Preface

The accelerated integration and convergence of communications, computing, and control over the last decade has inspired researchers and practitioners from a variety of disciplines to become interested in the emerging field of networked control systems (NCS). In general, a NCS consists of sensors, actuators, and controllers whose operations are distributed at different geographical locations and coordinated through information exchanged over communication networks. Some typical characteristics of those systems are reflected in their asynchronous operations, diversified functions, and complicated organizational structures. The widespread applications of the Internet have been one of the major driving forces for research and development of NCS. More recently, the emergence of pervasive communication and computing has significantly intensified the effort of building such systems for control and management of various network-centric complex systems that have become more and more popular in process automation, computer integrated manufacturing, business operations, as well as public administration.

Control over a communication network is not a new concept in automation. From tele-operation for space and hazardous environments to process regulation with distributed control systems, control systems with communications have already been developed and utilized in applications of real-world problems for more than 30 years. However, there are many factors that distinguish the current NCS and previous control with communications. Two of them are the most significant: (1) in the previous control with communications, the network is specialized and dedicated for the timeliness of information exchange and stability of process operation, while in the current NCS the network is general-purpose and public for various irrelevant yet concurrent applications, and thus real-time communication and stable operation are no longer ensured; (2) the functionality of the NCS from the previous to current has been diversified tremendously, from pure control to a variety of control and management or administrative functions, ranging from resource allocation, event scheduling, to task organization, etc., involving concept and methods from control and communication engineering, operations research, computer science, and management science.

Demands on diversity, complexity, and real-time performance for networked operations have brought new technological challenges to NCS. Today, many fundamental questions regarding the stability of interconnected dynamical systems, the effects of communication on the performance of control systems, etc., remain open and to be answered. Even from the perspective of control field alone, we need to think about what the new direction for research and application in this age of connected world would be. One potential approach is to extend the concept of "code on demands" with agent programming to "control on demands" with agent-based control (so called ABC). In other words, can we liberate control algorithms that are fixed to plants to be controlled to control agents that are free and mobile in a connected world? Once this is accomplished, various innovative methods based on connectivity can be employed for control and management, e.g., using "local simple, remote complex" principle to design low cost yet high performance and intelligent NCS that require less computing power, small memory space, and little upgrading. Indeed, there are many new, exciting, and challenging ideas, problems, and concepts in the emerging field of networked control systems.

This book is a follow up effort after the publication of the special issue on "Networking, Sensing, and Control for Networked Control Systems: Architectures, Algorithms, and Applications" in the *IEEE Transactions on Systems, Man, and Cybernetics–Part C*, vol. 37, no. 2, Mar. 2007. The book includes eleven chapters written by leading experts in NCS and addresses some of the questions and problems discussed above.

We start the book with two review chapters. The first chapter by Gupta and Chow provides an overview of NCS, its history, issues, architectures, components, methods, and applications. A case study of NCS with test-bed system iSpace is also described in this chapter. Chapter 2 by Wang presents the history and issues of agent-based control and management for NCS from the perspective of his own research group. He argues and calls for a paradigm shift from control algorithms to control agents so that agent-based control can be established as the new control mechanism for operation and management of networked devices and systems. The goal of his agent-based approach is to transform "code on demand" in programming into "control on demand" in control, and provides a platform for designing and building low cost but high performance networked equipment in the age of connectivity.

The remaining chapters address specific issues in design, analysis, and implementation of NCS. In Chapter 3, considering the fact that the design and implementation of many digital systems have been based on the emulation of idealized continuous-time blocks, and in analogy with sampled-data control system design, Tabbara, Nesic, and Teel explore an emulation-based approach to the analysis and design of NCS. For this purpose, they survey a selection of emulation-type NCS results in the literature and highlight the crucial role that scheduling between disparate components of the control systems plays.

They then detail several different properties that scheduling protocols need to verify together with appropriate bounds on inter-transmission times such that various notions of input-output stability of the nominal "network-free" system are preserved when deployed as an NCS. This could be an important method for designing NCS in the future. In Chapter 4, Liu addresses issues in analysis and design of NCS based on a novel control strategy, termed networked predictive control. The stability of the closed-loop networked predictive control system is analyzed. The analytical criteria are obtained for both fixed and random c ommunication time delays. The on-line and real-time simulation of networked predictive control systems is presented in detail.

