Information Sciences 259 (2014) 71–86

Contents lists available at ScienceDirect

Information Sciences

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

Observer-based adaptive fuzzy decentralized control for stochastic large-scale nonlinear systems with unknown dead-zones

Shuai Sui, Shaocheng Tong *, Yongming Li

Department of Mathematics, Liaoning University of Technology, Jinzhou, Liaoning 121000, China

ARTICLE INFO

Article history:
Received 7 February 2013
Received in revised form 12 June 2013
Accepted 24 September 2013
Available online 1 October 2013

Keywords:
Stochastic nonlinear large-scale system
Fuzzy adaptive decentralized control
Backstepping technique
Unknown dead-zone

ABSTRACT

This paper studies the problem of adaptive fuzzy decentralized output feedback control for a class of uncertain stochastic large-scale nonlinear systems. The considered systems have unknown nonlinear functions, unknown dead-zones, unmodeled dynamics and unmeasurable state variables. Therefore, fuzzy logic systems are utilized to approximate the unknown nonlinear functions, and a fuzzy state observer is established to estimate the unmeasurable states. Based on the backstepping design and the supply changing function technique, a robust adaptive fuzzy decentralized output feedback control approach is developed. The proposed control approach can ensure the closed-loop system to be input-state-practically stable (ISpS) in probability, and accommodate the unmodeled dynamics and unknown dead-zones as well. The effectiveness of the proposed control approach is illustrated by a simulation example.

1. Introduction

In the past decades, stochastic modeling has been played an important role in many real systems, for instance, nuclear processes, thermal processes, chemical processes, biology, socioeconomics, and immunology. Therefore, the control design on stochastic systems have drawn many researchers attention, and some important control methodologies, such as sliding mode control [14,24,41,43], Lyapunov function approach [8,40,46] and T–S fuzzy control [9,27,42,52,58], have been reported. Recently, the well-known backstepping design technique [1,17–19,48] has been applied to stochastic nonlinear systems [5–7,22,23,44,45]. The adaptive backstepping output feedback control design was investigated in [5,6,23] for stochastic single-input and single-output (SISO) nonlinear systems by using the quartic Lyapunov function. The robust adaptive backstepping output feedback control design approaches were proposed in [44,45] for stochastic SISO nonlinear systems with unmodeled dynamics by changing supply function or small-gain theorem. Subsequently, the above results were extended to stochastic nonlinear large-scale systems and several adaptive decentralized backstepping control approaches were developed in [7,15,22], respectively. However, above results are only suitable for special stochastic nonlinear systems, whose nonlinearities are linearly parameterized.

In order to solve the problem above, many adaptive fuzzy or neural network control design methods have been developed for stochastic nonlinear systems by employing fuzzy logic systems or neural networks (NN), for example, see [3,4,16,21,25,28,29,32,33,39,50,51,54,55,57] and reference therein. The results in [4,32,33,39,50,51,54] are for a class of SISO stochastic nonlinear systems with or without time delays; in [3,21,28,57] for SISO or MIMO stochastic nonlinear systems

* Corresponding author. Tel.: +86 04164199101.
E-mail address: jztongsc@163.com (S. Tong).

0020-0255/$ - see front matter © 2013 Elsevier Inc. All rights reserved.
http://dx.doi.org/10.1016/j.ins.2013.09.047

without unmeasurable states, while the results in [16,29,55] for stochastic large-scale nonlinear systems, respectively. Recently, robust adaptive output-feedback control methods were proposed in [30,37] for stochastic nonlinear systems with unmodeled dynamics. The obtained adaptive control schemes not only guarantee the stability of the closed-loop systems, but also have the robustness to the unmodeled dynamics.

Dead-zone is one of the most important non-smooth nonlinearities in many industrial processes. Its presence severely degrades the control system performance [2,10,34,38,49,53]. The fuzzy adaptive control methods were first developed in [34,49] for a class of stochastic nonlinear systems with unknown dead-zone. The corresponding the stability of the closed-loop systems were also proved. However, the proposed control approaches in [34,49] are only applied to a class of SISO stochastic nonlinear systems with the states being measurable. Moreover, the stochastic systems under study in [34,49] are free of unmodeled dynamics. Therefore, the corresponding adaptive controllers lack the robustness.

