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WAVELET- BASED ELECTROENCEPHALOGRAPHIC SUB-BANDS DECOMPOSITION TO HIGHLIGHT SENSORIMOTOR RHYTHMS

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Abstract. This paper emphasizes the characteristics of sensorimotor rhythms (mu and beta) produced by right and left hand motor imagery. The electroencephalographic (EEG) data were recorded with 8 g.tec active electrodes, placed on the scalp, by means of g.MOBIlab+ module. The EEG data are decomposed into sub-bands of interest (7.5…15 Hz – mu rhythm, 15…30 Hz – beta rhythm) using wavelet multiresolution analysis. By means of Coiflet 4 mother wavelet we highlight the desynchronization of sensorimotor rhythms on channels C3, C4, CP3 and CP4.

Key words: brain-computer interface; beta rhythm; sensorimotor rhythms; mu rhythm; wavelet analysis.

1. Introduction

The research on brain computer interface (BCI) domain is motivated by the hope of creating new communication channels for people with severe neuromuscular disabilities. The BCI system is a new frontier in science and technology. In addition to medical application, BCI can become popular in virtual application area (computer games, flight simulators).

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The BCI goal is to establish communication channels that translate human intentions, represented by the right signals, in signals which control the output devices, such as computer or a neuroprosthesis, (Mellinger *et al*., 2007).

BCI has the potential to offer the patients who suffer from “locked-in” syndrome the possibility to communicate with the environment, to control computers, or to drive external devices by regulation produced by brain activity alone, (Mason *et al*., 2003; Grainmann *et al*., 2010).

Wolpaw gives a definition of BCI accepted by most researchers in the area: BCI is a communication system in which the messages or the commands sent by an individual to the external world do not pass through normal output pathways of the brain, pathways constituted by peripheral nerves and muscles, (Wolpaw *et al*., 2000).

A BCI system can provide people who are paralyzed (*e.g*. amyotrophic lateral sclerosis, stroke or severe polyneuropathy) or lack muscle control, the ability to give quick answers to simple questions, to control the environment, to slow processing some words or even to control a neuroprosthesis.

A type of BCI is based on the detection and classification of sensorimotor rhythms (SMR) during different motor imaginary tasks such as imagining left/right hand movements. Frequency bands of interest in the EEG signal, in this case, are those of mu (8…12 Hz) and beta rhythms (12…30 Hz). Movement of a body part or even a single muscle contraction causes changes in brain activity. In fact, preparing a movement or imagining movements causes changes in SMR. SMR refer to oscillations recorded on brain activity in somatic sensorimotor areas, concentrated in the frequency bands of mu and beta rhythms (Aldea *et al*., 2013).

Decreasing oscillatory activity in a specific frequency band is called event related desynchronization – ERD. Similarly, increase of oscillatory activity in a specific frequency band is called event related synchronization – ERS. This patterns, ERD/ERS, can be produced by motor imagery, (Pfurtscheller *et al*., 1998).

Imagining left hand movement produces a desynchronization on C4 electrode in the right side of the scalp, while imagining right hand movement produces a desynchronization on electrode C3, on the left side of the brain. The cerebral activity caused by hand movement is localized in the sensorimotor area of the brain.

Frequency analysis using Fourier transform represents a current method used to analyse EEG signals, because the spectral components of the SMR may contain useful information. Usually, some features of interest are found especially in the frequency bands within 0…60 Hz domain. The Fourier transform highlights only the information concerning the spectral components revealed in the signal; it doesn’t presents the time localization. The localization in the time of spectral components may be performed by means of time-frequency analysis such as Short Time Fourier Transform (STFT) or the continuous and discrete wavelet transform.

The relevant information to this application is either in the time domain or in the frequency domain. Time-frequency analysis or multiresolution wavelet analysis represent a suited tool to get appropriate features. The aim of this paper is to find a possibility to emphasize sensorimotor rhythms based on sub-band wavelet analysis.

2. Multiresolution Wavelet Analysis of SMRs

In discrete time domain, digital filters with different cut off frequency are used to analyse the signal at different scales. The signal is passed through a series of high pass filters to analyse high frequencies and through a series of low pass filters to analyse low frequencies. The signal resolution (a measure of detail information carrier) changes by filtration and the scale by subsampling (decimation). Subsampling by a factor, *n*, reduced the number of samples *n* times.

