Distributed Modifier-Adaptation Schemes for the Real-Time Optimization of Interconnected Systems in the Presence of Structural Plant-Model Mismatch

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The desire to operate chemical processes in a safe and economically optimal way has motivated the development of so-called real-time optimization (RTO) methods [1]. For continuous processes, these methods aim to compute safe and optimal steady-state setpoints for the lower-level process controllers. A key challenge for this task is plant-model mismatch. For example, in the case of a model that is assumed to be structurally identical with the plant but has unknown parameters, the so-called two-step approach [2-4] has been proposed. It repeats two steps: In the first step, plant measurements are used to identify the parameters of the model. In the second step, the economically optimal setpoints for the updated process model are determined by solving an optimization problem. Unfortunately, a structurally correct process model is rarely available in practice. In that case, the optimal setpoints for the model determined by the two-step approach may not be optimal for the plant. To overcome this problem, the so-called modifier-adaptation (MA) methods have been developed [5]. In MA, no structurally correct model is required. Instead, plant measurements are used to formulate and solve a modified optimization problem at each iteration, such that, upon convergence, the first-order optimality conditions of the plant are guaranteed to be satisfied [5].

These and other available RTO methods usually treat the plant as a single entity, and compute the optimal setpoints in a centralized manner. However, this approach may be suboptimal or even infeasible for an increasing number of applications involving so-called interconnected systems. Interconnected systems are here defined as systems composed of subsystems that exchange material, energy or information, such as compressor networks, teams of autonomous vehicles or large industrial parks, in which different business units of a chemical company share certain resources. In these cases, distributed RTO methods can be employed, which utilize the available interconnection variables and exploit the inherent interconnection structure of the particular system.

Only a few distributed RTO methods have been reported in the literature, including the methods proposed by Brdys and Tatjewski [6]. Just as in the two-step approaches, structurally correct models are assumed. In addition to identifying the model parameters, the methods also try to estimate the values of the interconnection variables. Consequently, these methods may not yield the plant optimum in the presence of structural plant-model mismatch.

In this contribution, we propose a set of distributed RTO methods based on the modifier-adaptation framework for interconnected systems in the presence of structural plant-model mismatch. Thanks to the modifier-adaptation framework, all proposed distributed RTO methods are able to reach the plant optimum upon convergence despite possible plant-model mismatch. The proposed schemes employ different types of models, use different measurements, and differ in their algorithmic structure and required controller hierarchy, as well as in their communication topology, as detailed below.

The first method utilizes a model of the local objective function, a model for the dependence of local outputs on the local setpoints and outputs of other subsystems, and a model for the interconnection structure of the system. The algorithm resembles a double-loop structure: In the simulation-based inner loop, the local MA-problems are solved in parallel until the interconnection constraints are satisfied. As soon as the inner loop has converged, the computed setpoints are applied to the plant in the outer loop. When the plant has reached a new steady state, measurements are taken to improve the performance at the next iteration.

The second and third methods do not require a model of the interconnection structure of the system. Consequently, a single-loop algorithmic structure is sufficient. At every iteration, each subsystem computes local setpoints, which are immediately applied to the plant. At the corresponding steady state, plant measurements are taken to improve the performance at the next iteration. At this point, the second and third method proceed differently: The second method uses local measurements of the interconnection variables to each subsystem, whereas the third method additionally measures the local outputs. Consequently, the second method still uses a model describing the dependency of the local outputs on the local setpoints and local interconnection variables, whereas no such relationship is needed for the third method.

Because of their different characteristics, each of these algorithms has its specific advantages regarding applications. For example, the first method requires each subsystem to have a complete model of the full system and its interconnection topology. If these models are good, then fast convergence of this scheme with few setpoint changes can be expected. In applications, where providing a full model of the system to every subsystem is feasible and does not raise any privacy concerns, the first scheme may be the method of choice. The second and third schemes, in contrast, do not require an interconnection model. Therefore, they may be preferred for applications where different subsystems do not want to disclose their models to other subsystems. This could be the case when the different subsystems are owned by competing companies. Moreover, the lack of an interconnection model may be advantageous in certain applications with changing interconnection topologies, such as power system networks. Another advantage of the second and third method is their reduced local modeling effort if accurate measurements are available. On the other hand, these methods may need significantly more iterations to converge than the first method if accurate models are available.

In our contribution, we finally apply the proposed distributed modifier-adaptation schemes to numerical examples. The main features of each method are illustrated, revealing their potential for real-time optimization of interconnected systems with structural plant-model mismatch.

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