Available online at www.sciencedirect.com
ScienceDirect
Journal of the Franklin Institute 347 (2010) 1199–1213
Journal of The Franklin Institute
www.elsevier.com/locate/jfranklin

Observer-based sliding mode control for a class of discrete systems via delta operator approach

Hongjiu Yang[a], Yuanqing Xia[a,*], Peng Shi[b,c]

[a]Department of Automatic Control, Beijing Institute of Technology, Beijing 100081, China
[b]Department of Computing and Mathematical Sciences, University of Glamorgan, UK
[c]School of Engineering and Science, Victoria University, Melbourne, VIC8001, Australia

Received 28 November 2008; received in revised form 18 April 2010; accepted 4 May 2010

Abstract

In this paper, an observer-based sliding mode control (SMC) problem is investigated for a class of uncertain delta operator systems with nonlinear exogenous disturbance. A novel robust stability condition is obtained for a sliding mode dynamics by using Lyapunov theory in delta domain. Based on a designed sliding mode observer, a sliding mode controller is synthesized by employing SMC theory combined with reaching law technique. The robust asymptotical stability problem is also discussed for the closed-loop system composed of the observer dynamics and the state estimation error dynamics. Furthermore, the reachability of sliding surfaces is also investigated in state-estimate space and estimation error space, respectively. Finally, a numerical example is given to illustrate the feasibility and effectiveness of the developed method.

Keywords: Sliding mode observer; Sliding mode controller; Delta operator system; Robust stability; Linear matrix inequality (LMI)

1. Introduction

Digital processing techniques are based on representing a continuous-time signal by a discrete set of samples. Most research results used the standard shift operator in the development of discrete-time synthesis algorithms. Unfortunately, the algorithms to solve

*Corresponding author.
E-mail addresses: yanghongjiu@gmail.com (H. Yang), xia_yuanqing@bit.edu.cn, yxia@glam.ac.uk, xia_yuanqing@163.net (Y. Xia), pshi@glam.ac.uk (P. Shi).

0016-0032/$32.00
doi:10.1016/j.jfranklin.2010.05.003

these discrete-time equations experience numerical ill-conditioning when the sample period is sufficiently small. That is, the sample period approaches zero for discrete systems, the dynamic response does not converge smoothly to its continuous counterpart [1]. Goodwin introduced a delta operator method to avoid the ill-conditioned problems under fast sampling [2]. The relationships of optimal realization sets between shift and delta operator were established in [3]. The delta operator require smaller word length when implemented in fixed-point digital control processors than do shift operator [4]. The shorter the sampling period is, the better the system performances are for discrete time control systems [5]. Therefore, the delta operator method is significantly less sensitive than the standard shift operator method at high sampling rate. A little results have been reported on SMC by using delta operator in literatures, such as time delay system SMC [6], adaptive SMC [7]. However, to the best of the authors' knowledge, the sliding mode observer for delta operator systems has received little attention now.

Over the past decades, much attention has been focused on the problems of robust control for uncertain standard state-space systems, refer to [8–12] and so on. Furthermore, the state observer design problem has been also paid considerable attention at the same time, for examples [13–15], an observer was designed for discrete-time uncertain nonlinear systems with time delays [16]. A robust non-fragile H_∞ observer-based control was investigated for continuous-time delayed systems [17]. Based on input–output linearization method, a kind of state observer for nonlinear systems was presented in [18]. Some fuzzy observers were proposed for T–S fuzzy systems based on some relaxed stability conditions [19]. On the other hand, the variable structure control strategy by using sliding-mode concept has been widely studied and developed for control and state estimation problems since the works of Utkin in [20]. Furthermore, a robust predictor-based SMC for an uncertain linear discrete systems with input delays was designed for the stability analysis of quasi-sliding motion [21]. In addition, the problem of SMC of uncertain state continuous systems with input delay has been investigated both in [22,23]. The robust adaptive sliding mode control for discrete systems with time delay was given in [24]. A kind of sensorless sliding mode controller of induction motors by using operating condition dependent models was considered in [25]. Moreover, some problems on sliding mode identification and control for linear uncertain stochastic systems were investigated in [26].

Recently, sliding mode observers have been used for estimating states of discrete or continuous systems many times. For examples, an effective method to design sliding mode observers was presented for uncertain control systems [27]. A sliding-mode observer for estimation of vehicle dynamic parameters was obtained in [28]. A robust sliding mode observer was investigated for nonlinear systems in [29] and a second-order sliding-mode observer was used for mechanical systems in [30]. It is well known that a more general solution where the eigenvalues of the linear part of a observer are forced to lie in a specified region. This kind of sliding mode observer was used for nonlinear robust fault reconstruction and estimation [31]. In order to analysis and design nonlinear observers which can effectively deal with model or plant mismatches, a class of fuzzy sliding mode observers were investigated in [32]. An observer-based SMC problem was studied for state-delayed systems with unmeasurable states and nonlinear uncertainties [33]. For nonlinear uncertain neutral systems with unmeasurable states, both a sliding mode observer design problem and a observer-based SMC problem were investigated in [34]. The application of a particular sliding mode observer to the problem of fault detection and isolation was