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Adaptive fuzzy output feedback control for MIMO switched nonlinear systems with prescribed performances ☆

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Abstract

This paper proposes an adaptive fuzzy output-feedback control approach for a class of uncertain multiple-input and multiple-output (MIMO) switched nonlinear systems with prescribed performance and immeasurable states. In this research, fuzzy logic systems are used to identify the unknown nonlinear functions, a fuzzy switched state observer is established to observe the unmeasured states. Based on backstepping technique and the prescribed performance theory, a new adaptive fuzzy control method with prescribed performance is developed. It is proved that the proposed control approach can ensure that all the signals of the resulting closed-loop system are bounded, and the tracking errors are within the prescribed performance bounds for all times. Simulation studies illustrate the effectiveness of the proposed approach.

Keywords: Switched nonlinear systems; Fuzzy logic systems; Prescribed performance; Average dwell time

1. Introduction

In practice, most plants considered are nonlinear and multivariable in character. It is not surprising that control approaches for nonlinear multivariable have wide applications in practical engineering. In the past decades, many approximation-based adaptive fuzzy or neural backstepping controllers have been developed for uncertain MIMO nonlinear systems [1–11]. For example, the works in [1–7] considered adaptive fuzzy or neural state-feedback control design problem for MIMO nonlinear systems, while works in [8–14] proposed observer-based adaptive fuzzy output

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feedback control approaches for uncertain MIMO nonlinear systems by designing state observers. Meanwhile, in an effort to extend the backstepping control idea to larger classes of MIMO nonlinear uncertain systems, the authors in [15–17] studied the control problem of nonlinear MIMO strict feedback systems with unknown control directions, unknown dead zones, and time delays, respectively. However, the above schemes are only focused on MIMO non-switched nonlinear systems, instead of the MIMO switched nonlinear systems.

Recently, some control design methods have been proposed for several classes of switched nonlinear systems [18–22]. Based on multiple Lyapunov functions method, a switched adaptive control technique has been developed in [18] for a class of switched nonlinear systems. A robust adaptive fuzzy output feedback control scheme has been constructed in [19] for a class of switched nonlinear systems with unknown dead-zone. With the help of common Lyapunov function method, the works in [20,21] have investigated state-feedback control schemes for a class of nonlinear switched systems. With all admissible switched strategy, an adaptive neural network feedback control scheme has been developed in [22] for nonlinear switched impulsive systems. Obviously, all the above mentioned adaptive control approaches can ensure that all the signals of the resulting closed-loop system are bounded. But all the existing switched control methods have not investigated the problem of prescribed performance control (PPC).

It is well known that the PPC demands the convergence rate no less than a prescribed value, exhibiting a maximum overshoot less than a sufficiently small constant and the output or tracking error is confined within the prescribed performance bounds for all times. The robust adaptive control for SISO strict feedback nonlinear system and feedback linearizable MIMO nonlinear systems with PPC were investigated in [23] and [24]. An output feedback of robust adaptive control was considered in [25] with PPC based on dynamic surface approach. However, the prescribed performance design methodology is not yet applied to switched nonlinear systems and the output feedback design for switched nonlinear systems with triangular structure is still a challenge.

In this paper, an adaptive fuzzy output feedback control design with prescribed performance is developed for a class of uncertain MIMO nonlinear systems in block-triangular form with unmeasured states. Fuzzy logic systems are used to identifying the unknown nonlinear functions, and a fuzzy switched state observer is designed which enables unmeasurable states to be obtained. Combining the backstepping control design technique with the prescribed performance technique, a new adaptive fuzzy prescribed performance output feedback tracking control method is developed. It is shown that all the signals of the resulting closed-loop system are bounded. Moreover, the tracking errors can be kept within the prescribed performance bounds. Compared with the existed results, the main advantages of the proposed control scheme are as follows:

(i) This paper proposes an adaptive fuzzy output feedback tracking control design method for a class of uncertain MIMO switched nonlinear systems in block-triangular form. Based on the designing fuzzy switched state observer, the unmeasured state problem can be solved by the developed adaptive control method. The new adaptive fuzzy controller avoids the requirement that states measurable, in contrast with previous approach [18,20,21] that addressed the control design problem for switched nonlinear strict-feedback systems.

(ii) This paper studies the adaptive fuzzy output-feedback control design and control performance problem for the uncertain switched nonlinear systems. By introducing prescribed performance, the proposed adaptive control method cannot only guarantee the stability of the whole switched control system, but also can ensure that the tracking error converges to a prescribed arbitrarily small residual set for all the times, which cannot achieved in the previous literature [8–17].

The remainder of this paper is organized as follows. The problem formulation and preliminaries are given in Section 2. The switched fuzzy state observer design is given in Section 3. The adaptive fuzzy control design and stability analysis are in Section 4. The simulation example is given in Section 5, and followed by Section 6 which concludes the work.

2. Problem formulations and preliminaries

2.1. Systems descriptions and assumptions

Consider a class of uncertain MIMO switched nonlinear systems in the following block-triangular form: