

model predictive control theory and design

Model Predictive Control Theory and Design: A Deep Dive into Advanced Control Strategies

model predictive control theory and design provide one of the most powerful and versatile frameworks in modern control engineering. Whether you're working with chemical processes, robotics, automotive systems, or energy management, understanding the principles behind model predictive control (MPC) can open doors to optimized performance and enhanced system stability. This article aims to unravel the fundamentals of MPC theory, explore its design intricacies, and shed light on practical aspects that engineers and researchers alike will find useful.

Understanding the Foundations of Model Predictive Control Theory and Design

At its core, model predictive control is a type of control algorithm that uses a dynamic model of the system to predict its future behavior. Unlike traditional PID controllers that react solely to current errors, MPC anticipates future events by solving an optimization problem over a finite time horizon. This predictive capability is what makes MPC particularly suited for complex, multivariable systems with constraints.

What Makes MPC Different from Traditional Control Methods?

Traditional controllers like PID focus on error correction based on present and past states. In contrast, MPC leverages a model — typically a state-space or transfer function representation — to forecast future outputs. By optimizing control moves ahead of time, MPC can handle multiple inputs and outputs simultaneously, deal with system constraints explicitly, and improve overall robustness.

Here are some key advantages that arise from the theory behind MPC:

- **Multivariable control:** MPC can manage systems with several interacting variables.
- **Constraint handling:** Both input and output constraints are naturally incorporated.
- **Predictive optimization:** Control actions are optimized over a future horizon.
- **Flexibility:** It adapts easily to nonlinearities or time-varying dynamics when extended accordingly.

Core Components of Model Predictive Control Design

Designing an effective MPC controller involves several important steps, each crucial to ensuring the controller meets performance expectations.

1. System Modeling

The accuracy of the predictive model is paramount. Common models used in MPC design include linear state-space models, ARX (Auto-Regressive with Exogenous inputs), and nonlinear models when necessary. The model serves as the foundation for prediction and optimization.

2. Prediction Horizon and Control Horizon

The prediction horizon defines how far into the future the controller forecasts system outputs. A longer horizon may improve performance but increases computational complexity. The control horizon limits the number of control moves optimized at each step, often shorter than the prediction horizon to reduce computational load while maintaining control effectiveness.

3. Objective Function and Constraints

MPC solves an optimization problem at every control interval, minimizing a cost function that usually balances tracking performance and control effort. Constraints on inputs (such as actuator limits), outputs (safety or quality requirements), and rates of change are explicitly included, making MPC ideal for real-world systems with strict operational limits.

4. Optimization Algorithm

The choice of optimization solver is critical. Quadratic programming (QP) is commonly used for linear MPC problems due to its efficiency. For nonlinear MPC (NMPC), nonlinear programming solvers come into play, but at the cost of higher computational demands.

How Model Predictive Control Theory Addresses Practical Challenges

MPC's unique ability to handle constraints and multi-variable interactions makes it a go-to solution for many industrial applications. Let's explore some practical insights connected to its deployment.

Robustness to Disturbances and Model Mismatch

One challenge in MPC is ensuring the controller remains effective when the system deviates from the model assumptions. Robust MPC variants incorporate uncertainty bounds into the design, either by tightening constraints or by embedding disturbance models directly into the predictive framework. This approach reduces sensitivity to noise and unmodeled dynamics.

Computational Considerations

Since MPC requires solving an optimization problem at each sampling instant, computational efficiency is critical. Advances in hardware and algorithmic methods, such as explicit MPC – where solutions are precomputed offline – have made it feasible to implement MPC in fast, real-time scenarios like automotive control or robotics.

Integration with Other Control Strategies

Often, MPC is combined with other control methods to leverage their strengths. For example, a PID controller might handle low-level, fast dynamics, while MPC manages higher-level planning and constraint handling. Hybrid control architectures can enhance overall system performance and robustness.

Exploring Advanced Topics in Model Predictive Control Theory and Design

As MPC continues to evolve, researchers and practitioners are pushing the boundaries of its capabilities.

Nonlinear Model Predictive Control (NMPC)

For systems exhibiting significant nonlinearities, NMPC extends the predictive control approach by using nonlinear models and solvers. This branch of MPC is particularly relevant in chemical reactors, aerospace applications, and autonomous vehicles, where linear approximations are insufficient.

