range around setpoint and executing this by using as little control effort or energy as possible. To tune the weight factors in the objective function, an estimate of the maximum allowed value of each variable in the objective function is used. The optimization takes the constraints of the control structures into account. Every control time step, the optimal control actions are calculated, while only the first set of control actions is actually executed. This results in a controlled water system that is constantly maintaining the objective in an optimal way, while taking predictions, such as expected irrigation demands or extreme storm events and the constraints of the water system into account."

This reference book can be read at different levels, making it a powerful source of information. It presents most of the aspects of control that can help anyone to have a synthetic view of control theory and possible applications, especially concerning process engineering.

Model Predictive Control on Open Water Systems  
 Theory and Applications  
 Nonlinear Model Predictive Control  
 Theory, Algorithms, and Applications  
 Predictive Control for Linear and Hybrid Systems

**Over the past few years significant progress has been achieved in the field of nonlinear model predictive control (NMPC), also referred to as receding horizon control or moving horizon control. More than 250 papers have been published in 2006 in ISI Journals. With this book we want to bring together the contributions of a diverse group of internationally well recognized researchers and industrial practitioners, to critically assess the current status of the NMPC field and to discuss future directions and needs. The book consists of selected papers presented at the International Workshop on Assessment and Future Directions of Nonlinear Model Predictive Control that took place from September 5 to 9, 2008, in Pavia, Italy.**

**The second edition of "Model Predictive Control" provides a thorough introduction to theoretical and practical aspects of the most commonly used MPC strategies. It bridges the gap between the powerful but often abstract techniques of control researchers and the more empirical approach of practitioners. The book demonstrates that a powerful technique does not always require complex control algorithms. Many new exercises and examples have also been added throughout. Solutions available for download from the authors' website save the tutor time and enable the student to follow results more closely even when the tutor isn't present.**

**Model Predictive Control (MPC) has become a widely used methodology across all engineering disciplines, yet there are few books which study this approach. Until now, no book has addressed in detail all key issues in the field including a priori stability and robust stability results. Engineers and MPC researchers now have a volume that provides a complete overview of the theory and practice of MPC as it relates to process and control engineering. Model-Based Predictive Control, A Practical Approach, analyzes predictive control from its base mathematical foundation, but delivers the subject matter in a readable, intuitive style. The author writes in layman's terms, avoiding jargon and using a style that relies upon personal insight into practical applications. This detailed introduction to predictive control introduces basic MPC concepts and demonstrates how they are applied in the design and control of systems, experiments, and industrial processes. The text outlines how to model, provide robustness, handle constraints, ensure feasibility, and guarantee stability. It also details options in regard to algorithms, models, and complexity vs. performance issues.**

**Recent developments in model-predictive control promise remarkable opportunities for designing multi-input, multi-output control systems and improving the control of single-input, single-output systems. This volume provides a definitive survey of the latest model-predictive control methods available to engineers and scientists today. The initial set of chapters present various methods for managing uncertainty in systems, including stochastic model-predictive control. With the advent of affordable and fast computation, control engineers now need to think about using "computationally intensive controls," so the second part of this book addresses the solution of optimization problems in "real" time for model-predictive control. The theory and applications of control theory often influence each other, so the last section of Handbook of Model Predictive Control rounds out the book with representative applications to automobiles, healthcare, robotics, and finance. The chapters in this volume will be useful to working engineers, scientists, and mathematicians, as well as students and faculty interested in the progression of control theory. Future developments in MPC will no doubt build from concepts demonstrated in this book and anyone with an interest in MPC will find fruitful information and suggestions for additional reading.**

