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Tracking control for non-Gaussian stochastic distribution sampled-data fuzzy systems

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Received 27 July 2017; received in revised form 19 December 2017; accepted 5 February 2018

Abstract

This paper studies the tracking control problem for the non-Gaussian stochastic distribution sampled-data fuzzy systems. First, by constructing an augmented system, an asynchronous proportional-integral (PI) controller is designed such that the probability density functions (PDFs) of the system output can track the target one. Second, by introducing two sets (the extension reachable set and the ellipsoid set), the state trajectories of the augmented system with persistent reference input signal can be restricted in a given local region, namely, the state constrained problem can be addressed. Furthermore, in some existing asynchronous controller strategies, it is required that the derivative of the membership function of the system not explicitly depends on the system input. However, in this paper, by restricting the state into a specified region, a new asynchronous scheme is proposed so as to the above-mentioned requirement is removed. Finally, an example is given to demonstrate the efficiency of the presented method.

Keywords: Stochastic distribution systems; Sampled-data; Probability density functions (PDFs); Stochastic distribution control (SDC)

1. Introduction

As one of the important areas in control systems, Gaussian stochastic systems have attracted considerable attentions during the past years [1,2,7,13]. For such systems, the main objective of designing controller is to eliminate or minimize the difference of the mean or the variance between reference signals and the system actual output. However, due to system nonlinearities and the randomness of input source, there are many non-Gaussian variables in the practical control systems [45]. Motivated by this problem, the stochastic distribution control (SDC) strategy, originated by [35], has been proposed for non-Gaussian systems. The SDC strategy mainly focuses on controlling the system output probability density functions (PDFs), rather than the output itself [23]. Meanwhile, it aims to design a controller such that the PDFs of the system output follow the reference signal as much as possible. In view of the above-mentioned

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https://doi.org/10.1016/j.fss.2018.02.001
0165-0114/

advantages, the SDC method has been widely studied and many related results are developed in recent years, including minimum entropy control, optimal tracking control, robust tracking [11,21,44,46,50]. A constrained PI tracking controller strategy is proposed for nonlinear stochastic systems [46], where two-step neural networks are utilized for better identifying the nonlinear dynamic between the input and dynamic weight vector. [44] studies the fault diagnosis and fault tolerant control problems for non-Gaussian singular SDC systems, where the fault can be estimated well by an iterative learning observer. In [50], a robust tracking control problem for SDC systems is addressed and a new performance index is introduced to improve the performance of the controller. In [21], an adaptive fault-tolerant method is proposed for SDC systems so as to the adverse effects caused by the actuator faults can be reduced.

On the other hand, the study for the problem of local stability is meaningful for the systems, especially for the fuzzy systems. The reasons are as follows: 1) It is well known that nonlinear systems usually can be represented by T–S fuzzy models in a local region. 2) Due to the use of fuzzy Lyapunov functions in the stability analysis, the time-derivative of the normalized membership functions (NMFs), arising from the Lyapunov inequality, contains additional nonlinear terms [18]. To get a convex condition, the state should be restricted into a given region such that NMFs can be bounded by a determined value. 3) In real applications, some system states are required to be controlled in a local region. For the problem of local stability, many efforts have been made in recent years [17,25,28,36,37,42,49]. Different from the existing literatures, where NMFs has a determined boundary only by assumption, [25] gives a new LMI condition to guarantee the NMFs bounded by a determined value. The local stability problem for time-delay systems has been investigated in [36]. In [17], new sufficient conditions are provided to assess the local stability and to estimate invariant subsets of the DA for continuous-time T–S fuzzy systems. In [37], an H_∞ observer-based controller scheme is proposed for T–S systems with unmeasurable premise variables under the framework of the local stability. In this paper, inspired by the method of the local stabilization, a new scheme will be proposed to address the problem, where there are deviations between the NMFs of the system and the ones of the controller.

In addition, alone with the development of technology, digital controllers have gradually token the place of the continuous-time controllers to control dynamic systems, such as, sampled-data control systems. The basic control process is as follows: Via sampling the continuous-time measurement signals, the discrete time signal can be produced by the digital computer, then, the discrete time signal is transformed into continuous-time control signals by a zero-order hold. Many controller design methods have been proposed for sampled-data systems [4,20,29,34,38,41,43]. In [4], the problem of the sampled-data exponentially synchronization for a class of Markovian neural networks is studied, where a less conservative result can be got by employing the flexible terminal approach. In [38], a novel time-dependent Lyapunov functional is presented for chaotic Lur'e systems to improve the existing results. Semiglobal practical integral input-to-state stability for a class of sampled-data control interconnected systems is analyzed in [24]. However, to the best of the authors' knowledge, the results about the sampled-data control for non-Gaussian stochastic distribution fuzzy systems have rarely been reported, which motivates our presented work.

In this paper, a new controller strategy is proposed for non-Gaussian stochastic distribution sampled-data fuzzy systems. The design objectives are twofold: 1) The PDFs of the system output can track the desired one. 2) The state of the system can be constrained into a pre-determined domain, where the nonlinear system can be modeled as T–S fuzzy model and the boundary of the derivative of the membership function are less than the pre-specified value. To achieve the above objective, a PI sampled-data controller is designed by feed-backing the state of the augmented system. Meanwhile, the asynchronous difference between the normalized membership function of the fuzzy systems and the ones of the controller have been fully considered. Then, the sufficient conditions for the existence of such controller are given in terms of LMIs.

The main difficulties encountered in the design and advantages of the presented method are summarized below:

(1) In some existing approaches, the difference between the normalized membership function of the fuzzy systems μ_i and the one of the controller μ_{Ci} is assumed to be bounded by a given value, and the value depends on the derivative of the membership function $\dot{\mu}_i(t)$. And the controllers are often designed based on the assumption. However, since $\dot{\mu}_i(t)$ is usually dependent on the system input [14], the deviation bounds between μ_i and μ_{Ci} are hard to be determined. Hence, the existing methods are usually applicable for the systems where $\dot{\mu}_i(t)$ is not explicitly dependent on the system input. In this paper, motivated by [37], a new controller scheme is presented to restrict the state into a specified region, then, the deviation bounds can be determined without the requirement that $\dot{\mu}_i(t)$ is not explicitly dependent on the system input.

(2) For the time-delay systems or sampled-data systems, the Lyapunov–Krasovskii function is usually exploited to analyze the stability of the system. However, since the LKF usually includes an integral of functional of the entire