Characterization of the Temporal Pattern of Cerebral Blood Flow Oscillations

B. Benyó[1], G. Lenzsér[2], B. Paláncz[3]
[1] Széchenyi István University, Győr, Hungary
[2] Institute of Human Physiology, Semmelweis University, Budapest, Hungary
[3] Budapest University of Technology and Economics, Budapest, Hungary

Introduction

Oscillation of the cerebral blood flow (CBF) is a common feature in several physiological or pathophysiological states and may significantly influence the metabolic state of the brain. Inhibition of nitric oxide (NO) synthesis reportedly evokes CBF oscillations although the mechanism of this action has not been clarified yet. In isolated rat middle cerebral arteries it has been recently demonstrated that the induction of vasomotion after blockade of the NO synthesis is mediated mainly by the thromboxane-pathway [1]. In a subsequent in vivo study the vulnerability of the cerebral circulation to thromboxane-induced CBF-oscillations has been reported in the absence of NO [2].

The aim of the present study was to characterize the temporal pattern of the CBF oscillations induced by the stimulation of thromboxane-receptor in case of diminished NO synthesis. In an earlier paper Fourier transform (FFT) was successfully applied for the signal pattern recognition [2]. However, this method was not able to provide a general formula for the classification of the signals.

In this study for the signal classification an Artificial Neural Network (ANN) model based on supervised, backpropagation network has been developed. The benefit of such a model is the opportunity of systematic classification of different CBF signals.

Experimental Method

The experiments were carried out on anesthetized (urethan, 1.3 g/kg ip.), spontaneously breathing adult male Wistar rats. The head of the animals was fixed in a stereotaxic head holder, the skull was thinned over the parietal cortex on both sides where two laser Doppler (LD) probes were placed in predefined positions as described previously [3]. A 5-min segment of the LD flux (LDF) recording was evaluated before the administration of the NO synthase (NOS) inhibitor N^G-nitro-L-arginine methyl ester (L-NAME, 100 mg/kg iv.).

After 75 minutes the thromboxane receptor-agonist U-46619 was applied intravenously in a dose of 1 μg/kg. The pattern of the LDF recording was evaluated before and 25 minutes after the administration of U-46619.

Feature Extraction

In order to carry out classification of the time signals, we need a feature vector characterizing each signal. It goes without saying, that a feature vector should have considerably less elements than the number of the samples in time domain. Wavelet transformation proved to be a successful candidate for this data compression process [4]. Figure 1 shows a typical time signal. Employing Daubechies filter of second order for the 2^n samples of the time signal, discrete wavelet transformation (DWT) decomposes the signal into n resolution levels, into one approximation subband and n-1 wavelet subbands. In our case n = 16, see the phase space plot of DWT of the time signal on Figure 2.

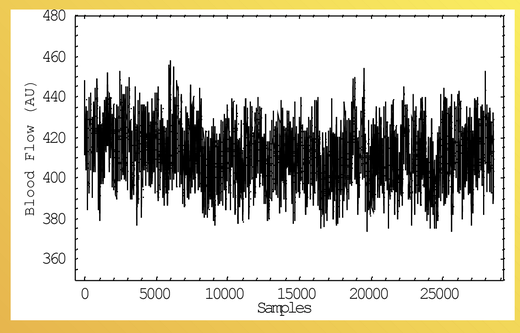

Fig.1 Time signal

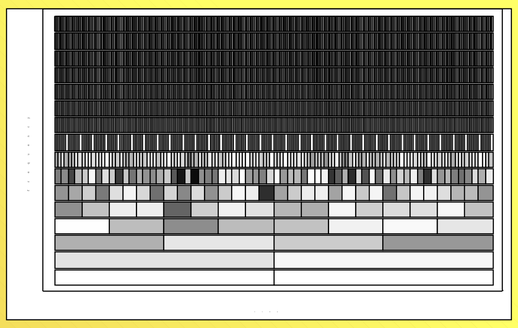

Fig. 2 Phase space plot of the DWT of the time signal

In the phase space plot, each rectangle represents a wavelet (vertical direction) and the darker a rectangle, the larger the absolute value of the corresponding wavelet coefficient. The residual trend is plotted in the bottom row, the finest detail, in the top row.

Preliminary investigations proved that the average energy content of the coefficients at higher resolutions is neglectable, see Figure 2, therefore the two coefficients of the approximation subband were considered as feature vector components. In addition the different values of the wavelet coefficients (represented by different gray levels), i.e. at the resolution level six, show that the frequency is time dependent, revealing the certain instacioner nature of the signal.

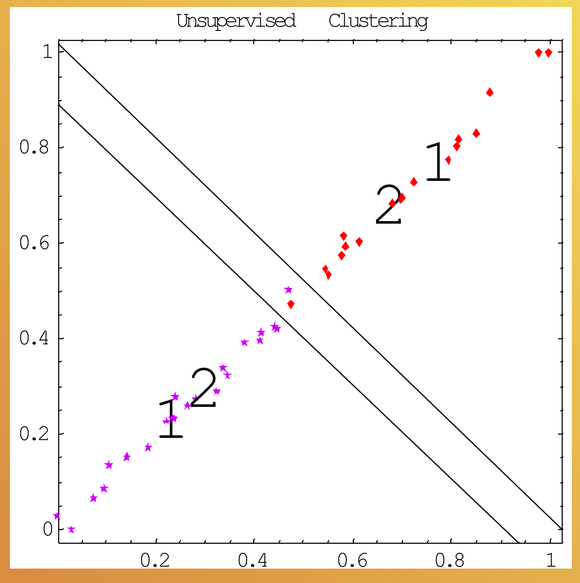

Fig. 3 Unsupervised classification of signals of right and left brain side

Signals of the right and left side of the brain do not differ from each other considerably, only a narrow band contains misclassified signals, see Figure 3. These results show that the applied feature representation can be accepted, especially considering that these signals resulted from direct measurements of different clinical experiments.

