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A mixture of experts network structure for modelling Doppler ultrasound blood flow signals

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Abstract

Mixture of experts (ME) is a modular neural network architecture for supervised learning. This paper illustrates the use of ME network structure to guide modelling Doppler ultrasound blood flow signals. Expectation–Maximization (EM) algorithm was used for training the ME so that the learning process is decoupled in a manner that fits well with the modular structure. The ophthalmic and internal carotid arterial Doppler signals were decomposed into time–frequency representations using discrete wavelet transform and statistical features were calculated to depict their distribution. The ME network structures were implemented for diagnosis of ophthalmic and internal carotid arterial disorders using the statistical features as inputs. To improve diagnostic accuracy, the outputs of expert networks were combined by a gating network simultaneously trained in order to stochastically select the expert that is performing the best at solving the problem. The ME network structure achieved accuracy rates which were higher than that of the stand-alone neural network models.

Keywords: Mixture of experts; Expectation–Maximization algorithm; Diagnostic accuracy; Discrete wavelet transform; Doppler signal; Ophthalmic artery; Internal carotid artery

1. Introduction

There have recently been widespread interests in the use of multiple models for pattern classification and regression in statistics and neural network communities. The basic idea underlying these methods is the application of a so-called divide-and-conquer principle that is often used to tackle a complex problem by dividing it into simpler problems whose solutions can be combined to yield

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a final solution. Utilizing this principle, Jacobs et al. [1] proposed a modular neural network architecture called mixture of experts (ME). The ME models the conditional probability density of the target output by mixing the outputs from a set of local experts, each of which separately derives a conditional probability density of the target output. The ME weights the input space by using the posterior probabilities that expert networks generated for getting the output from the input. The outputs of expert networks are combined by a gating network simultaneously trained in order to stochastically select the expert that is performing the best at solving the problem [2,3]. As pointed out by Jordan and Jacobs [4], the gating network performs a typical multiclass classification task [5–7].

Expectation–Maximization (EM) algorithm have been introduced to the ME architecture so that the learning process is decoupled in a manner that fits well with the modular structure [2–4]. The EM algorithm can be extended to provide an effective training mechanism for the MEs based on a Gaussian probability assumption. Though originally the model structure is predetermined and the training algorithm is based on the Gaussian probability assumption for each expert model output, the ME framework is a powerful concept that can be extended to a wide variety of applications including medical diagnostic decision support system applications due to numerous inherent advantages such as (i) a global model can be decomposed into a set of simple local models, from which controller design is straightforward. Each model can represent a different data source with an associated state estimator/predictor. In this case, the ME system can be viewed as a data fusion algorithm. (ii) The local models operate independently but provide output correlated information that can be strongly correlated with each other, so that the overall system performance can be enhanced in terms of reliability or fault tolerance. (iii) The global output of the ME system is derived as a convex combination of the outputs from a set of N experts, in which the overall system predictive performance is generally superior to any of the individual experts [2–5].

Neural networks have been successfully used in a variety of medical applications [8,9]. Recent advances in the field of neural networks have made them attractive for analyzing signals. The application of neural networks has opened a new area for solving problems not resolvable by other signal processing techniques [10,11]. However, neural network analysis of Doppler shift signals is a relatively new approach [12–14]. Doppler ultrasound is widely used as a noninvasive method for the assessment of blood flow both in the central and peripheral circulation [15,16]. 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 ophthalmic and internal carotid arteries [17–21].

Up to now, there is no study in the literature relating to the assessment of ME accuracy in analysis of Doppler shift signals. In this study, experimental results on ME predictions for diagnosis of ophthalmic arterial diseases and internal carotid arterial diseases were presented. In the configuration of ME for the diagnosis of ophthalmic arterial disorders, we used four local experts and a gating network, which were in the form of multilayer perceptron neural networks (MLPNNs), since there were four possible outcomes of the diagnosis of ophthalmic arterial conditions (healthy, ophthalmic artery stenosis, ocular Behcet disease, uveitis disease). In the development of ME for the diagnosis of internal carotid arterial disorders, we used three local experts and a gating network, which were in the form of MLPNNs, because there were three possible outcomes of the diagnosis of internal carotid arterial conditions (healthy, internal carotid artery stenosis, internal carotid artery occlusion). We were able to achieve significant improvement in accuracy by using the ME network structures compared to the stand-alone neural networks used in our previous studies [13,14].