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Decentralized adaptive fuzzy control for nonlinear large-scale systems with random packet dropouts, sensor delays and nonlinearities

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Abstract

This paper investigates the adaptive fuzzy decentralized control problem for a class of uncertain nonlinear large-scale systems. Different from the conventional backstepping-based adaptive output feedback control technique, the output measurements are imperfect and considered to suffer random packet dropouts (RPDs), random sensor delays (RSDs) and random sensor nonlinearities (RSNs), which result typically from a network environment such as sensor networks. A novel sensor model is established for describing the random phenomena within a unified representation by introducing a multi-Markovian variable. Based on this sensor model, two main difficulties arise: first is that the system output cannot be used directly for controller design due to the randomly occurring phenomena; second is how to deal with the complex nonlinear stochastic terms with unknown interconnections, unknown time-varying delays and unknown sensor nonlinearities entangled together. With the help of new coordinate transformations and mean value theorem, by using appropriate Lyapunov–Krasovskii functionals, a new adaptive decentralized memoryless output feedback controller is designed. It is proved that the constructed controller ensures the boundedness in probability of all the closed-loop signals in presence of RPDs, RSDs and RSNs. The simulation results are presented to show the effectiveness of the proposed scheme.

Keywords: Adaptive decentralized control; Nonlinear systems; Random packet dropouts; Random sensor delays; Random sensor nonlinearities

1. Introduction

A number of large-scale interconnected systems found in the real world enjoy the particular feature of having similar units and symmetrical interconnections. In the past years, nonlinear large-scale systems have been paid considerable attention, which can describe a large amount of practical systems such as electrical power systems, computer network systems, process control systems and economic systems [21,12,48,22]. The decentralized adaptive technique

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is believed a useful method to handle the control design problems of nonlinear large-scale systems since it can be designed independently for local subsystems and uses locally available signals for feedback propose. By combining the backstepping design technique, the structural restriction of the matching condition [17,14] is relaxed for copying with unknown interconnection terms. Therefore, the backstepping-based decentralized adaptive control approach has been widely applied to the nonlinear large-scale systems, see for examples [4–15]. In [52,51], the control scheme is employed to deal with the uncertain large-scale systems with time-delay interconnections combing neural networks (NNs), and dynamic surface control (DSC) technique [31–35] is incorporated in [23,50] to solve the "explosion of complexity" problem [28,42]. The paper [37] extends this method to pure-feedback nonlinear systems. Combing with fuzzy logic systems (FLSs), observer-based decentralized adaptive control methods are proposed for nonlinear large-scale system with unmeasured states in [30,19]. More recently, these design methods are applied to stochastic nonlinear large-scale systems in [40].

On the other hand, some network-induced phenomena such as random packet dropouts (RPDs), random sensor delays (RSDs) may more frequently appear in the large-scale interconnected networked systems [5,43]. For example, wireless sensor networks display complicated coupling between the sensor nodes and network-induced phenomena [5]. These random phenomena often make only partial information available from the measurements. The RPD (missing measurement) phenomenon often occurs due to the limited bandwidth of the channels for signal transmission, therefore, which receives considerable attention and many results have been reported in the literature [10,16,6]. A common way to describe the packet dropouts is to exploit multiple Bernoulli distributions [10,16]. In [6], however, considering the case when only partial data may be missing because of sensor aging and temporal faults, the random variables with probabilistic density functions are introduced, which includes the Bernoulli distribution as a special case. Another network-induced phenomenon, RSDs, is also inevitable in networked control systems (NCSs) due to the technological limitation or random congestion of packet transmissions. In [20,3], the observer-based output feedback control problems have been studied for discrete or continuous NCSs, where the sensor delay is assumed to be governed by a Markov process. In addition, in network environments, the sensor nonlinearities such as saturation may suffer randomly abrupt changes, for example, random sensor faults, sensor aging resulting, repairs of partial components, changes in the interconnections of subsystems, sudden environment changes, modification of the operating point of a linearized model of a nonlinear system, etc [43,5]. Thus, the RSN is firstly introduced to account for a sensor saturation in networked environments in [43,5]. Then a class of randomly occurred sensor nonlinearities with sector condition are investigated in [47]. Furthermore, [6,43,5] investigate some synthetic problems where two random phenomena are considered simultaneously. The above results are established based on linear networks or complex networks only including sector-like nonlinearities. Recently, an adaptive indirect fuzzy sliding mode control method is proposed in [15] for nonlinear NCSs subject to time-varying network-induced delay. However, for a wider class of uncertain nonlinear complex networks, there has been little theoretical work appeared on effective observer-based control designs. It should be pointed out that, the aforementioned observer-based decentralized adaptive control methods [10,13–16] cannot be applied to deal with the large-scale systems with imperfect measurement signals. It is, therefore, the main purpose of this paper to solve the adaptive decentralized control problem of a class of nonlinear large-scale systems in a network environment such as wireless sensor networks subject to RPDs, RSDs and RSNs.

In this paper, the adaptive fuzzy decentralized control problem is considered for a class of uncertain nonlinear large-scale systems with randomly occurring phenomena from sensor measurements. These random phenomena include RPDs, time-varying RSDs and RSNs which result typically from networked environments such as wireless sensor networks. It is shown that the presented control approach can guarantee all the signals of the resulting closed-loop system are bounded in probability. The main contribution of this paper lies in two aspects: (1) A novel sensor model is introduced to describe the RPDs, time-varying RSDs and RSNs within a unified framework. The multi-Markovian variable is introduced to represent the stochastic behaviors of multiple sensors in networked environments. (2) With the help of new coordinate transformations and mean value theorem, the difficulties from the unavailable output signal due to the randomly occurring phenomena are overcome by using the state estimate instead of system output in controller design.

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