Neurocomputing 207 (2016) 450–456

Contents lists available at ScienceDirect

Neurocomputing

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

Adaptive quantized control of switched stochastic nonlinear systems ☆

Fang Wang [a,b], Bing Chen [a,*], Chong Lin [a], Gang Li [b], Yumei Sun [a]

[a] The Institute of Complexity Science, Qingdao University, Qingdao 266071, China
[b] College of Mathematics and Systems Science, Shandong University of Science and Technology, China

ARTICLE INFO

Article history:
Received 16 December 2015
Received in revised form
2 May 2016
Accepted 9 May 2016
Communicated by Shaocheng Tong
Available online 14 May 2016

Keywords:
Adaptive fuzzy control
Backstepping technique
Switched stochastic nonlinear systems
Quantized input

ABSTRACT

This paper is concerned with a tracking control issue for a class of switched stochastic systems with quantized input. To overcome the difficulty caused by the switching and quantization, a nonlinear decomposition strategy for quantizer is firstly proposed, then by using the common Lyapunov function method, a systematic adaptive control scheme is presented. It is proved that, under the proposed control scheme, the good control performance is obtained although influenced by the effect of switching and quantization. Furthermore, the validity of the proposed control scheme is verified by the simulation results.

1. Introduction

The past decades have witnessed a growing interest in switched systems due to their widespread use in engineering practice [1–4]. Some properties of switched systems were extensively discussed by many researchers, and fruitful achievements are obtained. In these studies of switched systems, the common Lyapunov function (CLF) method (see [5,6]) and the multiple Lyapunov function (MLF) approach (see [7]) are generally utilized. As stated in [5], to guarantee the stability of switched systems under arbitrary switching, the key is finding a CLF for all subsystems. Following this principle, some remarkable results were achieved for the switched linear systems (see [8–12]). Combining the backstepping technique and the CLF method, the control synthesis of switched nonlinear systems was studied in [13–25]. Despite some achievements have been achieved, the existing results on switched systems ignore the quantization effect on the systems and the quantized control problem for switched systems is not mentioned.

Quantization control scheme has received a lot of attention in recent years due to the widespread use in networked control systems, multi-agent systems, and teleoperation systems(see e.g., [27–34]). In a quantized feedback control system, the controller and the plant are connected through the network with bandwidth limitations. As a result, the command signals are frequently quantized before transmission. Quantization brings up a new problem. That is, the system input contains nonlinear error introduced by quantization, which may lead to oscillations or chaos [35]. An important aspect of quantization scheme is how to deal with the quantization error to ensure the performance of the controlled system. To deal with the quantization error problem, many outstanding research results emerged in [32–43]. Among them, the results in [32–39] are for quantized linear systems, the results in [40–43] are for quantized nonlinear systems. Specifically, a new hysteretic quantizer was proposed in [42], which avoids the oscillation caused by logarithmic quantizer. By introducing the hysteretic quantizer, two adaptive stabilization schemes were put forward for strict-feedback nonlinear uncertain systems in [42,43]. Although some progress has been made in quantized control, some restrictions prevent their wide applications. First, most of the quantized control results require the controlled systems that are completely known or uncertain nonlinear systems are linear parametric (see [42,44,45]). In addition, some conservative assumptions are posed on the controlled systems. Second, most of the quantized control works neglect the effect of stochastic disturbances on the systems. Third, the existing studies on quantized feedback control are limited to the non-switched systems. And the switched control problem is not mentioned, since there seems to lack a general framework for extending to switching case. How to

☆This work was supported partially by the National Natural Science Foundation of China (Grant no 61473160, 61503223, 61573108), and partially by the Project of Shandong Province Higher Educational Science and Technology Program (J15LI09), and partially by China Postdoctoral Science Foundation funded project 2016M592140, and partially by Science and Technology Planning Project of Guangdong province (2013B040401015), and partially by the Research Award Funds for Outstanding Young Scientists of Shandong Province (BS2014SF005).

* Corresponding author.
E-mail address: chenbing1958@126.com (B. Chen).

http://dx.doi.org/10.1016/j.neucom.2016.05.024
0925-2312/

remove the conservativeassumptions on the plants and further develop the quantized control of the switched nonlinear systems still remain to be answered.

Motivated by the above considerations, this paper aims to propose a new framework for the quantized control problem of switched stochastic uncertain systems under arbitrary switching. The main contributions can be summarized as follows:

(1) Compared with the existing researches, this paper simultaneously takes the quantization effect and arbitrary switching effect into the stochastic nonlinear systems, which makes the controller design more sophisticated. To overcome this difficulty, a nonlinear decomposition strategy is presented in Theorem 1. Unlike the conventional linear decomposition, the proposed nonlinear decomposition can remove the restrictive assumptions for uncertain system in [43]. In addition, based on the strategy, the quantization problem and switched problem can be separated, which accordingly reduces the difficulty of control design.

(2) Compared with the existing work on stochastic switched system, the construction of the controller and virtual controllers in [26] requires that the nonlinear functions and the stochastic disturbance terms of switched system are available. Instead, by utilizing the universal approximation of fuzzy logic systems, the nonlinear terms and the stochastic disturbance terms of the controlled system are unnecessarily known in the proposed control method. Therefore, the constructed adaptive mechanism is more widely applied in the practical application.

2. Preliminaries and problem description

2.1. Stochastic stability

Consider the stochastic system as follows:

$$dx = f(x,t)dt + h(x,t)dw, \tag{1}$$

where $x \in R^n$ denotes the state variable, w stands for an independent r-dimension standard Brownian motion defined on the complete probability space $(\Omega, F, \{F_t\}_{t \geq 0}, P)$ with Ω representing a sample space, F being a σ-field, $\{F_t\}_{t \geq 0}$ being a filtration, and P denoting a probability measure.

