# Preface

The purpose of this volume in the newly established series Advances in Delays and Dynamics (ADD@S) is to provide a collection of recent results on the design and analysis of *Delays and Networked Control Systems*.

Networked systems represent today a general paradigm for describing phenomena in various domains such as Biology (for genes transcription networks or models of schools of fishes), Robotics (in teleoperated manipulators for medical applications or in coordinated unmanned vehicles), Computer Sciences (congestion control and load balancing in the Internet management), Energy Management (in electric grids), Traffic Control (fluid models of traffic flow), etc. The analysis and design of networked systems represents nowadays an important challenge in the Automatic Control community.

An enormous scientific and industrial interest has been shown in Networked Control Systems, which are ubiquitous in most of modern control devices. A Networked Control System (NCS) is a control system wherein its components (plants, sensors, embedded control algorithms and actuators) are spatially distributed. The defining feature of an NCS is that control and feedback signals are exchanged among the system's components in the form of digital information packages. The primary advantages of an NCS are reduced wiring, ease of diagnosis, and maintenance and increased flexibility. Despite these advantages, the use of communication networks also introduces several imperfections: limited information bandwidth, communication delays, complex interactions between control algorithms, real-time scheduling protocols, etc. Such imperfections may lead to poor system performances and even instability if not appropriately taken into account. The practical and theoretical challenges brought in the context of NCS rely on the consideration of the imperfections induced by the use of communication networks in control loops.

Several models have been proposed as abstractions to the complex phenomena occurring in NCS. The use of time-delay models is unavoidable in NCS since the transmission of information through a network is not instantaneous. The challenge here is to deal with the infinite dimensional nature of the obtained system.

Network links with limited capacity and bandwidth can be modeled in various manners. The first model consists of including into the control loop a *quantization* process, which basically constrains a signal evolving in a continuous set of values to a relatively small and possibly *saturated* discrete set. Another model has been proposed to describe the discretization in time of the exchanged information. Embedded control algorithms use *sampled versions* of the system state or output. The difficulty lies in fact that, in real time applications, sampling is often generated in an asynchronous manner. This issue makes the analysis and design of NCS a complex task. On one side, this asynchronism may represent an undesired phenomena (jitter or packet dropout) and it may be a source of instability. From the control theory point of view, it must be taken into account in a robust manner. On the other side, one may deliberately introduce asynchronism in the control loop via scheduling algorithms, in order to reduce the number of data transmissions and, therefore, optimize the computational costs. This corresponds to the recent research trend of *event-based control* where a data is transmitted only if a particular event has occurred.

The new challenges for control design of networked systems are particularly evident in large-scale interconnection of multiagent systems. For example, in formation and cooperation control, it is not reasonable, from the practical point of view, to allow all-to-all communication. Each agent has only a *local view* of the overall network and he may not be able to store and manipulate the complete state of the system. Hence, an agent is able to exchange information only with its neighbors in the space or in the communication graph.

The chapters in this volume deal with several aspects of time delays and networked systems. In the literature many different techniques have been proposed for the analysis and design of such systems. Widely used techniques include *Lyapunov*-based analysis and design in the time domain, and *spectral methods* in the frequency domain. The reader will find examples of these techniques in this volume. The main ideas of the individual papers included here were presented and discussed at a workshop organized by the International Scientific Coordination Network on Delay Systems (DelSys) in November 2013 at LAAS, Toulouse, France. The International scientific coordination network on Delay Systems DelSys, supported by the French Center Scientific Research (CNRS) gathers several European research teams working in the field of time-delay systems. The main objectives of "DelSys" are twofold: first, to better organize the European research on such topics and second to better emphasize the research trends in the field.

The book is collected under the following parts:

## Part I Delays in Large Scale and Infinite Dimensional Systems

The first part of the book is concerned with the presentation of recent tools for the analysis of time-delay systems. In the following chapters, a particular attention will be paid on several classical analyses and control problems of large scale or infinite dimensional systems with delays.

