Stochastic Model Predictive Control For Building Climate

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

Readers of this book will be shown how, with the adoption of ubiquituous sensing, extensive data-gathering and forecasting, and building-embedded advanced actuation, intelligent building systems with the ability to respond to occupant preferences in a safe and energy-efficient manner are becoming a reality. The articles collected present a holistic perspective on the state of the art and current research directions in building automation, advanced sensing and control, including: model-based and model-free control design for temperature control; smart lighting systems; smart sensors and actuators (such as smart thermostats, lighting fixtures and HVAC equipment with embedded intelligence); and energy management, including consideration of grid connectivity and distributed intelligence. These articles are both educational for practitioners and graduate students interested in design and implementation, and foundational for researchers interested in understanding the state of the art and the challenges that must be overcome in realizing the potential benefits of smart building systems. This edited volume also includes case studies from implementation of these algorithms/sensing strategies in to-scale building systems. These demonstrate the benefits and pitfalls of using smart sensing and control for enhanced occupant comfort and energy efficiency.

This thesis proposes an algorithmic controller synthesis based on the computation of probabilistic reachable sets for stochastic hybrid systems. Hybrid systems consist in general of a composition of discrete and continuous valued dynamics, and are able to capture a wide range of physical phenomena. The stochasticity is considered in form of normally distributed initial continuous states and normally distributed disturbances, resulting in stochastic hybrid systems.

The reachable sets describe all states, which are reachable by a system for a given initialization of the system state, inputs, disturbances, and time horizon. For stochastic hybrid systems, these sets are probabilistic, since the system state and disturbance are random variables. This thesis introduces probabilistic reachable sets with a predefined confidence, which are used in an optimization based procedure for the determination of stabilizing control inputs. Besides the stabilizing property, the controlled dynamics also observes input constraints, as well as, so-called chance constraints for the continuous state.

The main contribution of this thesis is the formulation of an algorithmic control procedure for each considerd type of stochastic hybrid systems, where different discrete dynamics are considered. First, a control procedure for a deterministic system with bounded disturbances is introduced, and thereafter a probabilistic distribution of the system state and the disturbance is assumed. The formulation of probabilistic reachable sets with a predefined confidence is subsequently used in a control procedure for a stochastic hybrid system, in which the switch of the continuous dynamics is externally induced. Finally, the control procedure based on reachable set computation is extended to a type of stochastic hybrid systems with autonomously switching of the continuous dynamics.

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.

Dynamical systems are subjected to various random external forcings that complicate theie control. In order to achieve optimal performance, these systems need to continually adapt to external disturbances in real time. This capability is provided by feedback based control strategies that derive an optimal control from the current state of the system. Model Predictive Control(MPC) is one such feedback-based technique. This thesis explores the application of a stochastic version of MPC to a reservoir system. The reservoir system is designed to maximize the revenue generated from the hydroelectricity while simultaneously obeying several exogenous constraints. An ensemble based version of the stochastic MPC technique is studied and applied to the reservoir to determine the optimal water release strategies. Further analysis is performed to understand the sensitivity of different parameters in the MPC technique. This book presents research results of PowerWeb, TU Delft’s consortium for interdisciplinary research on intelligent, integrated energy systems and their role in markets and institutions. In operation since 2012, it acts as a host and information platform for a growing number of projects, ranging from single PhD student projects up to large integrated and international research programs. The group acts in an inter-faculty fashion and brings together experts from electrical engineering, computer science, mathematics, mechanical engineering, technology and policy management, control engineering, civil engineering, architecture, aerospace engineering, and industrial design. The interdisciplinary projects of PowerWeb are typically associated with either of three problem domains: Grid Technology, Intelligence and Society. PowerWeb is not limited to electricity: it bridges heat, gas, and other types of energy with markets, industrial processes, transport, and the built environment, serving as a singular entry point for industry to the University’s knowledge. Via its Industry Advisory Board, a steady link

to business owners, manufacturers, and energy system operators is provided.
Despite its sub-optimality, Model Predictive Control (MPC) has received much attention over the recent decades due to its ability to handle constraints. In particular, stochastic MPC, which includes uncertainty in the system dynamics, is one of the most active recent research topics in MPC. In this dissertation, we focus on (1) increasing computation speed of constrained stochastic MPC of linear systems with additive noise and, (2) improving the accuracy of an approximate solution involving systems with additive and multiplicative noise. Constrained MPC for linear systems with additive noise has been successfully formulated as a semidefinite programming problem (SDP) using the Youla parameterization or innovation feedback and linear matrix inequalities. Unfortunately, this method can be prohibitively slow even for problems with moderate size state. Thus, in this thesis we develop an interior point algorithm which can more efficiently solve the problem. This algorithm converts the stochastic problem into a deterministic one using the mean and the covariance matrix as the system state and using affine feedback. A line search interior point method is then directly applied to the nonlinear deterministic optimization problem. In the process, we take advantage of a recursive structure that appears when a control problem is solved via the line search interior point method in order to decrease the algorithmic complexity of the solution. We compare the computation time and complexity of our algorithm against an SDP solver. The second part of the dissertation deals with systems with additive and multiplicative noise under probabilistic constraints. This class of systems differs from the additive noise case in that the probability distribution of a state is neither Gaussian nor known in closed form. This causes a problem when the probability constraints are dealt with. In previous studies, this problem has been

