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Neural-network-based decentralized fault-tolerant control for a class of nonlinear large-scale systems with unknown time-delayed interaction faults

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Abstract

This paper proposes an adaptive approximation design for the decentralized fault-tolerant control for a class of nonlinear large-scale systems with unknown multiple time-delayed interaction faults. The magnitude and occurrence time of the multiple faults are unknown. The function approximation technique using neural networks is employed to adaptively compensate for the unknown time-delayed nonlinear effects and changes in model dynamics due to the faults. A decentralized memoryless adaptive fault-tolerant (AFT) control system is designed with prescribed performance bounds. Therefore, the proposed controller guarantees the transient performance of tracking errors at the moments when unexpected changes of system dynamics occur. The weights for neural networks and the bounds of residual approximation errors are estimated by using adaptive laws derived from the Lyapunov stability theorem. It is also proved that all tracking errors are preserved within the prescribed performance bounds. A simulation example is provided to illustrate the effectiveness of the proposed AFT control scheme.

1. Introduction

The decentralized control design for nonlinear large-scale systems has been attracting significant attention in recent years due to the lack of computing capabilities required for a single central controller. The important consideration for the design is the management of the

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interaction relationship between subsystems. The first issue for the design of the decentralized control system is the development of techniques for handling uncertainties in interconnections between subsystems. The second issue is the development of techniques that deal with the time delay effects in interconnections due to the information transmission among subsystems. The third issue is the development of techniques that deal with unexpected faults in the interconnections. The first and second issues have been actively investigated for the decentralized adaptive control design (see [9,10,30,33] and the references therein). However, few results have been reported for the decentralized control of nonlinear large-scale systems with unexpected faults in interconnections (i.e., for the third issue).

The design of a reliable control system even in the presence of faults has been regarded as a challenging problem due to the inevitability and unpredictability of faults. These unexpected faults may cause a breakdown of the system and serious degradation of its performance. These problems necessitate the design of fault-tolerant (FT) controllers that can automatically compensate changes in system dynamics by various faults. Many FT approaches have been proposed using several control methods [3–7,13,14,28,29,31,32,34]. Despite these efforts, few research results have been reported on the decentralized FT control of nonlinear large-scale systems with unexpected faults in interconnections. In [23], a decentralized FT control approach was recently proposed for a class of nonlinear large-scale systems with interaction faults where the adaptive approximation method was used to compensate the faults. However, the approach [23] cannot deal with the time-delayed fault effects in interconnections which are necessary due to the existence of communication delays among subsystems. In addition, the transient performance of tracking errors cannot be guaranteed at time instants when the interaction faults occur without the information of the occurrence time and magnitude.

Motivated by these observations, in this paper, the decentralized AFT control problem is addressed for a class of nonlinear large-scale systems with unknown multiple time-delayed interaction faults. The interaction faults of each subsystem include unknown time-varying delays, and unknown magnitude and occurrence time. Since information on the time-delayed faults is unavailable, we design a decentralized time-delay independent AFT control system with prescribed performance bounds in an adaptive approximation framework. The prescribed performance bound of the tracking error of each subsystem is presented using the error transformation technique reported in [1]. The function approximation technique and appropriate Lyapunov–Krasovskii functionals are employed to compensate unknown time-delay interconnection effects and changes in model dynamics due to time-delayed interaction faults. It is shown that all the signals in the total closed-loop system are uniformly ultimately bounded and the tracking errors are preserved within prescribed performance bounds even in the presence of the time-delayed interaction faults. The contribution of this paper is three-fold: (i) it is the first trial to consider unknown time-varying delayed interaction faults in the decentralized AFT control field for nonlinear large-scale systems; (ii) the prescribed performance concept is firstly applied in the decentralized AFT control field and to systems with unknown time delays; and (iii) the design and stability analysis method with prescribed performance bounds are derived in the presence of unknown multiple time-delayed nonlinear interaction faults.

This paper is organized as follows. In Section 2, problem formulations along with necessary assumptions are given and the function approximation technique is reviewed briefly. In Section 3, a decentralized memoryless AFT control system with specified performance bounds is proposed for uncertain large-scale systems with nonlinear time-delayed interaction faults, and its stability is analyzed. Simulation results are discussed in Section 4, and conclusions are given in Section 5.