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LMI-based results on exponential stability of BAM-type neural networks with leakage and both time-varying delays: A non-fragile state estimation approach

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ABSTRACT

In this epigrammatic, the problem of exponential stability for BAM-type neural networks (BAMNNs) with non-fragile state estimator is investigated under time-varying delays. The delays in discrete and distributed terms are assumed to be time-varying, which means that the lower and upper bounds can be derived. Without involving the time-delays or the activation functions, the non-fragile estimators are constructed in terms of simple linear formation and also the implementation of state estimators are uncomplicated. In addition, the non-fragile estimators are reduced the possible implementation errors in neural networks. For consequence, reason of energy saving, the non-fragile estimators are designed with neural networks. By fabricating a suitable LKF (Lyapunov–Krasovskii functional) and enroling some analysis techniques, a novel sufficient conditions for exponential stability of the designated neural networks are derived in terms of Linear Matrix Inequalities (LMIs), which can be easily assessed by MATLAB LMI Control toolbox. Accordingly, the research proposed here, is advanced and less conservative than the previous one exists in the literature. Finally, two numerical examples with simulations and comparative studies are performed to substantiate the advantage and validity of our theoretical findings.

1. Introduction

Recently, the study on neural networks (NNs) in dynamical behaviors has received considerable attention due to their potential applications in different fields, such as robot signal processing, automatic control, static image treatment, optimization problems, parallel computing, signal processing, etc [4,12,18,24]. In particular, bidirectional associative memory (BAM) neural networks is a special type of recurrent NNs, which was coined by Kosko [22,23]. A BAM neural networks is

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composed of neurons arranged in two layers: the R-layer and S-layer. The neurons in one layer are fully interconnected to the neurons in the other layer. This type of networks has been successfully applied to pattern recognition and artificial intelligence due to its generalization of the single-layer auto-associative Hebbian correlator to a two-layer pattern-matched hetero associative circuit. Over the past few decades, according to the extensive range of fruitful applications, such as pattern recognition, associative memory, parallel computing, combinational optimization, signal and image processing, BAMNNs with or without time delays have attracted much attention, see e.g. [5,7,20,42,45,60].

As is well known, the arising of time delays in neural networks is inevitable because the finite switching speed of information storage processing or of amplifiers, communication time and transmission of signals [37,40]. For sequence, in a NNs, the appearance of time delay may affect the stability performance generating unstable, divergence and swinging or chaotic behavior [9,28]. Hence, the investigation of stability analysis for time-delayed BAM neural networks has been broad interests from numerous scholars, see Refs. [2,6,14,34]. The exponential stability for stochastic BAMNNs was discussed in [2]. The delay-dependent and delay-independent criteria are two categories of time delays in neural networks, which classified by the existing time-delayed results. So far as, one can observe from available literatures, the delay-dependent case is less conserved than the delay independent ones. In [8], Cho and Park developed some time-delayed conditions for the stability analysis of neural network systems through novel approaches.

Moreover, we specify that the propagation delays can be distributed over a period of time, because the variety of axon sizes and lengths are too large. Thus, the consideration of distributed delay term is meaningful in neural networks system. So, it is significant to inspect both the time delay results in the dynamical behaviors of neural systems, see for instance [19,35,39,56]. Nie and Cao have investigated the Multistability of competitive neural networks with mixed time delays. The mixed time-delayed stability criterion for BAM neural networks under impulsive effects was discussed by the authors Zhu and Cao [59]. At the same time, to conclude the speed of neural computations, the exponential convergence rate is used. So, it generates much attention from many researchers to studied the property of exponential stability [15,29,31,36]. In [38], the researchers studied the exponential stability of time-delayed neural networks via different Lyapunov functionals. Some criteria in terms of LMIs were presented to ascertain the BAMNNs with both time-delays to be exponentially stable [26,57]. Wu et al. extensively analyzed the stability in the exponential sense of NNs in [52].

It is noteworthy point out that a different case of time delay in neural networks that which incorporated to the negative feedback term of the system, namely forgetting or leakage terms. The present of this type of delays owing to some theoretical and technical difficulties. By the issue of leakage delays, the stability of the dynamical systems may affect and it leads to be unstable. So, over the previous years, time delay in leakage term has a extensive impact on the neural networks, see for Refs. [43,49,50]. Thus, the consideration of leakage term in neural networks is necessary to stability investigation. Zhou et al. [58], investigated and obtained some results related to the problem for stability of time delayed neural networks with leakage terms. Recently, some authors discussed the neural networks with delays in the leakage terms (see [17,27,30]).

On the other hand the actually parameters in the phenomenon of estimator or controller are marginally distinct due to several reasons such as the imprecision in analog-digital conversion, limited word length of the computer and numerical roundoff errors. So, we can noticed that the drifts or variations of the controller or estimator parameters could guarantee to dramatic alterations or system instability or performance degradation of the dynamical system which fact indicates as the fragility issue [10,21]. Consequently, the non-fragility have been received much attention in the past few decades and which ensures that the dynamical system performance is unresponsive to the permissible implementation errors for the estimators [13,32,33,51]. Still, the formation of non-fragile state estimator have not been fully analyzed and, only limited research efforts have been completed with design of non-fragile estimators for the time-delayed neural network systems. Hence, the investigation of exponential stability of BAM neural networks through non-fragile technique is very complicated and interesting one. The authors in [54], non-fragile control phenomenon treated for a H_∞ problem of neural networks via uncertain parameters. To deep investigation of gain parameters of non-fragile estimator, Fang and Park [11] handled the time-delay dependent techniques and different inequality approaches in neural networks. Moreover, by the aid of Wirtinger based inequality techniques, two distinct cases of memductance functions and time-delayed uncertainties in menristive neural networks are analyzed in [46].

Motivated by the aforementioned discussions, our main motivation of this paper is to investigate the exponential stability problem for time-delayed BAM neural networks with leakage delays, via non-fragile state estimation. By employing the matrix theory, some inequality techniques and also constructing an appropriate novel Lyapunov–Krasovskii functional, some new-brand sufficient conditions for exponential stability are formulated in terms of LMIs, which can be justified easily by LMI control toolbox in MATLAB software. Also, two numerical examples with their simulations are provided to illustrate the superiority and applicability with less conservatism of the proposed method. The main contributions of this research work are outlined as follows:

- BAM-type, non-fragile state estimators, leakage, discrete & distributed time-varying delays are taken into account for the exponential stability analysis of proposed neural networks.
- In this work, a simple linear form of structured non-fragile state estimators are designed with three constant gain matrices and also the gain matrices in state estimators are permitted to accept multiplicative parameter variations with in a certain range. This multiplicative formations can excellent reveal the gain dependent perturbations.