tackled by approximating the state as a Gaussian random variable or by approximating the probability bound as an ellipsoid. In this dissertation, we use the Cornish-Fisher expansion to approximate the probability bounds of the constraints. Since the Cornish-Fisher expansion utilizes quantile values with the first several moments, the probabilistic constraints have the same form as those in the additive noise case when the constraints are converted to deterministic ones. This makes the procedure smooth when we apply the developed algorithm to a linear system with multiplicative noise. Moreover, we can easily extend the application of the algorithm to a linear system with additive plus multiplicative noise.
Thepastthree decadeshaveseenrapiddevelopmentin the areaofmodelpred- tive 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 - erability, 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 - joyed signi?cant 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 thepracticalapplicabilityofNMPCwithinreachevenforveryfastsystems.This has led to a series of new, exciting developments, along with new challenges in the area of NMPC.
In this thesis, we develop a novel framework for model predictive control (MPC) which

combines the concepts of robust MPC and economic MPC. The goal of this thesis is to develop and analyze MPC schemes for nonlinear discrete-time systems which explicitly consider the influence of disturbances on arbitrary performance criteria. Instead of regarding the two aspects separately, we propose robust economic MPC approaches that integrate information which is available about the disturbance directly into the economic framework. In more detail, we develop three concepts which differ in which information about the disturbance is used and how this information is taken into account. Furthermore, we provide a thorough theoretical analysis for each of the three approaches. To this end, we present results on the asymptotic average performance as well as on optimal operating regimes. Optimal operating regimes are closely related to the notion of dissipativity, which is therefore analyzed for the presented concepts. Under suitable assumptions, results on necessity and sufficiency of dissipativity for optimal steady-state operation are established for all three robust economic MPC concepts. A detailed discussion is provided which compares the different performance statements derived for the approaches as well as the respective notions of dissipativity.
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.

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.

Model Predictive Control (MPC) refers to a class of control algorithms in which a dynamic process model is used to predict and optimize process performance. From lower request of modeling accuracy and robustness to complicated process plants, MPC has been widely accepted in many practical fields. As the guide for researchers and engineers all over the world concerned with the latest developments of MPC, the purpose of "Advanced Model Predictive Control" is to show the readers the recent achievements in this area. The first part of this exciting book will help you comprehend the frontiers in theoretical research of MPC, such as Fast MPC, Nonlinear MPC, Distributed MPC, Multi-Dimensional MPC and Fuzzy-Neural MPC. In the second part, several excellent applications of MPC in modern industry are proposed and efficient commercial software for MPC is introduced. Because of its special industrial origin, we believe that MPC will remain energetic in the future.

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 an Future Directions of Nonlinear Model Predictive Control that took place from September 5 to 9, 2008, in Pavia, Italy.

Robust & Stochastic Model Predictive Control

The book shows how the operation of renewable-energy microgrids can be facilitated by the use of model predictive control (MPC). It gives readers a wide overview of control methods for microgrid operation at all levels, ranging from quality of service, to integration in the electricity market. MPC-based solutions are provided for the main control issues related to energy management and optimal operation of microgrids. The authors present MPC techniques for case studies that include different renewable sources – mainly photovoltaic and wind – as well as hybrid storage using batteries, hydrogen and supercapacitors. Experimental results for a pilot-scale microgrid are also presented, as well as simulations of scheduling in the electricity market and integration of electric and hybrid vehicles into the microgrid. in order to replicate the examples provided in the book and to develop and validate control algorithms on existing or projected microgrids. Model Predictive Control of Microgrids will interest researchers and practitioners, enabling them to keep abreast of a rapidly developing field. The text will also help to guide graduate students through processes from the conception and initial design of a microgrid through its implementation to the optimization of microgrid management. 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.

