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State estimation of T–S fuzzy delayed neural networks with Markovian jumping parameters using sampled-data control ☆

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Abstract

In this paper, we are concerned with the problem of state estimation of Takagi–Sugeno (T–S) fuzzy delayed neural networks with Markovian jumping parameters via sampled-data control. Based on the fuzzy-model-based control approach and linear matrix inequality (LMI) technique, several novel conditions are derived to guarantee the stability of the suggested system. A new class of Lyapunov functional, which contains integral terms, is constructed to derive delay-dependent stability criteria. Some characteristics of the sampling input delay are proposed based on the input delay approach. Numerical examples are given to illustrate the usefulness and effectiveness of the proposed theoretical results.

Keywords: Lyapunov method; Linear matrix inequality; Sampled-data control; T–S fuzzy neural network; Time-varying delay

1. Introduction

In recent years, dynamical neural networks have attracted considerable attention because of their potential applications in various signal processing problems, such as optimization, image processing, and associative memory design. However, both constant and time varying time delays are often encountered due to the finite switching speeds of the amplifiers in electronic systems or the finite signal propagation time. In order to study neural networks, a delay parameter must be introduced into the equations of the neural network systems. The existence of time delay may lead to some complex dynamical behavior, such as chaos, oscillation, and instability. Therefore, the stability analysis of neural networks with time delays has been extensively studied in the past few years. Various sufficient conditions have

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been presented to ensure the global stability of the neural networks with time delays (see [1–8] and the references therein).

Fuzzy systems in the form of the Takagi–Sugeno (T–S) model [9] have attracted rapidly growing interest in recent years (see [10–14] and references therein). T–S fuzzy systems are nonlinear systems described by a set of IF–THEN rules. It has been shown that the T–S model method can give an effective way to represent complex nonlinear systems by some simple local linear dynamic systems with their linguistic description. Some nonlinear dynamic systems can be approximated by the overall fuzzy linear T–S models for the purpose of stability analysis [15]. Originally, Tanaka and his colleagues provided a sufficient condition for the quadratic stability of the T–S fuzzy systems (in the sense of Lyapunov) in [13] by considering a Lyapunov function of sub-fuzzy systems. Based on the above discussion, several authors [16,17] have extended the ordinary fuzzy models to describe the delayed neural networks with time-varying delays and have derived stability criteria.

Owing to the rapid growth of digital circuit technologies, powerful micro controllers and digital computers can be made available at low cost. Hence, controllers for some domestic or industrial applications are implemented using micro controllers or digital computers to reduce the implementation cost and time. However, in such cases, the overall control system becomes a sampled-data system of which the control signals are kept constant during the sampling period and are allowed to change only at the sampling instant. As a result, the control signals are stepwise, which introduces discontinuities and makes the system dynamics more complicated. Although the sampling period can be regarded as a time-varying delay [18,19], as a result of the discontinuous control signals, stability analysis methods such as [20–24] cannot be applied to sampled-data nonlinear systems. Thus, recently a linear sampled-data system was investigated in [19]. In [25], the robust sampled-data H_∞ control problem has been investigated for active vehicle suspension systems. A new approach to dealing with the sampled-data control problems has been proposed in [25,26].

The neuron state estimation problem is a hot research topic that has drawn considerable attention, see for example [27–32] and the references therein. Wang et al. [27] first introduced the state estimation problem on continuous time neural networks with time-varying delay through available output measurements, and derived some sufficient conditions for the existence of desired estimators. The main objective of the state estimation for delayed neural networks is to estimate neuron states by using the observed network measurements. The switched exponential state estimation and robust stability for interval neural networks with average dwell time has been investigated in [33]. The authors [34,35] pointed out the state estimation of neural networks with time-varying delays and Markovian jumping parameter based on passivity theory.

In applications, there will be some parameter variations in the structures of neural networks. These changes may be abrupt or continuous variations. Abrupt variations can be described by the switch or Markovian jump systems [35]. When the neural network incorporates abrupt changes in its structure, the Markovian jump linear system is very appropriate to describe its dynamics. The problem of stochastic robust stability for uncertain delayed neural networks with Markovian jumping parameters is investigated via the LMI technique [36]. At the same time, the sampled-data state estimation of neural networks has gradually caused researchers concern, due to the development of computer hardware technology. Recently, Markovian jumping recurrent neural networks and the sampled-data state estimation of delayed neural networks have been studied in [36–42]. The sampled-data state estimator was designed for Markovian jumping fuzzy cellular neural networks with mode-dependent probabilistic time-varying delays in [43–45]. In order to effectively deal with the sampled-data, the author investigated the sampled-data state estimation of neural networks by using a discontinuous Lyapunov functional approach in [46]. To the best of our knowledge, the sampled-data state estimation of T–S fuzzy neural networks with Markovian jumping parameters has not been investigated so far, and is still open and challenging. This motivates our current study.

Motivated by the above discussion, in this paper we apply the idea of state estimation for T–S fuzzy delayed neural networks with Markovian jumping parameters using sampled-data control. Based on Lyapunov–Krasovskii stability theory and LMI formulation, a new set of delay-dependent conditions are developed to estimate the state variables of fuzzy neural networks through available output measurements, such that the error system is asymptotically stable. Based on such stability conditions, a design method of sampled-data state feedback stabilization of fuzzy neural networks is proposed. Numerical examples are given to illustrate the usefulness and effectiveness of the proposed results, which can be solved by the LMI Toolbox in MATLAB.