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Non-fragile state observer design for neural networks with Markovian jumping parameters and time-delays

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HIGHLIGHTS

- The non-fragile observer design for jumping neural networks with delays is investigated.
- Delay-dependent stability criteria are obtained in terms of LMIs.
- The observer gains are given from the LMI feasible solutions.
- The practical system of quadruple tank process is considered for the example.

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ABSTRACT

This paper investigates the non-fragile observer based design for neural networks with mixed time-varying delays and Markovian jumping parameters. By developing a reciprocal convex approach and based on the Lyapunov–Krasovskii functional, and stochastic stability theory, a delay-dependent stability criterion is obtained in terms of linear matrix inequalities (LMIs). The observer gains are given from the LMI feasible solutions. Finally, three numerical examples are given to illustrate the effectiveness of the derived theoretical results. Among them the third example deals the practical system of quadruple tank process.

1. Introduction

Neural networks (NNs) can mimic the human brain, and they have been used for a wide variety of applications, for example, target tracking, machine learning, system identification and so on [1,2]. The analysis of dynamics for NNs in successful applications is preliminary. Time delays are unavoidably encountered both in biological and artificial neural systems, which may lead to oscillation and instability, hence in recent years increasing attention has been focused on stability analysis of NNs with time delays, see [3,4]. Many interesting results have been obtained, see [5–12], where [5,6] dealt the case of constant delays, authors in [9,10] studied the case of time-varying delays and the paper [11,12] considered the case of continuously distributed delays. Further, it is well known that delay-dependent results are generally less conservative than delay-independent results. Recently, delayed NNs have been focused on the stability analysis and a large amount of results have been available in the literature, see for example [13–17]. Further, most of the research on NNs has been restricted to simple cases of discrete delays. Since an NN usually has a spatial nature due to the presence of an amount of parallel

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pathways of a variety of axon sizes and lengths, it is desired to model them by introducing distributed delays, for details see [16,17] and the references therein. In practice, sometimes a NN has finite state representations and modes may switch (or jump) from one to another at different times [18–21]. Recently, it has been revealed in [22] that, switching (or jumping) between different NNs modes can be governed by a Markovian chain. Specifically, the class of NNs with Markovian jumping parameters (MJPs) has two components in the state vector. The first one which varies continuously is referred to be the continuous state of the NNs and the second one which varies discretely is referred to be the mode of the NNs. For a specific mode, the dynamics of the NNs is continuous, but the parameter jumps among different modes may be seen as discrete events, see for example [23].

A state observer is used usually to reconstruct the states of a dynamic system and has very important applications in many aspects such as realization of feedback control, system supervision, gas-fired furnace system, and fault diagnosis. Naturally the neuron states are not often fully available in the network outputs in many applications, the neuron state estimation problem becomes important to utilize the estimated neuron state. Initially, Wang et al. [24] have investigated the state estimation problem for continuous-time NNs with time-varying delay through available output measurements and derived some sufficient conditions for the existence of the desired estimators. Therefore, delay-dependent state estimation problem has been studied widely for continuous-time NNs, see [25–34]. Recently authors in [32–34] applied sampled data control approach to study the delay-dependent state estimation problems for NNs. Further the state estimation problem for delayed genetic regulatory networks with randomly occurring uncertainties has been dealt in [35]. Very recently authors in [36–43] have studied state estimation for recurrent NNs with MJPs and mixed time delays. Sampled data approach for state estimation for NNs with MJPs has been considered in [42,43]. Meantime, the delay-dependent state estimation problem was widely studied for continuous-time delayed NNs in [29–31,41] by employing delay decomposition methods, free weighting matrix method, triple-integral approaches and the sufficient conditions are derived using linear matrix inequalities (LMIs). However, most results of the state estimation problems have concerned with the uncertainties appearing in system matrices only. Up to now, the design of state estimator to cope with the non-fragile observers have not been thoroughly studied yet. This brings up a ‘‘fragility’’ problem that has been of great interest in the signal processing area for some time now, but has been considered only recently by the control community [44]. The problem is that of determining the level of computer accuracy required to insure closed-loop specifications. Although it is generally known that many feedback systems require very accurate controller implementation, there have been few studies on the level of accuracy required to met given specifications, and on the design of controllers that require the least possible amount of accuracy, that is, non-fragile controllers. However up to date only limited works have been done with respect to the design of non-fragile controllers [45–49] for the system of differential equations with time-delays. Non-fragile controllers minimize the cost of implementation, and allow for on-line tuning of control parameters that are essential in practical applications. Note that very little research efforts have been made to design the state estimator coping with the time-varying delays and non-fragile controllers in the observer gains. The lack of the existing works are probably due to the fragility problem of controllers. Therefore, the aim of this paper is to shorten such a gap by designing the state estimator for NNs with MJPs and non-fragile observers and mixed time-varying delays.

On the other hand, the reduction of the conservatism in delay-dependent criteria means that the feasible region is enlarged, which can increase the application region such as filtering, controller design, synchronization, and other important issues in control society. Therefore, the study of increasing the feasible region in delay-dependent stability criteria is an important and essential work in applying various control methods in dynamic systems with time-delays. In [50], authors have discussed reciprocally convex approach to derive stability results. In this paper, a similar type of stability criterion is applied to derive the sufficient conditions for the problem of state estimation for NNs with MJPs and non-fragile observers. To the best of authors' knowledge, the non-fragile observer based state estimation of NNs with mixed time-varying delays and MJPs using reciprocal convex method has not been investigated yet. Suitable Lyapunov–Krasovskii functionals (LKF), reciprocal convex method and some analysis techniques are employed to derive sufficient conditions for delay-dependent stability criteria for the considered NNs with MJPs in terms of LMIs, which can be easily calculated by MATLAB LMI Control Toolbox. Numerical examples are given to illustrate the effectiveness of the proposed method.

Motivated by the above discussions, the aim of this paper is to study the non-fragile observer based state estimation problem for a class of NNs with MJPs, and mixed time-varying delays. By constructing a suitable LKF including the available information of time-varying delays, sufficient conditions are established such that the resulting estimation error dynamics is asymptotically stable in the mean-square sense. The main contributions of this paper lie in the following two aspects: (i) the phenomena of non-fragile control is considered at the first time for the state estimation problem of NNs with MJPs; and (ii) the reciprocally convex combination method has been involved in that account for the improvement of the feasible region. Finally, numerical examples are provided to illustrate the developed state estimation scheme.

Notations. Throughout this paper, $\mathcal{R}^n$ and $\mathcal{R}^{n\times m}$ denote respectively the n-dimensional Euclidean space and the set of all $n\times m$ real matrices. The superscript T denotes the transposition and the notation $X \geq Y$ (respectively, $X > Y$), where X and Y are symmetric matrices, meaning that $X - Y$ is positive semi-definite (respectively, positive definite). I is the identity matrix with appropriate dimensions. $|\cdot|$ is the Euclidean norm in $\mathcal{R}^n$. Moreover, let $(\Omega, \mathcal{F}, \mathcal{P})$ be a complete probability space with a filtration $\{\mathcal{F}_t\}_{t\geq 0}$ satisfying the usual conditions. That is the filtration contains all $\mathcal{P}$-null sets and is right continuous. Denote by $L^{\mathcal{P}}_{\mathcal{F}_0}[-\delta, 0]$ the family of all $\mathcal{F}_0$-measurable $C([-\delta, 0]; \mathcal{R}^n)$-valued random variables $\varsigma = \{\varsigma(\theta) : -\delta \leq \theta \leq 0\}$