The discrete signal, denoted by $x(n)$, is passed thought a low pass filter, that cuts the superior half of the signal frequency band. The impulse response of the filter is $h(n)$. The filtration is equivalent to the signal convolution with the impulse response of the filter. In discrete-time convolution is defined as, (Tărniceriu, 2008)

$$y(n)=x(n)h(n)=\sum_{k=-\infty}^{\infty}x(k)h(n-k). \quad (1)$$

Wavelet analysis addresses approximations and details. Approximations are components at high scale and low frequencies. Details are components at low scales and high frequencies.

DWT is computed by complementary successive low pass and high pass filtering and subsampling, method known as *Mallat algorithm*, (Mallat, 1999).

The complementary filtrations applied to a real discrete signal lead to a double number of data compared to the original data. In order to maintain the information after each filtering, subsampling is used to reduce the number of such samples.

The impulse response of high-pass filter (HPF) is denoted by $h(n)$, and that of low pass filter (LPF), by $g(n)$. At each level, the HPF produces a signal of detail, $d(n)$, while the LPF associated with the scaling function produces a signal, $a(n)$, which is a rough approximation. For each level of decomposition, the filters produce signals which lie only on half of the original signal band, (Tărniceriu, 1996).

Thus, for the first level, after filtering with HPF and LPF and subsampling with 2 we obtain the following signals:

$$y_J(n)=x(n)g(n)=\sum_{k=-\infty}^{\infty}x(k)g(2n-k), \quad (2)$$

$$y_S(n) = x(n)h(n) = \sum_{k=-\infty}^{\infty} x(k)h(2n-k). \quad (3)$$

Theoretically, the process is iterative and could continue indefinitely. In reality, the decomposition is done until the detail contains one sample. In practice, we have to choose a suitable number of levels of decomposition based on the nature of the signal.

3. Data Sets and Results

The EEG signals used for this experiment were recorded by means of a g.tec acquisition system, namely g.MOBIlab+ module, and BCI2000 platform. The data were recorded with 8 wet active electrodes, placed on the scalp according to the international 10…20 system, (Jasper, 1958).

The electrodes are placed on channels: CP3, CP4, P3, C3, Pz, C4, P4 and Cz. These channels are selected in both hemispheres, in sensorimotor areas, due to the appearance of sensorimotor rhythms in these areas. The reference electrode is placed on the right ear.

The recordings were performed on 20 healthy volunteer students in the laboratory.

The subjects received instructions regarding their behavior during recording. The subjects were seated in front of a monitor that during the sessions will either be blank or displaying an arrow pointing left or right. When a left or right arrow is displayed, the subjects need to imagine the movement of the respective hand. When the screen monitor is blank, they must relax and stop any movement. Each left and right arrow appears 30 times. The time interval of the visual stimulus was 2 s.

In our previews work, (Aldea & Eva, 2013), we can see that sensorimotor rhythms are present on C3, CP3 channels for right hand motor imagery, and on C4 and CP4 channels for left hand motor imagery. Therefore, we applied multiresolution wavelet decomposition only for these channels. We tested a lot of wavelet types but the best to reveal desynchronizations on the selected channels are **Coiflet4, Daubechies4, Daubechies7 and Symlets4.**

Taking into account that the frequency components of the EEG signal are in the 0…120 Hz range, while the spectrum of the mu rhythm is around 8…12 Hz and beta rhythm around 12…30 Hz, a fourth level decomposition of the signal was required.

After the first level of decomposition, the EEG signal is decomposed in the detail coefficients of high frequency, $\mathbf{d_1}$, (60…120 Hz) and the approximation coefficients of low frequency, $\mathbf{a_1}$, (0…60 Hz). At the second level of the decomposition, the coefficients $\mathbf{a_1}$ are further decomposed in the detail coefficients, $\mathbf{d_2}$, (30…60 Hz) and approximation ones $\mathbf{a_2}$, (0…30 Hz). Following this procedure, the coefficients $\mathbf{d_3}$, (15…30 Hz), $\mathbf{a_3}$, (0…15 Hz), $\mathbf{d_4}$, (7.5…15 Hz) and $\mathbf{a_4}$, (0…7.5 Hz) are obtained.

