P. J. Antsaklis, "Hybrid System Modeling, Analysis and Design," Abstract, A RO-NASA W orkshop o n F ormal M odels f or I ntelligent C ontro l , MIT, Cambridge, MA, Sept. 30-Oct. 2. 1993.

Hybrid System Modeling, Analysis and Design

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ABSTRACT

Hybrid control systems contain two distinct types of systems, continuous-state and discrete-state, that interact with each other. Their study is essential in designing sequential supervisory controllers for continuous-state systems, and it is central in designing control systems with high degree of autonomy.

A brief introduction to the main ideas and concepts of intelligent autonomous control is first given, and the relation to hybrid control is discussed. Control systems with high degree of autonomy should perform well under significant uncertainties in the system and environment for extended periods of time. Highly autonomous control systems evolve from conventional control systems by adding intelligent components, and their development requires interdisciplinary research. For the intelligent autonomous control of continuous-state systems hybrid control is essential.

Appropriate quantitative models for hybrid control systems are needed so to identify the fundamental concepts, to analyze and understand properties important to control, and to design controllers that meet the control goals, while satisfying the design constraints. Such models are introduced here. In particular models for the plant, controller, and interface are discussed. Note that the interface must transform the plant's state vector into symbols which are representative of some "event". It must also transform control symbols (directives) issued by the supervisor into control signals which can be used by the plant. The plant together with the interface are seen by the sequential controller to be a DES, and DES techniques can be used to study such systems. For this, the interface must be chosen very carefully and this is in fact the key to being able to study, in depth, hybrid control systems. In our approach,the interface contains memoryless mappings between the supervisor's symbolic domain and the plant's nonsymbolic state space. The simplicity and generality afforded by the assumed interface allows us to directly confront important system theoretic issues in the design of supervisory control systems.such as determinism, quasideterminism, and the relationship of hybrid system theory to the more mature theory of logical discrete event systems. The notion of controllability of the logical DES theory is extended to DES derived from hybrid systems, and it is then used to extend DES controller design methods and to design controllers for hybrid control systems.

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Computationally efficient methods to design the interface and the DES controller are of great importance and interest, as they are essential in being able to design hybrid controllers for complex plants. Convex programming methods, able to handle large problems efficiently, are of particular interest. Interface requirements expressed in terms of linear inequalities are solved to derive a set of appropriate controls that ensure that the plant DES has the property of supervisability; the method of centers, framed as a learning algorithm is used. Inductive inference protocols and the elipsoid algorithm are used to learn appropriate symbol/event bindings in finite time for hybrid systems contained in the class of variable structure systems. Such learning procedures have a polynomial convergence time, suggesting that on line event identification is a practical technique in the control of highly complex plants.

An important challenge in control is the design of intelligent controllers for large scale physical systems, such as the ones found in automated manufacturing or chemical process control. The design of such controllers must integrate prior operator experience with a priori engineering models of the plant. The successful integration of these two knowledge domains will result in the development of hybrid control systems which perform robustly in the presence of plant variations. Such an approach is extremely valuable as it allows cooperative interaction between human operators and machine controllers in a way which predictably improves system performance. This integration of human/machine operators of large scale physical systems is under investigation. The basic framework being advocated is itemized below:

1. Translation of Engineering Specifications/Operator Procedures into DES Models.
2. Design of DES Controller.
3. Validation of DES Controller.
4. Translation of DES Controller to Operator Procedures.

In revising the operator's original procedures, we are incorporating analytical modeling information into the procedure. It is therefore possible to use the revised procedures to generate new DES plant models, and thereby iteratively determine a set of plant procedures which the human operator can effectively use to improve plant performance. The four step protocol outlined above presents a step by step outline as to how human and machine operators can be integrated to effectively control large scale plants. Prior work in intelligent or hybrid system control has tended to focus on various aspects of this problem. Here an integrated approach is proposed.

[1]. P. J. Antsaklis, M. D. Lemmon and J. A. Stiver, "Learning to be Autonomous: Intelligent Supervisory Control", Technical Report of the ISIS (Interdisciplinary Studies of Intelligent Systems) Group, No. ISIS-93-003, Univ of Notre Dame, April 1993. Also as a chapter in Intelligent Control Systems, IEEE Press. To appear.

[2]. J. A. Stiver and P. J. Antsaklis, "On the Controllability of Hybrid Control Systems", Proc of the 32nd IEEE Conference on Decision and Control, San Antonio, TX, Dec. 15-17, 1993.

[3]. M. D. Lemmon and P. J. Antsaklis, "Event Identification in Hybrid Control Systems", Proc of the 32nd IEEE Conference on Decision and Control, San Antonio, TX, Dec. 15-17, 1993.