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Stabilization of stochastic complex-valued coupled delayed systems with Markovian switching via periodically intermittent control

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This paper focuses on exponential stabilization of stochastic complex-valued coupled delayed systems with Markovian switching (SCCDM) via periodically intermittent control. The features of complex-valued systems, time-varying delays, stochastic disturbances and Markovian switching are taken into account. The mathematical model of this kind of complex-valued coupled systems is studied for the first time. To study the stabilization problem of SCCDM, two new differential inequalities on delayed Markovian jump systems are established. Then by utilizing Lyapunov method combined with Kirchhoff's Matrix Tree Theorem, sufficient criteria promising the stability of SCCDM via periodically intermittent control are derived, which have a close relationship with control period, control rate, control gain and the topological structure of the considered coupled network. Then we employ the theoretical results to study the stabilization problem of stochastic complex-valued coupled oscillators with Markovian switching via periodically intermittent control. Finally, numerical examples are provided to demonstrate the effectiveness and feasibility of the proposed results.

1. Introduction

In our real lives, many practical systems may be subjected to random abrupt changes in their structures and parameters, such as environmental variance, component failures or repairs, changing of subsystem interconnections and so on. Systems that experience above phenomena are usually called Markovian jump systems which are a set of dynamics with transitions among the models governed by a Markov process [1–4]. And Markovian jump systems have been applied to economic systems, power systems, network-based control systems and so on. Taking the economy model [5] as an example, it is assumed that the economy state could be roughly lumped into three operation modes (normal, boom and slump) and that the switching between them could be modeled as a Markov chain. Moreover, since time delays are often met and may cause undesirable phenomena such as oscillation and instability [6–9], it is meaningful to study the stability of Markovian jump systems with time delays. On the other hand, in recent years, much attention has been paid to large-scale nonlinear systems due to their potential applications in neural networks [10,11], epidemiology [12,13], biology systems [14,15] and so on. To better understand large-scale nonlinear systems, we can abstract them as coupled systems on networks (CSNs) [16–18]. Due to these points mentioned above, many interesting results about the stability of stochastic delayed CSNs with Markovian switching have been reported recently [19–23].

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Note that the references mentioned above all concern real-valued systems. Actually, many problems can be better solved by complex-valued systems. For example, the XOR problem cannot be solved with a single real-valued neuron. Only one complex-valued neuron is sufficient [24]. When modeling wind profile [25], the fully complex approach (i.e., simultaneously speed and direction as a complex vector) has major advantages over the dual-univariate approach (i.e., speed and direction as independent processes). In wave-related adaptive processing, we often obtain excellent performance with learning or self-organization based on the complex-valued neural networks compared with real-valued neural networks [26]. And up to now, numerous results with respect to the stability of complex-valued CSNs have been carried out. For example, in [27–30], the stability of complex-valued recurrent neural networks was studied. In [31], the boundedness and complete stability of complex-valued neural networks with time delay were investigated via the energy minimization method. Gong et al. used measure approach to investigate the stability of complex-valued neural networks [32]. It is worth noting that above literature dealt with the complex-valued systems by separating their real and imaginary parts. However, this method may make the dimension become double compared with the original system and may break the special data structure. Further, systems will suffer from high computational complexity and slow convergence. Hence, it is more efficient to retain the complex nature of complex-valued systems and consider their properties on complex space directly. Although some results on the stability of complex-valued CSNs without separating their real and imaginary parts have been reported [33,34], to the best of the authors' knowledge, there are few results on stability of stochastic complex-valued systems with Markovian switching.

In recent years, various control schemes have been proposed to deal with the stability and stabilization problem for CSNs. These include sampled-data control [6,35], adaptive control [11], state observer-based control [36–38], sliding mode control [39], impulsive control [7,34], intermittent control [40], and so on. Impulsive control and intermittent control are discontinuous control that do not require the control inputs to be activated incessantly. This merit can efficiently save control cost compared with continuous control. Moreover, compared with impulsive control [41,42], intermittent control has the advantage of easy implementation because it does not change the state instantaneously. By these merits, the recent years have witnessed an increasing interest in intermittent control. For example, in [43], Liu and Jiang studied the exponential stability for a class of mixed delayed genetic regulatory networks by periodically intermittent control. In [44], Chen et al. examined delay-independently periodically intermittent stabilization for a class of time-delay systems. In [45], exponential stabilization of chaotic systems with delay by periodically intermittent control was investigated. For other interesting results on this subject, one can refer to [46,47] and the references therein. It should be pointed that the applications of intermittent controls are all based on differential inequalities with delays. However, when considering Markovian switching, these differential inequalities cannot be extended directly. And until now, few results have been reported on the stabilization of stochastic CSNs with Markovian switching via periodically intermittent control, so there still exists a huge space in this area.

Inspired by the above discussions, this paper investigates the stabilization of stochastic complex-valued coupled delayed systems with Markovian switching (SCCDM) via periodically intermittent control. By establishing new differential inequalities with Markovian switching and delays and combining Lyapunov method with Kirchhoff's Matrix Tree Theorem in graph theory, two kinds of sufficient criteria, which are in the form of vertex-Lyapunov functions (see Definition 4) and the coefficients of the considered system respectively, are given. In order to illustrate the application of the main results, a class of stochastic complex-valued coupled oscillators with Markovian switching is studied. And numerical simulations are presented as well. The main contributions of this paper are three-folds.

1. Compared with the existing results on complex-valued systems, we consider the Markovian switching into complex-valued systems for the first time and do not separate systems' real and imaginary parts.
2. Compared with the results about periodically intermittent control, the stabilization problem of Markovian jump systems via periodically intermittent control is studied for the first time by establishing two new differential inequalities.
3. The derived stabilization criteria have a close relationship with control period T, control rate θ, control gain K_k and the topological structure of the studied coupled systems.

The remainder of this paper is organized as follows. In Section 2, the preliminaries and model formulation are presented. In Section 3, two kinds of sufficient criteria are derived. Then an application to stochastic complex-valued coupled oscillators with Markovian switching is given in Section 4. The numerical simulations are carried out in Section 5. Finally, the conclusion of this paper is provided in Section 6.

2. Preliminaries and model formulations

2.1. Preliminaries

For any complex vector (or complex number) x, let $x = x^R + \mathbf{i}x^I$, where $\mathbf{i} = \sqrt{-1}$ and x^R, x^I represent the real part and imaginary part of x, respectively. Let $\bar{x}$, x^{T} be the conjugate and transpose of x, respectively. Denote by $\mathbb{C}^n$ and $\mathbb{C}^{n\times m}$ the set of n-dimensional complex-valued vectors and the set of $n \times m$ complex-valued matrices, respectively. The norm of x is $\|x\| = \sqrt{x^{\mathrm{T}}\bar{x}}$. Let $\lambda_{max}(\cdot)$ denote the maximal eigenvalue of a Hermite matrix and I_n be an n-dimensional identity matrix. Besides, we write $C([-\tau, 0]; \mathbb{C}^n)$ for the family of continuous functions φ from $[-\tau, 0]$ to $\mathbb{C}^n$ where $\tau > 0$. Notations