DYNAMICAL FUNCTIONAL ARTIFICIAL NEURAL NETWORK: USE OF EFFICIENT PIECEWISE LINEAR FUNCTIONS

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***Abstract*— A nonlinear adaptive time series predictor has been developed using a new type of piecewise linear (PWL) network for its underlying model structure. The PWL Network is a D-FANN (Dynamical Functional Artificial Neural Network) the activation functions of which are piecewise linear. The new realization is presented with the associated training algorithm. Properties and characteristics are discussed. This network has been successfully used to model and predict an important class of highly dynamic and non-stationary signals, namely speech signals.**

***Keywords*— Adaptive signal processing, nonlinear prediction, time series prediction.**

I. INTRODUCTION

The prediction of a time series can be closely related to the modeling of the underlying mechanism responsible for its generation. Many of the real physical signals encountered in practice have two characteristics: nonlinearity and non-stationarity. Consider, for example, the case of speech signals. It is known that the use of prediction plays a key role in the modeling and coding of speech signals (Shuzo and Nakata, 1985). The production of a speech signal is the result of a dynamic process that may be both non-stationary and nonlinear. To deal with the non-stationary nature of speech signals, the customary practice is to invoke the use of adaptive filtering. However, the nonlinear modeling of the speech production process is of recent vintage (Eltoft and de Figueiredo, 2000) and continues to be a research topic of active interest. As a sample of the interest in the topic, the results of a special competition looking for improved performance in times series prediction were presented recently in Lendasse *et al*. (2007).

In recent years, several structures have been developed for identification of nonlinear systems, and modeling and prediction of time series. Among these, the conventional (Schetzen, 1981) and Generalized Fock Space (de Figueiredo and Dwyer, 1980; de Figueiredo, 1983; Zyla and de Figueiredo, 1993) models of the Volterra series, the multilayer perceptron (Knecht, 1994), and the radial basis functions network (Chen *et al.*, 1991) are some of the more evident. Other works in applying neural networks for time series also include Werbos (1988), Weigend *et al.* (1990) and de Figueiredo (1993). In Haykin and Li (1995) a pipeline recurrent neural network formed by a cascade of recurrent neural network was proposed.

A class of neural networks especially relevant to the developments in this paper is that of Dynamical Functional Artificial Neural Networks (D-FANNs). D-FANNs are artificial neural networks in which the synapses are represented by linear filters rather than memoryless links with prescribed gains or weights. For continuous-time systems, D-FANN structures without being so called, were introduced by Zyla and de Figueiredo (1993). They were reiterated as neural networks by Newcomb and de Figueiredo (1996). In 1998, generic D-FANNs both for the continuous-time and discrete-time cases were proposed and investigated by de Figueiredo (1998b). In 2000, Eltoft and de Figueiredo (2000) proposed a D-FANN for nonlinear time series prediction in which the synapses of the first layer are implemented by a filter bank built up of discrete cosine transform basis functions (DCT) and the activation functions of the first layer are smooth nonlinear functions (such as $tanh(x)$).

This work is addressed to the class of D-FANNs in which the synapses of the first layer are FIR filters and the activation functions are piecewise linear functions. It is presented here a study of an improved version of that class, a Piecewise Linear (PWL) D-FANN, that contemplates a recently proposed basis for the PWL representation. In addition, the PWL description in the present work includes saturation when the input signal exceeds the considered domain and allows to a more selective effect of the parameters on particular regions. In this way, we obtain good convergence properties and low complexity in terms of the number of parameters involved in the realization. Also, an associated learning algorithm is presented that leads to robust results in terms of convergence speed. Preliminary results on this subject by the authors were presented in Figueroa *et al*. (2002).

The paper is organized in the following manner. In Section 2 some concepts on time series prediction are briefly reviewed. The PWL-DFANN structure is presented and its properties are introduced in Section 3. In addition, an algorithm for training the network is discussed in Section 4. In Section 5, we present examples to illustrate the characteristics and performance of the proposed realization in terms of convergence and com-