Economic Model Predictive Control

Traditional MPC focuses on tracking setpoints, but economic MPC integrates cost-related objectives directly into the control problem. This approach optimizes operational expenses, energy consumption, or production efficiency, making it attractive for process industries and smart grids.

Learning-Based and Data-Driven MPC

With the surge in machine learning, data-driven MPC methods are gaining traction. Instead of relying solely on first-principles models, these methods incorporate real-time data to update models or even replace them with learned representations. This trend enhances adaptability in complex or poorly understood systems.

Tips for Successful Model Predictive Control Implementation

If you're planning to design and implement an MPC controller, here are several practical tips to keep in mind:

- **Start with a reliable system model:** Invest time in system identification or modeling; the controller's performance hinges on it.
- **Choose horizons wisely:** Balance prediction and control horizons to manage performance and computational load.
- **Incorporate realistic constraints:** Define input and output limits that reflect actual system capabilities to avoid infeasible solutions.

- **Test under different scenarios:** Simulate disturbances, setpoint changes, and model uncertainties to verify robustness.
- **Leverage available software tools:** Platforms like MATLAB's MPC Toolbox or open-source alternatives can accelerate design and tuning.

The Growing Importance of Model Predictive Control Theory and Design in Industry

The adoption of MPC is rapidly expanding across sectors such as chemical processing, energy systems, automotive control, and robotics. Its ability to optimize performance while respecting constraints aligns perfectly with modern industry demands for efficiency, safety, and sustainability. As computational resources become more accessible and algorithms more efficient, MPC is poised to become even more integral to advanced control system design.

By embracing the theory and design principles behind model predictive control, engineers can develop controllers that not only meet today's challenges but also adapt to future technological advancements and complex system requirements.

Frequently Asked Questions

What is Model Predictive Control (MPC) theory?

Model Predictive Control (MPC) is an advanced control strategy that uses a dynamic model of the system to predict and optimize future behavior over a finite time horizon, solving an optimization problem at each control step to determine the optimal control inputs while respecting constraints.

How does MPC differ from traditional control methods like PID?

Unlike PID controllers that use only current and past error information, MPC employs a model to predict future system outputs and optimizes control moves based on these predictions and constraints, enabling better handling of multivariable systems and complex constraints.

What are the key design steps in implementing an MPC controller?

Designing an MPC controller involves: 1) developing an accurate dynamic model of the system, 2) defining control and prediction horizons, 3) specifying constraints on inputs and states, 4) choosing a cost function to balance performance and effort, and 5) implementing a real-time optimization solver to compute control actions.

What types of optimization problems are solved in MPC design?

MPC typically solves constrained optimization problems such as quadratic programming (QP) for linear systems or nonlinear programming (NLP) for nonlinear systems, optimizing a cost function subject to system dynamics and input/state constraints at each control interval.

What are common challenges in MPC theory and design?

Common challenges include managing computational complexity for real-time implementation, ensuring model accuracy and robustness against uncertainties, handling nonlinearities and constraints effectively, and tuning prediction horizons and cost functions to achieve desired closed-loop performance.

Additional Resources

Model Predictive Control Theory and Design: An In-Depth Professional Review

model predictive control theory and design represents a pivotal advancement in modern control engineering, offering a sophisticated framework for managing complex, multivariable dynamic systems.

Rooted in optimization and system modeling, this approach has carved its niche across industries such as chemical processing, automotive systems, robotics, and aerospace. As control systems grow increasingly intricate, the relevance of model predictive control (MPC) theory and design continues to escalate, driven by its ability to anticipate future system behavior and optimize control moves accordingly.

Understanding the foundational principles and design methodologies behind MPC is essential for engineers and researchers aiming to deploy robust and efficient controllers. This comprehensive review explores the theoretical underpinnings, practical design considerations, and contemporary trends in model predictive control, emphasizing its unique strengths and inherent challenges.

Fundamentals of Model Predictive Control Theory

At its core, model predictive control theory revolves around the concept of predicting future system states over a defined horizon using an explicit dynamic model. Unlike traditional control methods that react solely based on current or past states, MPC leverages a model—often linear or nonlinear—to forecast system trajectories. The controller then solves an optimization problem at each sampling instant, selecting control inputs that minimize a cost function subject to constraints.

