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The interpretation of epileptiform abnormalities through the multiresolution wavelet analysis of EEG

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Abstract: - This study, starting from the results of a previous work, analyzes in more details the EEG patterns of subjects affected by epilepsy and in particular by partial complex crypto-genetic seizures. The interpretation of such signals was made by means of multiresolution wavelet analysis. The results appear encouraging.

Key-Words: - Signal processing, EEG interpretation, Wavelet Transform, Multiresolution Analysis, epilepsy.

1 Introduction

EEG is the name commonly used for electroencephalography. EEG is the most important test for diagnosing epilepsy because it records the electrical activity of the brain. It is safe and painless. The EEG shows patterns of normal or abnormal brain electrical activity. Some abnormal patterns may occur with a number of different conditions, not just seizures. For example, certain types of waves may be seen after head trauma, stroke, brain tumor, or seizures. A common example of this type is called "slowing," in which the rhythm of the brain waves is slower than would be expected for the patient's age and level of alertness.

Certain other patterns indicate a tendency toward seizures. These waves are commonly referred as "epileptiform abnormalities" or "epilepsy waves." These include spikes, sharp waves, and spike-and-wave discharges. Spikes and sharp waves in a local region of the brain, such as the left temporal lobe, indicate that partial seizures are beginning in that region. Primary generalized epilepsy, on the other hand, is suggested by spike-and-wave discharges that are widely spread over both hemispheres of the brain, especially if they begin in both hemispheres at the same time.

The interesting results, obtained in an our previous work by processing the EEG patterns of *normal* subjects through Wavelet Transform (WT) [1], induced our team to continue the study. Therefore we have examined a group of 15 subjects, of age ranging between 10 and 50 years, males and females, affected by epileptic

seizures named also as partial complex crypto-genetic seizures (PCCS). In order to better define the EEG readings several diagnostic tests were executed. The results were negative apart the EEG signals which showed alterations localized in the left/right central occipital region and in the occipital temporal region. The clinical neurology, even if a different syndrome phenomenology was showed for a short while, really, did not differ for the eegraphic alteration and for the localization both by the EEG response and by proposed methodology.

The use of the EEG methodology in the neurological pathologies supplies aspecific and not elective indications for some eegraphic readings characterizing the epilepsy. Therefore, in order to make a diagnosis it will be necessary to carry out a TAC or RMN and sometimes also the SPECT.

Such tests represent a completion and an ulterior verification for performing a differential diagnosis. Although the experience of the EEG reader could also concur to perform a diagnosis for various pathologies different from the epilepsy, it remains the doubt upon a typical symptomatological description is completed.

The epileptiform bioelectrical activities (e.g., tip wave, spike wave, complex sharp wave, slow wave), in agreement with the International Federation of the Society of EEG, are of undisputed evaluation. In fact, tips occurring isolated or in conjunction with slow waves, show several parameters recognized as standard in terms of amplitude and duration. Obviously, due to the aspects, sometimes, similar and overlapped to some activities generated by artifacts, it is quite difficult to study these graphical-elements during an EEG readings. The employment of the modern technology (i.e., digital filters, software and neural networks) concurs to reduce the presence of such artifacts which alter the background of cerebral bioelectrical activity.

The EEG , as the continuous “roar” or “noise” of the brain, contains a fairly wide frequency spectrum, but it is not simply a hodgepodge of frequencies. The frequency range of the EEG has a fuzzy lower and upper limit. There are ultra-slow and ultra-fast frequency components that play no significant role in the clinical EEG (with exception for the forensic problems). For these reasons, the frequency–response curve of an EEG apparatus concentrates on the clinically relevant frequency range, which is also the most important from the psychophysiological viewpoint. This range lies between 0.1/s (or cps or HZ) and 100/s and, in a more restricted sense, between 0.2/s and 70/s. In the normal adult, the slow ranges (0.3-7/s) and the very fast range (above 30(s) are sparsely represented; medium (8-13/s) and fast (14-30/s) ranges predominate.

These frequencies are broken down into the following bands or ranges:

Delta below 3.5/s (usually 0.1-3.5/s)
Theta 4-7.5/s
Alpha 8-13/s
Beta above 13/s (usually 14-40/s but unlimited in the upper range) or more recently;
Beta 14-30/s and Gamma above 30/s (unlimited in upper range).

The sequence of these Greek letters is not logical and can be understood only in the historical view [2].

