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Extended dissipative estimator design for uncertain switched delayed neural networks via a novel triple integral inequality☆

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ABSTRACT

This paper addresses the problem of extended dissipative estimator design for uncertain switched neural networks (SNNs) with mixed time-varying delays and general activation functions. Firstly, for dealing with triple integral term, a new integral inequality is derived. Secondly, based on the theory of convex combination, we propose a novel flexible delay division method and corresponding modified Lyapunov–Krasovskii functional (LKF) is established. Thirdly, a switching estimator design approach is contributed, which ensures that the resulting augmented system is extended dissipative. Combining the extended reciprocally convex technique with Wirtinger-based integral inequality, improved delay-dependent exponential stability criterion is obtained. Finally, a example with two cases is provided to illustrate the feasibility and effectiveness of the developed theoretical results.

1. Introduction

In recent years, due to the wide application in pattern recognition, signal processing, associative memories and other scientific areas, the study of artificial neural networks (NNs) has attracted a great deal of interests [1–7]. Meanwhile, as a special type of NNs, SNNs, which are governed by a switching rule to coordinate the switching among a variety of subsystems, have been studied extensively for their capacity in representing certain real-world systems such as power converter, wind turbine regulation and automotive geared box transmission systems, ect [8], to name just a few [9–12]. Time delay, which is an unavoidable phenomenon during the implementation of NNs, may cause instability or other unfavourable situations to deteriorate NNs' performance [13]. In addition, resulted from parametric variations, modeling errors, parametric uncertainties are also inescapable. Moreover, the characteristics of activation functions is always closely associated with NNs'

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trend. Hence, it is desirable in both theory and application to investigate SNNs with time delays, uncertain parameters and general activation functions [46–49].

Among various research areas, one of the hot topics of SNNs is state estimation [18–20]. In practical, due to either the difficulties in measuring state directly or the economic and utilizing limitations of measuring equipment, the neuron states are not often fully available, but in many real life situations, one needs to know the information about the neuron states for achieving certain objectives such as system modeling and state feedback control. So, state estimator design has been one of the most active areas over the past decades [25–29]. By using sampled data approach, [36] solved the reliable state estimation problem of an uncertain switched neutral system. The authors in [17] studied delay-dependent exponential dissipative and $\ell_2 - \ell_\infty$ filtering problems for discrete-time SNNs. [45] was concerned with asynchronous state estimation for a class of discrete-time switched complex networks with communication constraints. To guarantee non-weighting generalized H_2 performance index, a mode-dependent estimator was designed in [20]. In addition, the extended dissipativity which first proposed by Zhang et al. [21] encompassing the H_∞ performance, $L_2 - L_\infty$ performance, passivity and dissipativity by adjusting weighting matrices in a new performance index, was analysed for NNs with time-varying delays in [22]. However, it should be noted that most of aforementioned studies have examined discrete-time SNNs and failed to analyze the state estimator design problem with all well known performance index in a unified framework. This partly motivates our first interest to study on this issue.

On the other hand, to reduce the conservatism of obtained criterion as much as possible is one of the main directions that most results are working toward. Then, how to construct the LKF and how to estimate the derivative of LKF become the two important factors that determine the extent of conservatism [23,24]. In the direction on estimating the derivative of LKF, many mathematic inequalities and techniques, for example, Jensen's inequality [40], reciprocally convex technique [34], free-weighting matrix method [30], Wirtinger-based inequality [33], ect, are introduced. Nevertheless, most of the proposed inequalities are only applicable in dealing with simple or double integral terms, there are few ways for effectively estimating triple integrals. How to overcome this shortcoming, therefore, is still an opening issue. With regard to the construction of LKF, it has been proved that delay-partition-dependent LKF method can improve the criterion [15,16], but many works in recent publications use delay division method to get less conservative results at the sacrifice of increasing the computational burden for too many adjustable parameters were introduced [39,43]. Thus, a more effective delay division method is urgently needed. Moreover, for SNNs, the extended dissipative estimator design issue by delay division method has rarely been reported.

Motivated by the above discussion, in this paper, the problem of extended dissipative estimator design for SNNs based on a novel flexible delay division method is investigated. The main contributions of this paper are listed below.

(1) A new integral inequality is derived for estimating triple integral term. Resorting to Wirtinger-based integral inequality combined with extended reciprocally convex technique, the improved delay-dependent criterion is obtained. Moreover, the state desired estimator can be achieved by solving a set of LMIs.
(2) Inspired by Wang et al. [42], a novel flexible delay division method based on the theory of convex combination is established to study the state estimation issue of SNNs for the first time. In addition, corresponding modified LKF is established, especially the choice of $V_{i2}(t)$ in which the integral intervals are flexible.
(3) Different from the addressed state estimation problem in [14,35,41,44], we investigate the extended dissipative state estimation for SNNs, which make to analyze $L_2 - L_\infty$, strictly $(\mathcal{Q}, \mathcal{S}, \mathcal{R}) - \gamma -$ dissipative, H_∞ and passive state estimation problems in a unified way possible.

Notation: R^n denotes the n-dimensional Euclidean space, $R^{n\times m}$ represents the set of all $n \times m$ real matrices; $\mathcal{L}_2[0, \infty)$ denotes the space of square integrable vector functions over $[0, \infty)$; I and 0 are, respectively, the identity matrix and zero matrix; $0_{n\times m}$ represents the $n \times m$-dimensional zero matrix; A^T and A^{-1} stand for the transpose and inverse of matrix A respectively; $diag\{\ldots\}$ symbolizes a diagonal matrix and $[A; B]$ represents $[A^T, B^T]^T$; the notation $P > 0 (P \geq 0)$ means that P is a real symmetric positive definite matrix (positive semidefinite matrix); "*" represents the elements below the main diagonal of a symmetric matrix; $C([-\sigma, 0], R^n)$ is the family of continuous functions ϕ from $[-\sigma, 0]$ to R^n. Matrices, if their dimensions are not explicitly stated, are assumed to be compatible for algebraic operations.

2. Problem description and preliminaries

This paper considers SNNs in the presence of parameter uncertainties, discrete and distributed time-varying delays and general activation functions, with a set of individual NNs as the subsystems and can be described as follows.

$$\begin{cases} \dot{x}(t) = -A_{\sigma(t)}(t)x(t) + B_{\sigma(t)}(t)f(x(t)) + C_{\sigma(t)}(t)g(x(t-\tau(t))) \\ \qquad\quad +D_{\sigma(t)}(t)\int_{t-d(t)}^{t} h(x(s))ds + G_{1\sigma(t)}\omega(t) \\ y(t) = E_{\sigma(t)}x(t) + F_{\sigma(t)}\tilde{h}(t, x(t)) \\ z(t) = G_{2\sigma(t)}x(t) \\ x(t) = \phi(t), t \in [-r, 0] \end{cases} \tag{1}$$

where $x(t) = [x_1(t), x_2(t), \ldots, x_n(t)]^T \in R^n$ is the neuron state vector. $y(t) \in R^m$ is the measurement output vector. $z(t) \in R^q$ is the neuron signal to be estimated. $f(x(t)) = [f_1(x_1(t)), f_2(x_2(t)), \ldots, f_n(x_n(t))]^T$, $g(x(t)) =$