Preface to the Second Edition

The continuing research activities in the field of Nonlinear Model Predictive Control have resulted in various new developments which were not represented in the first edition of this book. Five years after its publication we therefore proposed to write a second, significantly updated edition and we were glad that the Springer-Verlag immediately approved this proposal.

In order to maintain the character of the book as a mixture between a research monograph and an advanced textbook, we decided to limit the new material. We added two topics which have reached a certain level of maturity and to which we ourselves have made contributions—and which received widespread interest in recent years. This is on the one hand the new paradigm of Economic Nonlinear Model Predictive Control, in which more general optimal control problems than those penalizing the distance to a desired reference solution are considered. In Chap. 8 we provide a detailed presentation of the most important properties of the resulting closed-loop solution: averaged optimality, asymptotic stability of an optimal equilibrium, and finite time or transient optimality, both for formulations with and without stabilizing terminal conditions. On the other hand, Chap. 9 gives an introduction into Distributed Nonlinear Model Predictive Control. Here, we first develop an abstract framework for distributed schemes and their feasibility and stability, and then show how a number of schemes proposed in the literature fit into this framework. Beyond these two new chapters, the material in the remaining chapters has been updated and all typos and inaccuracies we were aware of have been corrected. Most importantly, with Proposition 6.19 we have provided an alternative simplified version of Proposition 6.18 as the main building block for the analysis of schemes without terminal constraints. While being more conservative, Proposition 6.19 allows for a considerably simpler proof than Proposition 6.18, which is thus also suitable for presentation in lectures.

Like the first edition, the present second edition also benefitted from the help of many people. We would like to thank Frank Allgöwer, David Angeli, Bob Bitmead, Andrea Boccia, Philipp Braun, Moritz Diehl, Timm Faulwasser, Rolf Findeisen, Arthur Fleig, Matthias Gerdts, Achim Ilchmann, Chris Kellett, David Mayne, Matthias A. Müller, Vryan Gil Palma, Simon Pirkelmann, Jim Rawlings, Marcus

Reble, Willi Semmler, Tobias Sprodowski, Marleen Stieler, Andy Teel, Steve Weller, Karl Worthmann, and Mario Zanon for valuable discussions and critical comments on the material presented in this book, for joint research leading to new results presented or at least mentioned in this book, for pointing out inaccuracies and suggesting improvements and for proofreading the new chapters. LG particularly thanks Chris Kellett and Steve Weller for their fantastic hospitality during his sabbatical at the University of Newcastle, Australia. Finally, we thank Oliver Jackson from Springer for his continuing excellent support.

Bayreuth, Germany Lars Grüne
Bremen, Germany Jürgen Pannek
June 2016

Preface to the First Edition

The idea for this book grew out of a course given at a winter school of the International Doctoral Program "Identification, Optimization and Control with Applications in Modern Technologies" in Schloss Thurnau in March 2009. Initially, the main purpose of this course was to present results on stability and performance analysis of nonlinear model predictive control algorithms, which had at that time recently been obtained by ourselves and coauthors. However, we soon realized that both the course and even more the book would be inevitably incomplete without a comprehensive coverage of classical results in the area of nonlinear model predictive control and without the discussion of important topics beyond stability and performance, like feasibility, robustness, and numerical methods.

As a result, this book has become a mixture between a research monograph and an advanced textbook. On the one hand, the book presents original research results obtained by ourselves and coauthors during the last 5 years in a comprehensive and self-contained way. On the other hand, the book also presents a number of results—both classical and more recent—of other authors. Furthermore, we have included a lot of background information from mathematical systems theory, optimal control, numerical analysis, and optimization to make the book accessible to graduate students—on PhD and Master level—from applied mathematics and control engineering alike. Finally, via our web page www.nmpc-book.com we provide MATLAB and C++ software for all examples in this book which enables the reader to perform his or her own numerical experiments. For reading this book, we assume a basic familiarity with control systems, their state space representation as well as with concepts like feedback and stability as provided, e.g., in undergraduate courses on control engineering or in courses on mathematical systems and control theory in an applied mathematics curriculum. However, no particular knowledge of nonlinear systems theory is assumed. Substantial parts of the systems theoretic chapters of the book have been used by us for a lecture on nonlinear model predictive control for master students in applied mathematics and we believe that the book is well suited for this purpose. More advanced concepts like time varying formulations or peculiarities of sampled data systems can be easily skipped if only time invariant problems or discrete time systems shall be treated.

The book centers around two main topics: systems theoretic properties of nonlinear model predictive control schemes on the one hand and numerical algorithms on the other hand; for a comprehensive description of the contents we refer to Sect. 1.3. As such, the book is somewhat more theoretical than engineering or application-oriented monographs on nonlinear model predictive control, which are furthermore often focused on linear methods.

Within the nonlinear model predictive control literature, distinctive features of this book are the comprehensive treatment of schemes without stabilizing terminal constraints and the in-depth discussion of performance issues via infinite horizon suboptimality estimates, both with and without stabilizing terminal constraints. The key for the analysis in the systems theoretic part of this book is a uniform way of interpreting both classes of schemes as relaxed versions of infinite horizon optimal control problems. The *relaxed dynamic programming* framework developed in Chap. 4 is thus a cornerstone of this book, even though we do not use dynamic programming for actually solving nonlinear model predictive control problems; for this task we prefer direct optimization methods as described in the last chapter of this book since they also allow for the numerical treatment of high-dimensional systems.

There are many people whom we have to thank for their help in one or the other way. For pleasant and fruitful collaboration within joint research projects and on joint papers—of which many have been used as the basis for this book—we are grateful to Frank Allgöwer, Nils Altmüller, Rolf Findeisen, Marcus von Lossow, Dragan Nešić, Anders Rantzer, Martin Seehafer, Paolo Varutti, and Karl Worthmann. For enlightening talks, inspiring discussions, for organizing workshops and minisymposia (and inviting us) and, last but not least, for pointing out valuable references to the literature we would like to thank David Angeli, Moritz Diehl, Knut Graichen, Peter Hokayem, Achim Ilchmann, Andreas Kugi, Daniel Limón, Jan Lunze, Lalo Magni, Manfred Morari, Davide Raimondo, Saša Raković, Jörg Rambau, Jim Rawlings, Markus Reble, Oana Serea and Andy Teel, and we apologize to everyone who is missing in this list although he or she should have been mentioned. Without the proofreading of Nils Altmüller, Robert Baier, Thomas Jahn, Marcus von Lossow, Florian Müller, and Karl Worthmann the book would contain even more typos and inaccuracies than it probably does—of course, the responsibility for all remaining errors lies entirely with us and we appreciate all comments on errors, typos, missing references, and the like. Beyond proofreading, we are grateful to Thomas Jahn for his help with writing the software supporting this book and to Karl Worthmann for his contributions to many results in Chaps. 6 and 10, most importantly the proof of Proposition 6.18. Finally, we would like to thank Oliver Jackson and Charlotte Cross from Springer-Verlag for their excellent support.

Bayreuth, Perth
April 2011

Lars Grüne
Jürgen Pannek

Springer

http://www.springer.com/978-3-319-46023-9

Nonlinear Model Predictive Control
Theory and Algorithms
Grüne, L.; Pannek, J.
2017, XIV, 456 p. 80 illus., 22 illus. in color. With online files/update., Hardcover
ISBN: 978-3-319-46023-9