Chapter 9
Adaptive Neural Control of Uncertain Multi-variable Nonlinear Systems with Saturation and Dead-zone

Mou Chen, Shuzhi Sam Ge and Bernard Voon Ee How

Abstract In this chapter, adaptive neural control is developed for a class of uncertain MIMO nonlinear systems using neural networks. The MIMO system under study is a strict-feedback uncertain nonlinear system with non-symmetric input nonlinearities. Variable structure control (VSC) technique in combination with backstepping is proposed to tackle the input saturation and dead-zone. The spectral radius of the control coefficient matrix is introduced to design adaptive neural control in order to cancel the nonsingular assumption of the control coefficient matrix. Using the cascade property of system, the semi-global uniform ultimate boundedness of all signals in the closed-loop system is achieved. The tracking errors converge to small residual sets which are adjustable by updating design parameters. Finally, case study results are presented to illustrate the effectiveness of the proposed adaptive neural control.

9.1 Introduction

In the past decades, backstepping control has became one of the most popular robust and adaptive control system design techniques for some special classes of nonlinear systems. However, a number of works on backstepping design focus on single-input/single-output (SISO) nonlinear triangular systems [1–3], and the adaptive neu—
ral control of uncertain MIMO nonlinear systems with input nonlinearities need to be further investigated. In recent years, the universal approximation ability of neural networks makes it one of the effective tool in MIMO nonlinear system robust control design [4–8]. Direct adaptive control was investigated for a class of MIMO nonlinear systems using neural networks based on input-output discrete-time model with unknown interconnections between subsystems [4]. In [5], adaptive neural network (NN) control was proposed for a class of discrete-time MIMO nonlinear systems with triangular form inputs. Adaptive NN control was developed for a class of MIMO nonlinear systems with unknown bounded disturbances in discrete-time domain [6]. In [7], approximation-based control was presented for a class of MIMO nonlinear systems in block-triangular form with unknown state delays. By exploiting the special properties of the affine terms, adaptive neural control for two classes of uncertain MIMO nonlinear systems was proposed [8].

In practice, nonlinear systems usually possess time-varying disturbance, modeling error and other uncertainties [9–12]. It is important to develop effective control techniques for uncertain MIMO nonlinear systems which possess the above properties. One main challenge is the possible singularity of the control coefficient matrix which makes the control design complex. Existing research results mostly assume that the control coefficient matrix is known and nonsingular, or NN is used to approximate unknown control coefficient matrix and assume NN approximation nonsingular. In [13], robust backstepping control was developed for a class of nonlinear systems based on neural networks which requires the control coefficient matrix of each subsystem to be known and invertible. To relax the known restriction of the control coefficient matrix, robust tracking control for nonlinear MIMO systems with unknown control coefficient matrix via fuzzy approaches was investigated [14]. The proposed tracking control required the approximation of control coefficient matrix nonsingular, and the approximation error must satisfy a certain given condition. In [15], tracking control was proposed for affine MIMO nonlinear systems, and the nonsingularity requirement of control coefficient matrix was eliminated.

In this chapter, adaptive neural control is proposed for a class of uncertain MIMO nonlinear systems with saturation and dead-zone. Actuators cannot promptly respond to the command signal and saturation is unavoidable in most actuators as they can only provide a limited energy in a practical control system. There exist input dead-zone and saturation which are the most important non-smooth nonlinearities. Saturation and dead-zone can severely influence the control system performance. Thus, saturation and dead-zone as input nonlinearities have attracted a great amount of attention over the past years. The Takagi-Sugeno (T-S) fuzzy modeling approach was utilized to control the nonlinear systems with actuator saturation [16]. In [17], NN control was investigated for a class of nonlinear systems with actuator saturation. Globally stable adaptive control was proposed for minimum phase SISO plants with input saturation [18]. Dead-zone as a static nonsmooth input-output relationship gives zero output for a range of input values. To handle systems with unknown dead-zones, adaptive dead-zone inverse was proposed [19, 20]. Adaptive control was proposed for uncertain systems with unknown dead-zone nonlinearity by employing the dead-zone inverse [21]. In [22], after the introduction of practical