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Master-slave synchronization for nonlinear systems via reliable control with gaussian stochastic process

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ABSTRACT

In this paper, master-slave synchronization methods for nonlinear system are proposed under a reliable control scheme. In order to consider a more realistic situation in designing a reliable controller, Gaussian stochastic process is introduced to the concept of reliable control system. To confirm an effect of reliable control system, a new synchronization criterion of nonlinear systems under time-varying delay feedback and reliable control with Gaussian transition probabilities is derived within the framework of linear matrix inequalities (LMIs) based on Lyapunov method. Finally, two numerical examples are provided to show the effectiveness and applicability of the of the proposed results.

1. Introduction

Since master-slave synchronization scheme for chaotic systems was firstly proposed in [1], it has been applied to a variety of fields such as physical, chemical and ecological systems, human heartbeat regulation, secure communication, and so on [2–11]. Above all, for several decades, many researchers have studied various control methods of systems such as active control [12,13], adaptive control [14,15], fuzzy control [16,17], sampled-data control [18,19], sliding mode control [20–22], and so on. Chaos synchronization of perturbed Chua's system by using active control and adaptive control methods was studied in [12]. Taghvafard and Erjaee [13] investigated the phase and anti-phase synchronization between two identical and non-identical fractional order chaotic systems using techniques from active control theory. In [14], adaptive control and synchronization methods of a new hyperchaotic system with unknown parameters were proposed. Zhang et al. [15] studied the problem of adaptive synchronization between two different chaotic systems with unknown parameters. A fuzzy model-based adaptive design scheme which consists of the fuzzy drive and response system was presented for synchronization of chaotic systems with unknown parameters [16]. In [17], fuzzy model-based robust tracking control for the adaptive synchronization of uncertain chaotic systems was obtained. Pinning sampled-data synchronization problem for complex dynamical networks with probabilistic time-varying coupling delays and control packet loss was investigated in [18] and the authors of Zhang et al. [19] proposed a sampled-data controller design, in which the sampled-data measurements of the state are taken in a finite number of fixed sampling points in the spatial domain. The synchronization of two unified chaotic systems using a sliding mode control scheme was tackled in [20]. Wang et al. [21] investigated the chaos control problem for a

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general class of chaotic systems with sliding mode method. In [22], a novel controller design for stabilizing robust time-delay chaotic systems with input nonlinearity was proposed. However, in results [12–22] mentioned above, reliable control method for synchronization between two chaotic systems has not been considered. It is very important to ensure reliability of the systems in industrial process control because of their cost-effectiveness, reduced weight and power requirement, simple installation and maintenance, and high reliability [23]. With the increase of reliability of control systems, especially, reliable control criteria for various nonlinear systems have been proposed in [24–29]. The robust reliable H_∞ control criteria for uncertain nonlinear system were established in [24]. Liu et al. [25] studied the robust reliable control problem of nonlinear systems with norm-bounded uncertainties. The reliable control problem against actuator failures for a class of uncertain discrete-time stochastic nonlinear time-delay systems was studied in [26]. And in [27], the problem of robust reliable stabilization against actuator failures for a class of uncertain nonlinear neutral systems with time-varying delays was considered. Reliable fuzzy control for nonlinear networked systems with state delay was proposed in [28]. In [29], a designing reliable passive controller for stochastic switched time-delay systems was introduced. As mentioned above, the actuator failure model which consists of a scaling factor with upper and lower bounds to the signal to be measured or to the control action was introduced in [24–29]. It has been known that the class of reliable control for systems is to stabilize the systems against actuator failures or to design fault-tolerant control systems. However, the range of actuator failures was fixed in [24–29]. If reliable control parameters cannot be exactly known in advance or some of them are completely unknown, this problem cause unstable or oscillation for the control systems. To supplement its problem, various stochastic processes are introduced which are Gaussian process, Bernoulli process, Markov chain and so on. Above all, Gaussian process is widely utilized in many systems. In [30], the observer based finite-time stabilization problem for discrete-time Markovian jump linear systems with Gaussian transition probabilities was introduced. Therefore, by utilizing Gaussian transition probabilities, it is more realistic to choose the reliable control parameter. From the practical point of view, although there have been various control methods for synchronization of nonlinear systems, to the best of author's knowledge, the problem of synchronization for nonlinear system under reliable control with Gaussian stochastic process has not been investigated yet. Therefore, it is worth designing the reliable controller for synchronization between two chaotic systems.

