Applied Mathematics and Computation 268 (2015) 743–762

Contents lists available at ScienceDirect

Applied Mathematics and Computation

journal homepage: www.elsevier.com/locate/amc

Robust passivity analysis for stochastic impulsive neural networks with leakage and additive time-varying delay components ☆

Rajendran Samidurai*, Raman Manivannan

Department of Mathematics, Thiruvalluvar University, Vellore - 632 115, Tamil Nadu, India

ARTICLE INFO

Keywords:
Stochastic neural networks
Passivity
Leakage delay
Additive time-varying delays
Impulsive effect
Integral inequality technique

ABSTRACT

The purpose of this paper is to investigate the problem of robust passivity analysis for delayed stochastic impulsive neural networks with leakage and additive time-varying delays. The novel contribution of this paper lies in the consideration of a new integral inequality proved to be well-known Jensen's inequality and takes fully the relationship between the terms in the Leibniz–Newton formula within the framework of linear matrix inequalities (LMIs). By constructing a suitable Lyapunov–Krasovskii functional with triple and four integral terms using Jensen's inequality, integral inequality technique and LMI frame work, which guarantees stability for the passivity of addressed neural networks. This LMI can be easily solved via convex optimization techniques. Finally, two interesting numerical examples are given to show the effectiveness of the theoretical results.

1. Introduction

As is well-known that neural networks (NNs) have received intensive interest due to their wide applications in classification of pattern recognition, static image processing, signal processing, optimization problems, mechanics of structures and materials, smart antenna arrays and other scientific areas [1–49]. However the phenomena of time delay is commonly encountered in various physical and engineering systems such as in nuclear reactor, mechanical systems, biological systems, chemical processes, rolling mill, hydraulic systems, etc. Hence, these applications depend crucially on the dynamical behaviors (e.g., stability, instability, periodic oscillatory and chaos) of the neural networks, especially the stability of addressed problem. Therefore, stability analysis of NNs has received much more attention over the past years (see [1–4]). Time delays are inevitable in the implementation of artificial neural networks as a result of the finite switching speed of amplifier. Therefore, various issues of neural networks with time delays have been addressed, and many results have been reported in the literature (see, e.g., [5–49] and the references therein).

It is well known that the dissipativity theory plays an important role in the stability analysis of dynamical systems, nonlinear control and other areas (see,e.g., [5–16] and the references therein). Passivity, as a special case of dissipativity, tells more than just stability, which relates the input and output to the storage function, and hence defines a set of useful input–output properties. This is in contrast to Lyapunov stability which concerns the internal stability of a system. Passivity is a widely adopted tool for

☆ This work was supported by Department of Science and Technology (DST), Government of India, New Delhi, under research project no. SR/FTP/MS-041/2011.
* Corresponding author. Tel.: +919786125239.
E-mail addresses: samidurair@gmail.com (R. Samidurai), manimath7@gmail.com (R. Manivannan).

http://dx.doi.org/10.1016/j.amc.2015.06.116
0096-3003/

analyzing the stability of dynamical systems and is used in several domains of engineering sciences, such as in the analysis of electrical circuits, mechanical systems, chemical processes, electromechanical systems, control over networks, hybrid systems, etc. When we modeling real nervous systems, which are usually subjected to time delay, stochastic and impulsive perturbations that in turn affect dynamical behaviors of the systems. So it is important to consider the problems with influences of time delay, stochastic and impulsive perturbations.

Now, it has been well recognized that stochastic phenomenon is nearly inevitable owing to thermal noise in electronic devices in implementations of neural networks. Some stochastic input could destabilize a neural network. Therefore, the stability problem for stochastic networks with time delay becomes more important from the practical point of view, see, for instance [8,10–15,20,22,25,28,30,31,44]. Recently, a special type of time delay, namely, leakage delay (or forgetting delay), is identified and investigated due to its existence in many real systems such as neural networks, population dynamics, control systems and some fuzzy systems such as in [10,16–21,24,25,44]. Moreover, sometimes it has more significant effect on dynamics of neural networks than other kind of delays. Hence, it is significant important to consider the leakage delay effects on dynamics of neural networks. It has been shown that such kind of time delay (leakage delay) has a tendency to destabilize a system. Impulsive is also a phenomenon that has been taken into consideration when modeling the neural networks. Impulsive phenomenon, as well as time delays, can influence the dynamical behavior of the neural networks. Therefore, it is more important to study the stability of delayed neural networks with impulsive perturbations for instance can see related impulsive problems have been existing in literature, see [15,22–31,44].