Definition 1 (*[46]*). Define the following differential operator for $V(x,t)$ which is a twice continuously differentiable function:

$$LV = \frac{\partial V}{\partial t} + \frac{\partial V}{\partial x} f + \frac{1}{2}\mathrm{Tr}\left\{ h^T \frac{\partial^2 V}{\partial x^2} h \right\}, \tag{2}$$

where Tr represents a trace of the matrix.

Lemma 1 (*[47,48]*). *If there exist a function $V(x,t) \in C^{2,1}$, two positive constants c and b, κ_∞-functions α_1 and α_2, all of which satisfy*

$$\begin{cases} \alpha_1(\|x\|) \leq V(x,t) \leq \alpha_2(\|x\|) \\ LV \leq -cV(x,t) + b, \end{cases} \tag{3}$$

for $\forall x \in R^n$ and $\forall t > 0$, the system is bounded in probability.

Lemma 2 (*[49]*). *For the following dynamic system:*

$$\dot{\hat{\theta}}(t) = -\gamma \hat{\theta}(t) + \kappa \rho(t), \tag{4}$$

with γ and κ being positive constants and $\rho(t)$ being a positive function, under any given bounded initial condition $\hat{\theta}(t_0) \geq 0$, $\theta(t) \geq 0$ for $\forall t \geq t_0$.

2.2. System description

Consider the switched stochastic systems with quantized input as follows:

$$\begin{cases} dx_i = (x_{i+1} + f_{i,\sigma(t)}(\bar{x}_i))dt + g_{i,\sigma(t)}^T(\bar{x}_i)dw, \quad 1 \leq i \leq n-1, \\ dx_n = (q_{\sigma(t)}(u_{\sigma(t)}) + f_{n,\sigma(t)}(\bar{x}_n))dt + g_{n,\sigma(t)}^T(\bar{x}_n)dw, \\ y = x_1, \end{cases} \tag{5}$$

where $\bar{x}_i = [x_1, x_2, \ldots, x_i]^T \in R^i (i = 1, 2, \ldots, n)$ is the state vector and $y \in R$ stands for system output. $\sigma(t) : [0, \infty) \to M = \{1, 2, \ldots, m\}$ denotes a piecewise continuous switching signal. $\sigma(t) = k (k \in M)$ implies that the kth subsystem is active. w is defined in (1). $f_{i,k}(\cdot) : R^i \to R$ and $g_{i,k}(.) : R^i \to R^r$ $(i = 1, 2, \ldots, n)$ are unknown smooth nonlinear functions. $u_k \in R$ is the real control input, which is subject to quantization, and the quantized signal $q_k(u_k)$ represents the input of the switched stochastic systems, which is represented as shown below [42,43]:

$$q_k(u_k) = \begin{cases} u_{i,k}\,\mathrm{sgn}(u_k), & \frac{u_{i,k}}{1+\delta_k} < |u_k| \leq u_{i,k}, \dot{u}_k < 0, \text{or} \\ & u_{i,k} < |u_k| \leq \frac{u_{i,k}}{1-\delta_k}, \dot{u}_k > 0 \\ u_{i,k}(1+\delta_k)\,\mathrm{sgn}(u_k), & u_{i,k} < |u_k| \leq \frac{u_{i,k}}{1-\delta_k}, \dot{u}_k < 0, \text{or} \\ & \frac{u_{i,k}}{1-\delta_k} < |u_k| \leq \frac{u_{i,k}(1+\delta_k)}{1-\delta_k}, \dot{u}_k > 0 \\ 0, & 0 \leq |u_k| < \frac{u_{k,\min}}{1+\delta_k}, \dot{u}_k < 0, \text{or} \\ & \frac{u_{k,\min}}{1+\delta_k} \leq |u_k| \leq u_{k,\min}, \dot{u}_k > 0 \\ q_k(u_k(t^-)), & \text{other cases.} \end{cases} \tag{6}$$

where $u_{i,k} = \rho_k^{1-i} u_{k,\min}$ $(i = 1, 2, \ldots)$ and $\delta_k = \frac{1-\rho_k}{1+\rho_k}$ with parameters $u_{k,\min} > 0$ and $0 < \rho_k < 1$. $q_k(u_k)$ is in the set $U_k = \{0, \pm u_{i,k}, \pm u_{i,k}(1+\delta_k), i = 1, 2, \ldots\}$, the parameter $u_{k,\min}$ determines the range of the dead-zone for $q_k(u_k)$, and the parameter ρ_k can be seen as a measure of quantization density.

Remark 1. If $f_{i,\sigma(t)}(\bar{x}_i)$, $g_{i,\sigma(t)}^T(\bar{x}_i)$ are known functions and the quantized effect is not considered, the system (5) is reduced to the system (1) in [14]. If the switched effect is not taken into account, the system (5) can be reduced to the system (1) in [44]. Therefore, the system (5) is more general and interesting. However, there are no results for the quantized control of general switched stochastic systems due to its complexity. The challenge inspires the current research.

Remark 2. Superficially, the system (5) is similar to the controlled system in [15], however, the control method in [15] is only suitable for the deterministic systems, not for the stochastic system discussed in this manuscript. The control for such systems is more challenging than [15] under the effect of quantization and switched laws.

This paper aims to construct a common quantized controller such that the tracking error $y - y_d$ converges to an adjusted area of the origin under arbitrary switching and all closed-loop signals are bounded in probability.