International Journal of Innovative
Computing, Information and Control
Volume **5**, Number **10(B)**, October **2009**

ICIC International ©2009 ISSN 1349-4198
pp. **3527–3539**

OUTPUT REGULATION OF NONLINEAR SYSTEMS BASED ON ADAPTIVE OUTPUT FEEDBACK WITH ADAPTIVE NN FEEDFORWARD CONTROL

Ikuro Mizumoto[1], Yuji Okamatsu[1], Hiroki Tanaka[1] and Zenta Iwai[2]

[1]Department of Intelligent Mechanical Systems
Kumamoto University
2-39-1 Kurokami, Kumamoto 860-8555, Japan
ikuro@gpo.kumamoto-u.ac.jp

[2]Kumamoto Prefectural College of Technology
4455-1 Haramizu, Kikuyou-mach, Kikuchi-gun, Kumamoto 869-1102, Japan
iwai@kumamoto-pct.ac.jp

Received July 2008; revised December 2008

Abstract. *In this paper, we propose a new design method of an adaptive regulator based on output feedback control for nonlinear systems with higher order relative degree. The proposed method is an adaptive output feedback control based on the OFEP (Output Feedback Exponentially Passive) properties of the controlled system. To realize an adaptive output feedback control system, we introduce a PFC for a nonlinear system which does not satisfy OFEP conditions and design an adaptive feedforward input with a structure of neural networks in order to attain output regulation and remove the steady-state bias error from the PFC output. This method can design the robust adaptive controller with higher accuracy on output regulation.*
Keywords: Adaptive output feedback control, Adaptive neural networks, Parallel feedforward compensator, Output regulation

1. **Introduction.** Since most practical systems have some kind of nonlinearities, the control of nonlinear systems has attracted a great deal of interest and several kinds of control schemes including adaptive controls have been investigated [1, 2, 3, 4]. In the recent decade, much attention has been paid to high gain output feedback-based adaptive controls due to their simple structure and high robustness with respect to uncertainties and disturbances [5, 6, 7]. The most typical design condition for designing the output feedback-based adaptive control is recognized as the output feedback exponentially passive (OFEP) condition [7]. This condition is well known as the ASPR condition for linear systems [8]. Unlike other adaptive methods, under OFEP (or ASPR) condition, one can easily design an output feedback-based adaptive controller without a priori information of the order of the controlled system and without designing a state observer. The sufficient conditions for the system to be OFEP are that (1) the system is globally exponential minimum-phase, (2) the system has a relative degree of 1 and (3) the nonlinearities of the system satisfy the Lipschitz conditions [7]. Under these conditions, it has been presented that one can design a robust adaptive output feedback control and can stabilize uncertain nonlinear systems [5, 6, 15]. However, since most practical systems do not satisfy the above-mentioned OFEP conditions, the OFEP conditions are very severe restrictions for practical applications of the OFEP-based adaptive control.

With this in mind, several counter methods have been proposed. The backstepping method can deal with a problem in nonlinear systems with a higher order relative degree