553f Hybrid Predictive Control: Discrete Actuation and Sensing

Panagiotis D. Christofides, Prashant Mhaskar, and Nael H. El-Farra

The operation of chemical processes often requires respecting constraints on manipulated inputs and process states. Input constraints typically reflect limits on the capacity of control actuators, such as valves or pumps, while state constraints represent desirable ranges of operation for process variables, such as temperatures or concentrations. Constraints, however, limit the set of initial conditions, starting from where a process can be stabilized at a possibly open-loop unstable steady-state. Therefore, in control of constrained processes, it is important to obtain an explicit characterization of the region of closed-loop stability. Model predictive control (MPC) provides a suitable framework for implementing control that respects manipulated input and process variable constraints while meeting prescribed performance objectives (see, [1], for a survey). Unfortunately, the implicit nature of the feedback law in MPC (the control action is computed by solving on-line a constrained optimization problem at each sampling time) makes the a priori computation of the closed-loop stability region a very difficult task. Such a computation, however, is possible when Lyapunov-based bounded control techniques are used to design controllers for the stabilization of systems with manipulated input constraints.

Recently, we proposed a hybrid predictive controller that uses appropriately designed switching rules to detect instability like behavior under the predictive controller and utilizes a Lyapunov-based controller to provide a safety net for the implementation of predictive control designs for nonlinear systems [2], and for nonlinear systems subject to uncertainty [3]. The works in [2,3], however, assumed continuous availability of measurements, and the ability to continuously manipulate the control action. In practical applications, the process measurements may only be available at discrete sampling instances, and one may not be able to continuously change the value of the manipulated input, either due to computational-time requirement for the control action (when using, for instance, the predictive controllers) or due to physical limitations on actuators that limit how often the value of the control action can be changed. These factors can negatively impact the ability of the hybrid predictive controllers proposed in [2,3] to guarantee closed-loop stability from an explicitly characterized set of initial conditions (due to the backup Lyapunov-based controller no longer being stabilizing or the switching rules being unable to quickly detect instability like behavior under the predictive controller).

Motivated by the above considerations, the present work proposes a hybrid predictive control structure that seamlessly unites MPC and bounded control for stabilization of nonlinear processes with input constraints subject to discrete actuation and sensing. The proposed strategy is based upon the idea of characterizing the stability region of a Lyapunov-based controller subject to discrete actuation and sensing, embedding the implementation of MPC within the stability region of the bounded controller, and using this controller as a ``fall-back'' in the event that MPC is unable to achieve closed-loop stability (due, for example, to improper tuning of MPC parameters). Switching laws, that monitor the evolution of the state, and account for the fact that the measurements of the state variables are available only at discrete sampling times, are derived to orchestrate the transition between the two controllers in a way that reconciles their respective stability and optimality properties and safeguards closed-loop stability in the event of MPC infeasibility or instability. The theoretical underpinnings and practical implications of the proposed hybrid predictive control structure are highlighted, and possible extensions of the supervisory switching logic, that address a variety of practical implementation issues, are discussed. Finally, simulation studies are presented to demonstrate the implementation and evaluate the effectiveness of the proposed control strategy, as well as test its robustness with respect to modeling errors and measurement noise.

References:

[1] Mayne, D. Q., J. B. Rawlings, C. V. Rao and P. O. M. Scokaert, Constrained model predictive control: Stability and optimality, Automatica, 36:789-814, 2000.

[2] El-Farra, N. H., P. Mhaskar and P. D. Christofides, Hybrid Predictive Control of Nonlinear Systems: Method and Applications to Chemical Processes, Int. J. Rob. & Non. Contr., 14, 199-225, 2004.

[3] Mhaskar, P., N. H. El-Farra and P. D. Christofides, Robust Hybrid Predictive Control of Nonlinear Systems, Automatica, 41, 209-217, 2005.