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A recurrent neural network classifier for Doppler ultrasound blood flow signals

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Abstract

The aim of this study is to evaluate the diagnostic accuracy of the recurrent neural networks (RNNs) trained with Levenberg–Marquardt algorithm on the Doppler ultrasound blood flow signals. The ophthalmic arterial (OA) and internal carotid arterial (ICA) Doppler signals were decomposed into time–frequency representations using discrete wavelet transform and statistical features were calculated to depict their distribution. The RNNs were implemented for diagnosis of OA and ICA diseases using the statistical features as inputs. We explored the ability of designed and trained Elman RNNs, combined with wavelet preprocessing, to discriminate the Doppler signals recorded from different healthy subjects and subjects suffering from OA and ICA diseases. The classification results demonstrated that the proposed combined wavelet/RNN approach can be useful in analyzing long-term Doppler signals for early recognition of arterial diseases.

Keywords: Recurrent neural networks; Levenberg–Marquardt algorithm; Signal classification; Automatic diagnosis; Discrete wavelet transform; Doppler signal; Ophthalmic artery; Internal carotid artery

1. Introduction

There are a number of different quantitative models that can be used in a medical diagnostic decision support system including parametric methods (linear discriminant analysis or logistic regression), nonparametric models (*k* nearest neighbor or kernel density) and several neural network models. The main concept of the medical technology is an inductive engine that learns the decision characteristics of the diseases and can then be used to diagnose future patients with uncertain disease states. If there is a need to model complex nonlinear features of the data, the developer resorts to neural networks, such as the multi-layer perceptron neural network (MLPNN), radial basis function (RBF), self-organizing map (SOM), mixture of experts (ME), combined neural network (CNN), recurrent neural network (RNN). Neural networks have been used in a great number of medical diagnostic decision support system applications because of the belief that they have greater predictive power. Unfortunately, there is no theory available to guide an intelligent choice of model based on the complexity of the diagnostic task. In most situations, developers are simply picking a single model that yields satisfactory results, or they are benchmarking a small subset of models with cross validation estimates on test sets (West and West, 2000; Kordylewski et al., 2001; Saad et al., 1998).

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One of the most frequently used neural network for pattern classification is the MLPNN which is a feedforward network trained to produce a spatial output pattern in response to an input spatial pattern (Haykin, 1994; Chaudhuri and Bhattacharya, 2000). The mapping performed is static, therefore, the network is inherently not suitable for processing temporal patterns. Attempts have been made to use the MLPNN to classify temporal patterns by transforming the temporal domain into a spatial domain. An alternate neural network approach is to use RNNs which have memory to encode past history. Several forms of RNNs have been proposed and they may be classified as partially recurrent or fully recurrent networks (Saad et al., 1998; Gupta et al., 2000; Gupta and McAvoy, 2000). In partially recurrent networks, partial recurrence is created by feeding back delayed hidden unit outputs or the outputs of the network as additional input units. We used the partially recurrent networks, whose connections are mainly feedforward, but they include a carefully chosen set of feedback connections. One example of such a network is an Elman RNN which in principle is set up as a regular feedforward network (Elman, 1990).

Various methodologies of automated diagnosis have been adopted, however the entire process can generally be subdivided into a number of disjoint processing modules: preprocessing, feature extraction/selection, and classification (West and West, 2000; Kordylewski et al., 2001; Kwak and Choi, 2002; Übeyli and Güler, 2005b). Signal/image acquisition, artefact removing, averaging, thresholding, signal/image enhancement and edge detection are the main operations in the course of preprocessing. Feature extraction is the determination of a feature or a feature vector from a pattern vector. The feature vector, which is comprised of the set of all features used to describe a pattern, is a reduced-dimensional representation of that pattern. The module of feature selection is an optional stage, whereby the feature vector is reduced in size including only, from the classification viewpoint, what may be considered as the most relevant features required for discrimination. The classification module is the final stage in automated diagnosis. It examines the input feature vector and based on its algorithmic nature, produces a suggestive hypothesis (West and West, 2000; Kordylewski et al., 2001; Kwak and Choi, 2002; Übeyli and Güler, 2005b).

In the feature extraction stage, numerous different methods can be used so that several diverse features can be extracted from the same raw data. The Doppler shift signal contains a wealth of information about blood flow occurring within the sample volume of the Doppler ultrasonography. The most complete way to display this information is to perform spectral analysis (Evans et al., 1989; Wright et al., 1997; Wright and Gough, 1999; Güler and Übeyli, 2003; Übeyli and Güler, 2003, 2004). The wavelet transform (WT) provides very general techniques which can be applied to many tasks in signal processing. Wavelets are ideally suited for the analysis of sudden short-duration signal changes. One very important application is the ability to compute and manipulate data in compressed parameters which are often called features (Daubechies, 1990). Thus, the Doppler signal, consisting of many data points, can be compressed into a few parameters by the usage of the WT. These parameters characterize the behavior of the Doppler signal. This feature of using a smaller number of parameters to represent the Doppler signal is particularly important for recognition and diagnostic purposes (Aydın et al., 1999; Marvasti et al., 2004; Güler and Übeyli, 2004, 2005; Übeyli and Güler, 2005a,b). Therefore, in order to discriminate the Doppler signals, we have implemented Elman RNNs combined with wavelet preprocessing.

In the present study, we evaluate the classification capabilities of the Elman RNN trained with Levenberg–Marquardt algorithm on the Doppler ultrasound blood flow signals. The Doppler signals were recorded from ophthalmic arteries (OA) and internal carotid arteries (ICA). Doppler ultrasound is widely used as a noninvasive method for the assessment of blood flow, both in the central and peripheral circulation. It may be used to estimate blood flow, to image regions of blood flow and to locate sites of arterial disease as well as flow characteristics and resistance of arteries (Evans et al., 1989). Since OA stenosis, ocular Behcet disease and uveitis disease cause serious visual loss and result in blindness within a few years, early detection of changes in OA is important for prevention of blindness. Stenosis and occlusions in the ICA occurring due to plaques are the symptoms of ICA diseases (Übeyli and Güler, 2005a,b).

Our objective in the field of automated diagnosis of arterial diseases is to extract the representative features of the OA and ICA Doppler ultrasound signals and to present the accurate classification model. As in traditional pattern recognition systems, our model consists of three main modules: a feature extractor that generates a feature vector from the raw Doppler ultrasound signals (WT), feature selection (wavelet coefficients), and a feature classifier that outputs the class based on the features (RNN). A significant contribution of our work was the implementation of novel classifiers (RNNs trained on wavelet coefficients) for the Doppler ultrasound signals. The ability of WT to extract and localize specific transient patterns from the signal makes them a natural complement to our applications of the RNNs. Each studied segment of the Doppler signals was wavelet decomposed into multi-level low- and high-pass subbands, which were then input into the RNNs for training and testing purposes. We were able to achieve high accuracies by using the RNNs trained on the wavelet coefficients.

The outline of this study is as follows. In Section 2, we present the description of the Doppler ultrasound signals, wavelet decomposition of the Doppler signals in order to extract features characterizing the behavior of the signal under study, brief review of the RNNs. In Section 3, we present the application results of the RNNs to the OA and ICA Doppler signals. Finally, in Section 4 we conclude the study.