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Global exponential stability and lag synchronization for delayed memristive fuzzy Cohen–Grossberg BAM neural networks with impulses☆

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HIGHLIGHTS

- We not only consider the effects of fuzziness and memristor, but also investigate the impulsive effects.
- We obtain the uniqueness and global exponential stability of equilibrium point of the system without using the M-matrix theory.
- Some sufficient criteria for globally exponential lag synchronization are also obtained by using the Lyapunov–Krasovskii functional method.
- The given criteria in this paper are weaker and easier to be verified in numerical simulations than the previous results.

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ABSTRACT

This paper investigates the stability and lag synchronization for memristor-based fuzzy Cohen–Grossberg bidirectional associative memory (BAM) neural networks with mixed delays (asynchronous time delays and continuously distributed delays) and impulses. By applying the inequality analysis technique, homeomorphism theory and some suitable Lyapunov–Krasovskii functionals, some new sufficient conditions for the uniqueness and global exponential stability of equilibrium point are established. Furthermore, we obtain several sufficient criteria concerning globally exponential lag synchronization for the proposed system based on the framework of Filippov solution, differential inclusion theory and control theory. In addition, some examples with numerical simulations are given to illustrate the feasibility and validity of obtained results.

1. Introduction

Since chaotic phenomena have widely appeared in mathematics, physics, secure communication and engineering science, the dynamical behaviors of chaotic neural networks have received more and more attention of researchers. Synchronization implies that two or more systems are sharing a common dynamical behavior in the form of either chaotic or periodic by coupling or external force. Synchronization of chaotic systems has been extensively studied by a wide variety of methods due to the fact that chaos synchronization has been successfully applied in a series of engineering fields such as image processing, information science, secure communication, etc. For the developments of synchronization theory of delayed neural networks, we refer the readers to see Abdurahman, Jiang, and Teng (2016b), Feng, Zhang, and Wang (2011), Li, Fang, and Li (2017), Li and Rakkiyappan (2013), Xia, Yang, and Han (2009), Yang and Cao (2010),

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Yu and Cao (2007) and the references cited therein. For example, by using a nonlinear transformation, Yang, Cao, and Yu (2014) obtained the global exponential synchronization for memristor-based Cohen–Grossberg neural networks with time-varying discrete delays and unbounded distributed delays. In Ding, Han, and Li (2009), Xing and Peng (2012), Yang and Cao (2007a) and Yu, Hu, Jiang, and Teng (2012), the authors established the exponential lag synchronization of chaotic delayed neural networks and delayed fuzzy cellular neural networks with impulses and without impulses. Ratnavelu, Manikandan, and Balasubramaniam (2015) investigated the synchronization problem for fuzzy bidirectional associative memory (BAM) neural networks with various time delays by using Lyapunov–Krasovskii functional and linear matrix inequality (LMI) method. By applying the Lyapunov method and Ito's formula and designing the efficient impulsive control strategy, Sivaranjani and Rakkiyappan (in press) derived the exponential synchronization of considered complex dynamical networks in mean square sense. In Velmurugan, Rakkiyappan, and Cao (2016), by using Laplace transform, the generalized Gronwall's inequality and Mittag-Leffler functions, the problem of finite-time synchronization of memristive fractional-order neural networks with time delays was investigated under linear feedback controller.