The first chapter by *Islam Boussaada* and *Silviu-Iulian Niculescu* deals with the study of the multiplicity of imaginary crossing roots in some networks with delays. The proposed method is based on the properties of the Vandermonde matrices, which is proved to be an appropriate method to solve this problem. The second chapter by *Michaël di Loreto, Sérine Damak*, and *Sabine Mondié* addresses the problem of stability, stabilization, and control of a network of conservation laws. The method is based on the construction of a state-space realization for networks of linear hyperbolic conservation laws for deriving sufficient conditions for stability and stabilization of the systems. This part ends with a chapter by *Igor Pontes Duff, Pierre Vuillemin, Charles Poussot-Vassal, Corentin Briat,* and *Cédric Seren*. The chapter introduces a novel method for the model reduction of large scale time-delay systems using norm approximation. The method detailed in this work aims at overcoming some limitations by exploiting the recent $\mathscr{H}_2$ model reduction results for linear time invariant systems, which is well adapted to approximate infinite dimensional models.

## Part II Control Systems Under Asynchronous Sampling

The second part of the book focuses on the analysis and design of systems with asynchronous sampling intervals which occur in Networked Control Systems. Both linear and nonlinear systems are being considered.

The first chapter, by *Sylvain Durand*, *Nicolas Marchand* and *José Fermi Guerrero-Castellanos*, revisits the classical "universal stabilizer formula" in an event-triggered control configuration. The case of nonlinear systems affine in the control with delay in the state is considered using the existence of Control Lyapunov–Krasovskii/-Razumikhin functionals. The second chapter, by *Hassan Omran*, *Laurenţiu Hetel*, *Jean-Pierre Richard* and *Françoise Lamnabhi-Lagarrigue*, addresses the stability of bilinear systems with aperiodic sampled-data state-feedback controllers. The analysis is based on a hybrid system model and the use of linear matrix inequalities (LMI) criteria that allow to asses the local stability of the closed-loop system. The third chapter, by *Alexandre Seuret* and *Corentin Briat*, provides new LMI conditions for the stability of asynchronous sampled-data linear systems with input delay. The analysis is performed by the use of the Lyapunov–Krasovskii method and of loop functionals that allow to take into account the variations of the sampling interval. Chapter 4, by *Mahmoud Abdelrahim*, *Romain Postoyan*, *Jamal Daafouz* and *Dragan Nešić*, presents results for the synthesis of output event-triggered controllers for nonlinear systems. The key idea of the approach is to combine techniques from event- and time-triggered control, in order to turn the sampling mechanism on only after a fixed amount of time has elapsed since the last transmission.

## Part III Time-Delay Approaches in Networked Control Systems

The third part is dedicated to the use of time-delay models for the analysis and design of Networked Control Systems.

In the first chapter, by *Francesco Ferrante*, *Frédéric Gouaisbaut* and *Sophie Tarbouriech*, the effect of quantization is analyzed for control of linear systems with input delays. The saturating quantizer is studied locally, using convex optimization methods, using some modified sector conditions. The second chapter, by *Kun Liu*, *Emilia Fridman* and *Karl H. Johansson*, investigates the use of the time-delay approach for the analysis of Networked Control Systems under scheduling protocols. The key idea is to tackle the stability problem using delay dependent Lyapunov–Krasovskii methods. In the third chapter, by *Xu-Guang Li*, *Arben Cela*, and *Silviu-Iulian Niculescu*, networked control systems with hypersampling periods are analyzed. Stability regions are computed for linear systems using parameters sweeping techniques.

## Part IV Cooperative Control

The last part of the book exposes several contributions dealing with the design of cooperative control and observation laws for networked control systems. In these chapters, several discussions on the application of consensus algorithms are provided.

The first chapter of this part by *Alicia Arce Rubio, Alexandre Seuret, Yassine Ariba*, and *Alessio Mannisi* aims at presenting distributed control laws, which allow a fleet of two drones to carry a load in a cooperative manner. Two approaches based on the linear quadratic regulator method and on model predictive control are discussed. The second chapter by *Pablo Millan, Luis Orihuela Isabel Jurado, Carlos Vivas*, and *Francesco R. Rubio* exposes some recent tools which aim at taking into account delays in distributed estimation and control. Indeed, the influence delays and packet dropouts induced by communication are analyzed and robust control and estimation laws are provided. The third chapter by *Constantin Morarescu, Pierre Riedinger, Marcos C. Bragagnolo* and *Jamal Daafouz* exposes a novel method for the design and the analysis of a reset strategy for consensus in networks with cluster pattern. The next chapter by *Paresh Deshpande, Christopher Edwards*, and *Prathyush P. Menon* presents a synthesis of distributed control laws for multiagent systems. The key issue of this chapter is to design distributed control laws which are based on delayed relative measurements among the agents. The last chapter by *Constantin Morarescu* and *Mirko Fiacchini* concerns the implementation strategies for topology preservation in multiagent systems.

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