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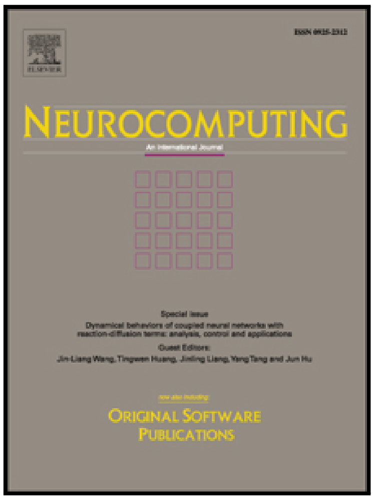

Classification of Transcranial Doppler Signals using Individual and Ensemble Recurrent Neural Networks

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Classification of Transcranial Doppler Signals using Individual and Ensemble Recurrent Neural Networks

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Abstract Transcranial Doppler (TCD) is a reliable technique with the advantage of being non-invasive for the diagnosis of cerebrovascular diseases using blood flow velocity measurements pertaining to the cerebral arterial segments. In this study, the Recurrent Neural Network (RNN) is used to classify TCD signals captured from the brain. A total of 35 real, anonymous patient records are collected, and a series of experiments for stenosis diagnosis is conducted. The extracted features from the TCD signals are used for classification using a number of RNN models with recurrent feedbacks. In addition to individual RNN results, an ensemble RNN model is formed in which the majority voting method is used to combine the individual RNN predictions into an integrated prediction. The results, which include the accuracy, sensitivity, and specificity rates as well as the area under the Receiver Operating Characteristic curve, are compared with those from the Random Forest ensemble model. The outcome positively indicates the usefulness of the RNN ensemble as an effective method for detecting and classifying blood flow velocity changes due to brain diseases.

Keywords: Doppler signals; recurrent neural network; pattern classification; stenosis.

1. Introduction

In the medical field, the Doppler principle is based on emitting sound waves into the body, and then monitoring the changes in frequency between the signals transmitted and signals reflected back from the target, detected by a transducer [1]. Satomura first used the Doppler technique in 1959 to measure Doppler noise (signals) from the blood vessels [2]. Because of the non-invasive nature, Doppler-based techniques became popular, and have been widely used since then. During an ultrasound examination of the carotid arteries, Austen et al. [3] discovered transient increased in the Doppler signal intensity. Similar signals were recorded in cases covering decompression sickness and angiography [4]. In [5], Doppler techniques were deployed for measuring the blood flow velocity in diagnosing vascular diseases. Specifically, shifts from the red blood cells detected by the Doppler technique were used for computing the blood velocity [5]. Indeed, Doppler sonography is typically preferred since angiography is costly and is an invasive method [6].

The key principle of transcranial Doppler (TCD) is similar to that of Doppler ultrasound [7]. Introduced by Aaslid et al. in 1982 [7], TCD sonography has been used to measure the blood flow velocity in large basal arteries in a non-invasive manner. The TCD technique provides measurements of blood flow changes, which are valuable in determining the decrease in cerebral blood flow that can cause neurologic sequela [2]. Because the TCD machine is portable, reliable, and cheaper as compared with other test methods [2], it is widely used nowadays.

Studies of TCD are generally concerned with evaluating stenosis of intracranial arterial, cerebral vasospasm, cerebral arteriovenous malformations, and cerebral hemodynamics [1]. Typical intra-brain blood flow measurements need high-end imaging methods. However, the diagnosis can be made using TCD, by detecting the increased or decreased blood flow velocity [1]. In the diagnosis of stenosis and occlusion of arteries, TCD is used for blood flow velocity measurements in the brain arteries [1]. This can be an alternative diagnostic method as compared with angiography and magnetic resonance methods [1]. Based on evidences from a variety of different cerebrovascular pathologies, TCD has been shown to be practical for clinical settings [7].

Computer aided diagnosis has been seen as a preferred direction for disease diagnosis [8]. Among many different methods, artificial neural networks (ANN) have been used in various applications, e.g. medical signal processing [9-10]. Application of ANNs to Doppler related problems includes classifying carotid arterial Doppler ultrasound signals [11-13]. In [11], the principal component analysis and fuzzy c-means clustering methods were used with a complex-valued artificial neural network (CVANN) to classify carotid artery Doppler signals in the early phase of atherosclerosis. In [12], the fast Fourier transform was used to process Doppler signals, and the processed signals were subsequently classified using the CVANN model. In [13], discrete wavelet transform was used for signal pre-processing while wavelet transform-CVANN and complex wavelet transform-CVANN models were used for classification of Doppler signals. Using TCD signals measured from the brain temporal region, the *k*-nearest neighbour (*k*-NN) algorithm was used for classifying the recorded signals [1]. The correlation dimensions with the maximum Lyapunov exponents were employed as the input features to the *k*-NN algorithm.