Alpha rhythm is the classical EEG correlate for a state of relaxed wakefulness best obtained with the eyes closed. A degree of higher alertness attenuates or suppresses the alpha rhythm, which is then supplanted by “desynchronized” low voltage fast activity. The earliest stage of drowsiness is characterized by “alpha dropout”. The trains of alpha waves become less and less continuous, and the last alpha fragments finally give way to a low voltage pattern of mixed slow (mostly theta range) and fast frequencies. This type of alpha dropout is a hallmark of a normal adult EEG. In adult with some organic cerebral problems and in old age, a posterior alpha rhythm of normal appearance may be replaced by activity in theta and delta range. [2].

Our method, starting from a previous work [1], for interpreting the EEG response, proposes an alternative approach based on the wavelet multiresolution transform. It concurs to define

also quantitatively the cerebral bioelectrical activity defined as *abnormal*.

In the last years many methodologies were proposed: neural networks and filtering systems based on the Fourier Transform (FT), the Short Time Fourier Transform (STFT), the Wavelet Transform (WT), etc. The tendency is to investigate on the eventual presence of spike, noise reduction and presence or not of artifacts, by analyzing the EEG signal of predetermined bipolar derivation.

Starting from this last consideration, it has been implemented a method for denoising and processing the signal based on the wavelet transform. It takes into account the contemporary study of two symmetrical hemispheric regions and their evolution as well as their contra-lateral correspondence and also peculiar characteristics inherent the polarity of signal, which could be used as an important indication of pathology.

2 Materials and methods

The EEG patterns of 15 subjects, 8 male and 7 female, of age ranging between 10 and 50 years, affected by partial complex crypto-genetic seizures, have been studied. All the subjects were followed for a long time by means of seriated EEG examinations performed by 10/20 system for a duration of approximately 30 min, with time constant of 0.3 and amplitude 5mm equivalent to 7 μV .

In order to reduce eventual artifacts due to the extra cerebral origin as well as to carry out a soft-denoising, a LP 15.0 Hz and HP 1.60 Hz as well as Notch algorithm were used to filter the EEG signal. The sampling rate was 256 Hz, whereas the amplitude was set to 7 mm/50 μV .

Moreover, for the original signal decomposition (time-frequency dominion) into more elementary ones the wavelet transform has been applied.

Periods of epochs of 8192 points = 2^{13} = 33 seconds were randomly examined from posterior derivations C3-O1, C4-O2 and T3-O1, T4-O2 (because in such regions the Alpha activity in condition of psycho-sensorial quiet is well represented). Moreover, for the decomposition of these pre-filtered signals into more elementary ones the wavelet transform was applied.

The traditional method used to analyze the time series EEG signals has been Fourier transform. It, however, can not capture the transient features in EEGs and time-frequency information is not readily in the transformed Fourier coefficients. For that reason the Fourier transform presents a limitation to the detection of abnormal brain activity.

In summary, wavelets offer a frequency/time representation of data that allows us time (respectively, space) adaptive filtering, reconstruction and smoothing.

Recall that a mother wavelet ψ is a function of zero h-th moment (e.g., see [3], [4], [5], [6])

$$\int_{-\infty}^{+\infty} x^h \psi(x)dx = 0\,, \quad h \in \mathbf{N}. \qquad (1)$$

From this definition, it follows that, if ψ is a wavelet whose all moments are zero, also the function $\psi_{ik}(x)$: = $2^{j/2}\psi(2^j x - k)$ is a wavelet.

Now consider a wavelet ψ and a function φ such that $\{\{\varphi_{j_0 k}\}, \{\psi_{jk}\}, k \in \mathbf{Z}, j = 0, 1, 2,\ldots\}$ is a complete orthonormal system. In this case, a given signal $s(t)$, decomposed by wavelet (i.e., CWT) is represented in the following detail function coefficients

$$d_{jk} = \int_{-\infty}^{+\infty} s(\tau)\cdot\frac{1}{\sqrt{2^j}}\psi\left(\frac{\tau-k}{2^j}\right)d\tau \qquad (2)$$

and in the approximating scaling coefficients as follows

$$a_{j_0 k} = \int_{-\infty}^{+\infty} s(\tau)\cdot\varphi(\tau-k)d\tau \qquad (3)$$

Note that, for any j, d_{jk} can be regarded, as a function of k. Consequently, if the signal $s(t)$ is a smooth function, then the relative details are zero, since, as said before, a wavelet has zero moments (for a detailed argumentation see [3]).

