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Stabilization of chaotic systems under variable sampling and state quantized controller

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Abstract

This paper investigates the problem of stabilization for chaotic systems based on a T–S fuzzy model under sampled-data control and state quantization. A novel Lyapunov–Krasovskii functional (LKF) is introduced to the sampled-data systems. The benefit of the new approach is that the LKF develops more information about the actual sampling pattern. In addition, some symmetric matrices involved in the LKF are not required to be positive definite. Based on a recently introduced Wirtinger-based integral inequality that has been shown to be less conservative than Jensen's inequality, much less conservative stabilization conditions are obtained to ensure the maximal sampling period. Then, the corresponding sampled-data controllers can be synthesized by solving a set of linear matrix inequalities (LMIs). Finally, an illustrative example is given to show the feasibility and effectiveness of the proposed method.

Keywords: Fuzzy systems; Sampled-data control; Quantization; Chaotic systems

1. Introduction

Over the past few decades, considerable attention has been attracted to chaotic system due to its potential applications in many fields such as secure communication, information processing, biological systems and chemical processing [1]. It is well known that a variety of essential and interesting approaches such as adaptive control, linear feedback control, active control and back stepping control have been appeared to analyze chaotic systems. Because of the effective method for the nonlinear control, Takagi–Sugeno (T–S) fuzzy model has received much attention from the control theorists. The T–S fuzzy model is a powerful tool for design and synthesis of fuzzy control systems, and many important results on T–S fuzzy systems have been established by all kinds of methods. For example, in [2,3], the stabilization problems have been investigated for T–S fuzzy systems.

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With the development of high-speed of digital computing technology, the digital devices which have the advantage of low installation cost, better reliability and easy maintenance are gradually utilized in industrial applications. This allows fuzzy systems only using the samples of continuous-time measurement signals at discrete time instants. These samples are used to control the continuous-time plant through a zero-order hold (ZOH). The approach drastically increases the efficiency of bandwidth usage and reduces the system information. This control system is considered to be sampled-data system. Because the control signals between any two continuous sampling instants will be held constant and only be changed at each sampling time, the analysis and synthesis of sampled-date systems are difficult and complex. Many approaches have been used to sampled-data control systems. The most popular approach is the so-called input delay approach [4–8]. In this approach, the sampled-data system is modeled as a continuous-time system with time-varying input delay induced by the ZOH. Then, the stability conditions in terms of LMIs will be established by the LKF method [9]. Under constant sampling, the problem of robust passive control for networked fuzzy systems was investigated in [10], where constant networked-induced delays were taken into account. The sampled-data control problem of T–S fuzzy systems has been studied for chaotic systems in [11–13] based on LMI methods. The problem of designing stochastic sampled-data controller for master-slave synchronization of chaotic Lur'e systems was investigated in [14]. As is well known, in digital control system, uniform sampling is a commonly used method. However, due to the uncertainty of the system itself and external disturbances, the uniform sampling period cannot be always guaranteed. Thus, it is necessary to study the case of time-varying sampling intervals. For the time-varying sampling case, the problem of master-slave synchronization for chaotic delayed Lur'e systems with sampled-data feedback control is investigated in [15]. The stabilization for nonuniform sampling fuzzy systems was discussed in [16,17]. In [2], the authors improved the results in [16] by constructing a novel LKF. For purpose of dealing with the cross term, Jensen inequality, which neglects some terms for obtaining the upper bound of the cross term, was used in the existing literatures. The results derived in the literatures were conservative. Recently, in [18] the authors proposed a new integral inequality, which can provide tighter bound than Jensen inequality. Hence, it is important and necessary to further improve the results obtained in the literatures, which motivates this study.

However, in sampled-data fuzzy systems, all data transmissions are considered to be performed with infinite precision and the effect of the data quantization is ignored. We consider that, in networked system, sampled data is usually quantized before being transmitted, because quantization is an indispensable step that aims at to save limited capacity and energy consumption of the system. In [19,20], the authors made significant research efforts on study of the networked control system with quantization. Some results on the stabilization of systems with quantized signal and quantization design methods were given in [21,22]. Problems of the quantized stabilization and $\mathcal{H}_\infty$ control design for networked control systems were considered in [23]. In [24], the output-feedback control problems were considered for networked control systems with signal quantization and data packet dropout. $\mathcal{H}_\infty$ filtering for nonlinear discrete-time systems subject to quantization and packet dropouts was investigated in [25]. By using adaptive back-stepping approach, the stabilization problem for nonlinear uncertain systems, where the input signal took quantized values, was considered in [26]. In [27] and [28], the problems of the stability for linear systems and sampled-data systems with state quantization were studied, respectively. Very recently, a stabilization problem of sampled-data fuzzy systems with state quantization was addressed in [29]. As far as we know, the stabilization problem for sampled-data fuzzy systems with quantization has received little attention. It is, therefore, the intention of this paper to study the sampled-data control for T–S fuzzy systems with quantization. Some sufficient conditions are given to guarantee the asymptotic stability of the trivial solution of the systems with and without quantization.

In this paper, the problem of quantized sampled-data fuzzy control for chaotic systems with variable sampling is investigated. The chaotic systems can be represented by a T–S fuzzy model. Then, the quantization effect of chaotic systems can be analyzed. We construct a novel looped LKF to address the stability of the fuzzy systems. Based on the looped LKF approach and Wirtinger-based integral inequality, the stabilization conditions are derived in the term of LMIs such that the fuzzy systems are stable. Then, the design procedures of the corresponding sampled-data controller are synthesized to obtain the maximum sampling interval. It is shown that the LKF develops more information about the fuzzy sampled-data systems. The simulation results have less conservatism than the existing ones.

Notations: Throughout this paper, a real symmetric matrix $P > 0 (\geq 0)$ denotes that P is a positive definite (positive semi-definite) matrix, and $X > Y (X \geq Y)$ means $X - Y > 0 (\geq 0)$. $\mathbb{R}^n$ is the n-dimensional Euclidean space. $\mathbb{R}^{m\times n}$ denotes the set of $m \times n$ real matrix. I is the identity matrix. For any positive integer r, $\mathbb{Z}_r := \{1, 2, ..., r\}$. The