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Finite-time stability of switched nonlinear systems with finite-time unstable subsystems

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Abstract

Up to now, the precondition that each subsystem should be finite-time stable or finite-time bounded is potentially assumed in most existing results for finite-time stability and finite-time boundedness of switched systems. If one subsystem of switched systems is not finite-time stable or finite-time bounded, the previous results may not work. In this paper, based on Lyapunov-like functions, finite-time stability and finite-time boundedness problems of switched nonlinear systems with subsystems that are not finite-time stable or finite-time bounded are discussed. Sufficient conditions are given under which switched nonlinear systems with subsystems that are finite-time unstable or finite-time unbounded are guaranteed to be still finite-time stable or finite-time bounded by virtue of Lyapunov-like functions respectively. The results also show the effect of switching signals and the total dwell time of finite-time unstable or finite-time unbounded subsystems on finite-time stability and finite-time boundedness of switched nonlinear systems. Numerical examples are employed to verify the efficiency of the proposed method.

1. Introduction

Switched systems consist of a family of subsystems described by differential or difference equations and a switching law that orchestrates switching between these subsystems. Lyapunov

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stability of switched systems, which is defined over an infinite time interval and shows the qualitative behavior of switched systems, is a basic topic in the research, such as [1–17]. However, in practice, not only the qualitative behavior of a dynamical system but also quantitative information is of great interest [18], such as networked control systems [19,20] and network congestion control [21]. Moreover, a system may be Lyapunov stable but possesses unacceptable transient performances [22]. In these cases, finite-time stability could be used, which focuses its attention on system transient behavior over a finite time interval. It should be noted that finite-time stability and Lyapunov asymptotic stability are independent concepts: a system could be finite-time stable but not Lyapunov asymptotically stable, and vice versa.

Some early results on finite-time stability problems date back to 1960s [23,24]. It has been revisited recently in the light of linear matrix inequality theory, and many valuable results have been obtained for this type stability [25–31]. However, it should be pointed out that the definition of finite-time stability in this note and references [23–30] means the boundedness of the state within a prescribed bound in a fixed time interval if a bound on the initial condition is given which is different from the definition proposed by Bhat and Bernstein [32]. The definition of finite-time stability in [32] means Lyapunov stability and finite-time convergence, and it is also discussed in [33,34].

Recently, finite-time stability of hybrid and switching systems has attracted much attention and some interesting results have been presented in many paper, such as [35–46]. Finite-time stability and stabilization of impulsive dynamical systems were discussed in [35,39–41]. In [36–38,43–46], finite-time stability and finite-time boundedness of switched systems with or without delays are discussed and finite-time L_2-gain problem was discussed to measure its disturbance tolerance capability. But, it should be pointed out that the potential assumption of the previous results is that each subsystem should be finite-time stable. If one subsystem of the switched systems is not finite-time stable, the results in the previous papers may not work.

In order to discuss finite-time stability of switched linear systems with finite-time unstable subsystems, sufficient conditions have been proposed in terms of a time-domain method in [47]. In this paper, finite-time stability of switched nonlinear systems with subsystems that are not finite-time stable is discussed by virtue of the Lyapunov method. Sufficient conditions are given under which switched nonlinear systems with subsystems that are finite-time unstable are guaranteed to be still finite-time stable. These results also show the effect of switching signals and the total dwell time of the finite-time unstable subsystems on finite-time stability of switched nonlinear systems. It can be used to discuss the finite-time stability of switched nonlinear systems with asynchronous switching [48,49]. Taking disturbances into account, finite-time boundedness of switched nonlinear systems with subsystems that are not finite-time unbounded is also discussed by virtue of the Lyapunov method.

The paper is organized as follows. In Section 2, some notations and problem formulation are presented. The definition of finite-time stability and finite-time boundedness for switched nonlinear systems is reviewed. In Section 3, finite-time stability problem of switched nonlinear systems with subsystems which are finite-time unstable is dealt with. Sufficient conditions which can guarantee the finite-time stability of switched nonlinear systems with finite-time unstable subsystems are presented. The effect of switching signals and the total dwell time of the finite-time unstable subsystems on finite-time stability of this class of switched systems is also discussed. In Section 4, sufficient conditions which can guarantee the finite-time boundedness of switched nonlinear systems with subsystems which are not finite-time bounded are presented. In Section 5, simulation results are presented to illustrate the efficiency of our approach. Concluding remarks are given in Section 6.