Key Components of MPC Theory

The essential elements constituting MPC include:

- **Prediction Model:** Typically a state-space or transfer function model that captures system dynamics. Linear Time-Invariant (LTI) models are common for simplicity, but nonlinear and adaptive models are increasingly utilized.
- **Cost Function:** A quadratic or more general function balancing tracking performance and control

effort, often incorporating terms for error minimization and input regularization.

- **Constraints:** Physical and operational limits on inputs, states, and outputs, such as actuator saturation, safety boundaries, or environmental restrictions.
- **Optimization Algorithm:** Solves the constrained optimization problem in real-time, determining the optimal sequence of control actions over the prediction horizon.
- **Receding Horizon Principle:** Only the first control input from the optimized sequence is applied, then the horizon shifts forward, and the process repeats at the next time step.

This predictive and optimization-based approach enables MPC to handle multivariable systems with coupled dynamics and constraints more effectively than classical PID or state-feedback controllers.

Design Methodologies in Model Predictive Control

Designing an MPC controller involves multiple stages, from system identification to real-time implementation. The theoretical elegance of MPC must be matched by practical considerations to ensure reliable and efficient operation.

System Modeling and Identification

Accurate models are the backbone of effective predictive control. Depending on the application, models may be derived from first principles, empirical data, or hybrid techniques. Linear models simplify the optimization problem but may lack fidelity in highly nonlinear regimes. Conversely, nonlinear MPC (NMPC) uses detailed models but demands more computational resources.

Defining the Prediction and Control Horizons

The selection of prediction horizon (N_p) and control horizon (N_c) critically influences controller performance and computational load. A longer prediction horizon allows the controller to anticipate distant future events but increases optimization complexity. Conversely, shorter horizons reduce computational demands but may sacrifice foresight.

Cost Function Formulation

The cost function typically penalizes deviation from setpoints and excessive control activity. Commonly used quadratic cost functions provide convex optimization problems, ensuring global minima can be found efficiently. Weighting matrices within the cost function allow designers to prioritize tracking accuracy or actuator effort, tailoring the controller to specific operational goals.

Constraint Handling

One of MPC's standout features is its systematic accommodation of constraints. Constraints ensure safe operation and prevent actuator saturation or damage. Incorporation of constraints transforms the optimization into a constrained quadratic programming (QP) problem for linear MPC, solvable by mature numerical solvers.

Optimization Solvers and Real-Time Implementation

Real-time feasibility hinges on efficient solvers capable of delivering solutions within the sampling interval. Advances in numerical optimization algorithms and dedicated hardware have broadened MPC's applicability to fast systems. Common solvers include interior-point methods, active-set methods, and gradient-based algorithms.

Applications and Comparative Advantages

Model predictive control theory and design have been widely adopted across various sectors, primarily due to their robustness in handling multivariable interactions and constraints.

Industrial Process Control

Chemical plants and refineries benefit from MPC's ability to optimize multiple interacting variables simultaneously, increasing throughput and reducing energy consumption. For instance, MPC enables precise temperature and pressure control in distillation columns, maintaining product quality under fluctuating feedstock conditions.

Automotive and Aerospace Systems

In automotive applications, MPC governs engine management, adaptive cruise control, and autonomous driving by forecasting vehicle dynamics and optimizing control inputs for safety and efficiency. Aerospace applications leverage MPC for flight control systems, offering adaptability to changing aerodynamic conditions and actuator limits.

Robotics and Manufacturing

Robotic manipulators employ MPC to ensure smooth trajectory tracking while respecting joint limits and avoiding collisions. In manufacturing, MPC optimizes machine tool operations, balancing speed and precision.

Advantages Over Traditional Control Methods

- **Constraint Handling:** MPC explicitly incorporates constraints, unlike PID controllers, which require ad hoc modifications.
- **Multivariable Control:** MPC naturally manages multiple inputs and outputs, an area where classical control struggles.
- **Predictive Capability:** Anticipation of future events improves disturbance rejection and setpoint tracking.
- **Flexibility:** Modular design allows easy adaptation to changing system dynamics and objectives.

Challenges and Limitations

Despite its benefits, model predictive control theory and design come with challenges that must be addressed during implementation.

Computational Demand

The requirement to solve an optimization problem at every sampling instant can be prohibitive for high-speed or resource-limited systems. Efforts to reduce computational complexity include explicit MPC, where control laws are precomputed offline, and fast online solvers.

