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Adaptive fuzzy fault tolerant tracking control for a class of uncertain switched nonlinear systems with output constraints

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Abstract

This paper studies the adaptive fuzzy fault tolerant tracking control problem for a class of switched multi-input multi-output (MIMO) nonlinear systems with output constraints under arbitrary switchings. The actuator faults under study consist of unknown stuck and loss of effectiveness. In the design procedure, the unknown control signals are approximated directly by fuzzy logic systems. To prevent constraints violation, a tan-type barrier Lyapunov function is incorporated into the Lyapunov function design. Based on the idea of estimating the bound on switching parameters, a novel adaptive fuzzy fault tolerant tracking control technique for the problem studied is set up by exploiting the common Lyapunov function method and backstepping. It is shown that under the proposed control law and adaption rules, all the signals remain bounded and the system output tracking error can be guaranteed to exponentially converge to a neighborhood of origin, while the constraints on the system output will not be violated during operation. Finally, simulation results are presented to show the effectiveness of the proposed approaches.

1. Introduction

A switched system is a type of hybrid system consisting of a family of continuous-time or discrete-time subsystems and a switching rule that orchestrates the switching between them.

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With the increasing number of applications in the field of air traffic control, networked control systems, and power systems, there has been a great surge in research towards controller design for such systems. One of the main objectives of this research is to find conditions under which the system preserves stability. Several efforts have been made to investigate this problem mainly using the theory of Lyapunov functions (LFs), for example, the system is stable under arbitrary switching upon the existence of a common Lyapunov function (CLF) [1]. Therefore, it is of great significance and growing interest for researchers to find a CLF to study the stability problem. However, it is often difficult and challenging to find a CLF due to the complexity of the system structure involving a family of subsystems and nonlinear assumption.

Recently, there have been some results reported on the stabilization problem for switched nonlinear systems in strict-feedback form under arbitrary switchings by exploiting CLF and the backstepping technique [2,3]. However, it is required in [2,3] that all system functions are known in advance. As a matter of fact, this assumption does not hold in many practical systems. If the system functions are unknown, the corresponding CLF and common virtual functions cannot be found or constructed. Also it should be mentioned that the systems presented in [2,3] are single-input single-output (SISO) systems, which is a particular case of MIMO systems in a sense. Thus, the stabilization problem of MIMO nonlinear systems, in particular, switched MIMO nonlinear systems, is more difficult and challenging as well, and stabilizing or controlling the switched MIMO nonlinear systems in general case is a motivation of this study.

Although various control design methods have been proposed for switched nonlinear systems [2–8], the constrained control problems have not been fully considered until now. It is worth pointing out that many complex system dynamics in real world are subjected to some limits or constraints. Violation of such constraints leads to performance degradation or result in instability of the system. Hence, it is of great theoretical and engineering significance to study the output constraints problem to maintain the control systems performances. A Barrier Lyapunov Function (BLF), firstly proposed in [9], is applied to solve the output constraints of switched nonlinear systems [10]. However, the result in [10] is derived under the assumption that the system dynamics are known in advance, and it is difficult to use the adaptive techniques to deal with system uncertainties. In addition, it cannot deal with the nonlinear systems with external disturbances.

On the other hand, in modern practical industrial devices, the actuators are vulnerable to faults during operation, which may result in an unsatisfactory performance and even instability. It is thus essential and significant to develop a fault tolerant control (FTC) scheme to ensure the effectiveness of system operation when faults occur. Recently, a number of design techniques have been reported in the literature [11–18]. To list a few, in [11,12], adaptive fault-tolerant controller design approaches are developed by estimating the efficiency factor online, where the type of faults under consideration is loss of actuator effectiveness. Based on a fault-diagnostic algorithm, a fault-tolerant control for Takagi–Sugeno (T–S) fuzzy systems with actuator faults is investigated in [13], where the faults are time-varying bias faults and time-varying gain faults. In [14], a fault estimation and FTC approach is developed for a class of fuzzy stochastic systems with simultaneous sensor and actuator faults. For general actuator fault model simultaneously including outage, loss of effectiveness and stuck, the authors in [15] propose a fault-tolerant control method for uncertain linear systems with quantization via sliding-mode output feedback. For a class of single-input single-output (SISO) nonlinear systems in parametric-strict-feedback form, some important results have been obtained based on the backstepping design technique [16,17]. Despite these efforts, however, to the best of the authors' knowledge, the FTC problem for uncertain switched MIMO nonlinear systems with actuator faults and output constraints still