Design of Process Operations Using Hybrid Dynamic Optimization*

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Abstract

Accurate nonlinear dynamic models of process operations such as start-ups, shut-downs, and complex changeovers include state dependent events that trigger discrete changes to the describing equations. Such models are best analyzed within a hybrid systems framework. The automated design of an optimal process operation can thus be formulated as a dynamic optimization problem with a hybrid system embedded. Often, the sequence of state events characterizing the solution trajectory can change as a function of the optimization parameters. Recent research has demonstrated that the resulting optimization problems are nonsmooth, which defeats existing gradient based deterministic solvers, although stochastic solvers can be applied to generate potentially suboptimal solutions.

The design of logic based controllers for abnormal situation management calls for formal verification of the safety properties of the controller design, including interactions with the underlying hybrid dynamic system. Formal verification problems can often be formulated as optimization problems. However, for safety verification purposes, it is necessary to guarantee that the global solution has been found.

These applications motivate the development of deterministic global optimization algorithms for nonconvex, nonsmooth dynamic optimization problems with nonlinear hybrid systems embedded. This paper will describe recent progress on the development of suitable algorithms. A control parameterization approach is employed because, compared to discrete time or total discretization approaches, this yields a much smaller Master optimization problem, often within the capabilities of existing global optimization algorithms. A method will be presented for constructing convex relaxations of general nonconvex NLP problems with linear dynamic systems embedded. These convex relaxations will then be extended to multistage problems with model switches between stages. Finally, integer variables will be introduced to represent different sequences of model switches, eliminating the aforementioned nonsmoothness. The ability to construct convex relaxations enables existing nonconvex MINLP algorithms to be applied to the resulting MIDO problems. In closing, we will discuss progress on incorporating nonlinear dynamic models within this framework.

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