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Sampled-data filtering of Takagi–Sugeno fuzzy neural networks with interval time-varying delays ☆

Eylem Yucel [b], M. Syed Ali [a], N. Gunasekaran [a], Sabri Arik [b]

[a] *Department of Mathematics, Thiruvalluvar University, Vellore, 632115, Tamil Nadu, India*
[b] *Department of Computer Engineering, Faculty of Engineering, Istanbul University, 34320 Avcilar, Istanbul, Turkey*

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Abstract

This paper is concerned with sample-data filtering of T–S fuzzy neural networks with interval time-varying delays, which is formed by a fuzzy plant with time delay and a sampled-data fuzzy controller connected in a closed loop. A Takagi–Sugeno (T–S) fuzzy model is adopted for the neural networks and the sampled-data fuzzy controller is designed for a T–S fuzzy system. To develop the guaranteed cost control, a new stability condition of the closed-loop system is guaranteed in the continuous-time Lyapunov sense, and its sufficient conditions are formulated in terms of linear matrix inequalities. By using a descriptor representation, the sampled-data fuzzy control system with time delay can be reduced to ease the stability analysis, which effectively leads to a smaller number of LMI-stability conditions. Information of the membership functions of both the fuzzy plant model and fuzzy controller are considered, which allows arbitrary matrices to be introduced, to ease the satisfaction of the stability conditions. By a newly proposed inequality bounding technique, the fuzzy sampled-data filtering performance analysis is carried out such that the resultant neural networks is asymptotically stable. Numerical example and simulation result are given to illustrate the usefulness and effectiveness of the proposed theoretical results.

Keywords: Lyapunov method; Sample-data control; T–S fuzzy neural filtering; Time-varying delays

1. Introduction

Neural networks have been extensively studied over the past few decades and have found application in a variety of areas, such as pattern recognition, associative memory, and combinatorial optimization. These applications strongly depend on the dynamic behavior of the network. In recent years, the stability of delayed neural networks has received considerable attention, such as recurrent neural networks (RNNs) with mixed discrete and distributed delays [1],

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E-mail addresses: eylem@istanbul.edu.tr (E. Yucel), syedgru@gmail.com (M. Syed Ali), gunasmaths@gmail.com (N. Gunasekaran), ariks@istanbul.edu.tr (S. Arik).

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delayed stochastic genetic regulatory networks [2], uncertain fuzzy systems with time-varying delays [3]. As is well known, stability is one of the main properties of neural networks, which is a crucial feature in the design of neural networks [4–6]. On the other hand, it has been recognized that the time delays often occur in various neural networks, and may cause undesirable dynamic network behaviors such as oscillation and instability. Therefore, the stability of time-delay neural networks has long been a focused topic of theoretical as well as practical importance [7–9].

However, in electronic implementation of neural networks, there also exist inevitably some uncertainties due to the existence of modelling errors, external disturbance and parameter fluctuation, which would lead to complex dynamical behaviors. Thus, a good neural network should have robustness against such uncertainties. If the uncertainties of a system are due to the deviations and perturbations of parameters, and if these deviations and perturbations are assumed to be bounded, then this system is called an interval system. Robust stability results are derived in [10–16].

Fuzzy systems in the form of the Takagi–Sugeno (T–S) model [17] have attracted rapidly growing interest in recent years [18–21]. TS 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 [18]. Originally, Tanaka and his colleagues have provided a sufficient condition for the quadratic stability of the T–S fuzzy systems in the sense of Lyapunov in [21] by considering a Lyapunov function of sub-fuzzy systems. Based on the above discussions, several authors [22–25] have extended the ordinary fuzzy models to describe the delayed neural networks with time-varying delays and have derived stability criteria.

Several control technologies such as state-feedback control, adaptive control, sliding mode control, fuzzy logic control, intermittent control and so on have been developed for controlling and synchronizing different dynamical systems. The necessary condition for implementing such control strategies is that the control input must be continuous, that is, state variables must be got, transmitted, and dealt with by the minute. Nevertheless, in many real world situations, it is difficult to guarantee that the state variables transmitted to controllers are continuous. On the other hand, with the rapid development of modern-high speed computers, micro electronics and communication networks, continuous-time controllers are tend to be replaced with digital controllers, which allows control of systems only using the samples of state variables at discrete time instants. Such an approach drastically reduces the amount of information transmitted in control-loop and enhances the efficiency of bandwidth usage, which make this method more efficient and useful in real-world applications. Therefore, sampled-data control theory has been rapidly developed. Some of them are based on the continuous-time or hybrid framework [26–35]. The stability conditions presented there are rather conservative though applicable to general systems. These results focused on continuous-time fuzzy systems. It is difficult to implement them directly to physical nonlinear systems by using digital devices. In a real situation, the outputs are measured only at sampling instants and control inputs can be constructed through those measured outputs in [36].

Overcome such difficulty, we look for a control design under sampling. In [37–39] a class of sampled-data fuzzy systems which is the form of continuous and discrete-time model, has been employed. An H_∞ control problem for fuzzy sampled-data systems was solved via similar approach in [40]. This paper introduced an input delay system approach to sampled data stabilization of linear system with time-varying state delays. Similar approach was taken to a filtering problem in [40]. To best of authors knowledge sampled-data filtering of uncertain T–S fuzzy neural networks with interval time-varying delays have not been studied yet.

Based on the above discussion, in this paper we studied sampled-data filtering of uncertain T–S fuzzy neural networks with interval time-varying delays. A sufficient condition in terms of LMIs using LKFs together with the zero function which guarantees the asymptotic stability of the neural networks is established. A design method of robust sampled-data state feedback stabilization of an uncertain fuzzy neural filtering is proposed. Finally the numerical example is given to illustrate the usefulness and effectiveness of the proposed results.

2. Problem statement and preliminaries

Notations: Throughout the paper, R^n denotes the n dimensional Euclidean space, and $R^{m\times n}$ is the set of all $m \times n$ real matrices. I denotes the identity matrix with appropriate dimensions. The symmetric term in a symmetric matrix is denoted by $\star$. We say $S > 0$ means that the matrix S is real symmetric positive definite with appropriate dimensions.

Consider the following neural network with interval time-varying delays in the form