Model Accuracy and Robustness

MPC performance heavily depends on model fidelity. Model mismatch or unmodeled disturbances can degrade control quality. Robust MPC formulations incorporate uncertainties but add complexity.

Tuning Complexity

Selecting horizons, weights in the cost function, and constraint parameters involves trial and error or sophisticated tuning algorithms. Poor tuning may lead to instability or suboptimal performance.

Integration with Legacy Systems

Deploying MPC in existing control architectures may require significant redesign, as traditional controllers differ fundamentally from MPC in operation and data requirements.

Emerging Trends in Model Predictive Control Theory and Design

Advancements in computational power and algorithms have sparked innovations in MPC, broadening its applicability.

Nonlinear and Adaptive MPC

To better handle nonlinearities and time-varying dynamics, adaptive MPC schemes update models and parameters online. This enhances control robustness in uncertain environments.

Stochastic and Robust MPC

Incorporating uncertainties in model parameters and disturbances via stochastic MPC offers probabilistic guarantees on constraint satisfaction, crucial for safety-critical systems.

Distributed and Decentralized MPC

Large-scale systems, such as power grids or traffic networks, benefit from distributed MPC architectures where multiple controllers coordinate while maintaining scalability.

Integration with Machine Learning

Hybrid approaches combining MPC with machine learning models enable capturing complex dynamics where first-principles models fall short. Data-driven MPC is an active research area enhancing prediction accuracy and adaptability.

Conclusion

Exploring model predictive control theory and design reveals a sophisticated, versatile control paradigm capable of addressing the complexities of modern dynamic systems. Its predictive nature, ability to handle constraints, and multivariable control aptitude distinguish MPC from classical strategies. Nonetheless, designers must navigate challenges related to computational demands, model accuracy, and tuning intricacies. With ongoing research and technological advancements, MPC continues to evolve, promising increasingly robust and efficient control solutions across diverse applications.

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model predictive control theory and design: Model Predictive Control Aris Daniilidis, Lars Grüne, Josef Haunschmied, Gernot Tragler, 2025-06-07 The book explores the field of model predictive control (MPC). It reports on the latest developments in MPC, current applications, and presents various subfields of MPC. The book features topics such as uncertain and stochastic MPC variants, learning and neural network approaches, easy-to-use numerical implementations as well as multi-agent systems and scheduling and coordination tasks. While MPC is rooted in engineering science, this book illustrates the potential of using MPC theory and methods in non-engineering sciences and applications such as economics, finance, and environmental sciences.

model predictive control theory and design: **Handbook of Model Predictive Control** Saša V. Raković, William S. Levine, 2018-09-01 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.

model predictive control theory and design: Model Predictive Control mit MATLAB und Simulink Rainer Dittmar, 2019-12-04 Modellbasierte prädiktive Regelungen dienen der Lösung anspruchsvoller Aufgaben der Mehrgrößenregelung mit Beschränkungen der Stell- und Regelgrößen. Sie werden in der Industrie in vielen Bereichen erfolgreich eingesetzt. Mit der MPC Toolbox™ des Programmsystems MATLAB®/Simulink® steht ein Werkzeug zur Verfügung, das sowohl in der industriellen Praxis als auch an Universitäten und Hochschulen verwendet wird. Das vorliegende Buch gibt eine Übersicht über die Grundideen und Anwendungsvorteile des MPC-Konzepts. Es zeigt, wie mit Hilfe der Toolbox MPC-Regelungen entworfen, eingestellt und simuliert werden können. Ausgewählte Beispiele aus dem Bereich der Verfahrenstechnik demonstrieren mögliche Vorgehensweisen und vertiefen das Verständnis. Das Buch richtet sich an in der Industrie tätige Ingenieure, die MPC-Regelungen planen, entwickeln und betreiben, aber auch an Studierende technischer Fachdisziplinen, die in das Arbeitsgebiet MPC einsteigen wollen. Model Predictive Control (MPC) is used to solve challenging multivariable-constrained control problems. MPC systems are successfully applied in many different branches of industry. The MPC Toolbox™

of MATLAB®/Simulink® provides powerful tools for industrial MPC application, but also for education and research at technical universities. This book gives an overview of the basic ideas and advantages of the MPC concept. It shows how MPC systems can be designed, tuned, and simulated using the MPC Toolbox. Selected process engineering benchmark examples are used to demonstrate typical design approaches and help deepen the understanding of MPC technologies. The book is aimed at engineers in industry interested in the development and application of MPC systems, as well as students of different technical disciplines seeking an introduction into this field. This book gives an overview of the basic ideas and advantages of the MPC concept. It shows how MPC systems can be designed, tuned, and simulated using the MPC Toolbox. Selected process engineering benchmark examples are used to demonstrate typical design approaches and help deepen the understanding of MPC technologies. The book is aimed at engineers in industry interested in the development and application of MPC systems, as well as students of different technical disciplines seeking an introduction into this field.

