Chapter 18
Identification of Nonlinear Systems Using a New Neuro-Fuzzy Dynamical System Definition Based on High Order Neural Network Function Approximators

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ABSTRACT

A new definition of adaptive dynamic fuzzy systems (ADFS) is presented in this chapter for the identification of unknown nonlinear dynamical systems. The proposed scheme uses the concept of adaptive fuzzy systems operating in conjunction with high order neural networks (HONN's). Since the plant is considered unknown, we first propose its approximation by a special form of an adaptive fuzzy system and in the sequel the fuzzy rules are approximated by appropriate HONN's. Thus the identification scheme leads up to a recurrent high order neural network, which however takes into account the fuzzy output partitions of the initial ADFS. Weight updating laws for the involved HONN's are provided, which guarantee that the identification error reaches zero exponentially fast. Simulations illustrate the potency of the method and comparisons on well known benchmarks are given.

DOI: 10.4018/978-1-61520-711-4.ch018

1. INTRODUCTION

Nonlinear dynamical systems can be represented by general nonlinear dynamical equations of the form

$$\dot{x} = f(x, u) \tag{1}$$

The mathematical description of the system is required, so that we are able to control it. Unfortunately, the exact mathematical model of the plant, especially when this is highly nonlinear and complex, is rarely known and thus appropriate identification schemes have to be applied which will provide us with an approximate model of the plant.

It has been established that neural networks and fuzzy inference systems are universal approximators (Hornik, Stinchcombe & White, 1989), (Wang, 1994), (Passino & Yurkovich, 1998), (Golea, Golea & Benmahammed, 2003), (Hojati & Gazor, 2002), that is, they can approximate any nonlinear function to any prescribed accuracy provided that sufficient hidden neurons and training data or fuzzy rules are available. Recently, the combination of these two different technologies has given rise to fuzzy neural or neuro fuzzy approaches, that are intended to capture the advantages of both fuzzy logic and neural networks. Numerous works have shown the viability of this approach for system modelling (Jang, 1993; Lin, 1995; Cho & Wang, 1996; Juang & Lin, 1998; Li & Mukaidono, 1995; Chui, 1994; Lin & Cunningham, 1995; Jang & Lin, 1998; Mitra & Hayashi, 2000).

The neural and fuzzy approaches are most of the time equivalent, differing between each other mainly in the structure of the approximator chosen. Indeed, in order to bridge the gap between the neural and fuzzy approaches several researchers introduce adaptive schemes using a class of parameterized functions that include both neural networks and fuzzy systems (Cho & Wang, 1996; Juang & Lin, 1998; Li & Mukaidono, 1995; Chui, 1994; Lin & Cunningham, 1995; Jang & Lin, 1998; Mitra & Hayashi, 2000). Regarding the approximator structure, linear in the parameters approximators are used in (Lin & Cunningham, 1995), (Chen, Lee & Chang, 1996), and nonlinear in (Spooner & Passino, 1996), (Narendra & Parthasarathy, 1990), (Polycarpou & Mears, 1998), (Lee & Teng, 2000), (Lina, Wang & Liub, 2004).

Recently (Kosmatopoulos & Christodoulou, 1996), (Christodoulou, Theodoridis & Boutalis, 2007), high order neural network function approximators (HONN's) have been proposed for the identification of nonlinear dynamical systems of the form (1), approximated by a fuzzy dynamical system. In this chapter HONN's are also used for the neuro fuzzy identification of unknown nonlinear dynamical systems. This approximation depends on the fact that fuzzy rules could be identified with the help of HONN's. The same rationale has been employed in (Theodoridis, Christodoulou & Boutalis, 2008), (Boutalis, Theodoridis & Christodoulou, 2009), where a neuro–fuzzy approach for the indirect control of unknown systems has been introduced.

In fuzzy or neuro-fuzzy approaches the identification phase usually consists of two categories: structure identification and parameter identification. Structure identification involves finding the main input variables out of all possible, specifying the membership functions, the partition of the input space and determining the number of fuzzy rules which is often based on a substantial amount of heuristic observation to express proper strategy's knowledge. Most of structure identification methods are based on data clustering, such as fuzzy C-means clustering (Chui, 1994), mountain clustering (Jang & Lin, 1998), and subtractive clustering (Mitra & Hayashi, 2000). These approaches require that all input-output data are ready before we start to identify the plant. So these structure identification approaches are off-line.