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Research article

Design of robust reliable control for T-S fuzzy Markovian jumping delayed neutral type neural networks with probabilistic actuator faults and leakage delays: An event-triggered communication scheme

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ABSTRACT

This study examines the problem of robust reliable control for Takagi-Sugeno (T-S) fuzzy Markovian jumping delayed neural networks with probabilistic actuator faults and leakage terms. An event-triggered communication scheme. First, the randomly occurring actuator faults and their failures rates are governed by two sets of unrelated random variables satisfying certain probabilistic failures of every actuator, new type of distribution based event triggered fault model is proposed, which utilize the effect of transmission delay. Second, Takagi-Sugeno (T-S) fuzzy model is adopted for the neural networks and the randomness of actuators failures is modeled in a Markov jump model framework. Third, to guarantee the considered closed-loop system is exponential mean square stable with a prescribed reliable control performance, a Markov jump event-triggered scheme is designed in this paper, which is the main purpose of our study. Fourth, by constructing appropriate Lyapunov-Krasovskii functional, employing Newton-Leibniz formulation and integral inequalities, several delay-dependent criteria for the solvability of the addressed problem are derived. The obtained stability criteria are stated in terms of linear matrix inequalities (LMIs), which can be checked numerically using the effective LMI toolbox in MATLAB. Finally, numerical examples are given to illustrate the effectiveness and reduced conservatism of the proposed results over the existing ones, among them one example was supported by real-life application of the benchmark problem.

1. Introduction

The research of neural networks (NNs) received significant interest during the past few decades. In particular, neural networks have been widely achieved in various applications, such as automatical control, signal processing, solving certain optimization problems, machine learning, and so on [1–7]. It should be noted, due to the finite switching speed of electronics involved and the inherent communication time between the neurons, inevitably time-delay exists regardless how small it may be. Precisely the time-delay is one of the main factor that can cause performance degradation and/or the instability of neural networks. It is therefore that the stability problem of neural networks with time delays has attracted considerable attention of many researchers in the last few decades and considerable stability research results have emerged [8–12]. Also, many dynamical neural networks are described with neutral functional differential equations that include neutral delay as their special case. These neural networks are called neural networks of neural-type. Recently, some results for neural networks of neural-type have been derived in the literature [13–15].

On the other hand, the connection weights of the neurons depend on certain resistance and capacitance values that include uncertainties (modeling errors). When modeling neural networks, the parameter uncertainties (also called variations or fluctuations) should be taken into account. And in recent years, the stability analysis issues for neural networks in the presence of parameter uncertainties perturbations have stirred some initial research attention [16–19]. Recently, the effect of leakage delay in nonlinear systems is one of the research topic and it has been studied by many researchers studied in the literature [20,21]. As pointed out in Ref. [22], the time delay in stabilizing negative feedback term has a trend to destabilize the system, and it has great impact on the dynamical behavior of neural networks. Therefore, there are many authors considering the problem of stability analysis and system involving time delay in the leakage term, see for example [23–25]. Different types of sta-

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bility criteria for neural networks have been obtained by different methods, such as asymptotical stability, complete stability, absolute stability and exponential stability. But the exponential stability gives exponential convergence rate which is often used to determine the speed of neural computations [26], it is a more favorite property than asymptotical stability [27–29].

The study of Markovian jumping neural networks is inspired by many real world technical problems involving random abrupt variations and switches in many practical systems. A Markov jump neural network that undergoes conversion from one mode to another, between a finite or denumerable number of possible modes. Since the study of the Markovian jumping neural networks with control techniques given more importance over the past few years, some of the important results have been reported [30–32]. Its applications can be found in many practical systems, such as networked control systems [33], electric power systems, fault-tolerant systems [34], target tracking systems [35] and so on. On another research direction, Takagi-Sugeno (T-S) fuzzy systems have been verified to be a powerful tool for controlling nonlinear systems owing to their universal approximation characteristics. The T-S fuzzy model approach combines the flexible fuzzy logic theory and successful linear system theory into a uniform framework to approximate a broad range of complex nonlinear systems. The advantages in using a small number of rules to model higher-order nonlinear systems based on T-S fuzzy model were exposed in Refs. [36–39]. In general, the Markov jump neural networks with local input-output relations are represented by T-S fuzzy systems which can be described by fuzzy IF-THEN rules. Since the study of Markovian jump neural networks and T-S fuzzy model has been of both theoretical and practical importance over the past few years, some of the important results have been reported [40,41]. In addition, there is an increasing need on reliability of industrial systems in issue of potential process abnormalities and component faults. Actuator failures can be commonly experienced in practical systems and they may degrade system performance, induce instability of the closed-loop system, what is worse, lead to fatal accidents [42–44]. Therefore, substantial attention has been drawn to the reliable control design issue so as to guarantee high reliability and robustness for industrial system against undesirable faults. However, how to design a reliable controller has not been fully studied in the above-mentioned papers, especially on the basis of the Markov jump T-S fuzzy model approach.

