Information Sciences 429 (2018) 1–11

Contents lists available at ScienceDirect

Information Sciences

journal homepage: www.elsevier.com/locate/ins

Event-triggered non-fragile control for linear systems with actuator saturation and disturbances

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ARTICLE INFO

Article history:
Received 18 January 2017
Revised 30 October 2017
Accepted 1 November 2017
Available online 2 November 2017

Keywords:
Event-triggered control (ETC)
Non-fragile control
Linear systems
Linear matrix inequalities (LMIs)

ABSTRACT

This paper investigates the problem of event-triggered non-fragile dynamic output feedback controller design for linear systems with actuator saturation and disturbances. The controller to be designed is supposed to include additive gain variations. By using Lyapunov stability theory and adding slack matrix variables, new sufficient conditions are derived to design the event-triggered parameters and the controller gains. Compared with the existing non-fragile dynamic output feedback controller design methods, the structural restriction on the Lyapunov matrix is relaxed. The effectiveness of the proposed method is demonstrated by two examples.

1. Introduction

Networked control systems (NCSs) have received substantial attention due to their advantages, such as flexibility, maintainability and easy installation [12,28,31]. Nevertheless, the communication bandwidth in NCSs is inevitably constrained. Facing the situation, a so-called event-triggered control (ETC) has been proposed to save the communication resources. In comparison to the conventional time-driven control approach, in which the measurement information is sent with a constant sampling period, the ETC approach can conserve communication resources, and guarantee desired performance. Recently, the ETC problem has attracted increasing attention and several valuable results have been developed [7–9,13,21,25,36,39–41]. In [38], the dynamic output feedback controller (DOFC) is designed for ETC systems. In [29] and [30], the event-triggered filters and controllers are designed to detect faults. In [5] and [14], the event-triggered H_∞ control problems for continuous and discrete stochastic systems are considered, respectively.

Owing to physical and safety constraints, one of the common control problems is actuator saturation. If the physical constraint on input is not considered in the design of controllers, then the saturation nonlinearity can result in performance deterioration or even instability for systems, which may further lead to catastrophic accidents. Hence, it is of great significance to study dynamic systems with actuator saturation, and abundant results have been obtained [1,3,6,15,26]. Furthermore, the ETC problems for linear systems with actuator saturation have also attracted considerable interest [20,22,23,32,37].

In the above mentioned results, an implicit assumption is that the controller or filter can be implemented exactly. However, in practice, controllers or filters do have a certain degree of inaccuracies. Such inaccuracies may be caused by a variety of factors, including the aging of the components, roundoff errors in numerical computation, etc. Therefore, how to design an insensitive controller or filter with respect to some variations in its gains is a significant issue, and this has re-

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https://doi.org/10.1016/j.ins.2017.11.003
0020-0255/

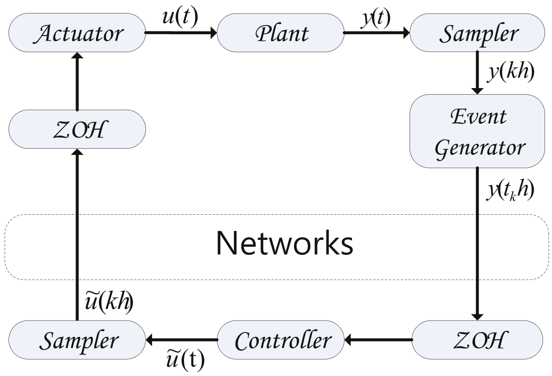

Fig. 1. The event-triggered control loop.

ceived considerable interest [4,10,24,33,34]. In [4,34], the non-fragile filter design problems have been investigated for linear continuous-time systems. The non-fragile state feedback control problems and the output feedback control problems are discussed in [18] and [35], respectively. In [35], both the ETC and the non-fragile control problem is taken into account. Nevertheless, the control method in [35] is unapplicable when the states are not available. On the other hand, the actuator saturation is a common phenomenon. Hence, it is attractive and challenging to design an event-triggered non-fragile DOFC for linear systems with actuator saturation, but there is no result about it.

Inspired by these points, this paper investigates the problem of event-triggered non-fragile DOFC design for linear systems with actuator saturation and disturbances. The main contributions are summarized as follows: 1) A discrete event-triggered mechanism is adopted to save communication resources. Under this mechanism, the resulting closed-loop system is represented as a saturated linear system with time delay. By using Lyapunov theory and adding some slack variables, novel controller design conditions are derived in terms of linear matrix inequalities (LMIs). 2) Compared with [18], the proposed controller design conditions in this paper remove the strict restriction on the Lyapunov matrix by introducing the slack variables. 3) In contrast to the results without considering the impact of controller gain variations, the proposed non-fragile control approach can ensure better steady-state performance when the controller is not implemented exactly.

Notation: For simplicity, the identity matrix with appropriate dimensions is abbreviated as I. The zero matrix with appropriate dimensions is denoted by 0. sgn$(\cdot)$ denotes the signum function. $diag\{\cdots\}$ means a block-diagonal matrix. $He(X)$ denotes $X+X^T$. Sometimes, the symmetric matrices $\begin{bmatrix} X & Z^T \\ Z & Y \end{bmatrix}$ is written as $\begin{bmatrix} X & * \\ Z & Y \end{bmatrix}$.

2. Problem statement and preliminaries

The structure diagram considered in this paper is shown as Fig. 1, which consists of the networks, the physical plant, the sampler, the event generator, the zero-order holder (ZOH), the controller and the actuator. In addition, the clock synchronization is adopted to keep the both samplers synchronized.

2.1. System description

Consider the system

$$\begin{cases} \dot{x}(t) = Ax(t) + B\sigma(u(t)) + G\omega(t) \\ y(t) = C_1x(t) \\ z(t) = C_2x(t) + L\sigma(u(t)) \end{cases} \tag{1}$$

where $x(t) \in \mathbb{R}^n$ is the system state; $y(t) \in \mathbb{R}^r$ is the measured output; $z(t) \in \mathbb{R}^p$ is the regulated output; $u(t) \in \mathbb{R}^m$ is the control input; $\omega(t) \in \mathbb{R}^q$ is the external disturbance belonging to $\mathcal{L}_2[0, \infty)$; A, C_1, C_2, G, B and L are known matrices of appropriate dimensions, and assume that B is of full column rank (the same assumption is also used in [2,16,19]).

$\sigma(\cdot)$ represents the standard saturation function, and it is defined as follows:

$$\sigma(u) = [\sigma(u_1)\ \sigma(u_2)\ \cdots\ \sigma(u_m)]^T,$$

among which $\sigma(u_i) = \text{sgn}(u_i)\min\{|u_i|, 1\}$ for $i = 1, 2, \cdots, m$. Here, the notation σ is slightly abused to denote the vector function and the scalar valued function.

2.2. Event-triggered generator and non-fragile DOFC

In order to reduce the communication load, an event generator is constructed between the sensor and the controller, which is used to determine whether the current sampled-data $(y(t_kh+ih), t_kh+ih)$ will be sent to the controller by the