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Outline for an Invited Session (accepted)

Controller Design based on Hybrid Models of Industrial Plants

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Keywords: Benchmark Systems, Hybrid Models, Large-Scale Systems, Discrete Event Control, Optimal Control, Predictive Control, Stabilization.

Session Objectives:

More than a decade of academic research on various control problems for hybrid systems has produced a multitude of modeling formalisms, solution concepts, and prototype tools. Many of these efforts, however, have been applied only to small or considerably abstracted examples thus far, but have not been validated for applications that are relevant outside academia – addressing this shortcoming is one of the main goals of the EU-funded network of excellence HYCON. The work area *Industrial Controls* is specifically focused on control problems which are motivated by the manufacturing and processing industries, and for which the use of hybrid system technology seems promising. Particular goals are to disseminate existing techniques to potential industrial users, to assess the applicability, and to identify and introduce necessary improvements.

The session proposed here is part of the disseminating activities of the work area *Industrial Controls*, and as such it will report on intermediate results to the community and aims at getting researchers and practitioners outside of HYCON interested and involved in the activities of the network. In detail, the session has the following objectives:

- to present a set of case studies derived from industrial applications for which the use of hybrid models is an appropriate choice. Attendees of the session are encouraged to apply their own control techniques to these case studies, and a benchmarking of solution concepts is desired.
- to demonstrate the potential and benefits that design techniques based on hybrid systems have for industrial applications. This is achieved by reporting on first promising control results for some of the case studies.
- to point out specific challenges and shortcomings of existing techniques that predominantly arise from the size, the nonlinearity, or the combinatoric complexity of the presented problems. The hope is that future research efforts are stimulated which address the challenges reported in this session.

Contents of the Session:

To achieve these goals, five contributions reporting on four different case studies investigated within HYCON are planned for the session. (Two papers report on different problems for the same application). The following papers are envisaged:

1. S. Haugwitz, P. Hagander: *Challenges in Start-Up Control of a Heat Exchange Reactor with Exothermic Reactions - A Hybrid Approach*

   Abstract: In this paper, the control of a continuous heat exchange reactor is investigated from a hybrid perspective with focus on the start-up phase and the transition to the optimal operating point. The temperature sensitive exothermic reaction leads to the possibility of multiple steady states and in combination with safety constraints forms an interesting challenge for a safe and efficient start-up. A

series of MPC controllers are developed with a switching logic that transfers the process from initial rest to continuous optimal operation mode. The control procedure is verified in simulations with a full nonlinear model of the Open Plate Reactor, an improved heat exchange reactor being developed by Alfa Laval AB.

2. D.S. Zambrano, C. Bordons, W. Garcia-Gabin, E.F. Camacho: *A Solar Cooling Plant: a Benchmark for Hybrid Systems Control.*

   Abstract: The paper describes the hybrid model of a solar cooling plant, which is used as a benchmark for hybrid controller design within the EU network of excellence HYCON. The different operating modes of the process are modelled by a finite state machine, where the transition conditions are formulated for discrete variables modelling electro-valves and pumps. The remaining part of the model is written as a mixed logical dynamical system, and is simulated using Stateflow/Simulink. The presented model is validated based on data obtained from the existing solar cooling plant.

3. I. Simeonova, F. Warichet, G. Bastin, D. Dochain, Y. Pochet: *Feedback Stabilization of the Operation of a Hybrid Chemical Plant*

   Abstract: This communication deals with the feedback stabilization of a hybrid chemical plant that is operated according to an optimal production schedule but is open-loop unstable. The considered plant consists of two tanks (a batch chemical reactor and a buffer tank), and is modelled by means of the hybrid automaton formalism. The determination of a cyclic optimal schedule that maximizes the plant productivity is first addressed. This optimization problem is solved by using a discrete time periodic scheduling method. However, the state trajectory of the optimal schedule is unstable, i.e. the actual plant trajectory diverges from the optimal one. The goal is to assess the efficiency of simple P- and PI-like controllers for the stabilization of this system. The performance of the controllers is illustrated through various simulation experiments carried out in the Matlab/Simulink/Stateflow environment. For the considered control laws, it is shown that the operation of the plant is stabilized in the sense that the plant trajectory converges towards a limit cycle which is close to the optimal cyclic schedule. The dependence of the closed loop performance on the choice of the controller parameters is graphically illustrated.

4. D. Gromov, S. Geist, J. Raisch: *Timed Discrete Event Control of a Parallel Production Line with Continuous Output*

   Abstract: In this paper, an approach to formulate and solve certain scheduling tasks using timed discrete event control methods is proposed. To demonstrate the approach, the special class of a cyclically operated chemical plant is considered, which consists of parallel reactors using common resources and a continuous output. This problem was motivated by a benchmark proposed within the EU Network of Excellence HYCON. For this system, it is shown how to pose the control problem within a discrete event framework by modelling system components as multirate timed automata. Safety and nonblocking properties are investigated which have to be achieved in the presence of bounded errors / disturbances.

5. C. Sonntag, O. Stursberg, S. Engell: *Dynamic Optimization of an Industrial Evaporator using Graph Search with Embedded Nonlinear Programming*

   Abstract: While hybrid models are often well suited to represent the dynamics of chemical processing systems, they frequently lead to (optimal) control problems for which the solution is particularly challenging. This is shown in this contribution for an industrial evaporation system which serves as a new case study in the NoE HYCON. The model is formulated as a hybrid automaton with state resets and continuous dynamics specified by large nonlinear DAE-systems. To solve the control problem of optimized start-up, a recently proposed graph-search algorithm with embedded NLP is applied. Since the algorithm in its original form does not lead to satisfactory results, this paper introduces improving modifications, most notably a progress criterion to suitably adjust time intervals for updating

the controls, and specific penalty functions for enabling state trajectories of low cost that are close to infeasible solutions. The paper contains results which show that good (suboptimal) solutions are obtained for the evaporation system.