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Decentralized fault tolerant model predictive control of discrete-time interconnected nonlinear systems

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Abstract

This paper presents a novel approach to address the decentralized fault tolerant model predictive control of discrete-time interconnected nonlinear systems. The overall system is composed of a number of discrete-time interconnected nonlinear subsystems at the presence of multiple faults occurring at unknown time-instants. In order to deal with the unknown interconnection effects and changes in model dynamics due to multiple faults, both passive and active fault tolerant control design are considered. In the Active fault tolerant case an online approximation algorithm is applied to estimate the unknown interconnection effects and changes in model dynamics due to multiple faults. Besides, the decentralized control strategy is implemented for each subsystem with the model predictive control algorithm subject to some constraints. It is showed that the proposed method guarantees input-to-state stability characterization for both local subsystems and the global system under some predetermined assumptions. The simulation results are exploited to illustrate the applicability of the proposed method.

1. Introduction

Model predictive control (MPC) (or receding horizon control (RHC)) is a control strategy that offers attractive solutions for regulation and tracking problem of constrained linear or nonlinear systems. MPC algorithms propose the intuitive way of addressing the control problem. In recent years, MPC has become an important research interest in control community within industry and academia. This is illustrated by its applications to industrial and practical implementations and by many valuable works on this topic. See for example [1–5].

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A fundamental question about MPC is its robustness to noise and model uncertainty. It is obvious that safe operation of plants relies, among other things, on controller designs that account for the inherently complex dynamics of the processes (manifested as nonlinearities), operational issues, such as constraints and uncertainties [6,7], as well as abnormalities (arising, for example, due to faults in sensors/actuators). The fault tolerant control (FTC) problem can be classified as a passive approach or an active one [8]. Passive fault tolerant control can be considered as a robust control technique which regards systems faults as special kind of uncertainties. Active fault tolerant control strategies actively reconfigure control actions when system failures occurred. All these actions aim to show that the stability and acceptable performance of the entire system can be maintained.

These considerations motivate development of control strategies that account for constraints, nonlinearities, uncertainty, and are tolerant to faults (fault-tolerant control). In real applications, it could be a challenge to address these problems in interconnected systems using a centralized architecture because of the constraints on the computational capabilities and the communication bandwidth. Consequently, the areas of distributed or decentralized control have attracted broad attention [9–11].

Thereafter, we review some recent results on decentralized model predictive control strategies. Magni et al. [12] presented a stabilizing decentralized model predictive control algorithm for nonlinear discrete time systems. No information was assumed to be exchanged between local control laws. Keviczky et al. [13] considered a detailed study on the design of decentralized receding horizon control (RHC) schemes for decoupled systems. They designed each RHC controller based only on the states of the node and its neighbours. In [14] the hierarchical and decentralized model predictive control (DMPC) strategy was presented for drinking water networks. A suboptimal DMPC which composed of a set of MPC controllers was derived and each element solved its control problem in a hierarchical order. Raimondo et al. [15] proposed a decentralized MPC scheme for nonlinear coupled dynamics at the presence of bounded external disturbances. In their work for each subsystem a MPC-based controller is designed and the effect of the other subsystems considered as disturbances. Then, the stability of the overall system was proven with the aid of regional input-to-state stability and a small-gain condition. In [16] a framework was proposed for distributed model predictive control (MPC) based on dynamic games. The centralized and decentralized control algorithms could be viewed as dynamical games with coupled control. The original optimization problem was decomposed into smaller coupled optimization problems in a distributed structure, which was solved iteratively. Mohamed et al. [17] designed new load frequency control (LFC) using the model predictive control. The effect of the uncertainty due to governor and turbine parameters variation and load disturbances were reduced by the MPC technique. Each local controller was designed independently such that stability of the overall closed-loop system was guaranteed. In all these works the faults are not considered explicitly and consequently would not address the active fault tolerant problem. It motivates us to seek a robust decentralized model predictive control approach that can be modified to active strategy in a straightforward manner.

In this paper, we present a novel approach to provide the decentralized fault tolerant model predictive control of a class of discrete-time interconnected nonlinear systems. It is proved that the proposed method guarantees the input-to-state stability (ISS) characterization for both local subsystems and the global system under predetermined assumptions. In order to deal with the unknown interconnection effects and changes in model dynamics due to multiple faults both passive and active fault tolerant control design are considered. In the active fault tolerant case an online approximation algorithm is applied to estimate the unknown interconnection effects and changes in model dynamics due to multiple faults. Besides, the decentralized control strategy is