
Preface

Modern means of communication make it easy to connect system components whenever information links may contribute to improving the overall system performance. Actuators, sensors and controllers can now exchange information from nearly any place within a technological system, and wireless connections allow to implement advanced control technology for mobile objects. Due to this flexibility, a new challenge for control theory is to elaborate systematic ways for the selection of information structures that are suitable for a given control task.

This new freedom in choosing the information topology of control systems is associated with some nondeterminism of the behavior of digital networks. As many networks used for control purposes act simultaneously as communication medium for other tasks, time delays in the delivery of the information or packet loss regularly occur and the controllers have to be made tolerant with respect to such imperfections.

Both, the flexibility of the communication structure and the imperfection of the communication links pose new challenges for the design and the implementation of control systems and have brought about *networked control systems* as a new area of control theory. This book gives a concise introduction to this area and describes new modelling paradigms, analysis methods for digitally networked dynamic systems, and design methods for distributed controllers. It provides an overview of the problems, methods and application areas that have been tackled in the recent past and which will initiate new development directions in industry in the near future.

Networked control systems cannot be handled with traditional methods for two reasons. First, the *event-driven mode of operation* of networked systems violates the precondition of discrete-time control theory that data is processed and transmitted with a constant sampling rate. Several chapters of this book are concerned with control problems in which event generators rather than clocks initiate the next communication, computation and control steps.

Second, the structure of the communication network is usually not predefined but the subject of control design. The data links may even adjust themselves to the needs and the technological constraints during operation. Under these circumstances, the question "*Which information is necessary to solve a control task?*" has stimulated the second leading research line of this book.

The tight combination of communication and control has direct consequences for the development of advanced control systems in industry. Networked systems open the way towards novel application areas like multi-agent systems that are controlled over wireless communication networks or smart grids of intelligent components that are supervised remotely. It broadens the importance of control in intelligent transportation systems, health care services, smart buildings, or telerobotics, just to name a few. Some of these applications are discussed in this book.

Structure and readership. The book is structured into seven chapters, each of which is devoted to one of the research problems that are currently discussed in the international literature and at all major control conferences:

1. **Introduction to networked control systems**
describes the motivation and surveys the main problems to be solved by the control theory of networked systems.
2. **Analysis of networked systems**
presents important properties of dynamic systems that are controlled over digital communication networks.
3. **Distributed estimation and control**
describes methods for state estimation and optimization of systems that are composed of subsystems with local control stations, which communicate over a data network.
4. **Distributed and networked model predictive control**
develops methods for distributed control algorithms that tolerate time delays and packet loss.
5. **Event-based control**
surveys six different approaches to replace the traditional periodic sampling by event-based triggering schemes.
6. **Multi-agent systems**
proposes new methods for controlling systems that have to satisfy a common control goal.
7. **Wireless networking for control**
investigates the requirements on the digital communication network, which is used for control purposes, and describes methods for the cross-design of control and communication.

The book is written as a **survey of recent results** on networked control systems with references to numerous journal papers and conference presentations, in which the ideas have been originally presented together with the formal proofs. Emphasis is laid on the presentation of the main results and the illustration of these results by examples. Each chapter starts with an

introduction to the problems considered, which includes a statement on how the chapter extends the current knowledge about networked control systems.

The results are presented in a uniform style, notation and terminology. Many cross-references show how the different lines of research belong together. The references are organized as a comprehensive list at the end of the book.

The intended readers of the book are graduate students, PhD students and researchers in control, communication, or mathematics, as well as practicing engineers with knowledge in systems theory who want to get an introduction to the main problems of networked control together with an up-to-date survey of recent results. Interesting practical examples illustrate the applicability of the methods and **extensive bibliographical notes** point to the origins of the presented ideas and the current research lines. The evaluation of the methods and the application results should help the reader to assess the available methods and the limits of the present knowledge about networked control with respect to their particular field of interest.

Priority Program 1305 of the German Research Foundation. The book presents, in a concise way, the results obtained by the participants of the Priority Program 1305 on *Control Theory of Digitally Networked Dynamic Systems* of the German Research Foundation (DFG). In this program, 17 PhD students have been working between 2007 and 2013 in 13 different research groups situated in control, mathematics, or communication departments at German universities. The book describes the research interests, the results, and the common expertise of 42 authors. All sections are co-authored by several researchers who have contributed to the corresponding topic. The authors are mentioned in alphabetic order with the responsible author first.

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