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Adaptive finite-time tracking control of switched nonlinear systems[☆]

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ABSTRACT

The finite-time tracking issue of switched nonlinear systems is taken into consideration in this paper. By combining the common Lyapunov function approach and the structural characteristic of neural networks, a simplified adaptive controller is constructed. Under arbitrary switching, the constructed common controller ensures that the system output is located in a small neighborhood of the reference signal in finite time. Different from the existing literature on the finite-time stabilizing issue, the linear growth conditions for the nonlinear functions of the controlled systems can be removed; besides, the tracking problem is considered, which covers the finite-time stabilization issue as a special case.

1. Introduction

In recent decades, the stability issue of switched nonlinear systems has been discussed broadly due to its practical importance in some areas such as networked control systems or spacecraft systems. By looking for a common Lyapunov function(CLF), several state feedback control strategies were presented for strict-feedback switched systems in [19,22]. The constructed controllers in [19,22] assure the stability of the switched systems under arbitrary switching laws. To deal with the state unmeasured problem, a novel particle filtering technique named sequential evolutionary filter was introduced in [45], a descriptor sliding mode observer design method was first proposed for switched systems with sensor and actuator faults in [43]. By combining an universal approximation ability of fuzzy logic system and an adaptive approach, two output-feedback stabilization schemes were brought up in [16,28]. Furthermore, the above common controller design methods were generalized to the stochastic switched nonlinear systems in [33]. By utilizing a multiple Lyapunov function approach and designing some appropriate switching laws, the adaptive control schemes were proposed for the switched nonlinear systems in [24–26]. However, the above results in [16,19,22,24–26,28,33,43,45] concentrate on the infinite-time stability, implying the control performance is achieved only when time approaches infinity. In practice, we expect a fast realization of the system

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performance. The control schemes in [16,19,22,24–26,28,33,43,45] cannot guarantee the system performance in finite time, which restricts applications in the switched nonlinear systems.

Instead, compared with the asymptotic stability, the finite-time stability can rapidly make system transient performances achieved and system states stabilized to equilibrium. In recent years, many outstanding results on the finite-time stabilization have been presented. By applying a terminal sliding mode method, robotic manipulators were stabilized in [31]. Furthermore, by establishing a terminal sliding manifold, [30] dealt with the singularity around the equilibrium in [31]. To overcome the chattering caused by the sliding controller, the Lyapunov theory of finite-time stability was first established in [2,3]. Then, by way of the Lyapunov method, the nonlinear systems were stabilized in [6,9,10,17,32,48] in finite-time. However, the results in [2,3,6,9,10,17,32,48] require the nonlinearity either to be linearly parameterized or to satisfy linear growth conditions. In the practical systems, due to modeling approaches and external distractions, nonlinearities of the plants are usually unknown and linear growth conditions of nonlinearities are not easy to be satisfied. Moreover, the existing publications concentrate on finite-time stabilization issue, while the tracking control is more meaningful and covers the stabilization control as a special case. On the other hand, many adaptive neural/fuzzy control schemes have been developed to deal with the systems containing completely unknown nonlinearities in [1,4,5,7,11–15,18,20,21,23,29,34–42,44,47]. However, all the strategies in [1,4,5,7,11–15,18,20,21,23,29,34–42,44,47] are based on the infinite-time stability of controlled systems. They cannot guarantee the system performances in finite time. The existing stability criterion in [1,4,5,7,11–15,18,20,21,23,29,34–42,44,47] does not work for the study of finite-time stability.

For reasons discussed above, this article aims to construct a common controller for a class of switched nonlinear systems, which can guarantee the tracking performance in finite-time. Comparing with the existing documents on finite-time problem, the thesis mainly has the following innovative points.

(1) The presented design strategy still achieves the good transient performance without linear growth conditions assumption of the nonlinear functions, which is more general than [2,3,6,9,10,17,32,48]. Therefore, the presented work considerably widens the potential application of finite-time control.

(2) The finite-time tracking control for switched nonlinear systems is taken into account, which is more general and meaningful than the stabilization issue in [2,3,6,9,10,17,32,48].

(3) By applying the CLF method and the structural characteristic of neural networks to the controller design, the controller is simplified, which is more convenient to implement than [2,3,6,9,10,17,32,48].

The remainder of this article is organized as follows. Section 2 provides responding preliminaries and problem formulation. A novel adaptive neural control scheme is developed in Section 3. The simulation example is provided to show the feasibility of the main result in Section 4. Conclusion is given in Section 5.

2. Preliminaries and problem formulation

2.1. Preliminaries

Definition 1. [48]. The equilibrium $\zeta = 0$ of the nonlinear system $\dot{\zeta} = f(\zeta, u)$ is semi-global practical finite-time stable (SGPFS) if for all $\zeta(t_0) = \zeta_0$, there exists $\varepsilon > 0$ and a settling time $T(\varepsilon, \zeta_0) < \infty$ to make $\|\zeta(t)\| < \varepsilon$, for all $t \geq t_0 + T$.

Lemma 1 ([8]). *For $z_j \in R$, $j = 1, \ldots, m$, $0 < p \leq 1$, the following relation holds.*

$$\left(\sum_{j=1}^{m} |z_j|\right)^{p} \leq \sum_{j=1}^{m} |z_j|^{p} \leq m^{1-p}\left(\sum_{j=1}^{m} |z_j|\right)^{p}. \tag{1}$$

Lemma 2 ([33]). *If $\dot{\hat{\varsigma}}(t) = -\gamma\hat{\varsigma}(t) + \kappa\nu(t)$ holds, then $\varsigma(t) \geq 0$ for $\forall t \geq t_0$ is deduced from $\hat{\varsigma}(t_0) \geq 0$, where constants $\gamma > 0$, $\kappa > 0$, and function $\nu(t)$ is positive.*

Lemma 3 ([27]). *For any real variables z, χ and any positive constants a, b, μ, the following inequality is satisfied:*

$$|z|^{a}|\chi|^{b} \leq \frac{a}{a+b}\mu|z|^{a+b} + \frac{b}{a+b}\mu^{\frac{-a}{b}}|\chi|^{a+b}. \tag{2}$$

Lemma 4. *For the system $\dot{\zeta} = f(\zeta, u)$, if there exist a function $V(x) \in C^2$, three constants $\lambda > 0$, $0 < \sigma < 1$ and $\tau > 0$, $\kappa_\infty-$functions α_1 and α_2, satisfies*

$$\begin{cases} \alpha_1(\|\zeta\|) \leq V(\zeta) \leq \alpha_2(\|\zeta\|) \\ \dot{V} \leq -\lambda V^{\sigma}(\zeta) + \tau, \end{cases} \tag{3}$$

for $\forall \zeta \in R^m$ and $\forall t > 0$. Then, the nonlinear system $\dot{\zeta} = f(\zeta, u)$ is SGPFS.

Proof. From (3), for $\forall 0 < \beta < 1$, one has:

$$\dot{V}(\zeta) \leq -\beta\lambda V^{\sigma}(\zeta) - (1-\beta)\lambda V^{\sigma}(\zeta) + \tau. \tag{4}$$