Advances in Industrial Control

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Editors

Case Studies in Control

Putting Theory to Work

Springer

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ISSN 1430-9491
ISSN 2193-1577 (electronic)
Advances in Industrial Control
ISBN 978-1-4471-5175-3
ISBN 978-1-4471-5176-0 (eBook)
DOI 10.1007/978-1-4471-5176-0
Springer London Heidelberg New York Dordrecht

Library of Congress Control Number: 2013941384

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

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.

Topics that arise from the interaction between control systems theory and the industrial practice of control in all its aspects have always been the focus of the *Advances in Industrial Control* monograph series. Some monographs in the series are solely about control theory that might find industrial application; others are concerned with the control problems in a particular industrial applications domain. A third class of monograph in the series begins from a particular control system theory framework and demonstrates its implementation using a simulated or an actual industrial application. Very few monographs in the series analyse in depth the general issues involved in the transfer or translation of control theory into industrial control engineering practice. For this reason, the Series Editors welcome the inclusion of *Case Studies in Control: Putting Theory to Work* edited by Stanko Strmčnik and Đani Juričić in the *Advances in Industrial Control* series.

In the opening chapter of this monograph, one of the classifications made is of "plant control systems" and "product control systems". Examples of plant control systems might be those of a cold-rolling steel mill, a wastewater-treatment process, an automobile-manufacturing production line, or a home central-heating system whilst examples of a product control system are those for a washing machine, or a CD/DVD disc-drive unit. Another aspect of this classification is whether the control engineer is contributing to the design of a process or product that has yet to be constructed, or whether the process or product already exists and has an existing control system that is being redesigned, or upgraded. These are just some of the typical factors that the monograph authors identify as complicating a description of the

control theory input to industrial engineering. To resolve these types of issues, the authors use their extensive control experience to seek a generic framework for the involvement of control theory. Their solution is to present a life-cycle perspective for the control system design and realisation activity. The totality of this activity then forms the basis for a "systems engineering" paradigm. These are fascinating topics that are not very often analysed or discussed in the control monograph literature yet they form a very significant component of the real industrial control engineer's lot; indeed more monographs on systems engineering would be very welcome in the series.

After this detailed introductory chapter, the contributing authors of *Case Studies in Control* proceed to share their experience of introducing advanced control theory into several industrial processes. Typical of the applications are an ammoniacal-nitrogen-removal process in a wastewater treatment plant and the temperature control in a plastic extruder machine. Towards the end of each chapter is a valuable section entitled either *Problems and Limitations in Applying the Theory* or *Discussion in the Context of Theory/Practice Issues* that gives an assessment of the successes or the shortcomings of the approach taken. Sometimes the academic control theory has to be modified to match the context and requirements of the application and sometimes the advanced control approach does not yield the benefits expected. The later chapters (Part III) of the monograph look at controller prototyping, a PLC-based development system for control and process-control-system-software engineering, respectively.

The breadth of the monograph's contents ranging from "theory into practice" generalities through the case studies of control applications to the material on control software implementation issues ensures that it will appeal to a wide range of readers. This readership will be from both the industrial and academic communities and this further intimates that *Case Studies in Control: Putting Theory to Work* is a very appropriate addition to the *Advances in Industrial Control* series.

Industrial Control Centre M.J. Grimble
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Foreword

Based on the experience with case studies the book treats the relations between theory and practice of automatic control systems. After a discussion of the so called gap between theory and practice the book presents in three parts contributions to adapt some theoretical control concepts to practical problems in general, to provide practical solutions to the control of concrete processes and to present tools and building blocks for the control software implementation. The considered processes are mainly from the industrial process industries for which valuable experience was gained in the Department of Systems and Control of the Jožef Stefan Institute in Ljubljana.

The general status of control implementation and performance is now quite mature in such areas as industrial processes, manufacturing, buildings, and transportation. Most important are still the control-oriented design of the process itself and an appropriate selection and placement of measurements and actuators, i.e. issues during design and construction. The commercially available digital control equipment then allows to configure various feedback controllers, mostly with PI-(proportional-integral), PID-(proportional-integral-derivative) or on-off behaviour and feedforward control. Their parameters are tuned by rules of thumb and probing, sometimes with implemented self-tuning aids. For processes with large dead times internal model control (an expanded Smith predictor) is occasionally used. The controller parameters may be adapted depending on the operating point, i.e. use is made of feedforward adaptive control. Strongly non-linear behaviour is mostly partially compensated by static non-linear characteristics.

However, many of the advanced control methods developed in the last three decades are not or only seldom used in practice. Examples are state controllers with observers, predictive control, fuzzy control, neural control, and multivariable and adaptive control.

This book now first analyses the relationships between theory and control engineering practice by discussing e.g. various views, the complexity, the life cycle from requirements engineering to operation and disposal, the lack of joint process and control design, different disciplines and players. It is then shown by presenting the results of different case studies, how different control approaches compared

to conventional ones lead to improvements or not and how the final results were obtained.

