Preface

In any formulation of control, observation, or diagnosis problems, the mathematical model developed in order to establish the control law or to design an observer does not exactly reflect the actual process. These differences may for example be due to unmodeled dynamics, changes in system parameters, or approximations of the complex behavior of the process. Nevertheless, it must ensure that, despite all these uncertainties, the resulting control law achieves the predefined objectives and/or the observer can give the most accurate estimation possible of physical system parameters. This must be done under assumptions clearly defined with working conditions. From a historical perspective, the study of systems has been approached with continuous modeling using differential equations. The impressive progress in recent years, including the use of faster and faster computers, motivates the development of theoretical tools for a qualitative description of the dynamics systems.

However, in many cases, such description does not represent the complexity and richness of the behavior of the systems. Thus, knowledge of continuous dynamics modeling is often necessary to the synthesis of a control law implementable by a controller, or the synthesis of a state observer. The mathematical model resulting from the coupling of differential equations and the automaton modeling the system evolution from what is known as a hybrid automaton leads to hybrid dynamical systems (HDS). HDS are systems involving both continuous dynamics and discrete events. They can operate in several different modes which are described by a dynamical subsystem. The mode changes are governed by some discrete dynamics.

Switching systems (SS) are probably one of the most important class of hybrid systems. They are called variable structures if the laws describing its evolution are still made using differential equations and the system switches between these different laws. A large class of dynamical systems is modeled by a family of continuous subsystems and a logical law orchestrates switching between these subsystems.

Stability of HDS is critical for all applications. Therefore, it has received a lot of attention since the last two decades. Most of the existing literature brings solutions to solve whether the system is stable under arbitrary switching or whether the stability is achieved for a limited class of switching signals (using either common Lyapunov function or multiple Lyapunov approach). The observability analysis and observer design in HDS has received the interest of many researchers.

The problem of observer design is related to the extraction of unknown variables from the knowledge of the measured output. It is well known that, under certain assumptions, the state trajectory and the output response of any dynamical system are uniquely defined once the initial condition and the input are fixed. The problem of observer design usually deals with: (a) estimation of the state, (b) estimation of the external input (which can be either disturbance or faults), and (c) system security analysis (fault detection and isolation (FDI)). Occurrence of faults can be extremely detrimental, not only to the equipment and surroundings but also to the human operator if they are not detected and isolated in time. Hence, the increasing demand for safety and reliability of HDS during the last years has stimulated the attention to FDI techniques.

From the economical point of view, the study of HDS would enable to enlarge the spectrum of applications. Indeed, the hybrid modeling framework covers a large class of systems, which leads, for instance, to their application in a wide range of physical and engineering systems (power converters, control systems, process, computer science, biology, robotics, automotive industry, system temperature control, etc.).

This book is a collection of new trends in *Hybrid Dynamical Systems*. We invited several active researchers in this field to present the recent contributions of their groups.

Chapter 1, by M.D. Di Benedetto, S. Di Gennaro, and A. D'Innocenzo proposes a procedure to check diagnosability for hybrid systems. When analyzing a hybrid system, the dimension of the state space is often so large that formal verification is out of the question. Its analysis can be carried out using abstraction, namely the constructing a system with a smaller state space, preserving the properties to verify in the original system. Making use of a notion of diagnosability for hybrid systems, generalizing the notion of observability, in this chapter it is shown an abstraction procedure translating a hybrid system into a timed automaton, in order to verify observability and diagnosability properties. This procedure is applied to an electromagnetic valve system for camless engines.

In Chap. 2, by Zs. Lendek, P. Raica, J. Lauber, and T.M. Guerra an observer is designed for discrete-time switching nonlinear systems with a Takagi–Sugeno representation. For designing the observers, a switching nonquadratic Lyapunov function is used. Such Lyapunov functions have shown real improvement in the design conditions for discrete-time Takagi–Sugeno models. The Lyapunov function can be defined for each subsystem or just for the moments when switching takes place. In the first case, the results are more general, but also more conservative. The second case represents a significant improvement for periodic models. Thanks to the Lyapunov function used, it is possible to design observers for some switching systems with unobservable subsystems. The developed conditions are formulated as linear or bilinear matrix inequalities.

Chapter 3, by M. Petreczky, presents a survey on realization theory for linear hybrid systems. It deals with the problem of existence and minimality of a linear time-invariant state-space representation of an input–output map. The implications of realization theory for estimation and control of hybrid systems are discussed.

Chapter 4, by M. Djemai, N. Manamanni and J.P. Barbot, deals with observability conditions and state observer design for a class of hybrid systems. First, a high-order sliding mode-based observer is used to estimate the continuous state and to generate a discrete output. Secondly, starting from this discrete output, a discrete state reconstructor is designed. An illustrative example is provided to show the efficiency of the proposed observer.

