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Introduction to the Special Issue on Hybrid Systems

Hybrid systems contain two distinct types of components, subsystems with continuous dynamics and subsystems with discrete dynamics that interact with each other. These systems typically contain variables or signals that take values from a continuous set and also variables that take values from a discrete, typically finite set. These continuous or discrete-valued variables depend on independent variables such as time, which may also be continuous or discrete; some of the variables may also be discrete event driven in an asynchronous manner.

Since the continuous and discrete dynamics coexist and interact with each other it is important to develop models that accurately describe the dynamic behavior of such hybrid systems. In this way it will be possible to develop control strategies that fully take into consideration the relation and interaction of the continuous and discrete parts of the system. There are several reasons for using hybrid models to represent the dynamic behavior of interest. Reducing complexity was and still is an important reason for dealing with hybrid systems, and this is accomplished by incorporating models of dynamic processes at different levels of abstraction. For example a thermostat typically sees a very simple, but adequate for the task in hand, model of the complex heat flow dynamics. In another example, one may choose to work with sets of simpler equations (e.g. linear) and switch among these simpler models in order to avoid dealing directly with a set of nonlinear equations. In recent years, the widespread use of digital machines has made hybrid systems very common. Whenever a digital device interacts with the continuous world, the behavior involves hybrid phenomena that need to be analyzed and understood. Hybrid systems are central in the analysis and design of intelligent control systems with high degrees of autonomy as they arise from the interaction of discrete planning algorithms and continuous control algorithms. The investigation of hybrid systems is creating a new and fascinating discipline bridging control engineering, mathematics and computer science.

Approaches to hybrid systems differ with respect to the emphasis on or the complexity of the continuous and discrete dynamics, and on whether they emphasize analysis and synthesis results or analysis only or simulation only. On one end of the spectrum there are approaches to hybrid systems that represent extensions of system theoretic ideas for systems (with continuous-valued variables and continuous time) that are described by ordinary differential equations to include discrete time and variables that exhibit jumps, or extend results to switching systems. Typically these approaches are able to deal with complex continuous dynamics and emphasize stability results. On the other end of the spectrum there are approaches to hybrid systems that are embedded in computer science models and methods, that represent extensions of verification methodologies from discrete systems to hybrid systems. Typically these approaches are able to deal with complex discrete dynamics described by finite automata and emphasize analysis results (verification) and simulation methodologies. In this special issue the emphasis is on approaches that combine concepts from continuous control systems described by linear and nonlinear differential/difference equations, and from supervisory control of discrete event systems that are described by finite automata and Petri nets to derive analysis and synthesis results for hybrid systems.

This special issue consists of four papers that describe different approaches to hybrid systems. The first paper, titled "Synthesis and Viability of Minimally Interventive Legal Controllers for Hybrid Systems" by Heymann, Lin and Meyer studies the control of Composite Hybrid Machines, which model a class of hybrid systems in a modular fashion that permits the introduction of the controller as a component of the system. Legal controllers that ensure the system never exits a set of specified legal configurations are of interest. Among the legal controllers minimally interventive (or minimally restrictive) controllers are of particular interest. Such controllers provide maximum flexibility in embedding additional controllers designed for other control objectives to operate concurrently, while eliminating the need to re investigate or re verify the legality of the composite controller with respect to the safety specification. The viability of controllers as related to the possibility of Zenoness, where the system can undergo an unbounded number of transitions in a bounded length of time is also examined.

The paper "Timed Petri nets in Hybrid Systems: Stability and Supervisory Control" by Koutsoukos, He, Lemmon and Antsaklis uses a class of timed Petri nets named programmable timed Petri nets (PTPN) to model

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hybrid systems. Using the PTPN, sufficient conditions for the uniform ultimate boundness of hybrid systems composed of multiple linear time invariant plants and swtching logical rules described by a Petri net are derived. This paper also examines the supervisory control of a hybrid system in which the continuous state is transferred to a region of the state space in a way that respects safety specifications on the plant's discrete and continuous dynamics.

The third paper titled "Modeling, Analysis, and Optimal Control of a Class of Hybrid Systems" by Pepyne and Cassandras introduces a modeling framework for a class of hybrid systems in which discrete entities have a state characterized by a temporal component whose evolution is described by event driven dynamics, and a physical component whose evolution is described by time driven dynamics. The paper examines an optimal control problem for a specific example involving a single stage manufacturing process. The defined framework is quite general and is applicable to a large class of realistic systems. The associated analysis of this case sheds light on potential directions for future research.

The paper "Fault Detection and Diagnosis in Distributed Systems: An Approach by Partially Stochastic Petri Nets" by Aghasaryan, Fabre, Benveniste, Boubour, Jard addresses the problem of identifying causal dependencies between alarms and faults in large scale distributed communication networks. The approach is based on an explicit description of fault propagation in which random and non-random variables must cooperate. To formalize this description, the authors introduce a "hybrid" framework in which "partially stochastic" Petri nets model fault propagation. The diagnosis problem is defined as the computation of the most likely history of the network and the authors provide solutions to this problem.

It is evident from the above papers that the area of hybrid systems is rich in challenging theoretical problems. The study of hybrid systems is very important if we want to understand clearly the interactions of the analog and digital worlds that exist in today's technology and design better systems. There is no doubt that the potential impact of appropriately combining the advantages of continuous and discrete approaches in a single system design or combining the advantages of analog and digital signals in a single silicon chip is immense. In this special issue we emphasized theoretical developments based on discrete event approaches to hybrid systems. So this special issue only represents a view of hybrid systems from a window in time that looks out toward particular approaches and covers specific classes of problems. We did not emphasize theoretical approaches that spring from nonlinear control theory or computer science and we did not discuss simulation software packages or real life applications. This special issue included a variety of approaches, but by no means is the coverage complete. Further information on hybrid systems may be found in references Grossman et.al. (1993), Antsaklis et.al. (1995), Alur et.al. (1996), Morse (1996), Antsaklis et.al. (1997), Antsaklis et.al. (1998), Antsaklis and Nerode (1998) and the references therein.

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