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New approach on designing stochastic sampled-data controller for exponential synchronization of chaotic Lur'e systems[☆]

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ABSTRACT

This paper investigates the problem of designing stochastic sampled-data controller for exponential synchronization of chaotic Lur'e systems (CLSs) via a new approach. Specially, first, multiple stochastic sampling intervals with given probabilities are considered and satisfy Bernoulli distribution. Second, unlike other studies, a unified probability framework, which takes sampling interval and time-varying delay into account, is proposed for the first time to design the controller. Based on this unified probability framework, an augmented Lyapunov–Krasovskii functional (LKF) with some new terms is constructed, which can take full advantage of the available information on actual sampling pattern. Different from some existing LKFs needing to be positive definite on the whole sampling intervals, by the new inequality in Lemma 1, the LKF is positive definite only requiring to be positive definite at sampling times. Third, less conservative synchronization criterion is derived and the desired stochastic sampled-data controller is designed. Finally, numerical simulations of Chua's circuit and neural network are provided to show the effectiveness and advantages of the proposed results.

1. Introduction

During the past decades, synchronization of chaotic systems has been extensively studied and applied in a variety of areas, such as chaos generator design, chemical reaction, biological system, and secure communication [1–6]. Master–slave synchronization, which aims to design a desired controller such that the output of the slave system follows the output of the master system, has attracted increasing attention since it exhibits more complicated and unpredictable behaviors than a single system. It has been known that many chaotic systems can be described as Lur'e systems, such as Chua's circuit, hyper chaotic attractors, and n-scroll attractors, which consist of a linear dynamical system and a feedback nonlinearity satisfying sector bound constraints. Hence, it is of great importance to investigate the master-slave synchronization for CLSs. Recently, a large amount of energy and attention has been devoted to the master–slave synchronization of CLSs and a great number of interesting research results have been reported in the literature [7–16].

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Meanwhile, various control schemes have been proposed to deal with synchronization problem for CLSs such as time delay feedback control [9], impulsive control [10], adaptive control [17], and proportional derivative control [18,19]. All the aforementioned control methods are using continuous-time feedback. However, in practical implementation, control strategy requires digital feedback [20]. Moreover, with the development of modern high-speed computers and communication networks, digital control takes merits in speed, small size, accuracy, and low cost during the control process for continuous-time systems [21–27]. Thus, sampled-data control, which only needs the samples of the state variables of the master–slave systems at discrete time instants, has received great attention for master–slave synchronization of CLSs [4,7,11–14,8].

Note that the sampling intervals in [4,11–14,28–30] are deterministic constants. In fact, due to the uncertain interferences induced by environmental and artificial factors, random phenomenon is a very common and important feature in many practical systems. In this case, most of the synchronization criteria for CLSs with deterministic sampling intervals may not be available anymore. It is known that the sampling intervals play a key role in synchronization process of CLSs. Hence, it is of importance to consider stochastically varying sampling interval for synchronization of CLSs. Unfortunately, although sampled-data control technologies have been developed relatively well in control theory, the synchronization problem for CLSs with stochastically varying sampling interval has so far received very little attention due to the existence of stochastic interference and mathematical complexity. In [31], the stochastic sampling interval has initially considered for synchronization of CLSs. But it should be pointed out that, the derived synchronization criteria in [31] may be conservative, since the available information on actual sampling patterns are neglected. Improved results have been given in [32], in which a sawtooth structure term has been constructed in its LKF. However, constrained by the not unified probability structures of sampling interval and time-varying delay, some sawtooth structure terms are hard to be constructed in the LKF, which makes the derived synchronization criteria still conservative to some extent. To the best of our knowledge, a unified probability framework, which takes sampling interval and time-varying delay into account, has not been considered for synchronization of CLSs with stochastic sampling.

Inspired by the aforementioned discussions, in this paper, the problem of exponential synchronization of CLSs is studied via stochastic sampled-data control. The main contributions of this paper are summarized as follows:

(1) A unified probability framework, which takes sampling interval and time-varying delay into account, is given for designing the desired controller. Based on this probability framework, some new sawtooth structure terms can be successfully constructed in the LKF, which can fully capture the information on the actual sampling pattern.

(2) More relaxed constraint conditions of the positive definition of the LKF are proposed. Different from the work in [31,32] to restrict the LKF to be positive definite on the whole sampling intervals, the LKF in this paper is positive definite only needing at sampling times thanks to the use of new inequality in Lemma 1. Therefore, the LKF is more desirable than those in [31,32].

(3) Compared with the remarkable existing papers [31,32], less conservative synchronization criterion is derived based on the new augmented LKF, and the desired stochastic sampled-data controller is designed.

The remainder of this paper is organized as follows. In Section 2, the problem formulation and some preliminaries are introduced. Our main results are presented in Section 3, where the new exponential synchronization criterion of CLSs is obtained. In Section 4, numerical examples are given to demonstrate the effectiveness and the benefit of the proposed results. Finally, the conclusion is drawn in Section 5.

Notations: Throughout this paper, $\Re^n$ and $\Re^{n\times n}$ denote the n-dimensional Euclidean space and the set of all $n \times n$ real matrices, respectively. I_n, 0_n, and $0_{n,m}$ stand for $n \times n$ identity matrix, $n \times n$, and $n \times m$ zero matrices, respectively. The superscript T means the transpose of a matrix. For real symmetric matrices X and Y, the notation $X > Y$ means that the matrix $X - Y$ is positive definite. $\lambda_{\min}(\cdot)$ and $\lambda_{\max}(\cdot)$ denote the minimum and maximum eigenvalue of a real symmetric matrix, respectively. $\mathrm{diag}\{\cdots\}$ stands for a block-diagonal matrix. $\mathrm{Sym}\{X\} = X + X^T$. The symmetric term in a matrix is denoted by $*$. $\|\cdot\|$ denotes the Euclidean norm of a vector and its induced norm of a matrix. $\mathscr{E}\{x\}$ means the mathematical expectation. If not explicitly stated, all matrices are assumed to be compatible dimensions for algebraic operations.

2. Problem description and preliminaries

Consider the following master–slave type of CLSs with stochastic sampled-data control:

$$
\begin{aligned}
&\mathscr{M}: \begin{cases} \dot{x}(t) = \mathcal{A}x(t) + \mathcal{W}f(\mathcal{D}x(t)), \\ p(t) = \mathcal{C}x(t), \end{cases} \\
&\mathscr{S}: \begin{cases} \dot{y}(t) = \mathcal{A}y(t) + \mathcal{W}f(\mathcal{D}y(t)) + u(t), \\ r(t) = \mathcal{C}y(t), \end{cases} \\
&\mathscr{C}: \quad u(t) = \mathcal{K}(p(t_p) - r(t_p)), \quad t_p \le t < t_{p+1},
\end{aligned}
\tag{1}
$$

which consists of the master system $\mathscr{M}$, slave system $\mathscr{S}$, and controller $\mathscr{C}$. $\mathscr{M}$ and $\mathscr{S}$ with $u(t) = 0$ are identical CLSs with state vectors $x(t)$, $y(t) \in \Re^n$, outputs of subsystems $p(t)$, $r(t) \in \Re^l$, respectively. $\mathcal{A} \in \Re^{n\times n}$, $\mathcal{C} \in \Re^{l\times n}$, $\mathcal{D} \in \Re^{m\times n}$, and $\mathcal{W} \in \Re^{n\times m}$ are known real matrices. $\mathcal{K} \in \Re^{n\times l}$ is the sampled-data controller gain matrix to be designed. $u(t) \in \Re^n$ is the