model predictive control theory and design: *Model Predictive Control of Wastewater Systems* Carlos Ocampo-Martinez, 2010-10-01 The series Advances in Industrial Control aims to report and encourage technology transfer in control engineering. The rapid development of control technology has an impact on all areas of the control discipline. New theory, new controllers, actuators, sensors, new industrial processes, computer methods, new applications, new philosophies ..., new challenges. Much of this development work resides in industrial reports, feasibility study papers and the reports of advanced collaborative projects. The series offers an opportunity for researchers to present an extended exposition of such new work in all aspects of industrial control for wider and rapid dissemination. The water and wastewater industry has undergone many changes in recent years. Of particular importance has been a renewed emphasis on improving resource management with tighter regulatory controls setting new targets on pricing, industry efficiency and loss reduction for both water and wastewater with more stringent environmental discharge conditions for wastewater. Meantime, the demand for water and wastewater services grows as the population increases and wishes for improved living conditions involving, among other items, domestic appliances that use water. Consequently, the installed infrastructure of the industry has to be continuously upgraded and extended, and employed more effectively to accommodate the new demands, both in throughput and in meeting the new regulatory conditions. Investment in fixed infrastructure is capital-intensive and slow to come on-stream. One outcome of these changes and demands is that the industry is examining the potential benefits of, and in many cases using, more advanced control systems.

model predictive control theory and design: *Model Predictive Control of High Power Converters and Industrial Drives* Tobias Geyer, 2017-02-28 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 it. 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.

model predictive control theory and design: Model Predictive Control for Nonlinear Continuous-Time Systems with and Without Time-Delays Marcus Reble, 2013 The objective of this thesis is the development of novel model predictive control (MPC) schemes for nonlinear continuous-time systems with and without time-delays in the states which guarantee asymptotic stability of the closed-loop. The most well-studied MPC approaches with guaranteed stability use a control Lyapunov function as terminal cost. Since the actual calculation of such a function can be difficult, it is desirable to replace this assumption by a less restrictive controllability assumption. For discrete-time systems, the latter assumption has been used in the literature for the stability analysis of so-called unconstrained MPC, i.e., MPC without terminal cost and terminal constraints. The contributions of this thesis are twofold. In the first part, we propose novel MPC schemes with guaranteed stability based on a controllability assumption, whereas we extend different MPC schemes with guaranteed stability to nonlinear time-delay systems in the second part. In the first part of this thesis, we derive explicit stability conditions on the prediction horizon as well as performance guarantees for unconstrained MPC. Starting from this result, we propose novel alternative MPC formulations based on combinations of the controllability assumption with terminal cost and terminal constraints. One of the main contributions is the development of a unifying MPC framework which allows to consider both MPC schemes with terminal cost and terminal constraints as well as unconstrained MPC as limit cases of our framework. In the second part of this thesis, we show that several MPC schemes with and without terminal constraints can be extended to nonlinear time-delay systems. Due to the infinite-dimensional nature of these systems, the problem is more involved and additional assumptions are required in the controller design. We investigate different MPC schemes with and without terminal constraints and/or terminal cost terms and derive novel stability conditions. Furthermore, we pay particular attention to the calculation of the involved control design parameters.