In 1971, Chua (1971) noticed that there were only three fundamental circuit elements: namely, the resistor, capacitor, and inductor between relating voltage and current, charge and voltage, and current and magnetic flux, respectively, however, there was no circuit primitive relating charge and magnetic flux. Chua introduced firstly the fourth circuit element called memristor—a portmanteau of memory and resistor and showed that the memristor possesses unique characteristics different from the other three fundamental circuits. A few years later, the concepts of memristors were generalized to describe an expanded class of devices known as memristive systems by Chua and Kang (1976). In previous nonlinear analog circuits of neural networks, the self feedback connection weights and connection weights are usually implemented by utilizing the traditional resistors. If the traditional resistors have been replaced by memristors, there appears a new class of neural network models—memristor-based neural networks. Recently, dynamics analysis of memristive neural networks has attracted the attention of many researchers in the fields of applied sciences such as signal processing, pattern recognition, reconfigurable computing, programmable logic, brain–computer interfaces and control system. There have been a large number of research results with respect to memristive neural networks, see Chandrasekar and Rakkiyappan (2016), Chandrasekar, Rakkiyappan, Cao, and Lakshmanan (2014), Li, Hu, and Guo (2014), Wu, Wen, and Zeng (2012), Wu and Zeng (2012, 2014, 2015), Zhang and Shen (2014), Zhang, Shen, Yin, and Sun (2013) and the references therein. In Rakkiyappan, Velmurugan, Rihan, and Lakshmanan (2016), Wen, Zeng, and Huang (2012) and Zhang, Shen, and Sun (2012), the authors considered the global exponential stability of memristor-based neural networks with time delays in the sense of Filippov solutions. In Guo, Wang, and Yan (2013), Rakkiyappan, Sivaranjani, and Velmurugan (2014) and Rakkiyappan, Velmurugan, Li, and O'Regan (2016), based on the knowledge of memristor and recurrent neural networks, several sufficient conditions were given to ensure the passivity of the memristor-based recurrent neural networks with time-varying delays and/or distributed delays. In Abdurahman and Jiang (2016), Bao, Park, and Cao (2015), Guo, Wang, and Yan (2015) and Wen, Bao, Zeng, Chen, and Huang (2013), the authors established some novel sufficient conditions ensuring the exponential synchronization results of memristor-based neural networks by using some analytical techniques and suitable Lyapunov functionals. In Abdurahman, Jiang, and Teng (2016a), Li and Cao (2016) and Zhang, Hu, and Shen (2015), the exponential lag synchronization for memristor-based neural networks with time delays was investigated by constructing novel Lyapunov–Krasovskii functionals. Anbuvithya, Mathiyalagan, Sakthivel, and Prakash (2016) and Sakthivel, Anbuvithya, Mathiyalagan, Ma, and Prakash (2016) studied the passivity and reliable anti-synchronization of memristor-based BAM neural networks with time delays by using differential inclusions theory and constructing proper Lyapunov–Krasovskii functional, respectively.

In order to research the uncertainties in human cognitive processes and modeling neural systems better, Yang and Yang (1996) applied fuzzy logic to the traditional cellular neural network. Combining the advantages of fuzzy operation theory and cellular neural network, Yang and Yang (1996) firstly proposed the fuzzy cellular neural networks in 1996. Due to the fact that it is a very effective tool in image processing and pattern recognition problems, fuzzy cellular neural networks with various kinds of delays have been extensively investigated by many authors. In Balasubramaniam, Kalpana, and Rakkiyappan (2011), Li, Li, and Ye (2010) and Zhang, Shao, and Liu (2013), the authors considered the global asymptotic/exponential stability of fuzzy cellular neural networks with time delays by Lyapunov–Krasovskii functionals, M-matrix theory and linear matrix inequality approach. By applying matrix theory, inequality analysis technique and contraction mapping principle, Yang (2014) investigated the existence and global exponential stability of periodic solution for fuzzy Cohen–Grossberg BAM neural networks with both time-varying and distributed delays as well as variable coefficients. Zhu and Li (2012) studied the exponential stability in the mean square and almost sure exponential stability of stochastic fuzzy delayed Cohen–Grossberg neural networks based on the Lyapunov–Krasovskii functional and stochastic analysis theory. By using the differential inclusions theory and Lyapunov–Krasovskii stability theory, Mathiyalagan, Anbuvithya, Sakthivel, Park, and Prakash (2016) and Sakthivel, Anbuvithya, Mathiyalagan, and Prakash (2015) considered non-fragile state estimation and synchronization problems for memristive neural networks with time-varying delays, respectively.

From the previous literature review, a lot of exponential stability and synchronization results have been established. However, to the best of our knowledge, in the existing literature, the authors usually considered only the stability and synchronization of either fuzzy cellular neural networks or memristor-based neural networks. Cohen–Grossberg neural networks are one of the most popular and typical neural network models and include cellular neural networks, Hopfield neural networks, and shunting inhibitory neural networks as special cases. On the other hand, Cohen–Grossberg neural networks have wide potential applications in many different areas such as pattern recognition, signal and image processing, parallel computations and nonlinear optimization problems. Therefore, it is necessary and important to consider the stability and synchronization for memristor-based fuzzy Cohen–Grossberg BAM neural networks with mixed delays (asynchronous time delays and continuously distributed delays) and impulses. The main contributions of this paper are listed as follows:

(1) Most of the existing stability and synchronization criteria for memristor-based neurodynamic systems ignore the impulsive effects on the systems, see Guo et al. (2015), Wen et al. (2012) and Zhang et al. (2015). In this paper, we not only consider the effects of fuzziness and memristor in dynamical systems, but also investigate the impulsive effects on the systems.

(2) By applying the inequality analysis technique and homeomorphism theory, we obtain the uniqueness and global exponential stability of equilibrium point of the system without using the M-matrix theory. However, in existing references (Wu & Zeng, 2015; Zhang et al., 2012), the authors considered only the existence of equilibrium point by applying some standard fixed point theorems.