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Dissipativity and passivity analysis for discrete-time T–S fuzzy stochastic neural networks with leakage time-varying delays based on Abel lemma approach

G. Nagamani*, S. Ramasamy

Department of Mathematics, Gandhigram Rural Institute – Deemed University, Gandhigram 624302, Tamil Nadu, India

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Abstract

In this paper, the problem of dissipativity and passivity analysis for discrete-time T–S fuzzy stochastic neural networks with leakage time-varying delays is investigated based on Abel lemma approach. In order to obtain less conservative results, Jensen inequality, free-weighting matrix approach and Wirtinger-based inequality have been intensively used in the context of time delay systems. In parallel, the above-mentioned approaches have also been applied to discrete time-delay systems. However, it is well-known that these inequalities may introduce an undesirable conservatism in the dissipativity and passivity conditions in the existing available literature. In this paper, we propose an alternative inequality based on Abel lemma, more precisely on the Abel lemma-based finite sum inequalities. By constructing suitable Lyapunov–Krasovskii functional and using the stochastic analysis technique, strictly $(\mathcal{Q},\mathcal{S},\mathcal{R})-\gamma-$dissipativity and passivity conditions are derived to the concerned neural networks. The proposed criterion that depends on the upper bounds of the leakage time-varying delay is given in terms of linear matrix inequalities, which can be solved by MATLAB LMI Control Toolbox. Finally, numerical examples are shown to demonstrate the usefulness and effectiveness of the proposed methods.

1. Introduction

Neural networks have been successfully applied in a variety of areas such as signal processing, pattern recognition, associative memories, parallel computation, combinatorial optimization and

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*Corresponding author.

E-mail addresses: nagamanigru@gmail.com (G. Nagamani), ramasamygru@gmail.com (S. Ramasamy).

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model identification, and these applications depend heavily on their dynamic behaviors. The dynamical behaviors of neural networks are the key to the above-said applications and also it is a necessary step for the practical design of neural networks. Up to now, there have been fruitful research results available in the literature about the dynamic behaviors of neural networks [14,23,28,42,47,48]. There are numerus results that have been investigated the dynamic behavior of continuous-time neural networks [3,23,28,44]. However, compared with continuous-time neural networks, discrete-time neural networks equally have a strong engineering application background for the sake of computer-based simulation and the dynamics of continuous-time neural networks cannot be preserved by discretization as mentioned in [19]. Hence, it is essential to study the dynamical behavior of discrete-time neural networks.

Moreover, time delays are frequently encountered in various engineering, biological, and economic systems [35]. Due to the finite speed of information processing and the inherent communication time of neurons, the existence of time delays usually causes oscillation, divergence, or even instability of neural networks. Therefore, it is of both theoretical and practical importance to study the dynamical behavior of neural networks with time delays. Examples of time delays in dynamical systems are computational delays, input delays, and measurement delays [9]. Furthermore, neural networks with leakage delay are a class of important neural networks as time delay in the leakage term has great impact on the dynamics of neural networks since time delay in the stabilizing negative feedback term has a tendency to destabilize a system. Recently, in [1], the authors investigated stability analysis for discrete-time neural networks with leakage time-varying delays by using reciprocally convex combination approach whereas stability of complex valued delayed neural networks with leakage delay is addressed in [5]. Moreover, in [10] the authors investigated stability analysis of neural networks with leakage time-varying delays.

It is well known that dissipativeness was initially introduced by “Willems” in terms of an inequality involving the storage function and supply rate. Dissipativity theory has played a critical part in the analysis and control design of linear and nonlinear systems, especially for high-order systems [36], since from the practical application point of view, many systems need to be dissipative for achieving effective noise attenuation [7,24,27]. This provides strong connection between Physics, system theory and control engineering. The dissipativity theory has proven to be essential and very useful tool for control applications like robotics, active vibration damping, electromechanical systems, combustion engines, circuit theory, and for control techniques like adaptive control, and inverse optimal control problems. The dissipative theory being a framework for the design and analysis of control systems using an input–output description based on energy-related consideration is applicable in characterizing important system behaviors, such as passivity, and has close connections with passivity theorem, bounded real lemma, Kalman–Yakubovich lemma, and the circle criterion [8,25]. On the other hand, passivity is part of a broader and a general theory of dissipativeness. The main idea of passivity theory is that the passive properties of a system can keep the system internally stable. In recent years, dissipativity and passivity results for neural networks are established in [26,39,40,43,44].

It is worth pointing out that the theory of “Fuzzy Sets” was introduced by Zadeh, which plays a vital role in the modeling and controlling of complex nonlinear systems. Based on the fuzzy set theory, the Takagi–Sugeno (T–S) fuzzy model [34] is regarded as an effective measure for the modeling of nonlinear systems. The T–S fuzzy dynamic model is described by a family of fuzzy IF–THEN rules that represent local linear input–output relations of a nonlinear system. The T–S fuzzy model introduced in [34] is essentially a multi-model approach in which some linear models are blended into an overall single model through nonlinear membership functions to