Chapter 5, by N. Manamanni, M. Djemai and J.P. Barbot, deals with nonlinear observer design for autonomous SS with jumps. The jumps can result from the system dynamics or from the diffeomorphism which makes it possible to lead the system to an observability canonical form. In this chapter, the authors relate the design of a second-order sliding mode-based observer ("Super Twisting Algorithm"). It allows for estimating both continuous and discrete state related to the active dynamic.

In Chap. 6, by H. Rios, J. Davila and L. Fridman, the problem of continuous and discrete state estimation for switched nonlinear systems is solved using high-order sliding-mode techniques. In the first part of this chapter, systems with exogenous switching are studied. The solvability of the observation problem, for continuous and discrete states, is proposed using structural properties of the system. The high-order sliding-mode techniques are introduced to guarantee finite time convergence to zero of the estimation error for the continuous state. The discrete state is reconstructed using the information of the equivalent output injection.

In Chap. 7, by A. Tanwani, H. Shim and D. Liberzon, an observer design for switched linear systems with state resets is proposed based on the geometric conditions for large-time observability. Without assuming the observability of individual subsystems, the basic idea is to combine the maximal information available from each mode to obtain a good estimate of the state after a certain time interval has passed.

Chapter 8, by M. Petreczky, A. Tanwani, and S. Trenn, studies the observability of switched linear systems. This chapter focuses on the recently introduced geometric characterization of observability which assumes knowledge of the switching signal. These geometric conditions depend on computing the exponential of the matrix and require the exact knowledge of switching times. To relieve the computational burden, some relaxed conditions that do not rely on the switching times are given; this also allows for a direct comparison of the different observability notions. Furthermore, the generalization of the geometric approach to linear switched differential algebraic systems is possible and presented as well.

Chapter 9, by L. Hetel and E. Fridman, considers the stabilization problem for switched affine systems with a sampled-data switching law. The switching law is assumed to be a function of the system state at sampling instants. Sampling interval may be subject to variations or uncertainty. Switching law design criteria, taking into account the sampled-data implementation and uncertainties, are provided.

Chapter 10, by M. Farza, M. M'Saad, and K. Busawon, addresses the observer design problem for a class of continuous time dynamical systems with nonuniformly sampled measurements. More specifically, an observer is proposed that runs in continuous-time with an output error correction term that is updated in a mixed continuous discrete fashion. The proposed observer is actually an impulsive system. It can be put under the form of a hybrid system composed of a continuous time high gain observer coupled with an inter-sample output predictor. Simulations results dealing with a flexible joint robot arm are given to highlight the performance of the proposed observer.

Chapter 11, by W. Aggoune, B. Castillo Toledo, and S. Di Gennaro, presents results on self-triggering control for nonlinear systems. Conditions guaranteeing the existence of a self-triggered control strategy stabilizing the closed-loop system are presented both for deterministic and stochastic nonlinear systems. The problems addressed are self-triggered stabilization and safety. In the stochastic case, the state equations are described by an Itô differential equation driven by a Wiener noise, where the input enters either in the deterministic dynamics or in the dynamics affected by the noise. This kind of model embraces a quite large class of systems, of particular interest since in practice.

Chapter 12, by M. Defoort, J. Van Gorp and M. Djemai, presents an interesting benchmark for control, observation, and diagnosis of HDS: the multicellular converter. The first part of this chapter deals with the controller design for switching power converters, which are a particular class of switched systems. Then, it deals with the observer design to solve the capacitor voltages estimation while taking into account the hybrid behavior of the converter. A hybrid observer, based on gathering partial information from individual modes of the switched system, is designed. Some simulations highlight the efficiency of the proposed control and observer schemes for the three-cells converter.

Finally, in Chap. 13, by T.M. Laleg-Kirati, Z. Belkhatir and F.D. Ledezma, another application field of HDS is presented: biological systems. In biological systems, discrete behaviors might originate from unexpected changes in normal performance, e.g., a transition from a healthy to an abnormal condition. Simplifications, model assumptions, and/or modeled (and ignored) nonlinearities can be represented by sudden changes in the state. In this chapter, the authors are interested in modeling the cardiovascular system (CVS). Hybrid properties appear naturally in the CVS thanks to the presence of valves, which depending on their state (close or open) divide the cardiac cycle into four phases. The objective of this chapter is to use the properties of hybrid systems to describe this complex system.

It is our hope that this book will provide a clear and complete picture on the current state of the art of HDS theory.

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