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Sampled-data fuzzy control for a class of nonlinear systems with missing data and disturbances

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Abstract

This paper considers the sampled-data fuzzy control of nonlinear systems in strict feedback form with disturbances and random missing input data. We propose a novel method in which a state observer and a disturbance observer are combined to construct a sampled-data fuzzy output feedback controller. The stochastic variables with a Bernoulli distributed sequence are used to model missing input data. Fuzzy logic systems are applied to approximate nonlinearities without requiring prior knowledge. The relation between observer gain and sampling period is established. The output feedback controller designed guarantees that the nonlinear system is globally stable. A simulation example of four degrees of freedom robotic arm is used to demonstrate the effectiveness and applicability of the proposed control scheme.

Keywords: Fuzzy logic systems; Sampled-data control; State observer; Disturbance observer; Missing input data

1. Introduction

Sampled-data control schemes have attracted much attention recently because most controllers are now digital or networked to the systems, and most controlled systems carry some form of nonlinearity [9,13,14,16,17,20,21,23,24,26,37,38]. In practice, the control input signals of a system may be missed for diverse reasons, such as intermittent actuator faults, uncertain dead-zone nonlinearity of the controller, packet losses in network, and others as discussed in [18,25,29,40]. It is difficult to achieve the desired performance if the control input information is randomly missing. In [28,35], the filtering problem for the case of missing measurements is considered. The sampled-data control with control packet loss problem is discussed in [4,15]. However, when the states are not available, and the controller is constructed by the estimated states and the estimated disturbances, the methods proposed in the aforementioned literature [4,5,15,28,34,35] are restrictive for designing an effective sampled-data controller that can deal with missing

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data and the stability problem of nonlinear systems. Inspired by the approaches [4,15,28,35], stochastic variables with a Bernoulli distributed sequence are applied to model missing input data in our work.

In engineering systems, external disturbances and noise from sensor and actuator are part of the system dynamic to deal with. When disturbances cannot be measured but must be rejected for effective control of the system, the disturbance estimation technique is an important way to mitigate the restrictions resulting from traditional feedforward control. To develop the disturbance estimation technique, the disturbance observer solution is often used, see [1,6,27]. However, many existing disturbance observers based control methods are only applied to systems that satisfy certain matching conditions. Matching occurs when that the disturbances are affecting the system by the same disturbance channels as the control inputs, or the disturbances can be converted to the same disturbance channels as the control inputs by coordinate transformations [2]. The development of the nonlinear disturbance observer has great importance for disturbance estimation of nonlinear systems. The work in [3,11,12] proposed some effective nonlinear disturbance observers to deal with nonlinear robotic manipulator control and fuzzy control. However, the disturbances have to meet some limited conditions. It is imperative to design new nonlinear disturbance observers to estimate more general disturbances for more general nonlinear systems. The aforementioned references [1,6,27] have not provided an effective method to tackle the problem that full states are not available for the nonlinear systems with mismatched disturbances. In this paper, we construct a nonlinear disturbance observer to enhance the ability of disturbance rejection under output feedback control, and when the control law is subject to random missing data.

Meanwhile, fuzzy logic systems are widely used to model nonlinearities and to relax the limited conditions or remove such restrictions [8,10,19,31]. The sampled-data controller approach used in [22] requires that the nonlinear terms must be bounded by growth conditions. With enough If–Then rules, a fuzzy logic system can approximate any smooth nonlinearity defined on a compact set with arbitrary accuracy [32]. Recently, numerous fuzzy control methods have been proposed for nonlinear systems in strict feedback form [30,36,39,41]. Fuzzy control for nonlinear systems with sampled and delayed measurements using the backstepping method is investigated in [33]. However, the controller only guarantees that the system is semiglobally uniformly ultimately bounded, and the effect of disturbances is not studied in this work. In our work, the global sampled-data fuzzy controller is designed to stabilize the nonlinear systems. Fuzzy logic systems are applied to approximate the unknown nonlinear functions without a prior matching condition. When only the sampled-data controller without fuzzy control is designed, the nonlinear functions require some restrictions. The limited conditions are generally difficult to be met in practice. If the nonlinear systems are subject to mismatched disturbances and are required to be globally stabilized by a sampled-data output feedback controller, then there are limitations using the existing approaches. When the controller is further subject to missing data, the control problem becomes even more complex.

The motivation of this work is in two fold: (i) in theory, since the disturbances are difficult to measure in many cases and the nonlinear terms are hard to estimate without matching conditions, it is important and useful to design a fuzzy sampled-data controller subject to missing data for the nonlinear systems with extra disturbances; and (ii) in practice, sampled-data controllers can be widely used in digital systems. Moreover, disturbance and random missing data have attracted much attention in both academic and industrial communities. Thus, sampled-data fuzzy control for nonlinear systems with disturbances and missing data has both theoretical and practical significance.

To the best of the authors' knowledge, there are few effective solutions available for the output feedback fuzzy stabilization problem of nonlinear systems with disturbances and missing input data. In this paper, the problem of sampled-data fuzzy control of a class of nonlinear systems with mismatched disturbances and random missing input measurements is investigated. The main contributions derived from this study are:

(i) A discrete-time state observer is designed for the nonlinear system with mismatched disturbances and random missing input data, and a nonlinear disturbance observer is constructed to estimate the mismatched disturbances.

(ii) By using the fuzzy logic systems to approximate the nonlinearities and using a random process with Bernoulli distribution to model missing input data, we can construct a sampled-data fuzzy output feedback controller to globally stabilize the nonlinear systems by the appropriate scaling gain and sampling period.

The robotic manipulator in the simulation part shows the potential of the design for practical applications.

Notation. The notation used throughout the paper is standard. $\mathbb{R}^n$ denotes the real n-dimensional space. $\mathbb{R}^{n\times m}$ denotes the real $n \times m$-dimensional space. The $|\cdot|$ stands for Euclidean norm. $\|x\| = \sup_{t\in[r_1,r_2]} |x(t)|$ stands for the 2-norm of a function $x \in C^1([r_1, r_2], \mathbb{R}^m)$, and for a given matrix $X_{m\times n} = (x_{ij}(t))_{m\times n}$, the 2-norm of X is $\|X\| = (\sum_{i=1}^{m} \sum_{j=1}^{n} \|x_{ij}\|^2)^{1/2}$. X^T denotes the transpose of matrix X. I is used to denote the $n \times n$ identity matrix.