



Research article

Adaptive fuzzy control design for nonlinear systems with actuation and state constraints: An approach with no feasibility condition

Abdesselem Boulkroune^{a,*}, Mohammed Haddad^{a,b}, Hongyi Li^c^a University of Jijel, LAJ, BP. 98, Ouled-Aissa, 18000 Jijel, Algeria^b Research Centre in Industrial Technologies (CRTI), P.O. Box 64, Cheraga, 16014 Algiers, Algeria^c School of Automation and the Guangdong Province Key Laboratory of Intelligent Decision and Cooperative Control, Guangdong University of Technology, Guangzhou 510006, China

ARTICLE INFO

Article history:

Received 25 March 2022

Received in revised form 28 July 2023

Accepted 28 July 2023

Available online 1 August 2023

Keywords:

Fuzzy adaptive control

Disturbance observer

Nonlinear pure-feedback systems

TFSCs

Actuators' constraints

ABSTRACT

In this article, an adaptive fuzzy tracking control scheme is developed for a class of pure-feedback uncertain nonlinear systems in the presence of time-varying full-state constraints (TFSCs), actuators' nonlinearities and external disturbances. Fuzzy logic systems (FLSs) are employed as universal approximators to online estimate unknown nonlinear functions. A barrier Lyapunov function (BLF) is used to deal with the state constraint problem. In contrast to numerous adjacent studies, this research diligently tackles the open problem relating to the virtual control laws (VCLs) feasibility in the BLF-based backstepping control design. The resolution to this problem involves formulating VCLs with predefined bounds. The utilization of disturbance observers within a backstepping framework allows for effective compensation of estimation errors arising from the implementation of a predefined bounded VCL. This approach also helps prevent the occurrence of the "complexity explosion", making it a practical solution. The control strategy being proposed guarantees that the output tracking error will effectively approach a small region near the origin. Additionally, all signals of the closed-loop system will remain uniformly ultimately bounded (UUB), and there will be adherence to all state-constraints, ensuring no violations occur. Ultimately, an illustrative simulation example is provided to demonstrate the efficacy of the theoretical findings.

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1. Introduction

Over the past few decades, addressing the control problem of nonlinear systems with uncertainties has emerged as a prominent and trendy subject [1–3]. In order to address the challenges posed by model uncertainties, researchers have proposed intelligent control approaches that rely on universal approximators like fuzzy logic systems (FLSs) and neural networks (NNs) [3–5]. FLSs or NNs have been introduced in these schemes to online estimate *function type uncertainties* and then integrating these estimates into the controller structure. In these works, the closed-loop system stability has been carefully analyzed via a Lyapunov method. In a different way from the works cited above, some authors use nonlinear disturbance observers to deal with system uncertainties rather than universal approximators [6–8]. Such observers make it possible to provide precise estimates of the disturbances (external perturbations + uncertain functions) which will be subsequently used in the control law. It is important to

note that most of the existing works in the literature primarily focus on nonlinear systems without state or actuation constraints. However, in practical applications, constraints can manifest in various ways, such as performance specifications, safety requirements, physical limitations, and saturation. Generally, two types of constraints are encountered: actuation constraints (such as saturation and dead-zone) [9], and state/output constraints [10–12]. Failure to consider these constraints during the design process could lead to disastrous outcomes, including significant degradation of closed-loop control system performance and, in some cases, even instability.

The utilization of BLFs has been proposed to cope with state/output constrained nonlinear systems [10–12]. BLFs, which speedily grow to infinity as (error/state) variables approach their constraints, are extensively employed for many physical systems, for instance: electrostatic micro-actuators, flexible rotary crane arm, rigid-flexible manipulators, and electrical circuit systems [11]. In [10,11], adaptive (fuzzy/neural) control schemes for nonlinear systems subject to output constraints have been devised, by employing BLFs. The use of these BLFs makes it possible to avoid the violation of the output constraints. To handle full-(or partial) states' constraints, BLFs have also been adopted in [12–19]. However, control strategies for state-constrained nonlinear systems

* Corresponding author.

E-mail addresses: boulkroune2002@yahoo.fr (A. Boulkroune), haddad.med@yahoo.com (M. Haddad), lihongyi2009@gmail.com (H. Li).