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State feedback synchronization control of impulsive neural networks with mixed delays and linear fractional uncertainties☆

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ABSTRACT

This study examines the synchronization problem of impulsive neural networks with mixed time-varying delays and linear fractional uncertainties. The mixed time-varying delays include distributed leakage, discrete and distributed time-varying delays. Moreover, the restrictions on derivatives of time-varying delays with upper bounds to smaller than one is relaxed by introducing free weight matrices. Based on suitable Lyapunov–Krasovskii functionals and integral inequalities, linear matrix inequality approach is used to derive the sufficient conditions that guarantee the synchronization criteria of impulsive neural networks via delay dependent state feedback control. Finally, three numerical examples are given to show the effectiveness of the theoretical results.

1. Introduction

Neural networks (NNs) are generally recognized as one of the simplified models of neural processing in the human brain which provides good performance and strong capability of information processing. In the last few decades, NNs have been extensively implemented in various applications, such as load frequency control in power systems [3], associative memories [6,28], machine learning [8], and so on.

Time delays often exist in many dynamical systems. The existence of time delay frequently causes poor performance and instability (see, [5,31,32]). During the implementation of NNs, the finite switching speed of amplifiers and the inherent communication time between the neurons inevitably introduce time delays, which might cause oscillation, divergence and instability. Here, it should be mentioned that many authors considered NNs model with discrete time delays or time-varying delays (see, e.g., [17,22,39]). In addition to discrete time-delay, distributed delay should also be incorporated in a NNs model due to the presence of a lot of parallel pathways with a variety of axon sizes and lengths (see, e.g., [13,29]).

Moreover, a typical time delay called as leakage delay, may occur in the negative feedback term of the NNs model and have a huge impact on the dynamic behaviors of NNs. For example, the authors in [10,24] argue that the leakage delay has a tendency to destabilize the system. Recently, the problem of state estimation for bidirectional associative memory NNs model is investigated with mixed delays which includes a constant delay in the leakage term, time-varying discrete delay

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and constant distributed delay in [24]. It should be noted that in most of the available existing literatures only NNs with leakage time delays or time-varying delays are studied. In addition, distributed time-varying delays in the leakage term also have a great impact on the dynamics of NNs [20,36,37]. Therefore, it is necessary to further investigate the stability problem for NNs with mixed time varying delays such as distributed leakage, discrete and distributed time-varying delays.

On the other hand, it is essential to analyze the stability of NNs with parameter uncertainties due to modeling errors, measurement errors and approximations [1,34]. Recently, a new type of uncertainties in linear fractional form is considered (see e.g., [2,14,23]) such that norm bounded parameter uncertainties as a special case. In general, impulsive effects in the states of NNs undergo unexpected changes at certain moments due to instantaneous perturbations. It is also affect the dynamical behaviors of NNs and it has been extensively studied in the literature [12,15,18]. As an example, in [18], the authors studied the problem of stochastic robust stability for NNs with time-varying delay, parameter uncertainties and impulses.

Synchronization problems are played an important role in nonlinear model due to their application in various fields such as secure communication systems, biological systems, image processing, combinatorial optimization and so on (see, [11,16,27,30] and the references therein). It is well known that, the synchronization of NNs is achieved in the accordance of the states of master system and slave system in a moment. Other words, when time approaches infinity, the state of error system will converge to origin eventually. Moreover, the impulsive effect on the exponential synchronization analysis of NNs with leakage delay under the sampled-data feedback control is investigated in [11].

In order to reduce the conservatism and to obtain the tight bounds for integral terms of quadratic functions, many approaches are used in the existing literature such as integral inequality [17,21] and free-weighting matrix method [9,39]. Also, the most of researchers utilized the Jensen inequality for analyzing the stability and synchronization results because this approach gives fewer decision variables and having a fine performance behavior with comparing existing results in literature. Recently, in [4] the authors discussed the conservatism of the Jensen inequality with the help of Gruss inequality. In the following, the Wirtinger based integral inequality is introduced in [26] which reduces the gap of Jensens inequality and it has been successfully applied to the various dynamical system for stability analysis. After that, the authors in [25] addressed Bessel–Legendre (B–L) inequality which enclosed the Jensen inequality and the Wirtinger-based integral inequality. Also, B–L inequality has been applied only to stability analysis of the system with constant delay. From the above motivation, the authors developed a new integral inequalities for quadratic functions via some intermediate terms (auxiliary functions) [19] to study the stability results of delayed dynamical systems. The auxiliary function based integral inequalities are more general because by choosing the auxiliary functions appropriately which turn into the above mentioned existing inequalities as a special case.

However, to the best of author's knowledge, there are no reports on synchronization analysis of impulsive NNs with mixed time-varying delays and linear fractional uncertainties. Thus from above motivations, in this paper the synchronization problem of delayed uncertain impulsive neural networks is studied via delay dependent state feedback control.

The major contributions of this paper are summarized as follows.

- The distributed leakage time-varying delay is introduced in the impulsive neural networks.
- The limitations of upper bounds on the derivatives of discrete time-varying delays are relaxed.
- Recently developed new double integral inequalities are utilized to estimate the upper bound of the derivative of Lyapunov–Krasovskii functional.
- Based on the suitable Lyapunov–Krasovskii functional and linear matrix inequalities, the mixed delay dependent sufficient conditions are derived for the error system which ensures the slave system is synchronized with the master system.

The structure of this paper is outlined as follows. In Section 2, the synchronization problem of impulsive neural networks is described and preliminaries are provided. The main results are presented in Section 3. The efficiency of the proposed results are demonstrated by numerical simulations in Section 4. Conclusion is drawn in Section 5.

Notations: Throughout this paper, $\mathbb{R}^n$ and $\mathbb{R}^{n\times n}$ denote the n-dimensional Euclidean space and the set of all $n\times n$ real matrices, respectively. $\mathbb{Z}_+$ and $\mathbb{R}$ represents the set of all positive integers and real numbers, respectively. I denotes the identity matrix with appropriate dimensions. Denote the transpose of the vector x as x^T and $*$ always denotes the symmetric term in a matrix. If not explicitly stated, the dimensions of the vectors and matrices are assumed to be compatible in the context. The notation $X\geq 0$ (respectively, $X>0$), where X is symmetric matrix, means that X is positive semi definite (respectively, positive definite). $\mathcal{PC}^1(\mathbb{J};\mathbb{R}^n)=\{\Psi:\mathbb{J}\to\mathbb{R}^n|\Psi(s)$ is continuously differentiable everywhere except of a finite number points $s\in\mathbb{J}\subseteq\mathbb{R}$ and at these points $\Psi^+(s),\ \Psi^-(s),\ \dot{\Psi}^+(s)$ and $\dot{\Psi}^-(s)$ exists and $\Psi(s)=\Psi^+(s),\ \dot{\Psi}(s)=\dot{\Psi}^+(s)$ denotes the derivative of $\Psi(s)\}$.

2. Problem formulation and preliminaries

Consider the following impulsive NNs with mixed time-varying delays and linear fractional uncertainties.