

Observer-based adaptive fuzzy output constrained control for MIMO nonlinear systems with unknown control directions[☆]

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Abstract

In this paper, an adaptive fuzzy output feedback control approach is proposed for a class of multi-input and multi-output (MIMO) uncertain nonlinear systems with unmeasured states and unknown control directions. In the control design, by using fuzzy logic systems to approximate the unknown nonlinear functions, a fuzzy adaptive state observer is designed for state estimation as well as system identification, and a Nussbaum gain function is introduced into the control design to solve the unknown control direction problem. By applying the backstepping design techniques, a fuzzy adaptive output feedback control is constructed recursively. To address the problems of output constraint and “explosion of complexity”, the barrier Lyapunov function method and dynamic surface control technique are employed, respectively. It is proved that the proposed control approach can guarantee the semi-globally uniform ultimate boundedness for all the signals and the tracking errors to a small neighborhood of the origin. Simulation studies illustrate the effectiveness of the proposed approach.

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1. Introduction

In the past decade, some adaptive fuzzy control methods have been proposed for multi-input and multi-output (MIMO) nonlinear uncertain systems with unknown nonlinear functions via fuzzy logic systems [1–9]. Refs. [3–9] proposed several novel adaptive fuzzy output feedback or state feedback control design methods for MIMO nonlinear uncertain systems with unknown control direction, receptively. However, the main limitation in [3–9] is that the unknown nonlinearities appear on the same equation as the control input in a state space representation, i.e., the controlled systems need to satisfy the matching condition. Nevertheless, the control design principle in [3–9] is based on the feedback linearization technique. Therefore, they cannot be applied to those MIMO nonlinear uncertain systems which do not satisfy matching condition.

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In recent years, adaptive fuzzy or neural networks (NN) adaptive control design for nonlinear systems [10–14] has achieved a great progress, and many fuzzy or neural networks adaptive backstepping control schemes have been reported for nonlinear uncertain MIMO systems without satisfying the matching condition, for example, see [15–20]. Among them, [15] proposed an adaptive fuzzy state feedback control scheme for a class of uncertain MIMO nonlinear systems. Ref. [16] proposed an adaptive neural networks control method for a class of uncertain MIMO nonlinear systems with input nonlinearities. To solve the immeasurable state problem, [17] proposed an adaptive fuzzy output feedback control approach for a class of uncertain MIMO nonlinear systems by designing fuzzy states observer. Refs. [18] and [19] investigated the state feedback and output feedback control problems for a class of uncertain MIMO nonlinear systems with unknown control directions.

It should be mentioned that because of the employment of the backstepping design technique, the previous control design methods in [15–19] inevitably suffer from the problem of “explosion of complexity,” which is caused by repeating differentiations of some nonlinear functions, i.e., the virtual controllers designed at each step with the conventional backstepping technique. As a result, the complexity of a controller drastically grows as the order of the system increases. To solve the problem of the “explosion of complexity”, a neural adaptive control approach was developed by [20] for a class of single-input and single-output (SISO) nonlinear systems by using DSC design technique. Afterwards, some adaptive fuzzy or NN dynamic surface control approaches have been extensively studied in [21,22] for several classes of uncertain MIMO nonlinear systems, where the result in [21,22] is state feedback control, while [23] is an output feedback control. However, the control approaches in [21–23] all cannot solve the output feedback control problem for uncertain MIMO nonlinear systems with unmeasured states and unknown control direction.

Though the above adaptive fuzzy or NN control design gained much progress, they did not consider the system output constraint problem. It should be mentioned that many control systems have constraints on their outputs or states in the form of the physical stoppage, performance and safety specifications. During operation, violation of the constraints leads to performance degradation, hazards or system damage. Thus, the output constraints in control design are very important. By far, several control important design methods have been proposed to handle the output constraints, including model predictive control [24], reference governors [25]. Besides these, the design based on Barrier Lyapunov function (BLF) is a very effective method since such a function yields a value that approaches infinity whenever its arguments approach some limits. By using the BLF, [26] proposed a control design for the Brunovsky-type systems with output constraints, [27,28] developed the adaptive backstepping state-feedback control designs for a class of output constraint nonlinear systems, [29] studied the problem of output constraint for electrostatic microactuators, and [30] and [31] investigated the problem of control output constraint for switching system and time-varying output constraint system, respectively. Ref. [32] investigated the state feedback control design problem of control output and input constraints for a class of uncertain SISO nonlinear systems. However, the control design methods in [27–32] are restricted to a class of systems with the states measured. Refs. [33] and [34] proposed two adaptive fuzzy and neural backstepping output feedback control methods for a class of SISO nonlinear systems without state measurement. Refs. [35] and [36] proposed fuzzy adaptive output feedback control method for a class of SISO nonlinear systems with actuator faults or unmodeled dynamics, but they still do not consider the unknown direction problem. To the author’s best knowledge, by far, no adaptive fuzzy or neural control results are available for uncertain MIMO nonlinear systems with unmeasured states, unknown control direction and output and input constraints based on dynamic surface control.

Motivated by the above observations an adaptive fuzzy output feedback control approach is investigated for a class of MIMO uncertain nonlinear systems with unmeasured states, output constraint and unknown control directions. In the control design, fuzzy logic systems are used to approximate the unknown nonlinear functions, a fuzzy adaptive observer is designed for state estimation as well as system identification. A Nussbaum gain function is introduced into the backstepping control design to solve the unknown control direction problem, and the barrier Lyapunov function method and dynamic surface control technique are employed to solve the problems of output constraint and “explosion of complexity”, respectively. Compared with the existing literature, the main advantages of the proposed control scheme are as follows.

(i) The proposed adaptive control method did not need the assumptions in [21,22] and [27–32] that all states must be available for measurement. Ref. [23] considered the adaptive fuzzy output feedback control schemes for a class of MIMO nonlinear systems with unmeasured. However, they did not consider the unknown control directions problem of MIMO nonlinear systems.

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