Recently, networked control systems (NCSs) have received considerable attention due to their low cost, reduced weight and power requirements, simple installation and maintenances, sharing of the resources, etc [45–47]. However, the introduction of a communication network can also bring about many problems, such as network-induced delay and packet dropout. Therefore, the tasks in traditional systems, such as the control problems and signal estimation problem, should be reconsidered. In recent years, the stability analysis and control design for NCSs have been invested, and several outstanding results have been obtained [48,49]. In these works, most are based on the periodic triggered control method, which is called a time-trigged control. In this triggering scheme, the fixed sampling period is determined under worst conditions such as external disturbances, uncertainties, and time-delays. To this end, a so-called event-triggered mechanism has been proposed, which is more convenient and effective than the classical time-triggered mechanism due to the advantages in reducing the number of transmissions while maintaining satisfactory closed-loop stability of system [50–52]. Recently many of the researcher concentrates with event-triggered communication scheme with combination of both Markovian jumping parameters, T-S fuzzy based approach. For example, in Ref. [53] the authors studied decentralized event-triggered synchronization of uncertain Markovian jumping neutral-type neural networks with mixed delays. The work in Ref. [54] examined event-triggered asynchronous guaranteed cost control for Markov jump discrete-time neural networks with distributed delay and channel fading. More specifically, T-S fuzzy non-linear system with event triggered scheme was discussed in Refs. [55,56].

Moreover, in NCSs, the temporary measurements failure and probabilistic distortion are usually unavoidable for a variety of reasons, for example, networked delay, actuators electromagnetic interference, and zero shift, which may lead to unbearable system performance [57,58]. Therefore, from a safety as well as performance point of view, it is required to design a reliable controller with event-triggered that can tolerate actuators failures as well as networked delay. Recently, the fault model with event-triggered has received a lot of interest, and lots of outstanding results have been obtained [59–62]. In Ref. [59], the authors considered the problem of reliable dissipative control for Markov jump systems using an event-triggered sampling information scheme. The problem of event-triggered in neutral system with probabilistic sensor and actuator faults is discussed in Ref. [60]. The authors, [61] investigated event-triggered reliable control for fuzzy Markovian jump system with mismatched membership functions. The problem of event-triggered reliable H_∞ filter design for networked systems with multiple sensor distortions were researched in Ref. [62]. Noting the importance of reliable and probabilistic actuator faults, it is natural to wonder how to address the reliable event-triggered control problem for Markovian jumping parameters by T-S fuzzy approach. To the best of our knowledge, little effort have been devoted to this issue, which motivates of our work.

Motivated by the above discussions, in this article, we tackle the event-triggered reliable control problem for T-S fuzzy Markovian jump neural networks with uncertain parameters and probabilistic actuator faults. In particular, the novelty of this article lies in the fact that based on fuzzy logic rules, a more realistic actuator model consisting probabilistic faults/failures is considered. Therefore, the highlights and major contributions of this paper lies in the following bullet points:

- An event-triggered scheme shows an effective way to keep balance for the system control performance and network communication bandwidth burden.
- By adopting a generalized actuator fault model and the reliable controller with event-triggered is designed for a class of uncertain T-S fuzzy Markov jump neural networks.
- By employing the Lyapunov-Krasovskii theory, LMI technique, free weighting approach and some integral inequality techniques, we obtain the exponential stability of delay-dependent reliable control scheme to deal with the effects of interval time-varying delays, leakage delay.
- The obtained stability conditions are formulated in terms of LMIs that can be easily solved by using standard software packages. Finally, numerical examples with simulation results are presented to illustrate the effectiveness and which are compared with some existing results to show the less conservatism of the developed results. In addition, to show the real-life application, the quadruple tank process system (QTPS) is considered in this paper in terms of an NN model, which is realized in the sense of an exponential stability performance.

Notation: The superscripts "T" and "-1" stand for matrix transposition and matrix inverse, respectively; $\mathbb{R}^n$ and $\mathbb{R}^{n\times m}$ denote the n-dimensional Euclidean space and the set of all $n \times m$ real matrices, respectively; the notation $P > 0\,(\geq 0)$ means that P is real, symmetric, and positive definite (positive semi-definite); I is the identity matrix of appropriate dimension; the notation $\mathbb{E}[\cdot]$ stands for the expectation operator; and "$*$" is used to represent a term that is induced by symmetry. Let $(\Omega, \mathcal{F}, \mathcal{P})$ be a complete probability space which

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