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Sliding mode control of quantized systems against bounded disturbances ☆

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ABSTRACT

This paper investigates the sliding mode control problem of quantized systems with simultaneous input and output disturbances. In a network environment, the output measurements are supposed to be quantized with a logarithmic strategy before transmitting over the digital channels. The main difficulties in this design are as follows: (1) there exists input/output disturbances and state time-delay in the plant under consideration, such that model discretization is difficult to be implemented. The design work is therefore forbidden to be considered in continuous-time domain; (2) the quantized signals (piecewise constants) cannot be used to synthesize a continuous-time sliding mode surface; (3) traditional observer technique is not effective to handle output disturbances. In this paper, a filtering-based technique is proposed to solve these difficulties, based on which a sliding-mode observer-based control scheme is developed to stabilize the resulting closed-loop systems. Finally, the effectiveness of the proposed methodology is illustrated via a numerical example.

1. Introduction

Networked control systems (NCSs), connected over networked media, have received increasing research interest due to its wide applications [28,14,2,18,7,17]. In NCSs, output measurements are always transmitted via a digital communication channel for feedback control and filtering design, and data information is thus required to be quantized before transmission [10,26,25,27,24]. In this setting, real valued signals are mapped into piecewise constant signals taking values in a finite set [1]. However, conventional control strategies may not be effective to deal with quantized effect, and have to be re-designed before being applied to NCSs [15,16]. Recent years a large number of results have been developed for NCSs with or without signal quantization [9,22,23].

In practical industrial systems, sensor/actuator faults and disturbances can always result in serious degradation of the system stability and performance, and it may even cause a complete breakdown of the process operation [19,21]. Due to this fact, fault-tolerant control (FTC) against faults and/or disturbances has attracted extensive research attention [3,5,13]. On the other hand, it is well known that sliding mode control (SMC) has been an effective tool to deal with matched nonlinearities

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and external disturbances [4,6]. In addition, sliding mode observer (SMO) techniques have been also developed to deal with fault/disturbance estimation and reconstruction [11,20].

It should be pointed out that, in modern industrial processing, the controller/filter design are always realized via digital computers in a networked environment, and thus data sampling and quantization are inevitable [12]. In this setting, it is always required to perform model discretization, based on which the controller and filter design is considered in a discrete-time domain. However, in modern industrial process external disturbances and state time-delay always exit in a plant, and these effects will make it difficult to implement the model discretization. In this case, it is not feasible to design a discrete-time SMC scheme to solve the corresponding stabilization problem. We therefore consider the question: under the presences of signal quantization, disturbances and state time-delay, whether it is possible to design a SMC scheme *in continuous-time domain*?

Motivated by the above discussion, in this paper, we are interested in the SMC design problem for quantized systems with matched disturbances and state time-delay in continuous-time domain. The presented approach is divided into the following several steps: (i) in this design the quantized data are piecewise constant signals, which cannot be used directly to design a continuous-time SMC strategy. A filtering technique is therefore presented to generate continuous variables from the quantized data (piecewise constant signals); (ii) it is further proved that the detectability of the augmented system composed of the plant and the filtering dynamics is equivalent to that of the plant; (iii) by utilizing the output measurements of the filter, a sliding-mode observer-based control strategy is developed to stabilize the resulting closed-loop system. It is shown that the proposed SMC laws can guarantee the rearchability of the designed sliding mode surface. Finally, a numerical example is illustrated to show the effectiveness and applicability of the proposed technique.

Notations: Throughout the paper, $\|\cdot\|$ and $|\cdot|$ denotes, respectively, the Euclidean norm and 1-norm of a vector; given a symmetric matrix A, the notation $A > 0$ ($A < 0$) denotes a positive definite matrix (negative definite, respectively); I_n denotes an identity matrix with dimension n.

2. Problem formulation

We consider the following linear continuous-time system with state time-delay

$$\begin{cases} \dot{x}(t) = Ax(t) + A_h x(t-h) + B(u(t) + d(t)), \\ x(t) = \phi(t), \quad t \in [-h, 0], \\ y(t) = Cx(t), \end{cases} \tag{1}$$

where $x(t) \in \mathbb{R}^n$ is the state, $h > 0$ is the known constant delay time, $\phi(t) \in \mathbb{R}^n$ is a continuous vector-valued initial function, $A,\ A_h \in \mathbb{R}^{n\times n},\ B \in \mathbb{R}^{n\times m},\ C \in \mathbb{R}^{p\times n}$ are system matrices, $u(t) \in \mathbb{R}^m$ is the control input, $y(t) \in \mathbb{R}^p$ is the output measurement, $d(t) \in \mathbb{R}^m$ is the unknown external disturbance.

The structure of the quantized control system is shown in Fig. 1. In this paper, the output $y(t)$ are quantized before transmitted over networks with the following form

$$q(\cdot) = [q_1(\cdot), q_2(\cdot), \ldots, q_p(\cdot)]^T. \tag{2}$$

In this paper, $q_i(\cdot)$ in (2) is assumed to be symmetric, that is,

$$q_i(y_i(t)) = -q_i(-y_i(t)), \quad i = 1, \ldots, p. \tag{3}$$

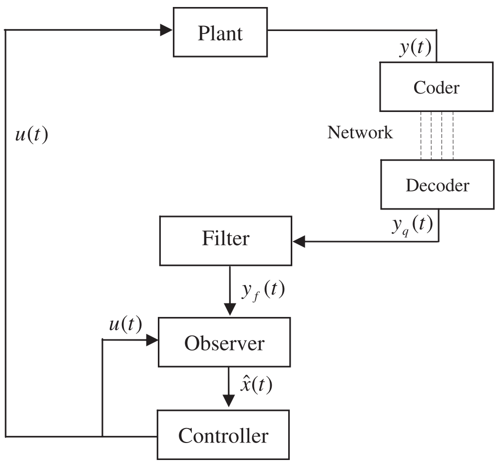

Fig. 1. The structure of a quantized system.