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Global output-feedback stabilization for a class of switched uncertain nonlinear systems

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ABSTRACT

This paper is mainly concerned with the problem of global output feedback stabilization for a class of switched nonlinear systems with uncertain control coefficients. First of all, it is shown that the unknown control coefficients are lumped together via a common coordinate transformation, thus the original switched nonlinear system is transformed into a new switched system for which control design is feasible. Second, by constructing a common Lyapunov function relying on the designed state observer, the common output feedback controller independent of switching signals is designed based on the backstepping method so as to guarantee the global asymptotic stability of the resulting closed-loop switched system under arbitrary switchings. Two examples are included for verifying the effectiveness of the method proposed.

1. Introduction

Global output-feedback stabilization of non-switched nonlinear systems with linearly unmeasured states dependent growth is an important topic in control theory and has been extensively investigated over the last decade [5,9–11,14,20,23,24,30,33,43]. However, for switched nonlinear systems with linearly unmeasured states dependent growth, the global output-feedback stabilization problem has been limitedly investigated in the past few years [12,13,15,17,19,28,31].

It is well-known that the output feedback control is one of the most important problems of nonlinear systems since only the plant output can be measured in many cases [1,2,21,27,26,40,41]. Generally speaking, the separation principle does not work for nonlinear systems which makes the design of output feedback control more complicated and difficult [12]. Furthermore, a more challenging issue for output feedback in the field of nonlinear control is global stabilization [10,20]. The nonlinear systems in output feedback form are a kind of significant nonlinear systems. The feedback controllers of such a kind of nonlinear systems can be constructed systematically by the backstepping approach and its variations [9,11,14,18,24,43].

On the other hand, switched systems have been attracting a great deal of attention in the past decades due to the high performance requirements of control systems for handling nonlinearities, uncertainties and operating condition variations and also fault-induced dynamic changes [16,29,32,34–36,39,42]. A switched system is a kind of hybrid systems that comprises a collection of subsystems together with a switching rule that specifies the switching among these subsystems [28]. Stability is the first requirement for a system to work normally; thus, stability of switched systems is also the first and important task in researches on switched systems [8]. Due to the interaction between continuous dynamics and discrete

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dynamics, switched systems may have a very complicated behavior. Consequently, the study of stability for switched systems is more difficult than the study for continuous systems or discrete systems, and so becomes a challenging issue. Moreover, a common Lyapunov function (CLF) for all subsystems guarantees stability under arbitrary switchings [13].

Naturally, how to construct a CLF to study stability is of great importance. Recently, numerous methods have been proposed to construct such a CLF. For example, global stabilization for switched nonlinear systems in triangular structure by state feedback under arbitrary switchings is achieved via backstepping or forwarding which provides a CLF [15,19,31]. Besides, in [4], an adaptive control scheme via state feedback for switched nonlinear systems in strict-feedback form was proposed for switching with a certain dwell-time. It is worth pointing out that the results [10,15,19,20,31] are based on the assumption that full state measurements are available. However, in many systems, this assumption does not hold and an output-feedback control scheme such as observer has to be used. However, to the best of our knowledge, output-feedback stabilization of switched nonlinear systems with unknown control coefficients has only been studied in [17], due to the lack of effective tools and the complexity arising the impact of the system structure on switching. When we consider full state measurements are unavailable, the key problem is how to achieve the global stabilization via design of a proper state observer and output feedback controllers of subsystems which have to be based on state estimates ?

In this paper, we consider the problem of global stabilization via output feedback for a class of switched nonlinear systems with unknown control coefficients by exploiting the CLF method and backstepping. It is assumed that the system studied admits a certain structure, which is much more general than strict-feedback form in switched nonlinear systems. The remarkableness of the paper, compared with the closely related works, can be shown from the following two aspects:

Firstly, we investigate the global stabilization for a class of switched nonlinear systems with unknown control coefficients by output feedback. When considering the case where full state may not be measurable and thus state feedback is not implemented, we designed an appropriate state observer. Secondly, we also constructed a common coordinate transformation at each step of the backstepping. Based on the observer designed and the common coordinate transformation, we constructed output feedback controllers for subsystems via state estimates. Moreover, it is worth pointing out that, since these results [15,19,31] are based on the assumption that full state measurements are available. Their methods cannot be used in the system studied in this paper.

The remainder of the paper is organized as follows. Section 2 formulates the system model and the control objective. Section 3 provides the globally stabilizing control design scheme via output feedback and summarizes the main results. In Section 4, a numerical example is given to illustrate the effectiveness of the theoretical results. The paper ends with some concluding remarks.

2. Problem formulation

Consider a class of switched nonlinear systems with unknown control coefficients as follows:

$$\begin{cases} \dot{\eta}_i = g_i\eta_{i+1} + \psi_{i\sigma(t)}(t,\eta,u_{\sigma(t)}), \quad i = 1,\ldots,n-1, \\ \dot{\eta}_n = g_n u_{\sigma(t)} + \psi_{n\sigma(t)}(t,\eta,u_{\sigma(t)}), \\ y \ = \eta_1, \end{cases} \tag{1}$$

where $\eta = [\eta_1,\ldots,\eta_n]^T \in R^n$ is the system state vector with the initial value $\eta_0 = \eta(t_0); u \in R$ and $y \in R$ are the control input and system output, respectively; $g_i \neq 0, i = 1,\ldots,n$ are unknown constant called unknown control coefficients and $\psi_{i\sigma(t)} : [t_0,+\infty] \times R^n \times R, i = 1,\ldots,n. \sigma(t) : [0,+\infty) \to M = \{1,2,\ldots,m\}$ is the switching signals which is assumed to be a piecewise continuous (from the right) function of time; In what follows, suppose only the system output is measurable and available for feedback, and for notational simplicity, let $t_0 = 0$.

More specifically, the goal of the paper is to design output-feedback controllers for subsystems and state observer which globally stabilizes the system (1) under arbitrary switchings. To this end, the following two assumptions are imposed on the system (1).

Assumption 1. There exist some unknown positive constants $\theta_{0k}, k \in M$ such that

$$|\psi_{i\,k}(t,\eta,u_k)| \leqslant \theta_{0k}(|\eta_1| + |\eta_2| + \ldots + |\eta_i|), \quad i = 1,\ldots,n, \forall k \in M. \tag{2}$$

Assumption 2. The signs of $g_i, i = 1,\ldots,n$ are known, and there exist known positive constants $\underline{g}$ and $\bar{g}$ satisfying

$$\underline{g} \leqslant g_i \leqslant \bar{g}, \quad i = 1,\ldots,n.$$

Remark 1. From Assumptions 1 and 2, it is easy to see that system (1) has uncertain control coefficients and unmeasured states dependent nonlinearities. Assumption 1 is a linear growth condition. It gives some information about the nonlinearities. Assumption 2 is a standard assumption in the study of non-switched nonlinear systems. Assumption 2 means that the known signs of g_i play an important role in controller design. Otherwise, we cannot decide the direction along which the control designs, and the closed-loop system may be unstable.