Advances in Industrial Control

Panagiotis D. Christofides
Jinfeng Liu
David Muñoz de la Peña

Networked and Distributed Predictive Control

Methods and Nonlinear Process Network Applications

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Springer

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Series Editors' Foreword

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.

In some *Advances in Industrial Control* monographs, the author's perspective is one of looking back at successful developments that have found application in practice. Other monographs in the series explore future possibilities, presenting a coherent body of theory with supporting illustrative examples and case studies. This entry to the *Advances in Industrial Control* series, *Networked and Distributed Predictive Control: Methods and Nonlinear Process Network Applications* by Panagiotis D. Christofides, Jinfeng Liu, and David Muñoz de la Peña is a very persuasive exemplar of the "future possibilities" monograph category.

The starting point for the authors' development is the question: if a process has an existing point-to-point (hard-wired) control system, how do we design a networked control system (wired or, more in tune with recent technological developments, wireless) to augment the existing control and what performance benefits can be achieved? What follows from this is a thorough analysis and assessment of different control architectures blended with advanced control design methods. The control design techniques are selected as model predictive control for nonlinear processes but accommodating typical disruptive network characteristics of asynchronous feedback and communication delays.

The reader, whether an industrial engineer or academic researcher, will find a coherent theoretical development that unites model predictive control and Lyapunov stability methods as a control technique termed Lyapunov-based model predictive control. This is shown to have some nice properties of practical utility concerning closed loop stability and the stability region. The authors use this technique and progress through a sequence of increasingly advanced networked control system configurations, devoting a chapter to each particular control structure.

A major strength of the monograph is the attention given to careful and detailed process control examples and case studies that illustrate the characteristics and performance potential of individual networked control systems. One of these is an in-depth case study treatment of a wind–solar energy generation plant, whilst other examples are taken from the chemical process industries. All that is missing from these studies is an estimate of implementation costs and a cost benefit analysis! Process, chemical, and control engineers will find these simulated examples illuminating.

As a forward-looking monograph series on control design, technology, implementation and industrial practice, we are pleased to add this volume to the series as its first entry on networked control systems. As wireless control technology gains in reliability we expect to see many further theoretical and practical developments in this field. This monograph also complements the *Advances in Industrial Control* series's first entry on the closely related field of control using the Internet, so that readers may find the monograph, *Internet-based Control Systems: Design and Applications* (ISBN 978-1-84996-358-9) by Shuang-Hua Yang of interest.

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Preface

Traditionally, process control systems rely on control architectures utilizing dedicated, wired links to measurement sensors and control actuators to regulate appropriate process variables at desired values. While this paradigm to process control has been successful, we are currently witnessing an augmentation of the existing, dedicated control systems, with additional networked (wired and/or wireless) actuator/sensor devices which have become cheap and easy-to-install. Such an augmentation in sensor information, actuation capability and network-based availability of data has the potential to dramatically improve the ability of process control systems to optimize closed-loop performance and prevent or deal with abnormal situations more effectively. However, augmenting dedicated control systems with real-time sensor and actuator networks poses a number of new challenges in control system design that cannot be addressed with traditional process control methods, including: (a) the handling of additional, potentially asynchronous and delayed measurements in the overall networked control system, and (b) the substantial increase in the number of process state variables, manipulated inputs and measurements which may impede the ability of centralized control systems (particularly when nonlinear constrained optimization-based control systems like model predictive control are used), to carry out real-time calculations within the limits set by process dynamics and operating conditions.

This book presents rigorous, yet practical, methods for the design of networked and distributed predictive control systems for chemical processes described by nonlinear dynamic models. Beginning with an introduction to the motivation and objectives of this book, the design of model predictive control systems via Lyapunov-based control techniques accounting for networked control-relevant issues, like handling of asynchronous and delayed measurements, is first presented. Then, the book focuses on the development of a two-tier networked control architecture which naturally augments dedicated control systems with networked control systems to maintain closed-loop stability and significantly improve closed-loop performance. Subsequently, the book focuses on the design of distributed predictive control systems, that utilize a fraction of the time required by the respective centralized control systems, to cooperate in an efficient fashion and to compute optimal manipulated input trajectories that achieve the desired stability, performance, and robustness for large-scale nonlinear process networks. Throughout the book, the control methods are applied to large-scale nonlinear process networks and wind–solar energy generation systems and their effectiveness and performance are evaluated through detailed computer simulations.

The book requires basic knowledge of differential equations, linear and nonlinear control theory, and optimization methods and is intended for researchers, graduate students, and process control engineers. Throughout the book, practical implementation issues are discussed to help engineers and researchers understand the application of the methods in greater depth.

In addition to our work, Prof. James F. Davis, Dr. Benjamin J. Ohran, doctoral candidates Mohsen Heidarinejad and Xianzhong Chen, and doctoral student Wei Qi, all at UCLA, contributed substantially to the research results included in the book and in the preparation of the final manuscript. We would like to thank them for their hard work and contributions. We would also like to thank all the other people who contributed in some way to this project. In particular, we would like to thank our colleagues at UCLA and the Universidad de Sevilla for creating a pleasant working environment, and the United States National Science Foundation and the European Commission for financial support. Last, but not least, we would like to express our deepest gratitude to our families for their dedication, encouragement, and support over the course of this project. We dedicate this book to them.

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Abbreviations

CSTR	Continuous stirred tank reactor
DMPC	Distributed model predictive control
LCS	Local control system
LMPC	Lyapunov-based model predictive control
MPC	Model predictive control
NCS	Networked control system
PI	Proportional-integral
PID	Proportional-integral-derivative
RHC	Receding horizon control

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