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Quantized adaptive decentralized control for interconnected nonlinear systems with actuator faults

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ABSTRACT

This paper studies quantized adaptive decentralized output feedback control technique for a class of interconnected nonlinear systems with quantized input and possible number of actuator failures up to infinity. A modified backstepping approach is proposed by the use of high-gain k-filters, hyperbolic tangent function property and bound-estimation approach to compensate for the effect of possible number of actuator failures up to infinity and input quantization. It is proved both mathematically and by simulation that, all the signals of the closed-loop system are globally bounded despite of input quantization and possible number of actuator failures up to infinity.

1. Introduction

Decentralized adaptive control has been a hot topic recently. Local signals are utilized in this approach to construct controller for each subsystem locally which in turn considerably simplifies the controller design process. However, these local controllers designs triggers the challenge to deal with the uncertain interactions among subsystems in stability analysis of the whole closed-loop system. Decentralized adaptive control was proposed for the first time in [1] by imposing the linear growth condition on subsystems interactions. Dynamic input and output regulation was stated in [2] and [3], respectively. Global stability and asymptotic property was sacrificed to propose a simplified backstepping design of controller in [4]. Decentralized unknown control direction problem was investigated in [5]. In [6], a decentralized backstepping design for uncertain interconnected nonlinear systems with possible number of actuator failures up to infinity was proposed. A decentralized sliding mode quantized state feedback approach was proposed for large-scale systems with actuators devices containing dead-zone nonlinearity in [7]. In [8], interconnected nonlinear systems with uncertainties and disturbances were investigated via generalized decentralized approach. Decentralized approach was employed for interconnected systems to study the problem of unknown actuator failures in [9]. Recently a decentralized approach was proposed for a class of interconnected nonlinear systems with input quantization in [10].

Considerable effort has been noticed recently in the design of network control schemes. Low cost, flexible implementation and maintenance with ease are the main reasons of its attraction. To develop new and efficient network control schemes literature contains several efforts see e.g. [11–17]. For linear systems with quantization parameter mismatch a sliding mode control design was proposed in [11]. In [12], for linear uncertain systems quantized sliding mode controller was proposed. In [13], the problem of finite-time robust fault tolerant control was addressed for a class of perturbed linear

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systems. Uncertain linear and nonlinear systems adaptive quantized control was studied in [14] and [15]. Later [16] pointed out some restrictions in [14] and [15], such as it is hard to know the stability conditions before controller implementation as they depend on the controller output. In [16], for a class of nonlinear SISO systems adaptive quantized stabilization approach was proposed, however it requires the system nonlinearities to be Lipchitz continuous. A new adaptive quantized backstepping approach stated in [17] and [18] later removed these restrictive conditions. Recently adaptive tracking problem has been investigated for multi-agent systems in [24]. A two step backstepping approach was proposed in [19] for uncertain nonlinear systems with input quantization and actuator failures.

It is worth mentioning that all the above results are based on state feedback approach. Very few results about quantized adaptive output feedback control has yet been reported. Linear-like controller was proposed in [20] for a class of quantized output feedback control systems. In [21] an adaptive output feedback control problem was addressed with both quantized input and output. A new quantizer was developed in [22] with a restrictive condition that the quantization error is always bounded. For the first time non-smooth analysis was performed in [23], which removed the restrictive conditions of [22] to some extent. H-infinity based non-fragile quantized control via output feedback was investigated for nonlinear systems with quantized input and output in [25]. A quantized fuzzy sliding mode controller was proposed for a class of T-S fuzzy nonlinear systems via memory-based strategy in [26].

