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A two-layer architecture for economically optimal process control and operation

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ABSTRACT

A two-layer architecture for dynamic real-time optimization (or nonlinear modelpredictive control (NMPC) with an economic objective) is presented, where the solution of the dynamic optimization problem is computed on two time-scales. On the upper layer, a rigorous optimization problem is solved with an economic objective function at a slow time-scale, which captures slow trends in process uncertainties. On the lower layer, a fast neighboring-extremal controller is tracking the trajectory in order to deal with fast disturbances acting on the process. Compared to a single-layer architecture, the two-layer architecture is able to address control systems with complex models leading to high computational load, since the rigorous optimization problem can be solved at a slower rate than the process sampling time. Furthermore, solving a new rigorous optimization problem is not necessary at each sampling time if the process has rather slow dynamics compared to the disturbance dynamics. The two-layer control strategy is illustrated with a simulated case study of an industrial polymerization process.

1. Introduction

In the past twenty years, model-predictive control (MPC) has established itself in industry as one of the most important tools for controlling continuous processes operated at steady-state set-points. In these processes, the control architecture often consists of several layers operating on different time-scales. Tatjewski [1] and Scattolini [2] have reviewed vertical as well as horizontal decomposition approaches for MPC.

Fig. 1(a) shows the well-known two-layer architecture involving a model-based constrained controller (MPC) and a real-time optimizer (RTO). A separation in time-scales and control objectives is performed between both layers. A RTO problem based on a stationary process model is solved at the upper layer with an economic objective function to compute set-points for the underlying MPC. The lower layer operates at a high sampling rate; its functionality comprises regulatory tasks to enforce set-points under the influence of disturbances. The MPC at the lower layer often relies on a linear model valid in the vicinity of the operating point, whereas a rigorous nonlinear model is employed at the upper layer. The base layer typically comprises decentralized control loops to stabilize the plant. Often, an additional task is performed at the MPC-layer. This so-called steady-state target optimization [1,3] recalculates the set-points at the sampling rate of the MPC. Detailed reviews of this architecture can be found for example in the work of Qin and Badgwell [4] or Engell [5]. Robust approaches to integrate both layers taking into account process uncertainties have been presented recently by Adetola et al. [6] and Odloak [7]. The two-layer RTO architecture has already been successfully applied to large-scale and complex plants in the chemical and petrochemical industries.

However, the two-layer RTO architecture has some disadvantages, as stressed, for example, by Engell [5]. It was pointed out that the models used in the optimization and in the control layer are not consistent; in particular, their steady-state gains are often different. The slow time-scale on the upper layer may lead to unsatisfactory economic performance. Since the economic optimization is only carried out when the plant reaches steady-state, the waiting time required to reach a new steady-state leads to a delay for computing a new set-point. It may thus happen that, due to uncertainties, the economically optimal operating point of the plant has shifted but the controller still tries to enforce the previously optimal operating point. Furthermore, due to frequent external disturbances, some plants are rarely operating in a steady-state mode. This will lead to infrequent optimization instances as the plant first has to reach a steady-state before a new optimization may be performed.

Because of these disadvantages of the RTO architecture, several authors have shifted towards integrating the economic optimization and MPC problem into a single dynamic optimization problem (e.g. [5,8,9]). The integrated problem shown in Fig. 1(b) corresponds to a nonlinear model-predictive control (NMPC) problem with economic objective function, which will also be termed dynamic real-time optimization (DRTO) problem in the following. However,

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