Model Predictive Control has become a prevailing technique in practice by virtue of its natural inclusion of constraint enforcement in sub-optimal feedback design through repeated solution of finite-horizon, open-loop control problems. However, many approaches are lacking in proper accommodation of output feedback using imperfect measurements, as is normally required in practice. The conventional workaround for this disconnect between control theory and practice is the use of certainty equivalent control laws, which subsume best available state estimates in place of the system state in order to salvage methods available for state-feedback Model Predictive Control. This dissertation explores Stochastic Model Predictive Control in the general, nonlinear output-feedback setting. Starting the receding horizon development from Stochastic Optimal Control, we attain inherent accommodation of imperfect measurement data through propagation of the conditional state density, the information state. This setup further results in the control signals being of dual, probing nature: the control balances the typically antagonistic requirements of regulation and exploration. However, these conflicting tasks inherent to Stochastic Optimal Control also embody the associated computational intractability. While properties such as optimal probing and numerical performance bounds on the infinite time-horizon require solution of Stochastic Optimal Control problems, obtaining these solutions is typically not possible in practice due to the exorbitant computational demands. We suggest two methods for tractable Stochastic Model Predictive Control. Firstly, we propose approximation of the information state update by a Particle Filter, which may be merged naturally with scenario optimization to generate control laws. While computationally tractable, this method does not maintain duality without additional measures. Alternatively, the nonlinear output-feedback problem can be approximated--or even cast--as a Partially Observable Markov Decision Process, a special class of systems for which Stochastic Optimal Control is numerically tractable for reasonable problem size, enabling dual optimal control with provable infinite-horizon properties. Throughout this dissertation, we examine two classes of examples from healthcare: individualized appointment scheduling, a problem not requiring duality; medical treatment decision making, where dual control decisions are often required to balance optimally when to order diagnostic tests and when to apply medical intervention.

Power systems have experienced several changes since smart grids and renewable resources increased their penetration. Traditionally, power systems operation has been addressed with unit commitment and economic dispatch problems that rely on a centralized operator. These operation methods are usually performed on a day-ahead basis, i.e., every 24 hours. As a result of volatility in renewable resources and demand, it is better to shorten the operation period, e.g., every hour. Centralized methods might not be feasible for solving short-term economic dispatch, especially in systems with several agents. Thereby, the research questions this thesis are what method can be used for solving short-term economic dispatch in the presence of smart grid elements?

Second, what models can be designed in order to optimally dispatch power plants and operate different agents in a smart grid environment? Third, how uncertainty can be considered in such models without increasing dimensionality and keeping tractability? Fourth, what is the best way to operate power systems with smart grid elements? In order to solve all these questions, we deeply analyzed economic dispatch methods and smart grid elements. Next, we proposed two distributed economic dispatch methods that are feasible for hourly and ultra-short term periods. In addition, we integrated stochastic programming through a data-driven scenario generation in order to include randomness of power system variables. Finally, a hierarchical operation of hourly and ultra-short term was proposed to enhance operation performance. The results obtained in this thesis show that proposed methods answer our research questions and serve as a basis for operating power systems more efficiently. Under uncertainty framework, it is better to use stochastic approaches rather than deterministic ones. For using stochastic approaches, it is necessary to pass from centralized controllers to distributed architectures as it has been proposed in this work.

Model based control has emerged as an important way to improve plant efficiency in the process industries, while meeting processing and operating policy constraints. The reader of Methods of Model Based Process Control will find state of the art reports on model based control technology presented by the world's leading scientists and experts from industry. All the important issues that a model based control system has to address are covered in depth, ranging from dynamic simulation and control-relevant identification to information integration.

Specific emerging topics are also covered, such as robust control and nonlinear model predictive control. In addition to critical reviews of recent advances, the reader will find new ideas, industrial applications and views of future needs and challenges. Audience: A reference for graduate-level courses and a comprehensive guide for researchers and industrial control engineers in their exploration of the latest trends in the area.

Automotive control has developed over the decades from an auxiliary te- nology to a key element without which the actual performances, emission, safety and consumption targets could not be met. Accordingly, automotive control has been increasing its authority and responsibility – at the price of complexity and di?cult tuning. The progressive evolution has been mainly ledby speci?capplicationsandshorttermtargets,withthe consequencethat automotive control is to a very large extent more heuristic than systematic. Product requirements are still increasing and new challenges are coming from potentially huge markets like India and China, and against this ba- ground there is wide consensus both in the industry and academia that the current state is not satisfactory. Model-based control could be an approach to improve performance while reducing development and tuning times and possibly costs. Model predictive control is a kind of model-based control design approach which has experienced a growing success since the middle of the 1980s for “slow” complex plants, in particular of the chemical and process industry. In the last decades, severaldevelopments haveallowedusing these methods also for “fast”systemsandthis hassupporteda growinginterestinitsusealsofor automotive applications, with several promising results reported. Still there is no consensus on whether model predictive control with its high requi- ments on model quality and on computational power is a sensible choice for automotive control.

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.

