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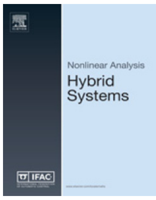

A generalized robust decentralized control methodology for a class of interconnected nonlinear systems subject to uncertainties and disturbances

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ABSTRACT

This paper studies the problem of robust decentralized control for a class of large-scale interconnected systems subject to uncertainties and disturbances via a generalized output feedback control method. First, a generalized extended state observer is constructed separately for each subsystem with less dependence of the precise system information and structure. Second, an explicit formula of the easy-transplantable decentralized robust control law is presented with an active compensation of disturbance. Moreover, the proposed methodology is extended to the sampled-data control case without any additional assumptions and hence will ease the practical implementations. It is shown that by a delicate analysis procedure of both continuous-time and hybrid scenarios, the closed-loop system can be rendered semi-globally asymptotically stable only using decentralized output feedback anti-disturbance controller. Numerical simulations show the efficiency of the proposed method.

1. Introduction

In engineering practices, interconnected systems are widely exist which depict a particular feature of having similar units and symmetrical interconnections. As is already known to the control community, those systems are very susceptible to the internal uncertainties and external disturbances since their operating environment is often poorly known, and their parameters cannot be calculated with sufficient accuracy to be used for online controllers. Due to its obvious practical application to systems such as electric power systems, industrial manipulators, computer networks, etc., decentralized control of these systems has been recognized to be an imperative but challenging research area [1–6]. Different from centralized control strategy that requires the states information from all subsystems, a decentralized control method is usually preferred because it permits reduced amount of information exchange between subsystems, which leads to less time delays and reduces computational burden. Significant progresses of decentralized control have been achieved for both linear and nonlinear interconnected systems with various control techniques. To name only a few, one can refer to [1,7–9] and references therein.

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Compared to those existing well-known advanced control strategies such as classical adaptive control [10], H∞ control [11,12], nonsmooth control method [13] and nonlinear output regulation method [14,15] etc., there are fewer results that can be found on the design of effective decentralized active disturbance rejection method which will provide compensation or elimination of the adverse effects caused by internal uncertainties or external disturbances. Active anti-disturbance control, rather than which is called "inactive" anti-disturbance control method, adopts a disturbance estimation procedure in order to construct a composite control law consisting both feedback part and disturbance compensation part, hence provides strong robustness of the controlled system even in a large working range [16,17]. In the literature, most notably, disturbance observer based control (DOBC) [18,19] and active disturbance rejection control (ADRC) (also called extended state observer based control (ESOBC)) [20–22] have become three most effective ways in the disturbance/uncertainty attenuation control community. Original pioneer works proposed by [20,22] and thereafter made practical by simplifying its implementation and the design transparent to engineers [21,23,24], the extended state observer based control (ESOBC) now becomes one of the most popular anti-disturbance methods in engineering-oriented practices.

The use of extended state observer based state and disturbance estimation procedure has certain apparent advantages since most practical plants may have limited output measurements and the disturbance item is too hard to measure by a real sensor. The major difficulty in designing an ESOBC for those interconnected systems is the presence of the uncertainties presented with the system nonlinearities from other subsystems. In other words, designing a decentralized stabilizer for a single subsystem only by using its own outputs while this subsystem is also driven by the unmeasurable states of other subsystems is not a trivial task. In the existing literature, an early research [3] deals with nonlinear functions that can depend on unbounded unmeasurable states, however the result is not a global one. [5] proposed a decentralized adaptive tracking algorithm using nonlinear output feedback control law. The problem of robust output feedback and almost disturbance decoupling for those interconnected systems is discussed in [25]. In an inspiring work [26], the authors construct a linear output feedback controller by adopting a high-gain observer [27] and the domination method [28] with the assumption of vanishing disturbances. In order to simplify the digital implementation of the robust decentralized control method, a linear decentralized sampled-data control method with global and semi-global stabilization objectives is proposed in a recent paper [29].

However, noting that estimating unmeasurable states with the aim of robust output feedback control is well addressed, such as [30,25,26,29], using a compensator estimating both non-vanishing disturbances and unmeasurable states for a class of uncertain nonlinear system is not a trivial task and fewer results can be referred in the literature. In this paper, aiming to tackle the problem of decentralized control using a generalized disturbance attenuation and output feedback control method for a class of interconnected nonlinear systems, we explicitly construct the control law by integrating the output feedback domination approach [28,31] with feedforward disturbance compensation technique. The output feedback portion is adopted to dominate the uncertain nonlinear items while the disturbance compensation portion is used to eliminate the adverse effects caused by the lumped disturbances. Furtherly, with an aim of easier practical implementations, a sampled-data robust decentralized control method is also developed. With the basis on the proposed continuous-time design strategy, the semi-global attractivity and local stability are delicately proved by carefully selecting a scaling gain using the output feedback domination approach and a sampling period sufficiently small to restrain the state growth under a zero-order-holder input. Distinguished with those existing related results, the proposed method now has the following new features:

- First, the strict-feedback structure and Lipschitz continuous condition of the system are removed. The proposed generalized design methodology adopts a same extended state observer of each subsystem neglecting the interaction of states information from other subsystems.
- Second, with an explicit design and analysis procedure, it is shown that the continuous-time control result can be extended to the sampled-data control case which will ease the implementations into real-life plants.

The paper is organized as follows. Section 2 introduces the system model and the problem statement. Section 3 gives the explicit control law construction procedure in continuous-time design framework. In Section 4, the sampled-data control case is discovered for easier practical implementations. Numerical simulations are presented in Section 5 to demonstrate the efficacy and promising implementation of the proposed robust decentralized control method. Then a conclusion and a reference list end the paper.

2. Problem statement and preliminaries

In this paper, we consider the disturbance/uncertainty attenuation problem for a class of m interconnected uncertain nonlinear systems of order n of the form

$$\text{Subsystem (i)} \begin{cases} \dot{\xi}_{i,1}(t) &= \xi_{i,2}(t) + f_{i,1}(\xi, t) \\ \dot{\xi}_{i,2}(t) &= \xi_{i,3}(t) + f_{i,2}(\xi, t) \\ & \vdots \\ \dot{\xi}_{i,n}(t) &= u_i(t) + f_{i,n}(\xi, t) + d_i(t, \omega, \xi) \\ y_i(t) &= \xi_{i,1}(t), \end{cases}$$
$$i = 1, 2, \ldots, m, \tag{2.1}$$