Inspired by previous work, this paper investigates the adaptive decentralized fuzzy control problem of uncertain large-scale stochastic nonlinear systems. The considered systems contain unknown functions, unknown dead-zone, unmodeled dynamics and unmeasured states. Fuzzy logic systems are first utilized to approximate the unknown nonlinear functions, and then a fuzzy state observer is designed for estimating the unmeasurable states. By using the backstepping design technique and the supply changing function, a robust adaptive fuzzy decentralized output feedback control approach is developed. It is proved that all the variables of the closed-loop system are ISpS in probability, and the observer errors and the output of the system can be regulated to a small neighborhood of the origin. The main contributions of this paper are as follows: (i) the restrictive requirement like that in [34,49] that all the states are measurable can be removed and (ii) both the unmodeled dynamics and unknown dead-zone problems can be solved simultaneously.

2. System descriptions and preliminaries

2.1. Problem statements and basic assumptions

In this paper, we consider the following stochastic nonlinear large-scale systems:

$$\begin{cases} dz_i = f_{i,0}(t,z_i,y_i)dt + g_{i,0}(t,z_i,y_i)dw_i \\ dx_{i,j} = [x_{i,j+1} + f_{i,j}(\underline{x}_{i,j}) + \Delta_{i,j}(t,z_i,y)]dt + g_{i,j}(t,z_i,y)dw_i \\ j = 1,\ldots,n_i - 1, \\ \vdots \\ dx_{i,n_i} = [u_i + f_{i,n_i}(\underline{x}_{i,n_i}) + \Delta_{i,n_i}(t,z_i,y)]dt + g_{i,n_i}(t,z_i,y)dw_i \\ y_i = x_{i,1} \end{cases} \tag{1}$$

where $\underline{x}_{i,j} = [x_{i,1},\ldots,x_{i,j}]^T \in R^j$, $i = 1,\ldots,N$, $j = 1,\ldots,n_i$ are the states, $y = [y_1,\ldots,y_N]^T \in R^N$ is the output vector, and $z_i \in R^{m_i}$ are unmodeled dynamics and $\Delta_{i,j}(t,z_i,y)$ are the dynamical disturbances. $f_{i,j}(\cdot)$, $j = 1, 2, \ldots, n_i$ are unknown smooth nonlinear functions. $f_{i,0}(\cdot)$, $g_{i,0}(\cdot)$, $\Delta_{i,j}(\cdot)$ and $g_{i,j}(\cdot)$ are uncertain functions; $w_i \in R$ is an independent standard Brownian motion defined on a complete probability space. u_i is the output of the dead-zones defined by:

$$u_i = D_i(v_i) \triangleq \begin{cases} m_{i,r}(v_i - b_{i,r}) & \text{if } v_i \geqslant b_{i,r} \\ 0 & \text{if } -b_{i,l} < v_i < b_{i,r} \\ m_{i,l}(v_i + b_{i,l}) & \text{if } v_i \leqslant -b_{i,l} \end{cases} \tag{2}$$

In (2), $v_i \in R$ is the input to the dead zone; $m_{i,r}$ and $m_{i,l}$ are the right and the left slopes of the dead-zone characteristic; $b_{i,r}$ and $b_{i,l}$ are the breakpoints of the input nonlinearity. Here the coefficients $m_{i,r}$, $m_{i,l}$, $b_{i,r}$ and $b_{i,l}$ are assumed to be unknown strictly positive constants.

This paper assumes that the states $x_{i,j}$, $i = 1,\ldots N$, $j = 2,\ldots,n_i$, the output of dead-zone u_i and unmodeled dynamics z_i are not available for the controller design. The control objective is to design an adaptive controller v_i, such that the closed-loop system is ISpS in probability and the output y_i converges to a small neighborhood of the origin.

Remark 1. It is well known that output feedback control design is an important topic for nonlinear system, and some important research results have been reported. For example, see [26,47]. The method in [26] is for the discrete-time Takagi–Sugeno fuzzy systems with time-varying delays, while the result in [47] is for the networked systems with discrete and distributed delays. However, the underlying control methods in [26,47] did not study the unmodeled dynamics or unknown dead-zone problems.

Throughout this paper, the following assumptions are made for the system in (1).

Assumption 1 [22]. For each $i = 1,\ldots,N$, $j = 1,\ldots,n_i$ there are unknown constants $p_{i,j}^* \geqslant 0, q_{i,j}^* \geqslant 0$ and known smooth functions $\varphi_{i,j,0} \geqslant 0$, $\varphi_{i,j,l} \geqslant 0$, $\psi_{i,j,0} \geqslant 0$ and $\psi_{i,j,l} \geqslant 0$ such that $\forall (t,z_i,y) \in R_+ \times R^{m_i} \times R^N$,