Hence, this book shows the advantages of theoretical pre-design stages and the adaptation of the control methods during the implementation to practical needs. Therefore it shows how the so called gap can be decreased and overbridged.

Technische Universität Darmstadt Prof. Dr.-Ing. Dr. h.c. Rolf Isermann
Darmstadt, Germany
5 February 2013

Preface

Control is a ubiquitous technology that guarantees functionality and predictable operation of devices, machines, vehicles, plants, etc. New challenges for control designers emerge as a result of the increasing complexity of the new generation of systems and processes. The effective creation of workable solutions under physical, economic, social, human, and other constraints is therefore of significant practical importance. In real life it usually turns out to be a creative blend of rigorous control theory and the art of engineering where "details" can take a substantial effort and creativity. However, the vast majority of published books concentrate on control theory issues. On the other hand, there is a tiny minority that concerns putting theory to work, i.e. they treat the overall process of the design and implementation of real-life control systems in a more holistic manner. This book belongs to that minority.

The aim of this book is to present a comprehensive view of the relation between theory and practice, on the one hand, and to demonstrate different ways of putting theory to work, on the other. The latter is a two-way process. It goes from theory and brings theoretical methods closer to practical use. On the other hand, it might start from practice and seek a proper theory for solving practical problems. An important backing process that helps put theory to work is the development of tools and building blocks for efficient implementation of (advanced) control solutions. Following this concept, the contributions are organised into the introductory chapter and three sets of chapters dedicated to particular case studies.

The introductory chapter analyses the relationship between control theory and control engineering design. The latter can be understood as the mapping of functional and non-functional control system requirements to solutions. By assessing the potential of control theory to fulfil particular requirements one can gain a more objective picture of the role of control theory and, at the same time, an improved understanding of the well known theory/practice gap.

In the first group of chapters, the emphasis is on shaping theory to solve particular practical problems. Starting from an abstraction of reality and developing the control solution on a model of reality, the natural question is whether the solution will perform properly in the real world. Chapters 2 through 5 stress the importance

of assessing ideas beyond simulation by means of assorted experimental conditions in real processes. The case studies presented in this part address identification and control using piece-wise Hammerstein models, explicit model predictive control, non-linear control using divide-and-conquer methods, and advanced control of biological wastewater treatment processes.

In contrast to the first group, Chaps. 6 through 9 start from the needs and requirements defined by end users and conclude with practical solutions. Here the engineering approach prevails, while the extent of the theory used varies from case to case and depends on a large number of different factors. In this part of the book the following case studies are addressed: self-tuning temperature control of a blow-moulding machine, tension control in a steel slitting line, quality control in the manufacturing of electrical motors, and model-based quality assessment of burn-protective garments.

The third group of contributions is related to the development of tools and building blocks that enable more efficient use of the advanced methods. This segment has often been somewhat neglected by researchers. Moreover, contrary to expectations, in many cases the commercially available tools fail to fully comply with all the designer's needs. The last three contributions, Chaps. 10 through 12, discuss a rapid prototyping environment for control systems implementation, a PLC-based advanced controller, and a model-based approach to control software development.

Each of the contributions finishes with a closing section in which a summary of the most instructive experiences are outlined. Although the views expressed are subjective, they are deemed to deepen the understanding of the gap.

The book addresses a broad readership, foremost engineers and scientists with less first hand experience in practical applications. It might prove to be instructive for graduate and postgraduate students, who will gain a flavour of the importance of the interplay between engineering and scientific problem solving in advanced control applications. In that respect, it can also help educators at universities interested in enriching curricula in a way so as to disseminate ideas by rightly pointing out the merit of the entire life cycle. In addition, it is hoped that the positive experience documented in the case studies motivate researchers in academia to increasingly address real-life problems or at least keep an eye on the target application areas when shaping the research agenda. Finally, the book might be of interest to all those exposed to the gap, i.e. engineers in industry, consultancies, and system integrator enterprises, who will learn from these interesting case studies how theory can be applied to specific problems under particular requirements and constraints.

The contributors to the book (mainly members of the Department of Systems and Control at the Jožef Stefan Institute) have been working together for many years on putting theory to work. This has been done through basic and applied research projects, as well as through numerous real-life applications for a wide range of industrial users. We would like to thank all of them for putting the case studies into a form in which their knowledge and experience can be of help to a broad spectrum of potential readers. We would also like to thank Mr. Dean J. DeVos for English

language editing of the book, as well as Mrs. Jolanda Karada, Mr. Miro Štrubelj, Mr. Miha Glavan, and Mr. Jernej Mrovlje for assisting in preparing the material in a form suitable for printing. Finally, many thanks go to Springer personnel, especially Ms. Charlotte Cross and Mr. Oliver Jackson for invaluable help in bringing this project to a successful conclusion.

Ljubljana, Slovenia
December 2012

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