Nonlinear Analysis: Hybrid Systems 23 (2017) 61–75

Contents lists available at ScienceDirect

Nonlinear Analysis: Hybrid Systems

journal homepage: www.elsevier.com/locate/nahs

Adaptive fuzzy output constrained decentralized control for switched nonlinear large-scale systems with unknown dead zones

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ARTICLE INFO

Article history:
Received 13 December 2015
Accepted 21 July 2016

Keywords:
Switched nonlinear large-scale systems
Decentralized state observer
Fuzzy logic systems
Prescribed performance theory
Unknown dead zones

ABSTRACT

In this paper, an adaptive fuzzy output-feedback control design with output constrained is investigated for a class of switched uncertain nonlinear large-scale systems with unknown dead zones and immeasurable states. Based on dynamic surface backstepping control design technique and incorporated by the average dwell time method and the prescribed performance theory, a new adaptive fuzzy output-feedback control method is developed. It is strictly proved that the resulting closed-loop system is stable in the sense of uniformly ultimately boundedness and both transient and steady-state performances of the outputs are preserved. Comparison simulation studies illustrate the effectiveness of the proposed approach.

1. Introduction

A large-scale system is often considered as a set of interconnected subsystems, such as power systems, computer and telecommunications networks, economic systems and multiagent systems. Owing to the complexity of control synthesis and the physical restrictions on information exchange among subsystems, it is often required to design for each subsystem a decentralized controller depending only on local measurements, even if to achieve an objective for the whole large-scale system [1]. Since fuzzy logic system and neural networks are the universal approximator, and can approximate any nonlinear function with arbitrary precision [2]. During the past two decades, various adaptive decentralized control schemes have been developed for large-scale nonlinear systems [2]. In [3–7], adaptive neural network and fuzzy decentralized state feedback control designs were proposed for large-scale nonlinear systems in strict feedback form. In [8,9], adaptive neural network and fuzzy decentralized output feedback control methods were studied for large-scale nonlinear systems by designing a state observer for estimating the unmeasured states. The above mentioned adaptive fuzzy or neural decentralized control approaches can provide an effective methodology to control those uncertain nonlinear large-scale systems. Nevertheless, they need not require that the nonlinear functions included in the controlled systems be known or be linearly parameterized. However, the above mentioned results are only suitable for the non-switched nonlinear large-scale systems, instead of the switched nonlinear large-scale systems.

Recently, some control design methods have been proposed for several classes of switched nonlinear systems in [10–16]. Two state feedback control approaches in [10,11] have proposed for a class of switched single-input and single-output (SISO) nonlinear systems based on the common Lyapunov function method. By applying average dwell-time

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http://dx.doi.org/10.1016/j.nahs.2016.07.002
1751-570X/

technique, works in [12,13] have been investigated switched adaptive control schemes for a class of switched nonlinear systems with time-varying delay, and [14] firstly solved the problem of output feedback control design for stochastic nonlinear switched systems with unmodeled dynamics. In [15], a novel adaptive neural network control method has been presented for a class of SISO switched nonlinear systems with switching jumps. An adaptive fuzzy output tracking control problem has been investigated in [16] for a class of switched uncertain nonlinear large-scale systems under arbitrary switchings. Obviously, all the above mentioned adaptive control approaches can ensure that all the signals of the resulting closed-loop system are bounded. But all the existing switched control methods are not investigated in the problem of prescribed performance control (PPC).

It is well known that the PPC demands the convergence rate no less than a prescribed value, exhibiting a maximum overshoot less than a sufficiently small constant and the output or tracking error is confined within the prescribed performance bounds for all times. The robust adaptive control for SISO strict feedback nonlinear system and feedback linearizable multiple-input and multiple-output (MIMO) nonlinear systems with PPC were investigated in [17,18]. A multiple constraints control was considered in [19,20] with PPC approach. The dead zone issues have been skillfully addressed with the prescribed performance theory for a class of non-switched systems in [21,22]. However, the prescribed performance design methodology still not be applied to switched nonlinear systems and the output feedback design for switched nonlinear large-scale systems with unknown dead zone is still a challenge.