The multiresolution decomposition is realized with different types of wavelet on C3, CP3, C4 and CP4 channels. The plotted signals are just those ones of interest: the detailed coefficient of fourth level with 7.5…15 Hz frequency band (corresponding to mu rhythm) and the detailed coefficient of third level decomposition with 15…30 Hz frequency band (corresponding to beta rhythm).

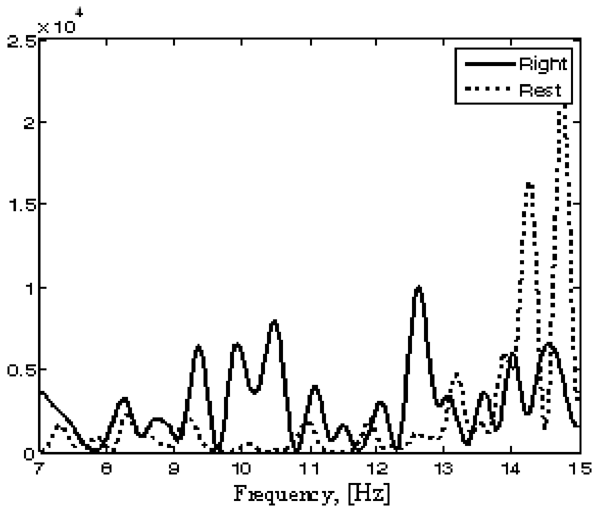

Fig. 1 – Frequency response for right hand motor imagery signal *vs*. rest signal on C3.

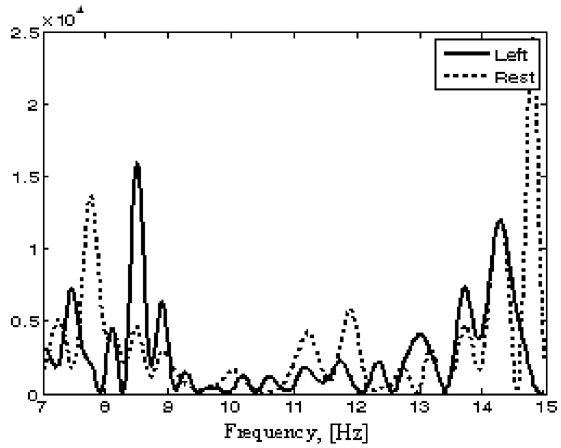

Fig. 2 – Frequency response for left hand motor imagery signal *vs*. rest signal on C4.

Figs. 1 and 2 present the frequency responses of the signal recorded during right/left hand movement imagining *versus* rest at the 7.5…15 Hz frequency band, that fits mu rhythm, on channels C3 and C4. This decomposition of the signal was obtained by applying multiresolution wavelet analysis using **Coiflet4.** On the frequency ranges of 8…9 Hz and 11…12 Hz, in Fig. 1, we can observe a decrease in the signal amplitude that means the desynchronizations of the mu rhythm. In Fig. 2 the desynchronizations is obvious the frequency range of 9…12 Hz.

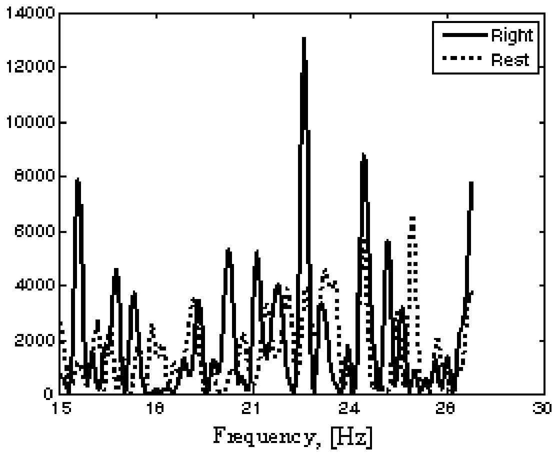

Fig. 3 – Frequency response for right hand motor imagery signal *vs*. rest signal on C3.

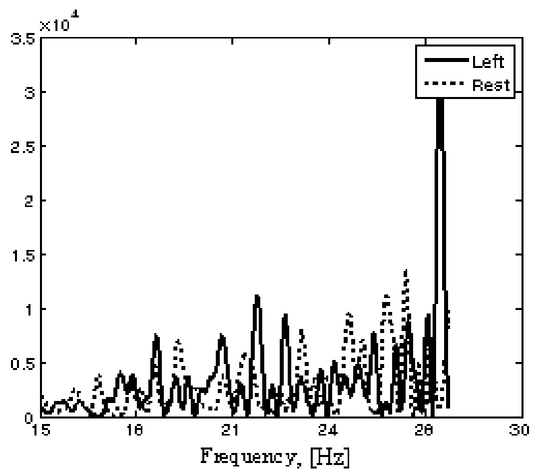

Fig. 4 – Frequency response for left hand motor imagery signal *vs*. rest signal on C4.

