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Decentralized dynamic output feedback control for affine fuzzy large-scale systems with measurement errors

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Abstract

This paper investigates the decentralized output feedback control problem for affine fuzzy large-scale systems with unknown interconnections. A decentralized piecewise dynamic output feedback controller is constructed, and the measurement errors between actual outputs and measured outputs are considered in control synthesis. By introducing the S-procedure and a cyclic-small-gain condition, novel controller design conditions in terms of linear matrix inequalities (LMIs) are derived, which allow for reducing the worst case peak output due to measurement errors with satisfying an L_∞-norm constraint. Finally, two examples are given to illustrate the effectiveness and superiority of the new results.
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Keywords: Fuzzy large-scale systems; Measurement errors; Decentralized control; Cyclic-small-gain condition; Linear matrix inequalities (LMIs)

1. Introduction

Over the past few decades, large-scale systems have attracted considerable attention, and been applied to many practical situations, such as industrial processes, transportation networks, power systems, and others. Many methods have been proposed to investigate the stability analysis and control synthesis problems for large-scale systems (see [1–6] and the references therein). In [2], the author investigated the decentralized output feedback stabilization problem of the nonlinear interconnected systems with linear subsystems and nonlinear interconnections, and a sufficient condition was presented for existence of the decentralized output feedback control of the problem. In [5], by integrating a simple version of the cyclic-small-gain theorem and assigning appropriate weighting matrices for each subsystem, asymptotic stability was achieved with the controller design for each subsystem only utilized local states without knowing the system dynamics. The approaches mentioned above provide effective solutions for decentralized control problems of large-scale systems with linear subsystems and nonlinear interconnections. However, studies on large-scale systems with nonlinear subsystems and unknown interconnections are still insufficient.

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Recently, fuzzy logic systems have been extensively used for the modeling and control design for nonlinear systems due to their approximation ability to the nonlinear smooth functions [7–14]. Especially, the model reduction problem for T–S fuzzy switched systems with a Hankel-norm sense was well solved in [13]. In an effort to extend the adaptive fuzzy control idea to larger-scale nonlinear systems, the authors in [15–17] proposed adaptive fuzzy decentralized control methods for large-scale nonlinear strict-feedback systems. For more general large-scale nonlinear systems, the authors in [18–21] extended some linear control techniques to nonlinear systems, and presented fuzzy decentralized control synthesis conditions in the form of LMIs. In [22,23], the decentralized output feedback control problem for T–S fuzzy large-scale systems was discussed, and different fuzzy-observer-based controllers were obtained. Decentralized fuzzy H_∞ filter designs for T–S fuzzy large-scale interconnected systems were discussed in [24,25].

Most of the existing fuzzy decentralized controller/filter design methods are derived under the assumption that the premise variables of the fuzzy controller/filter are the same as the ones of the fuzzy plant. However, in practice, due to the unexpected variations in external surroundings, limitations of measurement technique, and obsolescence problem for measuring equipments, there may appear measurement errors such that the actual outputs are no longer equivalent to the measured outputs [26–28]. In this case, the above cited PDC controller/filter design methods cannot be employed. To the best of our knowledge, there is no result about the decentralized control for large-scale systems with measurement errors, which motivates us to make an effort in this paper.

This paper investigates the decentralized control problem for uncertain affine fuzzy large-scale systems with measurement errors. First, system outputs are chosen as the premise variables of fuzzy plants, and the output-space of each subsystem is partitioned into operating and interpolation regions. Then, a decentralized piecewise dynamic output feedback controller is constructed. By introducing the S-procedure and a cyclic-small-gain condition, the information of measurement errors is considered in control synthesis, and a decentralized dynamic output feedback control method is derived in the form of LMIs. The main contributions of this paper are summarized as follows: 1) Affine fuzzy models are exploited to describe the considered nonlinear large-scale systems, which need fewer rules and have much improved function approximation capabilities than the linear T–S fuzzy models discussed in [10–14,18–25]. 2) Measurement errors on system outputs and the resulting unmatched regions are considered in control synthesis. Compared with the results without considering the influence of measurement errors, the proposed control scheme can guarantee better steady performance when the measured values of system outputs are inaccurate. 3) A convex decentralized dynamic output feedback controller design method is derived by introducing some slack matrices, which loosens the restrictive constraints on the Lyapunov matrix imposed in [18,22,23].

The structure of this paper is as follows. The system description and the problem under consideration are given in Section 2. In Section 3, the decentralized dynamic output feedback control problem is addressed. Two examples are given in Section 4 to show the effectiveness and superiority of proposed method. Finally, conclusions are drawn in Section 5.

Notations: For a symmetric matrix M, $M > 0$ ($M < 0$) means that it is positive definite (negative definite). M^T denotes the transpose of matrix M, $He(M) = M + M^T$. The symbol $*$ is used in some matrix expressions to denote the transposed elements in the symmetric positions of a matrix.

2. System description and problem statement

2.1. System description

The following uncertain affine fuzzy large-scale model is used to represent a class of complex nonlinear large-scale systems, with the ith fuzzy subsystem S_i ($1 \le i \le N$) is described as

$$\begin{cases} \dot{x}_i(t) = \sum_{j=1}^{r_i} h_{ij}(y_i(t))((A_{ij} + \triangle A_{ij})x_i(t) + B_{ij}u_i(t) + a_{ij} + \triangle a_{ij} + G_{ij}w_i(t) + H_{ij}\Psi_i(x(t))) \\ y_i(t) = C_i x_i(t) \end{cases} \tag{1}$$

where r_i is the number of inference rules of the ith fuzzy subsystem, $x_i(t) \in R^{n_i}$ is the system state vector; $u_i(t) \in R^{m_i}$ is the control input vector; $w_i(t) \in R^{q_i}$ is the bounded external disturbance vector; $y_i(t) \in R^{s_i}$ is the output vector and chosen as premise variables of the fuzzy model; A_{ij}, B_{ij}, a_{ij}, G_{ij}, H_{ij}, C_i are known constant matrices with

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