In this paper, an adaptive fuzzy output feedback control design with prescribed performance is developed for a class of Switched nonlinear large-scale systems with unknown dead zone. The main contributions of the proposed control scheme are as follows: (i) by introducing the prescribed performance control technique, both transient and steady-state performances of the hybrid switched large-scale systems with unknown dead zone and immeasurable states are ensured; (ii)parameter adaptive method is adopted to deal with unknown dead-zone issues, which makes the controller has better robustness.

The remainder of this paper is organized as follows. The problem statement and preliminaries are given in Section 2. The decentralized switched fuzzy state observer design is given in Section 3. Adaptive controller design and stability analysis are in Section 4. The simulation studies are given in Section 5, and followed by Section 6 which concludes the work.

2. Problem statement and preliminaries

2.1. Systems descriptions and assumptions

Consider a class of uncertain switched nonlinear large-scale systems that is composed of N subsystems interconnected by their outputs. The ith switched subsystem can be described by switched nonlinear systems:

$$\begin{cases} \dot{x}_{i,1} = x_{i,2} + f_{i,1}^{\sigma(t)}(\underline{x}_{i,1}) + \Delta_{i,1}^{\sigma(t)}(\bar{y}) + d_{i,1}^{\sigma(t)} \\ \dot{x}_{i,2} = x_{i,3} + f_{i,2}^{\sigma(t)}(\underline{x}_{i,2}) + \Delta_{i,2}^{\sigma(t)}(\bar{y}) + d_{i,2}^{\sigma(t)} \\ \vdots \\ \dot{x}_{i,n_i-1} = x_{i,n_i} + f_{i,n_i-1}^{\sigma(t)}(\underline{x}_{i,n_i-1}) + \Delta_{i,n_i-1}^{\sigma(t)}(\bar{y}) + d_{i,n-1}^{\sigma(t)} \\ \dot{x}_{i,n_i} = D_i^{\sigma(t)}(u_i^{\sigma(t)}) + f_{i,n_i}^{\sigma(t)}(\underline{x}_{i,n_i}) + \Delta_{i,n_i}^{\sigma(t)}(\bar{y}) + d_{i,n}^{\sigma(t)} \\ y_i = x_{i,1} \end{cases} \tag{1}$$

where $\underline{x}_{i,j} = [x_{i,1}, x_{i,2}, \dots, x_{i,j}]^T \in \Re^i$, $i = 1, 2, \dots, N;\ j = 1, 2, \dots n_i$ are the states, $y_i \in \Re$ is the output. The function $\sigma(t) : [0, \infty) \to M = \{1, 2, \dots, m\}$ is switching signal which is assumed to be a piecewise continuous (from the right) function of time. Moreover $\sigma(t) = k$ implies that the kth switched large-scale system is active. $f_{i,j}^{\sigma(t)}(\underline{x}_{i,j})$, are unknown smooth nonlinear functions. $\Delta_{i,j}^{\sigma(t)}(\bar{y})$, $(\bar{y} = [y_1, y_2, \dots, y_N])$ are unknown smooth functions representing the interconnection effects between the ith subsystem and the other subsystems. $D_i^{\sigma(t)}(u_i^{\sigma(t)}) \in \Re$ is the output of the dead-zones.

In addition, we assume that the state of the system (1) does not jump at the switching instants, i.e., the solution is everywhere continuous, which is a standard assumption in the switched system literature [16,23].

Now we recall the definition of average dwell time, which plays a key role in research of switched nonlinear control. A switched nonlinear large-scale system (1) is called to have a switching signal $\sigma(t)$ with average dwell time τ_a, if there exist two positive numbers N_0 and τ_a such that

$$N_\sigma(T, t) \le N_0 + \frac{T - t}{\tau_a} \quad \forall T \ge t \ge 0 \tag{2}$$

where $N_\sigma(T, t)$ is the number of switches occurring in the interval $[t, T)$.

Let $T > 0$ be an arbitrary time. Denote by $t_1, \dots, t_{N_\sigma(T,0)}$ the switching times on the interval $(0, T)$ $(t_0 = 0)$. When $t \in [t_j, t_{j+1})$, $\sigma(t) = k_j$, that is, the k_jth large-scale system is active. In this study, we assume $k_j \ne k_{j+1}$ for all j.