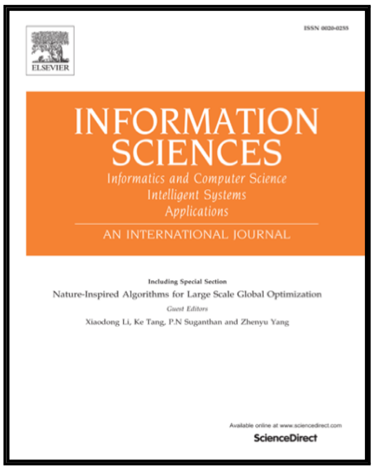
Accepted Manuscript



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PII: S0020-0255(17)30021-X
DOI: 10.1016/j.ins.2017.01.014
Reference: INS 12699

To appear in: *Information Sciences*

Received date: 25 April 2016
Revised date: 12 December 2016
Accepted date: 2 January 2017

Please cite this article as: Shigen Gao, Hairong Dong, Bin Ning, Xiuming Yao, Single-parameter-learning-based fuzzy fault-tolerant output feedback dynamic surface control of constrained-input nonlinear systems, *Information Sciences* (2017), doi: 10.1016/j.ins.2017.01.014

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Information Sciences

Information Sciences 00 (2017) 1–17

Single-parameter-learning-based fuzzy fault-tolerant output feedback dynamic surface control of constrained-input nonlinear systems[1]

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Abstract

This paper addresses the problem of adaptive fuzzy fault-tolerant dynamic surface control for a class of constrained-input nonlinear systems. To resolve this problem, the design of an observer-based single-parameter-learning (SPL) control method using output feedback is proposed. The Takagi-Sugeno (T-S) fuzzy system is used to identify and approximate online the uncertain nonlinear dynamics, requiring no knowledge. The barriers that restrict the applications of the traditional backstepping and approximation-based approach, including the explosion of complexity and the dimension curse problems, are circumvented via dynamic surface control and SPL techniques. The merit of the proposed method lies in that only one parameter in the entire control scheme requires online adjustment, regardless of the number of parameters in the T-S fuzzy system that characterizes the fuzzy rules; the calculation burden, in this sense, is reduced to the extent of the minimum value. The truncated adaptation method is used to avoid the chattering and instability caused by constrained input. It is shown with rigorous proof using the Lyapunov and invariant set theorems that all the closed-loop signals are guaranteed semi-globally uniformly ultimately bounded. The output tracking error is adjustable by means of design parameters in an explicit form, and can be adjusted to an arbitrarily small value around zero by appropriately chosen control parameters, even under faulty and constrained actuators. Simulation and comparative results are provided to demonstrate the effectiveness of the proposed control approach.

Keywords: Fuzzy fault-tolerant control, dynamic surface control, input saturation, single parameter learning, fuzzy approximation

1. Introduction

Approximation-based backstepping design methodology has been recognized as a powerful tool for the control of high-order uncertain nonlinear systems, as can be seen from the recent works presented in [17][22][29][39][40][49]. The backstepping method was originally proposed to control nonlinear strict-feedback systems with a parametric structure, which is in fact not applicable to controlling nonlinear systems with structural uncertainties. By means of the online approximation property of the fuzzy logic system, fuzzy approximation-based adaptive backstepping methods have been greatly concerned and have advanced during the past decades. To name a few, in the study presented in [28], adaptive fuzzy backstepping robust control was developed for a class of uncertain nonlinear systems using small-gain, in [30], the design of an adaptive fuzzy output feedback tracking backstepping control for a class of strict feedback nonlinear systems in the presence of unknown dead zones was presented, and in [50], the development of an adaptive control of a class of nonlinear pure-feedback systems via the fuzzy backstepping approach was described. In summary, a fuzzy approximation-based adaptive backstepping controller can be designed using the following three main procedures [2] [3]: i) construction of fuzzy logic systems using available states as the input, which are used to approximate uncertain functions; ii) design of parameter adaptation laws to tune the coefficients in the fuzzy rules of fuzzy logic systems and selection of appropriate control parameters to guarantee periodical stability via Lyapunov stability; and iii) recursive extension of high-order nonlinear systems via a backstepping design.

However, the problems of "explosion of complexity" and the "dimension curse" are two main barriers to implementing the fuzzy approximation-based adaptive backstepping control method in applications. As can be seen from the traditional backstepping design [19], the differentiations of virtual controllers r_i, $i = 1, \cdots, n-1$, are used at step $i+1$, where n

[1]Project supported jointly by the Fundamental Research Funds for Central Universities (No. 2016RC054) and the National Natural Science Foundation of China (No. 61672088).