Figs. 3 and 4 present the frequency responses of the signal recorded during right/left hand movement imagining *versus* rest at the 15…30 Hz frequency band, which represented beta rhythm, on channels C3 and C4.

For channel C3, in Fig. 3, it can be seen desynchronizations of beta rhythm at the frequency band of 18…19 Hz, 21 Hz and 23…24 Hz, while for channel C4, in Fig. 4, desynchronnizations is obvious at frequency band of 19 Hz and 23…24 Hz.

The next four figures present the responses of the signal recorded during right/left hand movement imagining *versus* rest at the 7.5…15 Hz and 15…30 Hz frequency bands, that fits both mu and beta rhythms, on channels CP3 and CP4.

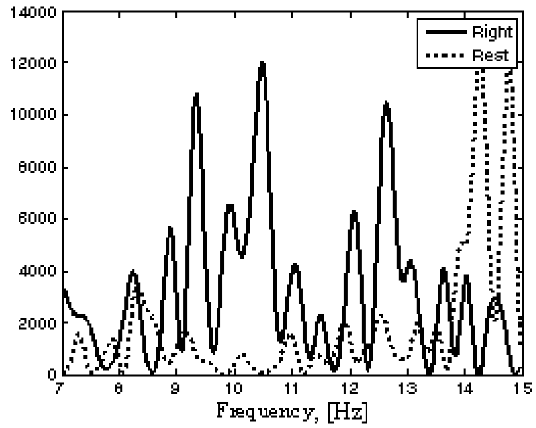

Fig. 5 – Frequency response for right hand motor imagery signal *vs*. rest signal on CP3.

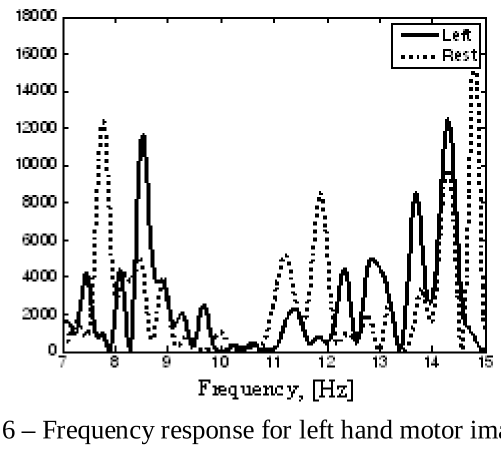

Fig. 6 – Frequency response for left hand motor imagery signal *vs*. rest signal on CP4.

At frequency band of 11…12 Hz, in Fig.5, we can observe desynchronizations of the mu rhythm. In Fig. 6 the desynchronizations can be seen at 9…12 Hz.

In case of Fig. 7 the desynchronization of beta rhythm is observed at 18…19 Hz frequency band, while in the case of Fig. 8, on CP4 channel the desynchronization is more obvious at 19…20 Hz and 24…28 Hz frequency bands.

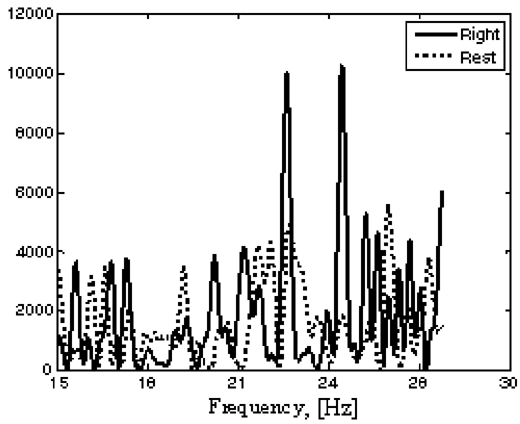

Fig. 7 – Frequency response for right hand motor imagery signal *vs*. rest signal on CP3.

