Lecture Notes in Control and Information Sciences

Volume 464

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Developments in Model-Based Optimization and Control

Distributed Control and Industrial Applications
Preface

This edited volume emerged from the two workshops dedicated to *Optimisation-based Control and Estimation* held in France at CentraleSupélec in November 2013 and November 2014, with participation of academic partners from Bulgaria, France, Italy, Norway, Portugal, Romania, Spain, and Slovakia. The aim of these workshops was to bring together specialists in control theory, applied mathematics, and from selected application domains, notably bio-reactors/industrial bioprocesses, robotic vehicle systems, and power systems, to discuss topics related to the design of advanced model-based strategies relying on optimization for identification, estimation, and control. The research teams invited for these events have been involved in several collaborative projects from whose results most of the contributions presented in this volume were extracted. The authors have been given the freedom to improve and further complement the results presented at the workshop, in order to enrich the book and highlight the relevance of the optimization-based control and estimation. The submitted chapters underwent a two-stage evaluation process involving detailed reviews and updates of the contributions which converged to the collection of chapters composing the present volume.

The support of CAMPUS France (the French national agency for the promotion of higher education, international student services, and international mobility) via bilateral projects is acknowledged here together with the partner institutions in:

- **University of Porto—Pessoa project** “Advanced control of a fleet of heterogeneous autonomous vehicles” coordinated in Portugal by Prof. Fernando Lobo Pereira
- **Bulgarian Academy of Sciences—RILA project** “Robust Distributed Model Predictive Control of Medium- and Large-Scale Systems” coordinated in Bulgaria by Assoc. Prof. Alexandra Grancharova
- **Norwegian University of Science and Technology, Trondheim—Aurora project** “Connections between constrained control design and the theory of positive dynamical systems” coordinated in Norway by Prof. Morten Hovd
• University of Udine—Galileo project “Set theoretic analysis of switched and time delay systems with application to fault tolerant control systems” coordinated in Italy by Prof. Stefano Miani
• University of Craiova—Brâncusi project “Predictive and adaptive control of bioprocesses (modeling, identification and control of interconnected bio-processes)” coordinated in Romania by Prof. Dan Selisteanu
• Slovak University of Technology in Bratislava—Stefanik project “Complexity, Sensitivity and Robustness of explicit predictive control laws” coordinated in Slovakia by Assoc. Prof. Michal Kvasnica
• GEPEA Laboratory Saint-Nazaire, France—with Assoc. Prof. Mariana Titica as principal investigator in the Brâncusi project
• University of Galati, Romania—with Prof. Sergiu Caraman as principal investigator in the Brâncusi project
• Polytechnic University of Catalonia—with Assoc. Prof. Carlos Ocampo Martinez as main collaborator in Spain

It is a great pleasure to thank all of the participants of the workshop for their contributions that have made these events a success. We would like to express our gratitude to our colleagues Cristina Stoica Maniu, Sihem Tebbani, and Pedro Rodriguez Ayerbe, who coordinated the research projects in France and participated skillfully and enthusiastically in the organization of the Workshops. With respect to the local arrangements, the financial support of Direction de Recherche et Relations Internationales of CentraleSupélec was an important asset and it is acknowledged here.

Gif-sur-Yvette Sorin Olaru
Sofia Alexandra Grancharova
Porto Fernando Lobo Pereira
September 2015
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Introduction

Motivation

This book concerns optimization methods as tools for decision making and control of dynamic systems in the presence of uncertainties and disturbances. By pooling broad areas of Applied Mathematics and Computation Sciences, this subject has been building a huge impact on an increasing range of diverse application areas which encompass fields such as economics, agriculture, environment and other natural resources management, social sciences, bio-systems, industrial processes, aeronautics, robotic vehicle systems, transportation power systems, electronics, as well as other engineering areas. The present volume targets the enhancement of the specific use of these tools in engineering and, more specifically, in automatic control design, with emphasis on its key components: analysis of dynamical systems, estimation, and feedback control design.

The Book Flavor and Main Contributions

This book contains a selected set of recent contributions ranging from novel formulations of model predictive control design, to the set-theoretic characterization of dynamical systems and including the recent decentralized and cooperative formulations of control laws. Together with these contributions we find eight chapters dedicated to optimization-based tools for robustness analysis, to decision making in relationship with feedback mechanisms (including fault detection and recovery, as a notable example), and to applications to biotechnology or multi-agent systems or impulsive dynamical systems.
Book Organization

This book mirrors the spiralling bidirectional interplay between conceptual optimization-based control frameworks and challenging requirements emerging from state-of-the-art applications that so fruitfully has been shaping the fast paced research in this wide area. Given the vast Research & Development network and the program of the workshops which paved the way for the present volume, we felt natural to organize the book into five parts, each reflecting a current research trend:

1. **Complexity and Structural Properties of Linear Model Predictive Control.**
   Structural technical issues targeting novel formulations fulfilling more sophisticated real-time specifications and performance requirements related to the predictive control design for linear systems. In Chap. 1 I. Necoara, A. Patrascu, and A. Nedić discuss the computational certifications for convex programming with a direct impact on real-time MPC. In Chaps. 2 and 3, the inverse optimality of continuous piecewise affine functions is investigated by N.A. Nguyen, M. Gulan, S. Olaru, P. Rodriguez-Ayerbe, M. Hovd, I. Necoara, and B. Rohal-Ilkiv with a straightforward interpretation of the explicit linear model predictive control design and implementation via equivalent real-time optimization schemes.