In Chapter 5, Yue, Han, and Lam discuss the design of robust H_∞ controllers and H_∞ filters for uncertain NCS with the effects of both network-induced delay and data dropout taken into consideration. In this chapter, a new analysis method for H_∞ performance of NCS is provided by introducing slack matrix variables and employing the information of the lower bound of the network-induced delay. Numerical examples and simulation results are given to illustrate the effectiveness of their proposed method. In Chapter 6, Nikolakopoulos, Panousopoulou, and Tzes propose a switched output feedback control scheme for networked systems, and apply the scheme to client–server architectures where the feedback control loop is closed over a general purpose wireless communication channel between the plant (server) and the controller (client). To deal with network delay effects, a linear quadratic regulator (LQR)-output feedback control scheme is introduced, whose parameters are tuned according to the variation of the measured round trip latency times. The overall scheme resembles a gain scheduler controller with the latency times playing the role of scheduling parameter. The proposed control scheme is applied in both experimental and simulation studies to an NCS over different communication channels.

Yang and Zhang in Chapter 7 have developed a guaranteed cost networked control (GCNC) method and established the corresponding stability for Takagi–Sugeno (T–S) fuzzy systems with time delay. Both analytical studies and simulation results show the validity of their proposed control scheme. A robust H_∞ networked control method for T–S fuzzy systems with uncertainty and time delay is also presented in this chapter, along with sufficient conditions for robust stability with H_∞ performance. In Chapter 8, Sun and Wu have proposed a discrete-time jump fuzzy system for the modeling and control of a class of nonlinear NCS with random but bounded communication delays and packets dropout. In this chapter, a guaranteed cost control with state feedback is developed by constructing a sub-optimal performance controller for the discrete-time jump fuzzy systems in such a way that a piecewise quadratic Lyapunov function (PQLF) can be used to establish the global stability of the resulting closed-loop fuzzy control system. When not all states are available, an output feedback controller is designed. For the NCS based on the mixed networks, a neuro-fuzzy controller is developed. Simulation examples are carried out to show the effectiveness of their proposed approaches. Chen in Chapter 9 investigates the boundary control of damped wave equations using a boundary measurement in an NCS setting. In his approach, induced delays in this networked boundary control system are lumped as the boundary measurement delay. The Smith predictor is applied to this problem and the instability problem due to large delays is solved and the scheme is proved to be robust against a small difference between the assumed delay and the actual delay. He also analyzes the robustness of the time-fractional order wave equation with a fractional order boundary controller subject to delayed boundary measurement.

The last two chapters address two basic methods for NCS. In Chapter 10 Li and Wang discuss the coordination mechanism of multi-agent systems using an adaptive velocity strategy. In previous works, much attentions and correlative efforts for swarm intelligence have been focused on constant speed models in which all agents are assumed to move with the same constant speed. In this chapter, they have proposed an adaptive velocity model with a more reasonable assumption in which every agent not only adjusts its moving direction but also adjusts its speed based on the degree of direction consensus among its local neighbors. The adaptive velocity model provides a powerful mechanism for coordinated motion in both biological and technological multi-agent systems. In Chapter 11, Yu and Wang study the robust synthesis problem for strictly positive real (SPR) transfer functions. By using the complete discrimination system (CDS) for polynomials, complete characterization of the (weak) SPR regions for transfer functions in coefficient space is given. They have proposed an algorithm for robust design of SPR transfer functions. Their algorithm works well for both low-order and high-order polynomial families.

Finally, as the editors of the book, we would like to express our sincere appreciation to all authors for their time and effort, and to Springer's Engineering Associate Editor Oliver Jackson for his patience and great help. Although every effort has been made to include a wide spectrum of methods and applications in this emerging field, a book like this can only include a rather small number of selected chapters, and we must say that the coverage here is by no means comprehensive.

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