With motivations mentioned in above discussions, in this paper, a synchronization for nonlinear systems is investigated by time-varying delayed feedback and reliable control. In particular, to represent a more realistic mathematical model, Gaussian stochastic process is applied to reliable parameter. On the other hand, in practice, time-delay frequently occurs in many dynamical systems. Therefore, another essential and important job is stability analysis and stabilization for the systems with time-delay. Stability analysis methods of time-delay systems can be classified into delay-dependent stability criteria and delay-independent ones. Since it is well known that delay-dependent stability criteria are less conservative than delay-independent ones, thus, more attentions have been paid to the derivation of delay-dependent stability criteria for time-delay systems [31]. To get solutions better than existing criteria of stability for the systems with time-varying delay, many researchers have been studying some mathematical and technical lemma such as some new Lyapunov–Krasovskii functionals (LKFs) and lemmas to improve stability criteria of the systems with time-delay [32–37]. By constructing new Lyapunov–Krasovskii functionals and utilizing lemmas such as reciprocally approach [35], Wirtinger-based integral inequality [36] and Finsler's lemma [37], a sufficient condition of designing controller for master-slave synchronization of nonlinear systems is established in terms of linear matrix inequalities. Firstly, a reliable controller design method for nonlinear system with interval time-varying delays and Gaussian stochastic process will be discussed in Theorem 1. Next, based on the result of Theorem 1, a conventional synchronization criterion for nonlinear system will be presented in Corollary 1. Finally, through two numerical examples, it will be shown that the obtained criteria are superior, effective and necessary in synchronization of nonlinear systems.

Notation. $\mathbb{R}^n$ is the n-dimensional Euclidean space and $\mathbb{R}^{m\times n}$ denotes the set of all $m \times n$ real matrix. I_n, 0_n and $0_{m\times n}$ respectively denote $n \times n$ identity matrix, $n \times n$ and $m \times n$ zero matrix. diag$\{\cdots\}$ and sym$(\cdot)$ denote the block diagonal matrix and the symmetric matrix, respectively. $\star$ represents the symmetric parts. X^T denotes the transpose for X. $X^\perp$ denotes a basis for the null-space of X. For a given matrix $X \in \mathbb{R}^{n\times n}$, we define $X^\perp \in \mathbb{R}^{n\times(n-r)}$ as the right orthogonal complement of X. $\|\cdot\|$ refers to the Euclidean vector norm and the induced matrix norm. The notation $\exists$ means *there exists*. $\mathbf{E}[X]$ is the expectation of X. For symmetric matrices X and Y, the notation $X > Y$ ($X \geq Y$) means that the matrix $X - Y$ is positive definite (positive semi-definite).

2. Problem statements

Consider a master-slave synchronization scheme with time-varying delay feedback control:

$$\mathbf{M}: \begin{cases} \dot{m}(t) = Am(t) + B\psi(v(t)), \\ v(t) = Cm(t), \end{cases} \tag{1}$$

$$\mathbf{S}: \begin{cases} \dot{s}(t) = As(t) + B\psi(w(t)) + u(t), \\ w(t) = Cs(t), \end{cases} \tag{2}$$

$$\mathbf{C}: u(t) = L(v(t-h(t)) - w(t-h(t))) \tag{3}$$

with master system **M**, slave system **S** and controller **C**, where $m(t)$ and $s(t) \in \mathbb{R}^n$ are the state vectors, $v(t)$ and $w(t) \in \mathbb{R}^m$ are the output vectors, $u(t) \in \mathbb{R}^n$ is the control input. $A \in \mathbb{R}^{n\times n}$, $B \in \mathbb{R}^{n\times m}$ and $C \in \mathbb{R}^{m\times n}$ are given system matrices. The delay