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An iterative scheme for distributed model predictive control using Fenchel's duality

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ABSTRACT

We present an iterative distributed version of Han's parallel method for convex optimization that can be used for distributed model predictive control (DMPC) of industrial processes described by dynamically coupled linear systems. The underlying decomposition technique relies on Fenchel's duality and allows subproblems to be solved using local communications only. We investigate two techniques aimed at improving the convergence rate of the iterative approach and illustrate the results using a numerical example. We conclude by discussing open issues of the proposed method and by providing an outlook on research in the field.

1. Introduction

Nowadays, model predictive control (MPC) is widely used for controlling industrial processes [1], and it also has been studied thoroughly by the scientific community [2,3,4]. MPC can naturally handle operational constraints and, moreover, it is designed for multi-input multi-output systems, both of which contributed to the popularity of MPC. Another advantage of MPC is that it relies on optimization techniques to solve the control problem. Hence, improvements in optimization techniques can help to broaden the applications of MPC for more complex problems.

When considering a control problem for a large-scale networked system (such as complex manufacturing or infrastructure processes), using MPC in a centralized fashion may be considered impractical and unsuitable due to the computational burden and the requirement of global communications across the network. It is also inflexible against changes of network structure and the limitation of information exchange between different authorities who might be in control of a local subsystem. In order to deal with these limitations, distributed MPC (DMPC) has been proposed for control of such large-scale systems, by decomposing the overall system into small subsystems [5,6]. The subsystems then employ distinct MPC controllers that only solve local control problems, use local information from neighboring subsystems, and collaborate to achieve globally attractive solutions.

DMPC is an emerging topic for scientific research. The open issues of DMPC have recently been discussed in [7,8]. Several DMPC methods were proposed for different problem setups. For systems with decoupled dynamics, a DMPC scheme for multiple vehicles with coupled cost functions was proposed in [9], utilizing predicted trajectories of the neighbors in each subsystem's optimization. A DMPC scheme with a sufficient stability test for dynamically decoupled systems was presented in [10], in which each subsystem optimizes also over the behaviors of its neighbors. In [11], Richards and How proposed a robust DMPC method for decoupled systems with coupled constraints, based on constraint tightening and a serial solution approach. For systems with coupled dynamics and decoupled constraints, a DMPC scheme has been developed in [12] based on a Jacobi algorithm that deals with the primal problem, using a convex combination of new and old solutions. In [13], the neighboring subsystem states are treated as bounded contracting disturbances, and each subsystem solves a min–max problem. A partitioning-based algorithm was proposed in [14,15], with sufficient conditions for the a posteriori stability analysis. In [16], Li et al. proposed an algorithm with stability conditions in which subproblems are solved in parallel in order to get a Nash equilibrium. Several DMPC algorithms based on decomposing of the global optimization problems were proposed in [17–19]. Other recent work on applications of DMPC is reported in [20–22].

In this paper, we present a decomposition scheme based on Han's parallel method [23,24], aiming to solve the centralized optimization problem of MPC in a distributed way. This approach results in two distributed algorithms that are applicable to DMPC of large-scale industrial processes. The main ideas of our algorithms

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