Chapter 51
Fuzzy Adaptive Controller for Uncertain Multivariable Nonlinear Systems with Both Sector Nonlinearities and Dead-Zones

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ABSTRACT

This chapter presents two fuzzy adaptive variable structure controllers for a class of uncertain multi-input multi-output nonlinear systems with actuator nonlinearities (i.e. with sector nonlinearities and dead-zones). The design of the first controller concerns systems with symmetric and positive definite control-gain matrix, while the design of the second one is extended to the case of non-symmetric control-gain matrix thanks to an appropriate matrix decomposition, namely the product of a symmetric positive-definite matrix, a diagonal matrix with diagonal entries +1 or -1, and a unity upper triangular matrix. An appropriate adaptive fuzzy-logic system is used to reasonably approximate the uncertain functions. A Lyapunov approach is adopted to derive the parameter adaptation laws and prove the stability of the closed-loop control system. Finally, some simulation results are carried out to show the effectiveness of the proposed controllers.

INTRODUCTION

Problems of process control are more and more complex as the involved systems are multivariable in nature and exhibit uncertain nonlinear behaviours. This explains the fact that only few engineering solutions are available. Thanks to the universal approximation theorem (Wang, 1994), some adaptive fuzzy control systems have been developed for a class of multivariable nonlinear uncertain systems (Ordonez & Passino, 1999; Chang, 2000; Tong et al., 2000; Chekireb et al., 2003; Golea et al., 2003; Li & Tong,

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2003; Tong & Li, 2003; Labiod et al., 2005; Tong et al., 2005; Essounbouli et al., 2006). The stability of the underlying control systems has been investigated using a Lyapunov approach. The robustness issues with respect to the fuzzy approximation error and external disturbances have been enhanced by appropriately modifying the available adaptive fuzzy controllers. The corner stone of such a modification consists in a robust control term which is conceived using a sliding mode control design (Ordonez & Passino, 1999; Chekireb et al., 2003; Golea et al., 2003; Tong & Li, 2003; Labiod et al., 2005; Tong et al., 2005) or an H^{∞} based robust control design (Chang, 2000; Tong et al., 2000; Li & Tong, 2003; Essounbouli et al., 2006). A key assumption in the available fuzzy adaptive control systems (Ordonez & Passino, 1999; Chang, 2000; Tong et al., 2000; Chekireb et al., 2003; Golea et al., 2003; Li & Tong, 2003; Tong & Li, 2003; Labiod et al., 2005; Tong et al., 2005; Essounbouli et al., 2006) is that the actuator dynamics may be reasonably approximated by a linear model. This is more an exception than a rule in the engineering practice.

The control problem of uncertain multi-input multi-output (MIMO) systems with input nonlinearities has received a remarkable attention because of those ubiquitous actuator nonlinearities, namely saturation, quantization, backlash, dead-zone and so on (Gutierrez & Ro, 1998; Hsu et al., 2004). It is well known that the existence of input nonlinearities may leads to poor performance or even instability of the control system. It is thereby more advisable to take into account the actuator nonlinearities in the control design as well as the stability analysis. Decentralized variable-structure controllers have been proposed in (Hsu, 1999; Shyu et al., 2003; Shyu et al., 2005) for a class of systems with input sector nonlinearities and/or dead-zones. In (Hsu et al., 2004; Niu & Ho, 2006), the authors have designed sliding mode control systems for nonlinear MIMO systems subject to both sector nonlinearities and dead-zones. The underlying results suffer from two fundamental limitations. Firstly, the considered class of systems is relatively reduced. Secondly, the gain reduction tolerances of the nonlinear dead-zones and upper bounds of uncertain nonlinear functions are required to be known.

More recently, adaptive neural or fuzzy control systems have been respectively developed for a special class of multivariable nonlinear systems with unknown dead-zones and gain signs in (Zhang & Ge, 2007; Zhang & Yi, 2007). These contributions suffer from two restrictive modelling assumptions motivated by technical purposes regarding the stability analysis and control design. The first one consists in assuming a lower triangular structure for the system under control while the second one concerns the boundedness of the high-frequency control gains. Moreover, a fuzzy adaptive control for a class of multivariable nonlinear systems with unknown dead-zones has been designed in (Boulkroune et al., 2010a). Note that, in (Zhang & Ge, 2007; Zhang & Yi, 2007; Boulkroune et al., 2010a), simple dead-zones having linear and nonlinear functions outside the dead-band have been considered.

In this chapter, one aims at designing two fuzzy adaptive controllers for two different classes of uncertain nonlinear multivariable systems containing both sector nonlinearities and dead-zones. These classes of systems differ only by the structure of the control-gain matrix, namely a symmetric positive definite matrix or a matrix with known signs of its leading principal minors. Though this work borrows from the available results, it presents a fundamental contribution to the fuzzy adaptive control of uncertain multivariable nonlinear systems from an applicability point of view. Unlike in contributions (Hsu et al., 2004; Niu & Ho, 2006), the class of the considered systems is relatively larger and the gain reduction tolerances of the nonlinear dead-zones and the upper bounds on uncertain nonlinear functions are not assumed to be known. These bounds are indeed estimated using adaptive fuzzy systems. And compared with contributions (Zhang & Ge, 2007; Zhang & Yi, 2007; Boulkroune et al., 2010a), there are three features that are of practical interest. Firstly, the considered class of systems is more larger as