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Finite-time non-fragile passivity control for neural networks with time-varying delay☆

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ABSTRACT

In this paper, the problem of finite-time non-fragile passivity control for neural networks with time-varying delay is studied. *We* construct a new *Lyapunov–Krasovskii* function with triple and four integral terms and then utilizing Wirtinger-type inequality technique. The sufficient conditions for finite-time boundedness and finite-time passivity are derived. Furthermore, a non-fragile state feedback controller is designed such that the closed-loop system is finite-time passive. Moreover, the proposed sufficient conditions can be simplified into the form of linear matrix inequalities (LMIs) using Matlab LMI toolbox. Finally, three numerical examples are presented to illustrate the effectiveness of the proposed criteria.

1. Introduction

Neural networks have been widely investigated due to their extensive applications in classification of pattern recognition, signal processing, associative memories, image processing, solving certain optimization problems and so on, see [1–4] and the references cited therein. Most of these applications will depend on the quality of neural networks designed for equilibrium and behaviors that determine the equilibrium point. Therefore, the study of neural networks gained considerable attention in the last decades, and various types of neural networks [5–8] investigated the behavior and dynamics of neural networks are said to be many important decisions. In the hardware implementation of neural networks, time-delays in particular time-varying delays are unavoidably encountered in the signal transmission among the neurons due to the finite speed of switching and transmitting signals, which may cause undesirable dynamical behaviors such as instability and oscillation. Therefore, the main focus of attention is on the stability analysis of neural networks with time delays during the past several years and many important and interesting results have been proposed in terms of considerable amount of methods in the literatures [9–15] owing to their wide range of applications.

Passivity is an important concept of system theory and provides a nice tool for analyzing the stability of dynamical systems. The passivity problem first proposed by [16] is an important research issue in control field and has found successful

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applications in diverse areas such as stability [17], complexity [18], signal processing [19], group coordination [20], fuzzy control [21], chaos control and synchronization [22,23]. The passivity theory intimately related to circuit analysis methods has received a lot of attention from the control community since 1970s. In the first place, many systems need to be passive in order to attenuate noises effectively. In the second place, the robustness measure such as robust stability or robust performance of a system often reduces to a subsystem or a modified system that is passive. Passivity analysis is a major tool for studying stability of uncertain or nonlinear systems, especially for high-order systems, and thus the passivity analysis approach has been used in control problems for a long time to deal with robust stability problems for complex uncertain systems. It should be pointed out that the essence of the passivity theory is that the passive properties of a system can keep the system internal stability. Therefore, passivity analysis of neural networks have received a great deal of attention, and a great many of related literatures have been published [24–31].

Moreover, the problem of non-fragile control has been an attractive topic in theory analysis. In the implementation of controller, there are some perturbations appeared in controller gain, which may result from either the actuator degradations or the requirements for readjustment of controller gains during the controller implementation stage. Therefore, it is necessary and reasonable that any controllers should be able to tolerate some level of controller gain variations. Further, the non-fragile control concept is how to design a feedback control that will be insensitive to some error in gains of feedback loop [32]. Many studies have investigated the non-fragile controller design problem [33–36]. In [33], the problem of non-fragile state-feedback control has been considered for a class of uncertain neutral systems with time-varying delays both in state and input. In [34], the non-fragile passive control has been presented for uncertain singular time-delay systems. In [35], authors investigated the problem of non-fragile state observer design for neural networks with Markovian jumping parameters and time-delays. Recently, the non-fragile state estimation for continuous neural networks with time-delays have been studied in [36].

However, it will be the passivity analysis that studies the Lyapunov asymptotic stability theory defined on infinite time interval, that are used must be specified. Many practical applications, a fixed finite-time interval paid more attention to the dynamics of the behavior of a system. For example the property that the state does not exceed a certain threshold in a finite-time interval with a given bound of the initial condition, which is relevant to the finite-time stability. Therefore, the concept of finite-time analysis problem was first proposed by Dorato in 1961 [37], and extended to finite-time bounded by taking the presence of external disturbances into account [38]. Many interesting results for finite-time stability of various dynamical systems can be found in [39–47]. In [39], the authors investigated the problem of stochastic finite-time boundedness for Markovian jumping neural networks with time-varying delays. Recently, the finite-time boundedness and stabilization problem of uncertain switched neural networks with time-varying delay has been considered in [40]. A new protocol for finite-time consensus of detail-balanced multi-agent networks have been studied in [41]. In [42], the authors discussed finite-time synchronization problem for coupled neural networks systems. In [43], the problem of finite-time H_∞ control for continuous-time Markovian jump system has been investigated through the new Lyapunov functions finite-time boundedness of state estimation for neural networks with time-varying delays. In [44], the problem of finite-time passivity and passification for stochastic time-delayed Markovian switching systems have been derived. The sufficient conditions for finite-time boundedness and finite-time passivity of discrete-time delayed neural networks with time-varying delays was studied in [45]. In [46], the authors investigated the problem of finite-time passive control for a class of nonlinear uncertain systems with time-delays. More recently, the problem of finite time non-fragile dissipative control for uncertain T-S fuzzy system with time-varying delay was discussed in [47]. However, to the best of authors knowledge, so far, no result on the finite-time boundedness non-fragile passivity control for neural networks with time-varying delay has been reported. This motivates our present research.

Based on the above discussion, in this paper, we consider the problem of finite-time non-fragile passivity control for neural networks with time-varying delay. The main contributions of this paper are summarized as follows:

- The finite-time non-fragile passivity control result for neural networks with time-varying delay is proposed for the first time.
- A new Lyapunov–Krasovskii function with triple and four integral terms is provided, and Wirtinger-type inequality technique and convex combination approach are adopted.
- *Sufficient conditions are obtained* to ensure that the closed-loop system is finite-time boundedness and finite-time passivity.
- Based on the results obtained, a non-fragile passivity controller is designed such that the corresponding system is finite-time passive.
- The conditions in our main results can be converted into linear matrix inequalities easily, which can be solved by using Matlab LMI toolbox.

The contributions of the above techniques are demonstrated through three numerical examples.

Notations: Throughout this paper, the superscripts -1 and T stand for the inverse and transpose of a matrix, respectively. $\mathbb{R}^n$ denotes the n-dimensional Euclidean space, $\mathbb{R}^{n\times m}$ is the set of all $n \times m$ real matrices. A real symmetric matrix $P > 0$, (≥ 0) denotes P being a positive definite (positive semi-definite) matrix. $\lambda_{\max}(P)$ and $\lambda_{\min}(P)$ represent for the maximum and minimum eigenvalues of the matrix P respectively. The symmetric terms in a symmetric matrix are denoted by $*$. I is an appropriately dimensioned identity matrix, and $\text{sym}\{X\} = X + X^T$.