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Decentralized H_∞ fuzzy filter for nonlinear large-scale sampled-data systems with uncertain interconnections

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Abstract

This paper proposes a decentralized H_∞ fuzzy filter technique for nonlinear large-scale interconnected systems that are based on the Takagi–Sugeno fuzzy model. The large-scale system has unknown interconnection terms that are assumed to satisfy the quadratic bounds. An error system between the nonlinear large-scale system and the decentralized filter is constructed. By using the fuzzy Lyapunov technique, sufficient conditions are proposed for both showing asymptotic stability and guaranteeing H_∞ fuzzy filter performance. These sufficient conditions are derived in terms of linear matrix inequalities. Finally, simulation examples are given to demonstrate the effectiveness of the proposed technique.

Keywords: H_∞ decentralized fuzzy filter; Large-scale system; Sampled-data system; Takagi–Sugeno (T–S) fuzzy model; Uncertain interconnection; Linear matrix inequality

1. Introduction

Recently, large-scale systems have attracted considerable attention due to their application in many practical systems, such as, manufacturing, transportation systems, mobile robotics, and communication networks [1–3]. Due to the structural constraints and coupling between each subsystem, the large-scale system has some disadvantages, such as, high dimensionality, interacting dynamic phenomena, and uncertain information on the interconnections, as well as conventional problems like nonlinearity and stability. To overcome the high dimensionality and interaction problems, a decentralized technique has been investigated [4,5], as it can reduce the complexities of the system dynamics by using only the local information of the large-scale system. The decentralized fuzzy technique using the Takagi–Sugeno (T–S) fuzzy model is one of the most efficient techniques for the large-scale system, because the fuzzy technique can easily solve the nonlinearity problem by using a convex combination method [6–8]. In previous studies [9–14], various decentralized fuzzy techniques have been proposed to control the nonlinear large-scale system. In [12], the

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decentralized fuzzy observer technique for the oscillating or unstable, uncertain system is proposed. In [13], the decentralized fuzzy output feedback technique for the affine large-scale system is studied. In [14], an adaptive fuzzy decentralized tracking output feedback technique is given for a switched large-scale system. However, studies on decentralized filtering issues with uncertain or nonlinear interconnections are still inadequate. The uncertain or nonlinear interconnections problem is important because the system model is not exactly known and all measurements are not reflected in the filter when the interconnection terms are uncertain or unknown. In addition, the parallel distributed compensation (PDC) scheme, which was proposed in [15], cannot be applied to the nonlinear interconnection case because the premise variable consists of the state variables of the other subsystem, when it must consist of only state variables of each subsystem.

On the other hand, it is well known that the filtering problem is important for stable and reliable system operation. Although the Kalman filter technique has been widely used, mainly in applications such as signal processing, tracking, and localization [16,17], its disadvantage is that it performs well only when the external noise is caused by white processes with known statistical properties. To compensate for this disadvantage, the H_∞ filtering technique has been studied in recent years [18–25] because it only requires the external noise to be an arbitrary signal with bounded energy. Thus, remarkable results have been proposed for the time-delay system [18], uncertain system [19], large-scale system [20,21], and sampled-data system [22–25]. The H_∞ fuzzy filtering technique for the sampled-data system is important because most engineering applications consist of a continuous-time system and a discrete-time output. Thus, many sampled-data filter techniques have been proposed and can be categorized into two approaches: time-delay converting [22,23]; and discretization methods [24,25]. In the time-delay converting method, the sampled-data signals are converted into continuous time-delay signals. In the discretization method, the sampled-data system is transformed into a discrete-time system, and the filter is designed based on the discrete-time domain. However, the sampled-data filter technique for the nonlinear large-scale system has not been well studied. Although the decentralized filter for the nonlinear sampled-data large-scale system was studied in [24] using the discretization method, it had the following limitations. The first limitation was the small feasible region of the stability conditions. The second limitation was its inapplicability to the large-scale system with uncertain or nonlinear interconnections.

Motivated by problems of the previous techniques, this paper proposes the decentralized H_∞ fuzzy filter for the nonlinear large-scale sampled-data system. To solve the uncertain interconnection problem, the interconnection term is assumed to satisfy a quadratic bound. Based on the T–S fuzzy model, the error system between the nonlinear large-scale sampled-data system and the decentralized fuzzy filter is considered. The asymptotic stability conditions of the error system are proposed and the H_∞ disturbance attenuation performance is guaranteed via a fuzzy Lyapunov function that was originally proposed in [29]. In addition, their constructive sufficient conditions are converted into linear matrix inequalities (LMIs), which are easily solved using the Matlab LMI toolbox. Finally, the performance of the proposed methods is compared with that of the previous filter techniques using two simulation examples.

This paper is organized as follows: Section 2 describes the T–S fuzzy system with measurable sampled-data output and the decentralized fuzzy filter. Section 3 formulates LMI-based asymptotic stability using the fuzzy Lyapunov function. In Section 4, it is shown that the H_∞ disturbance attenuation performance of the decentralized fuzzy filter is guaranteed. The procedure is validated via a simulation example in Section 5. Finally, Section 6 concludes the paper.

Notation: The subscripts i and j denote the fuzzy rule indices and l and m denote the subsystem indices. The notations $(\cdot)^T$ and $*$ are used for the transpose of the argument and the transposed element in the symmetric position, respectively. The space of functions $\phi : [-h, 0] \to \mathbb{R}^n$, which are absolutely continuous on $[-h, 0)$, have a finite $\lim_{\theta \to 0^-} \phi(\theta)$ and have square integrable first-order derivatives, is denoted by W with the norm

$$||\phi||_W = \max_{\theta\in[-h,0]} |\phi(\theta)| + \left[\int_{-h}^{0} |\dot{\phi}(s)|^2 ds \right]^{1/2}.$$

2. Preliminaries and problem formulation

Consider a large-scale T–S fuzzy system with unknown interconnections, which is composed of n subsystems. The lth subsystem can be described by the following IF–THEN rule:

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