ANN Model for Signal Classification

In order to develop a model for classifying measured clinical signals, we employed a supervised, backpropagation neural network with sigmoid activation functions. The network has two input and two output nodes, and one hidden layer with two nodes. The teaching set consists of the 75% of the total number of the signals (30 signals) and rest served for testing (10 signals).

The network learned the teaching set, however one inconsistent signal was recovered, see Figure 4.

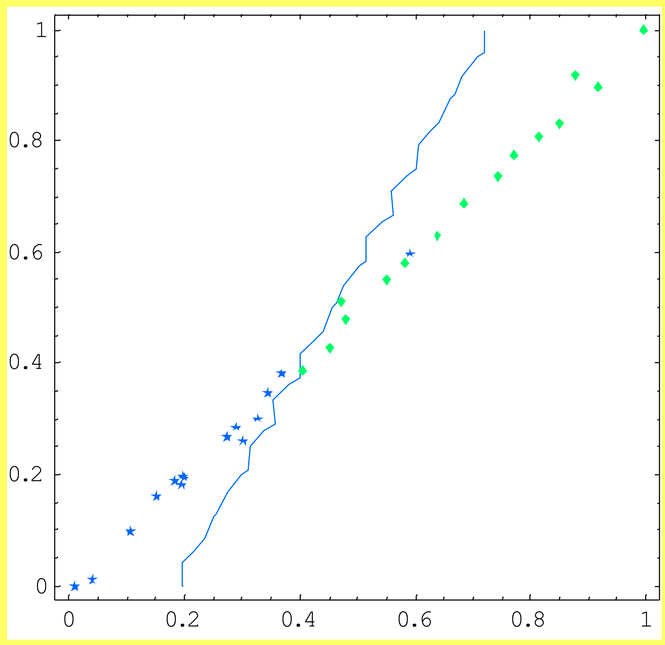

Fig. 4 Supervised classification with backpropagation network having two hidden nodes

Our ANN model, used for signal classification, can be expressed in analytical form as it can be seen on Figure 5. Parameters w1 and w2 are the wavelet coefficients of the approximation subband of DWT of the time signal. This function, after rounding, gives {1, 0} and {0, 1} as output for the two classes, respectively.

$$\left\{-272.322+\frac{272.422}{1+e^{-33.9811+176.416\,w1-97.6414\,w2}}+\frac{273.155}{1+e^{34.0373-176.736\,w1+97.8106\,w2}},\ 273.322-\frac{272.422}{1+e^{-33.9811+176.416\,w1-97.6414\,w2}}-\frac{273.155}{1+e^{34.0373-176.736\,w1+97.8106\,w2}}\right\}$$

Fig. 5 Analytical form of the ANN model for signal classification

Employing this model only two signals were misclassified from the 10 elements of the testing set having not been involved in the teaching process.

Summary

For clinical time signal classification, an ANN model based on supervised, backpropagation network was developed. Feature extraction of the time signal having 2^{16} samples at 200 Hz sampling rate, was carried out with discrete wavelet transformation using Daubechies filter of second order. Because of the dominating average energy content of the approximation subband coefficients, these two coefficients were considered as a feature vector for the signals. Unsupervised classification showed that this feature vector is an acceptable representation of the time signals. It also turned out that the difference between normal signal and a signal indicating drug injection effect is significant, and much more dominant than the difference between signals of the right and left brain sides.

In order to avoid overlearning, a simple ANN model with two hidden nodes was suggested for classification of the signals. Using symbolic algebra, the analytical form of this model could be given.

In the future, having more measurements, further investigations would be necessary to examine other feature extraction methods as well as ANN models for the classification. However, these clinical experiments are very expensive, therefore physiological modeling and simulations would be also needed.

For the computations Mathematica 5 and its Neural Networks Application were used. The original Mathematica notebook file can be found on the following site: www.sze.hu\~benyo\research\CBF_oscillations.html.

References

[1] Lacza Z, Hermán P, Görlach C, Hortobágyi T, Sándor P, Wahl M, Benyó Z: NO synthase blockade induces chaotic cerebral vasomotion via activation of thromboxane receptors. Stroke 2001; 32: 2609-2614

[2] Lenzsér G, Hermán P, Komjáti K, Sándor P, Benyó Z: Nitric oxide synthase blockade sensitizes the cerebrocortical circulation to thromboxane-induced CBF oscillations. Journal of Cerebral Blood Flow and Metabolism, 2003; 23: S88

[3] Lacza Z, Erdös B, Görlach C, Wahl M, Sándor P, Benyó Z: The cerebrocortical microcirculatory effect of nitric oxide synthase blockade is dependent upon baseline red blood cell flow in the rat. Neuroscience Letters, 2000; 291: 65-68

[4] Goswami, J.C and Chan, A.K.: Fundamentals of Wavelets, John Wiley, New York, 1999

This research has been supported by the Hungarian National Research Fund, Grants No. OTKA F046726, T042990 and by Hungarian Ministry of Education Grant No. 200/2001.