It is well known that in practice system actuators may fail during operation. These failures may lead to instability and serious issues as they are often uncertain in value, pattern and time. Safety and reliability are in great demand for any control system therefore in literature considerable effort has been made to deal with this issue in [27–33] . In the above references except [33] the total number of actuator failures are considered finite as to ensure boundness of the overall Lyapunov functions with the occurrence of jumps. Lyapunov function experience jumps due to the parameter estimation errors that results from failures uncertainties included therein. [33] addressed the issue of infinite number of actuator failures with some restrictive conditions, such as knowledge of the bounds of failures uncertainties and parameters are required. In [34] a new decentralized adaptive backstepping approach was proposed for a class of interconnected nonlinear systems and these rigorous condition in [33] were relaxed. For the first time asymptotic tracking was achieved in [19], it also relaxed the restrictive conditions of [33] and proposed a two step backstepping design for uncertain nonlinear systems with input quantization and actuator failures.

Based on the above observations it can be noticed that no result for quantized adaptive output feedback control for nonlinear systems with actuator failures have yet been reported, so this remains an open challenge. In this paper we propose quantized adaptive decentralized control for a class of interconnected nonlinear systems with possible number of actuator failures up to infinity. Main contributions of this paper are summarized as follows: (1) By the use of a modified backstepping approach, bound estimation approach and hyperbolic tangent function property the effect of possible number of actuator failures up to infinity and input quantization are successfully compensated. (2) Up to date to the best of our knowledge no results are presented for adaptive quantized output feedback control for interconnected nonlinear systems with possible number of actuator failures up to infinity. (3) Different from the existing quantized output feedback control literature [20,25], this paper proposes quantized adaptive decentralized control for a class of interconnected nonlinear systems and considers unknown number of actuator failures. (4) In this paper more effort is required than [19] in which a state feedback control approach is proposed and system states are considered known. In this work we propose output feedback control by a transformable high-gain k-filters for estimating the system states.

This note is organized as follows; Sections 2 and 3 state the problem statement and adaptive quantized fault tolerant controllers design. Section 4 presents the closed loop analysis followed by simulation and conclusion in Sections 5 and 6.

2. Problem statement

An interconnected nonlinear system with N subsystems is considered as follows:

$$\begin{aligned} \dot{x}_i &= A_i x_i + \psi_i(y_i)\theta_i + b_i \sum_{j=1}^{k_i} \Phi_{i,j}(y) q(u_{i,j}) + \Delta_i(y_1, \ldots, y_N, t), \\ y_i &= x_{i,1}, \end{aligned} \tag{1}$$

where, $i = 1, \ldots, N$, $A_i = \begin{pmatrix} 0 & 1 & 0 & \cdots & 0 \\ 0 & 0 & 1 & \cdots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 0 & \cdots & 1 \\ 0 & 0 & 0 & \cdots & 0 \end{pmatrix} \in R^{n_i \times n_i}$, $b_i = \begin{bmatrix} 0 \\ \vdots \\ 0 \\ \bar{b}_i \end{bmatrix} \in R^{n_i}$, the states $x_i = [x_{i,1}, \ldots, x_{i,n_i}]^T \in R^{n_i}$ are unmeasured, quantized outputs of the actuators $q(u_{i,j}) = [q(u_{i,1}), \ldots, q(u_{i,k})]^T \in R^{k_i}$, control signals $u_{i,j} = [u_{i,1}, \ldots, u_{i,k}]^T \in R^{k_i}$ and the output $y_i \in R$, $\theta_i \in R^{p_i}$ and $\bar{b}_i = [b_{i,m_i}, \ldots, b_{i,0}]^T \in R^{m_i+1}$ are unknown constants, with $b_{i,m_i} \neq 0$, $\psi_i(y) = [\psi_{i,1}(y_i), \ldots, \psi_{i,n}(y_i)]^T \in R^{n_i \times p_i}$ with $\psi_{i,q}(y_i) \in R^{p_i}$ and $\Phi_{i,j}(y_i) \neq 0 \in R$ are known smooth functions, $\Delta_i = [\Delta_{i,1}(y_i, t), \ldots, \Delta_{i,n_i}(y_i, t)]^T \in R^{n_i}$ are unknown nonlinear functions. Here, the same as [16], the following hysteretic