2. **Distributed-coordinated and Multi-objective Features of Model Predictive Control.**
   Novel formulations which highlight the interconnections of control and data sharing among subsystems are presented in this part of the volume with the ultimate goal of enabling the optimization-based coordination of decentralized systems. Chapter 4 is dedicated to distributed predictive control of interconnected polytopic systems where A. Grancharova and S. Olaru extend the recent results on this topic in order to achieve robustness. Chapter 5 by J. Sandol Moreno, J.J. Martinez, and G. Besancon discuss a distributed-coordinated optimal control base on a price-driven approach complying with requirements arising in power generation systems. Chapter 6 is dedicated to dynamical tuning of multi-objective control where J. Barreiro-Gomez, C. Ocampo-Martinez, and N. Quijano point out the advantages of an evolutionary game-based selection of prioritization weights of predictive control objective function (and the positioning on the Pareto front of solutions).

3. **Collaborative Model Predictive Control.**
   This part of the book consists of a set of three chapters discussing issues arising in cooperative path following for, a possibly reconfigurable, formation of robotic vehicles in an optimization-based control design perspective. In Chap. 7 by A. Rucco, A. Pedro Aguiar, F.A.C.C. Fontes, F. Lobo Pereira, and J. Borges de Sousa, a model predictive control-based architecture that enables the decentralized cooperative path-following of multiple Unmanned Aerial Vehicles is presented. The stability of the generated trajectories with a prescribed rate of convergence while satisfying both state and control constraints are shown. I. Prodan, S. Olaru, C. Stoica Maniu, F.A.C.C. Fontes, F. Lobo Pereira, and S. Niculescu discuss, in Chap. 8, a computationally efficient predictive control-based framework for path
following. Issues concerning the optimal dynamical task assignment formulation of multi-agent systems, coupled with fault detection and isolation capabilities, are discussed by M.T. Nguyen, C. Stoica Maniu, S. Olaru, and A. Grancharova in Chap. 9 addressing MPC-based formation reconfiguration techniques.

4. Applications of Optimization-Based Control and Identification. Selected consolidated cases showing the benefits of customized optimization-based control that encompass applications in bio-processes are presented in this part. While, S. Tebbani, M. Titica, G. Ifrim, M. Barbu, and S. Caraman present results on the optimal operation of a lumostatic microalgae cultivation process in Chap. 10, in the ensuing chapter, heuristic optimization techniques are discussed by D. Sendrescu, S. Tebbani, and D. Selisteanu to estimate bioprocess parameters. An implementation of a real-time predictive control for both supervisor and regulatory levels of a pasteurization plant is provided by A. Rosich, and C. Ocampo-Martinez in Chap. 12.

5. Optimization-Based Analysis and Design for Particular Classes of Dynamical Systems. This part concerns contributions that show how optimization-based control techniques are amenable to take advantage of particular features exhibited by specific classes of dynamic models. This last part of the volume collects five chapters promoting pioneering inroads in dynamic optimization. The reader can find optimization-based control design formulation for impulsive control systems by F. Lobo Pereira, F.A.C.C. Fontes, A. Pedro Aguiar, and J. Borges de Sousa in which invariance and stability are the key issues in Chap. 13, and bilinear systems by M. Vatani, M. Hovd, and S.Olaru in which linear parameter varying control design is discussed in Chap. 14. A class of linear parameter varying systems by F. Blanchini, D. Casagrande, G. Giordano, and S. Miani in which the importance of the parameterization of the stabilizing control laws is underlined in Chap. 15, and linear systems with state-dependent bounds on disturbances by S. Olaru and V. Reppa in which robust invariance sets and ultimate bounds are derived in a set-theoretic context are discussed in Chap. 16. Finally, Chap. 17 concerns the minimal invariant set characterization by F. Stoican, C. Oara, and M. Hovd where the zonotopic disturbances are interpreted in dual terms of optimal control sequences.

It is clear from the flow of ideas throughout the various chapters that cases of the virtuous cycle of invention-discovery are demonstrated in this book. In the research areas pertinent to model-based optimization and control, it is illustrated how the persistent interaction between the dynamic “real-world challenges”-driven conceptual research (leading to new discoveries), and the consistent field trial of advanced scientific tools (leading to the invention of new scientific tools) play a fruitful role in scientific and technological progress with a huge potential societal impact.
**Intended Audience**

The book is intended to offer postgraduate students and researchers a perspective on new control problems involving optimization-based methods. It presents in a comprehensive manner the structural properties of the manipulated techniques, unveils the challenges, positions the research trends, and points to application from emerging fields. In this respect, it can be useful for both academic and industrial researchers.