As the complexity and scale of chemical processes has increased, engineers have desired a process control strategy that can successfully and safely regulate modern processes. These processes are often subject to random noise and uncertainties in parameters or model structure which make regulation and control difficult. Stochastic model predictive control (SMPC) is an advanced process control strategy that can systematically seek tradeoffs between multiple (possibly competing) control objectives in the presence of constraints for multi-input multi-output systems. Furthermore, SMPC explicitly considers the stochasticity of system states and parameters, allowing for the systematic trade off of robustness and performance. Another key advantage of SMPC is the ability to implement chance constraints, which can be violated with a specified probability, instead of hard constraints which must be satisfied in all conditions. Because SMPC employs a probabilistic description of states and parameters, uncertainty propagation techniques are needed to determine the time evolution of these probability distributions. Monte Carlo methods are a widely used uncertainty propagation technique, but are too computationally expensive for real time optimization and control. Three approaches to efficient SMPC implementations are investigated in this dissertation. A SMPC algorithm with hard input constraints and joint chance constraints in the presence of (possibly) unbounded noise is presented. By recasting the nonlinear SMPC optimal control problem as a convex iterative deterministic program, the computational cost of determining the optimal control policy is significantly decreased. Two uncertainty propagation methods, the Fokker-Planck equation and adaptive polynomial chaos, are presented in the context of optimal control. The Fokker-Planck equation is a partial differential equation that can propagate the full probability distribution of uncertainties. This allows for shaping of the probability distribution function of states to desired distributions in an open loop sense as well as eliminating the need for conservative approximations when evaluating chance constraint violation. Closed-loop simulations of a SMPC controller regulating a bioreactor demonstrate the ability to shape the

product probability distribution function when using the Fokker-Planck equation as an uncertainty propagation technique. Adaptive polynomial chaos (aPC) is an efficient technique that propagates the moments of (possibly) cross-correlated distributions. Unlike similar techniques, aPC only requires knowledge of the statistical moments of uncertain states and parameters, which can be readily estimated from experimental data. The error convergence properties of aPC are investigated in a continuous stirred tank reactor (CSTR) with correlated reaction kinetic parameters. All three approaches to uncertainty propagation and constraint handling in the context of SMPC discussed in this dissertation demonstrate promise for decreasing computational cost and reducing reliance on conservative approximations.
This book constitutes the refereed proceedings of the 25th International Conference on Analytical and Stochastic Modelling Techniques and Applications, ASMTA 2019, held in Moscow, Russia, in October 2019. Methods of analytical and stochastic modelling are widely used in engineering to assess and design various complex systems, like computer and communication networks, and manufacturing systems. The 13 full papers presented in this book were carefully reviewed and selected from 22 submissions. The papers detail a diverse range of analysis techniques, including Markov processes, queueing theoretical results, reliability of stochastic systems, stochastic network calculus, and wide variety of applications.
In the thesis, two different model predictive control (MPC) strategies are investigated for linear systems with uncertainty in the presence of constraints: namely robust MPC and stochastic MPC. Firstly, a Youla Parameter is integrated into an efficient robust MPC algorithm. It is demonstrated that even in the constrained cases, the use of the Youla Parameter can desensitize the costs to the effect of uncertainty while not affecting the nominal performance,

and hence it strengthens the robustness of the MPC strategy. Since the controller u = KLQX + c can offer many advantages and is used across the thesis, the work provides two solutions to the problem when the unconstrained nominal LQ-optimal feedback KLQ cannot stabilise the whole class of system models. The work develops two stochastic tube approaches to account for probabilistic constraints. By using a semi closed-loop paradigm, the nominal and the error dynamics are analyzed separately, and this makes it possible to compute the tube scalings offline. First, ellipsoidal tubes are considered. The evolution for the tube scalings is simplified to be affine and using Markov Chain model, the probabilistic tube scalings can be calculated to tighten the constraints on the nominal. The on- line algorithm can be formulated into a quadratic programming (QP) problem and the MPC strategy is closed-loop stable. Following that, a direct way to compute the tube scalings is studied. It makes use of the information on the distribution of the uncertainty explicitly. The tubes do not take a particular shape but are defined implicitly by tightened constraints. This stochastic MPC strategy leads to a non-conservative performance in the sense that the probability of constraint violation can be as large as is allowed. It also ensures the recursive feasibility and closed-loop stability, and is extended to the output feedback case.

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.

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 approx- imation 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 tech- nical assumptions in the literature can be dispensed with by using a slightly more complex controller.

Large scale manufacturing systems are often run with constant process parameters although continuous and abrupt disturbances influence the process. To reduce quality variations and scrap, a closed-loop control of the process variables becomes indispensable. In this thesis, a modeling and control framework for multistage manufacturing systems is developed, in which the systems are subject to abrupt faults, such as component defects, and continuous disturbances. In this context, three main topics are considered: the development of a modeling framework, the design of robust distributed controllers, and the application of both to the models of a real hot stamping line. The focus of all topics is on the control of the product properties considering the available knowledge of faults and disturbances.