Preface

From a technological viewpoint, networked control systems (NCSs) are comprised of the system to be controlled and of actuators, sensors, and controllers whose operation is coordinated through some form of communication network. The widely accepted feature of NCSs is that the component elements are spatially distributed and may operate in an asynchronous manner, but have their operation coordinated to achieve some overall objective. In this regard, the proliferation of these systems has raised fundamentally new questions in communications, information processing, and control, dealing with the relationship between operations of the network and the quality of the overall system operation. A wide range of recent research activities have been dealing with problems related to controlling the formation of ad hoc networks of spatially distributed systems, system-dependent data rate requirements in digital feedback channels, real-time fusion and registration of data from distributed heterogeneous sensors, and the theory of cooperative control of networks of autonomous agents.

To shed light on the evolution of control technology, one can trace the timeline of the technological evolution from classical feedback control to digital control to networked control. The early work dealt in an increasingly rigorous way with design principles of specific feedback systems. A solid theoretical foundation for frequency domain methods was subsequently laid by many pioneering scientists. By the mid 1950s, there was growing interest in the use of digital computers as instrumentation for feedback control. In passing from the continuous-time/continuous-state models used in classical feedback designs to the discrete-time/quantized-state design of digital control, design choices involving sampling rates, effects of finite word length, and compensation for phase lags needed to be made. After half a century of research and implementation experience, the foundations of digital control theory are now firmly established and can be found in textbooks.

Control systems with spatially distributed components have existed for several decades. Examples include chemical processes, refineries, power plants, and airplanes. In the past, in such systems, the components were connected by hardwired connections, and the systems were designed to bring all the information from the sensors to a central location where the conditions were being monitored and decisions were taken on how to act. The control policies then were implemented via the actuators, which could be valves, motors, etc.

What is different today is that technology can put low-cost processing power at remote locations via microprocessors, and that information can be transmitted reliably via shared digital networks or even wireless connections. These technology-driven changes are fueled by the high costs of wiring and the difficulty in introducing additional components into the systems as the needs change. In 1983, Bosch GmbH began a feasibility study of using networked devices to control different functions in passenger cars. This appears to be one of the earliest efforts along the lines of modern networked control. The study bore fruit, and in February 1986, the innovative communications protocol of the Control Area Network (CAN) was announced at the Congress of the Society of Automotive Engineers, Detroit, MI. By mid-1987, CAN hardware in the form of Intel's 82526 chip had been introduced, and today, virtually all cars manufactured in Europe include embedded systems integrated through CAN. NCSs are found in abundance in many technologies, and all levels of industrial systems are now being integrated through various types of data networks.

Throughout this book, the following terminologies, conventions, and notations have been adopted. All of them are quite standard in the scientific media and only vary in form or character. Matrices, if their dimensions are not explicitly stated, are assumed to be compatible for algebraic operations. In symmetric block matrices or complex matrix expressions, we use the symbol $\bullet$ to represent a term that is induced by symmetry.

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