**Classical, Robust and Stochastic**

**Non-linear Predictive Control**

**Theory and Practice**

**Minimax Approaches to Robust Model Predictive Control**

**Solving Urban Infrastructure Problems Using Smart City Technologies**

**Theory and Design**

This book finds its origin in the WIDE PhD School on Networked Control Systems, which we organized in July 2009 in Siena, Italy. Having gathered experts on all the aspects of networked control systems, it was a small step to go from the summer school to the book, certainly given the enthusiasm of the lecturers at the school. We felt that a book collecting overview on the important developments and open problems in the field of networked control systems could stimulate and support future research in this appealing area. Given the tremendous current interests in distributed control exploiting wired and wireless communication networks, the time seemed to be right for the book that lies now in front of you. The goal of the book is to set out the core techniques and tools that are available for the modeling, analysis and design of networked control systems. Roughly speaking, the book consists of three parts. The first part presents architectures for distributed control systems and models of wired and wireless communication networks. In particular, in the first chapter important technological and architectural aspects on distributed control systems are discussed. The second chapter provides insight in the behavior of communication channels in terms of delays, packet loss and information constraints leading to suitable modeling paradigms for communication networks.

The advantage of model predictive control is that it can take systematic account of constraints, thereby allowing processes to operate at the limits of achievable performance. Engineers in academia, industry, and government from the US and Europe explain how the linear version can be adapted and applied to the nonlinear conditions that characterize the dynamics of most real manufacturing plants. They survey theoretical and practical trends, describe some specific theories and demonstrate their practical application, derive strategies that provide appropriate assurance of closed-loop stability, and discuss practical implementation. Annotation copyrighted by Book News, Inc., Portland, OR

This book offers readers a thorough and rigorous introduction to nonlinear model predictive control (NMPC) for discrete-time and sampled-data systems. NMPC schemes with and without stabilizing terminal constraints are detailed, and intuitive examples illustrate the performance of different NMPC variants. NMPC is interpreted as an approximation of infinite-horizon optimal control so that important properties like closed-loop stability, inverse optimality and suboptimality can be derived in a uniform manner. These results are complemented by discussions of feasibility and robustness. An introduction to nonlinear optimal control algorithms yields essential insights into how the nonlinear optimization routine—the core of any nonlinear model predictive controller—works. Accompanying software in MATLAB® and C++ (downloadable from [extras.springer.com/](http://extras.springer.com/)), together with an explanatory appendix in the book itself, enables readers to perform computer experiments exploring the possibilities and limitations of NMPC. The second edition has been substantially rewritten, edited and updated to reflect the significant advances that have been made since the publication of its predecessor, including: • a new chapter on economic NMPC relaxing the assumption that the running cost penalizes the distance to a pre-defined equilibrium; • a new chapter on distributed NMPC discussing methods which facilitate the control of large-scale systems by splitting up the optimization into smaller subproblems; • an extended discussion of stability and performance using approximate updates rather than full optimization; • replacement of the pivotal sufficient condition for stability without stabilizing terminal conditions with a weaker alternative and inclusion of an alternative and much simpler proof in the analysis; and • further variations and extensions in response to suggestions from readers of the first edition. Though primarily aimed at academic researchers and practitioners working in control and optimization, the text is self-contained, featuring background material on infinite-horizon optimal control and Lyapunov stability theory that also makes it accessible for graduate students in control engineering and applied mathematics.

Model Predictive Control System Design and Implementation Using MATLAB® proposes methods for design and implementation of MPC systems using basis functions that confer the following advantages: - continuous- and discrete-time MPC problems solved in similar design frameworks; - a parsimonious parametric representation of the control trajectory gives rise to computationally efficient algorithms and better on-line performance; and - a more general discrete-time representation of MPC design that becomes identical to the traditional approach for an appropriate choice of parameters. After the theoretical presentation, coverage is given to three industrial applications. The subject of quadratic programming, often associated with the core optimization algorithms of MPC is also introduced and explained. The technical contents of this book is mainly based on advances in MPC using state-space models and basis functions. This volume includes numerous analytical examples and problems and MATLAB® programs and exercises.

Handbook of Model Predictive Control  
 Distributed Model Predictive Control Made Easy  
 Predictive Control for Spacecraft Rendezvous

This book addresses modern nonlinear programming (NLP) concepts and algorithms, especially as they apply to challenging applications in chemical process engineering. The author provides a firm grounding in fundamental NLP properties and algorithms, and relates them to real-world problem classes in process optimization, thus making the material understandable and useful to chemical engineers and experts in mathematical optimization.