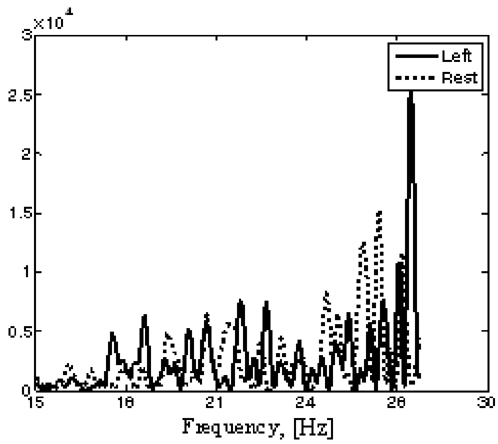

Fig. 8 – Frequency response for left hand motor imagery signal *vs*. rest signal on CP4.

4. Conclusions

Although the basic of mu/beta rhythms are identical for all humans, spatial patterns and exact frequency are different from person to person. Thus, it is necessary to obtain these subject-specific parameters *prior* to any feedback experiments.

Multiresolution wavelet analysis allows us to decompose the signal into sub-band components of interest with frequency band corresponding to sensorimotor rhythms. The method allows reducing the dimension of the data and this is an important advantage.

We tested various types of wavelets families but the best to reveal desynchronizations on the selected channels are Coiflet4, Daubechies4, Daubechies7 and Symlets4. In this paper the results obtained only with Coiflet4 wavelet are presented for the reason of pagination.

Patients discriminated both mu and beta rhythms, but the best desynchronized was beta rhythm.

In conclusion, the EEG data which we recorded can be used for implementing a brain computer interface system.

REFERENCES

Aldea R., Eva O., *Detecting Sensorimotor Rhythms from the EEG Signals Using the Independent Component Analysis and the Coefficient of Determination*. Proc. of the 11th IEEE Internat. Symp. on Sign. Circ. a. Syst. (ISSCS'13), 2013, **11**, 13-16.

Grainmann B., Allison B., Pfurtsheller G., *Brain Computer Interfaces. Revolutionizing Human-Computer Interaction.* Springer, Graz, Austria, 2010, 11-20.

Jasper H.H., *The Ten-Twenty Electrode System of the International Federation.* Electroencephalogr. Clin. Neurophysiol., **10**, 370-375 (1958).

Mallat S., *A Wavelet Tour to Signal Processing*. Acad. Press, 1999.

Mason S.G., Birch G.E., *A General Framework for Brain-Computer Interface Design.* IEEE Trans. Neural Net. Syst. Rehab. Engng, **11**, 70-85 (2003).

Mellinger J., Schalk G., *BCI2000: A General-Purpose Software Platform for BCI Research.* MIT Press, Cambridge, Mass, USA, 2007.

Pfurtscheller G., Niedermeyer E., Lopes da Silva F. H., *EEG Event-Related Desynchronization (ERD) and Event-Related Synchronization (ERS).* Electroencephalogr.: Basic Princ., Clinical Appl. a. Related Fields, **4**, 958-967 (1998).

Tărniceriu D., *Bazele prelucrării numerice a semnalelor.* Ed. Politehnium, Iaşi, 2008.

Tărniceriu D., *Generalized Tree Structures Used in Multiresolution Analysis of Signals*. Proc. Internat. Symp. on Commun.'96 Techn. Milit. Acad., Bucureşti, Nov. 27-29, 1996, 404-409

Wolpaw J. *et al*., *Brain-Computer Interface Technology: A Review of the First International Meeting*. IEEE Trans. on Rehabil. Engng., **8**, 164-173 (2000).

DESCOMPUNEREA WAVELET A SEMNALELOR ELECTROENCEFALOGRAFICE ÎN SUB-BENZI PENTRU A EVIDENȚIA RITMURILE SENZORIMOTOARE

(Rezumat)

Se evidențiază caracteristicile ritmurilor senzorimotoare (mu şi beta) produse în timpul imaginării mâinii stângi sau drepte. Datele EEG au fost înregistrate cu ajutorul a 8 electrozi, plasați pe scalp, prin intremediul modulului g.MOBIlab+.

Semnalele EEG sunt apoi descompuse în sub-benzile de interes (7,5...15 Hz, ritm mu şi 15...30 Hz, ritm beta), utilizând analiza wavelet multirezoluție. Cu ajutorul waveletului Coiflet4 s-a evidențiat desincronizarea ritmurilor senzorimotoare pe canalele C3, C4, CP3 şi CP4.