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Sensitivity-based coordination in distributed model predictive control

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ABSTRACT

A new distributed model-predictive control method is introduced, which is based on a novel distributed optimization algorithm, relying on a sensitivity-based coordination mechanism. Coordination and therefore overall optimality is achieved by means of a linear approximation of the objective functions of neighboring controllers within the objective function of each local controller. As for most of the distributed optimization methods, an iterative solution of the distributed optimal control problems is required. An analysis of the method with respect to its convergence properties is provided. For illustration, the sensitivity-driven distributed model-predictive control (S-DMPC) method is applied to a simulated alkylation process. An almost optimal control sequence can be achieved after only one iteration in this case.

1. Introduction

Chemical processes are usually described by dynamic mathematical models featuring several input and output variables. Typically, industrial plants are operated by decentralized control technology based on single-input single-output PID loops enhanced by supervisory controllers [1]. The decentralized controllers are designed without an explicit consideration of the interactions between the different loops in the plant. Hence, optimization-based methods such as linear or nonlinear model predictive control (MPC) or dynamic real-time optimization (DRTO) have become important technologies, as they maintain operational constraints. We refer to the papers of Kano and Ogawa [1] and Qin and Badgwell [2] for a summary on the industrial state of the art on MPC-technology. Model-predictive controllers consider all interactions due to their centralized implementation. Typically, favorable constraint pushing and good performance can be achieved. However, the design and maintenance of large-scale centralized predictive controllers is involved. Decentralization of the established constraint-handling controllers with negligible performance deterioration is therefore desirable.

Today, an increasing activity in research on model-based decentralized and distributed control methods can be observed. This trend is driven by opportunities to achieve better computational performance [3] and to remove possible communication bottlenecks. Furthermore, reliability and maintainability could be improved compared to a monolithic centralized solution [4]. Last but not least, completely new applications requiring decentralized control have to be addressed. These new applications are positioned mainly in the field of autonomous vehicles [5–7], such as aircrafts or satellites. Typically these systems are modeled by some linear mechanical systems, where each subsystem is modeled by the same dynamics [8]. An important characteristic of this class of systems, commonly referred to as multi-agent systems (MAS), is the autonomy of the different subsystems (or agents). They are not coupled and hence do not interact. However, these agents share some common goals such as consensus [8], pattern formation (e.g. flocking) or the avoidance of collisions [5,9]. In order to achieve these common goals, control methods are applied, that lead to a rational interaction between the agents in MAS. These methods use various modern control tools, including linear matrix inequalities [7] or control barrier functions [9]. While the systems considered can usually be described by low order models, one of the main challenges is the time-dependent communication topology. This time-dependence is caused by varying communication links due to changing distances, appearing obstacles or exogeneous disturbances. While in many papers a constant topology is assumed (e.g. [10,11]), first results exist on time-dependent topologies (e.g. [12,13]).

Process control problems usually feature several differences compared to MAS. In particular, they are characterized by high order dynamics with strong nonlinearities. In a faultless system, the (communication) topology is fixed. Typically, there is no complete interaction structure linking a subsystem with all others; rather, a subsystem interacts only with a few neighbors.

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