Recently, the authors in [32–44] reported that the signals transmitted, in the network control system, from one point to another passes through few segments of networks, which can possibly induce successive delays with different properties due to the variable network transmission conditions which may cause time delay with some different characteristics in practical applications. Based on this, a new model for neural networks with two additive time-varying delays has been proposed in [32–34]. For example, the time delay in the dynamical model such as $\dot{x}(t) = Ax(t) + BKx(t - \tau_1(t) - \tau_2(t))$ where $\tau_1(t)$ is the time delay induced from sensor to controller and $\tau_2(t)$ is the delay induced from controller to the actuator. The stability analysis for such systems has been carried out in [35,37,38] by using two additive time-varying delay components, $\tau_1(t) + \tau_2(t) = \tau(t)$. Compared with the single-delay systems, this model is under a stronger background of application. Therefore, taking the model with two additive time-varying delay components into consideration is meaningful. Recently, Xiao and Jia [34] derived a stability problem for neural networks with two additive time-varying delay components. By constructing the Lyapunov–Krasovskii functional and considering the relationship between time-varying delays and their upper delay bounds, delay-dependent stability criteria are obtained by using reciprocally convex method and convex polyhedron method respectively. Shao and Han [39] discussed the stability and stabilization problem for systems with two additive time-varying input delays arising from networked control systems. A new Lyapunov functional is constructed and a tighter upper bound of the derivative of the Lyapunov functional is derived by applying a convex polyhedron method. Very recently, Liu et al. [42] consider the problem of robust stability of uncertain neural networks with two additive time varying delay components. The activation functions are monotone nondecreasing with known lower and upper bounds. By constructing of a modified augmented Lyapunov function, some new stability criteria are established in term of linear matrix inequalities (LMIs), which is easily solved by various convex optimization techniques. More recently, Rakkiyappan et al. [43] focused on the problem of synchronization for singular complex dynamical networks with Markovian jumping parameters and two additive time-varying delay components. Based on the appropriate Lyapunov–Krasovskii functional, introducing some free weighting matrices and using convexity of matrix functions, a novel synchronization criterion is derived. Currently, Jun et al. [44] presented the stability problem for a class of impulsive neural networks model, which includes simultaneously parameter uncertainties, stochastic disturbances and two additive time-varying delays in the leakage term. However, to the best of our knowledge, there is no work that considers the problem of passivity analysis for a class of stochastic impulsive neural networks with leakage and additive time-varying delays via convex optimization technique available in the existing literature. Therefore, this motivates our present study the problem of passivity analysis for a class of stochastic impulsive neural networks with leakage and additive time-varying delays.

Motivated by the above discussions, the main objective of this paper is to study of passivity analysis for a class of addressed neural networks. We introduce a new Lyapunov–Krasovskii functional by taking the information of integral terms leakage delay and derivative of variables into account and moreover, the leakage delay occurs not only in single and double integral terms also in triple and four integral terms in order to derive the desirable results. All the derived conditions obtained here are expressed in terms of LMIs whose feasibility can be easily checked by using numerically efficient MATLAB LMI Control toolbox. Finally, two numerical examples are given to show the effectiveness and advantage of the present results.

Notations: The notations are quite standard. Throughout this paper, $\mathbb{R}^n$ and $\mathbb{R}^{n\times n}$ denote, respectively, the n-dimensional Euclidean space and the set of all $n \times n$ real matrices. $\|.\|$ refers to the Euclidean vector norm. A^T represents the transpose of matrix A and the asterisk "$*$" in a matrix is used to represent the term which is induced by symmetry. I is the identity matrix with compatible dimension. $X > Y$ means that X and Y are symmetric matrices, and that $X - Y$ is positive definite. Let $(\Omega, \mathfrak{F}, \{\mathfrak{F}_t\}_{t\geq 0}, \mathcal{P})$ be a complete probability space with a filtration $\{\mathfrak{F}_t\}_{t\geq 0}$ satisfying the usual conditions (i.e. it is right continuous and $\mathfrak{F}_o$ contains all $\mathcal{P}$-null sets). $\mathbb{E}\{\cdot\}$ stands for the mathematical expectation operator with respect to the given probability measure $\mathcal{P}$. Denote by $L^2_{\mathfrak{F}_0}([-\tau, 0], \mathbb{R}^n)$ the family of all $\mathfrak{F}_o$-measurable $C([-\tau, 0], \mathbb{R}^n)$-valued random variables $\Psi = \{\Psi(s) : s \in [-\tau, 0]\}$ such that $\sup_{s\in[-\tau,0]}\mathbb{E}\{| \Psi(s) |\} < \infty$. Matrices, if not explicitly specified, are assumed to have compatible dimensions.