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model predictive control theory and design: Distributed and economic model predictive control: beyond setpoint stabilization Matthias A. Müller, 2014 In this thesis, we study model predictive control (MPC) schemes for control tasks which go beyond the classical objective of setpoint stabilization. In particular, we consider two classes of such control problems, namely distributed MPC for cooperative control in networks of multiple interconnected systems, and economic MPC, where the main focus is on the optimization of some general performance criterion which is possibly related to the economics of a system. The contributions of this thesis are to analyze various systems theoretic properties occurring in these type of control problems, and to develop distributed and economic MPC schemes with certain desired (closed-loop) guarantees. To be more precise, in the field of distributed MPC we propose different algorithms which are suitable for general cooperative control tasks in networks of interacting systems. We show that the developed distributed MPC frameworks are such that the desired cooperative goal is achieved, while coupling constraints between the systems are satisfied. Furthermore, we discuss implementation and scalability issues for the derived algorithms, as well as the necessary communication requirements between the systems. In the field of economic MPC, the contributions of this thesis are threefold. Firstly, we analyze a crucial dissipativity condition, in particular its necessity for optimal steady-state operation of a system and its robustness with respect to parameter changes. Secondly, we develop economic MPC schemes which also take average constraints into account. Thirdly, we propose an economic MPC framework with self-tuning terminal cost and a generalized terminal constraint, and we show how self-tuning update rules for the terminal weight can be derived such that desirable closed-loop performance bounds can be established.

model predictive control theory and design: Model Predictive Control Corrine Wade, 2015

Although industrial processes are inherently nonlinear, many contributions for controller design for those plants are based on the assumption of a linear model of the system. However, in some cases it is difficult to represent a given process using a linear model. Model Predictive Control (MPC) is an optimal control approach which can effectively deal with constraints and multivariable processes in industries. Because of its advantages, MPC has been widely applied in automotive and process control communities. This book discusses the theory, practices and future challenges of model predictive control.

model predictive control theory and design: *Distributed Model Predictive Control Made*

Easy José M. Maestre, Rudy R. Negenborn, 2013-11-10 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.

model predictive control theory and design: Relaxed Barrier Function Based Model

Predictive Control Christian Feller, 2017 In this thesis, we introduce the novel concept of relaxed barrier function based model predictive control and present a comprehensive theoretical and algorithmic framework for the design, analysis, and implementation of relaxed barrier function based MPC approaches. Instead of treating the underlying optimization as an idealized static map, a key motive of the MPC results and algorithms presented in this thesis is to study the interconnected dynamics of controlled plant and iterative optimization algorithm in an integrated barrier function based framework and to analyze the resulting overall closed-loop system both from a systems theoretic and algorithmic perspective. One of the presented main results is a novel class of barrier function based anytime MPC algorithms that guarantee important properties of the closed-loop system independently of the number of optimization algorithm iterations that are performed at each sampling step. The obtained theoretical results are illustrated by various numerical examples and benchmark tests as well as by an experimental case study in which the proposed class of barrier function based MPC algorithms is applied to the predictive control of a self-driving car.

model predictive control theory and design: Nostradamus 2014: Prediction, Modeling and

Analysis of Complex Systems Ivan Zelinka, Ponnuthurai Nagaratnam Suganthan, Guanrong Chen, Vaclav Snasel, Ajith Abraham, Otto RöSSLer, 2014-06-09 The prediction of behavior of complex systems, analysis and modeling of its structure is a vitally important problem in engineering, economy and generally in science today. Examples of such systems can be seen in the world around us (including our bodies) and of course in almost every scientific discipline including such "exotic" domains as the earth's atmosphere, turbulent fluids, economics (exchange rate and stock markets), population growth, physics (control of plasma), information flow in social networks and its dynamics, chemistry and complex networks. To understand such complex dynamics, which often exhibit strange behavior, and to use it in research or industrial applications, it is paramount to create its models. For this purpose there exists a rich spectrum of methods, from classical such as ARMA models or Box Jenkins method to modern ones like evolutionary computation, neural networks, fuzzy logic, geometry, deterministic chaos amongst others. This proceedings book is a collection of accepted papers of the Nostradamus conference that has been held in Ostrava, Czech Republic in June 2014. This book also includes outstanding keynote lectures by distinguished guest speakers:

René Lozi (France), Ponnuthurai Nagarathnam Suganthan (Singapore) and Lars Nolle (Germany). The main aim of the conference was to create a periodical possibility for students, academics and researchers to exchange their ideas and novel research methods. This conference establishes a forum for presentation and discussion of recent research trends in the area of applications of various predictive methods.

model predictive control theory and design: *Computationally Efficient Model Predictive Control Algorithms* Maciej Ławryńczuk, 2014-01-24 This book thoroughly discusses computationally efficient (suboptimal) Model Predictive Control (MPC) techniques based on neural models. The subjects treated include: · A few types of suboptimal MPC algorithms in which a linear approximation of the model or of the predicted trajectory is successively calculated on-line and used for prediction. · Implementation details of the MPC algorithms for feed forward perceptron neural models, neural Hammerstein models, neural Wiener models and state-space neural models. · The MPC algorithms based on neural multi-models (inspired by the idea of predictive control). · The MPC algorithms with neural approximation with no on-line linearization. · The MPC algorithms with guaranteed stability and robustness. · Cooperation between the MPC algorithms and set-point optimization. Thanks to linearization (or neural approximation), the presented suboptimal algorithms do not require demanding on-line nonlinear optimization. The presented simulation results demonstrate high accuracy and computational efficiency of the algorithms. For a few representative nonlinear benchmark processes, such as chemical reactors and a distillation column, for which the classical MPC algorithms based on linear models do not work properly, the trajectories obtained in the suboptimal MPC algorithms are very similar to those given by the "ideal" MPC algorithm with on-line nonlinear optimization repeated at each sampling instant. At the same time, the suboptimal MPC algorithms are significantly less computationally demanding.

model predictive control theory and design: *Beitrag zu iterativ lernenden modellprädiktiven Regelungen* Fabian Kennel, 2017 In der Industrie laufen viele Prozesse zyklisch und damit wiederholend ab. Eine hohe Regelgüte ist hierbei unabdingbar. Daher kommen iterativ lernende Regelungsmethoden zum Einsatz, welche die Regelung des Prozesses zyklisch verbessern. In dieser Dissertation werden iterativ lernende modellprädiktive Regelungsverfahren vorgestellt. Die entwickelten Methoden ermöglichen durch ihre modellbasierte Struktur eine zyklische Steigerung der Regelgüte bei gleichzeitiger Berücksichtigung der Systembeschränkungen. Zyklische unbekannte Störungen und Dynamiken lassen sich hiermit iterativ erlernen und unterdrücken. Eine Robustifizierung der Verfahren gegenüber Messrauschen sowie Unsicherheiten wird in dieser Arbeit aufgezeigt. Rechenzeit und Speicherbedarf stellen die größten Herausforderungen der optimierungsbasierten Verfahren dar. Verschiedene effiziente Ansätze zur Reduktion von Speicher- und Rechenbedarf werden in der Dissertation dargelegt. In den optimierungsbasierten Entwurf lassen sich weitere Optimierungsziele einbinden. Gerade für industrielle Prozesse stellt eine Reduktion des Energiebedarfs sowie eine Reduktion der Prozesszeiten ein wichtiges Optimierungskriterium dar. Diese Kriterien können in einfacher Weise in die entwickelten Verfahren integriert werden. Je nach Prozess sind Energieeinsparungen von über 50% realisierbar. Die Prozesszeiten lassen sich teilweise mehr als halbieren. Die Verfahren selbst wurden an drei Beispielsystemen praktisch erprobt. Die Ergebnisse sind zufriedenstellend und für die Industrie von praktischer Relevanz.

model predictive control theory and design: *Learning-based Model Predictive Control with closed-loop guarantees* Raffaele Soloperto, 2023-11-13 The performance of model predictive control (MPC) largely depends on the accuracy of the prediction model and of the constraints the system is subject to. However, obtaining an accurate knowledge of these elements might be expensive in terms of money and resources, if at all possible. In this thesis, we develop novel learning-based MPC frameworks that actively incentivize learning of the underlying system dynamics and of the constraints, while ensuring recursive feasibility, constraint satisfaction, and performance bounds for the closed-loop. In the first part, we focus on the case of inaccurate models, and analyze learning-based MPC schemes that include, in addition to the primary cost, a learning

cost that aims at generating informative data by inducing excitation in the system. In particular, we first propose a nonlinear MPC framework that ensures desired performance bounds for the resulting closed-loop, and then we focus on linear systems subject to uncertain parameters and noisy output measurements. In order to ensure that the desired learning phase occurs in closed-loop operations, we then propose an MPC framework that is able to guarantee closed-loop learning of the controlled system. In the last part of the thesis, we investigate the scenario where the system is known but evolves in a partially unknown environment. In such a setup, we focus on a learning-based MPC scheme that incentivizes safe exploration if and only if this might yield to a performance improvement.

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