The sequence of spaces $\{V_j, j \in Z\}$, generated by φ is called a multiresolution analysis (*MRA*) of $L^2(R)$ if it satisfies the following main properties

$$V_j \subset V_{j+1}, j \in Z \text{ and } \bigcup_{j\geq 0} V_j \text{ is dense in } L^2(R).$$

It follows that if $\{V_j, j \in Z\}$, is a *MRA* of $L^2(R)$, we say that the function φ generates a *MRA* of $L^2(R)$, and we call φ the father wavelet.
Besides, based on Parseval theorem, for any $s \in L^2(R)$, it follows that

$$s(t) = \sum_k a_{j_0 k} \varphi_{j_0 k}(t) + \sum_{j=j_0}^{j_1} \sum_k d_{jk} \psi_{jk}(t) \quad (4)$$

The relation (4) is called a multiresolution expansion of s. This means that any $s \in L^2(R)$ can be represented as a series (convergent in $L^2(R)$), where a_k and d_{jk} are some coefficients, and $\{\psi_{jk}\}, k \in Z$, is a basis for W_j, where we define

$$W_j = V_{j+1} - V_j, j \in Z.$$

In (1) $\{\psi_{jk}(t)\}$ is a general basis for W_j. The space W_j is called resolution level of multiresolution analysis. In the following, by abuse of notation, we frequently write "resolution level *j*" or simply "level *j*". We employ these words mostly to designate not the space W_j itself, but rather the coefficients d_{jk} and the function ψ_{jk} "on the level *j*".
In the present work it has been applied the filter proposed by Daubechies, named dB4, which includes both wavelets strongly localized and wavelets strongly regular.

3 Results

The results obtained by examining the 15 pathological subjects, are depicted in the figures below. The diagrams show, in low frequency range (i.e., from 1 to 5000 points), a bad correlation of the curves representing the right and left central occipital region EEG response.
The following figures, just an example, show the results obtained by processing the signals by means of the multiresolution wavelet transform.
General remark: in the pictures showed below the dotted line represents the signal derived from the right cerebral region whereas the continuous line represents the left one.

- **Case # 1 (Fig. 1a.b):** Boy, 13 years, shows in anamnesis an altered behavior and lessening of scholastic performances, partial complex seizures characterized by aura, subsequent losses of conscience followed by automatism, mental confusion and sleep.

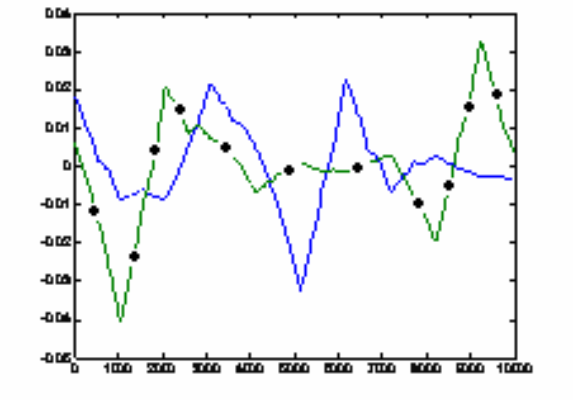

Fig. 1a Case # 1, Comparison of wavelet coefficients at level j = 11

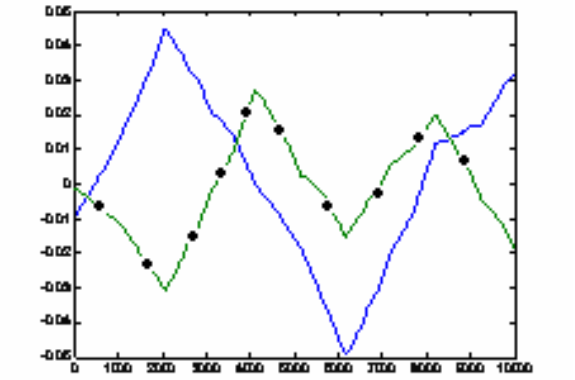

Fig. 1b Case # 1, Comparison of wavelet coefficients at level j = 12

- **Case # 2 (Fig. 2a.b and 3a.b):** Adult (male), 22 years, affected by clonic convulsions localized in the right cerebral region which interested the face and the arm followed by loss of conscience and axial hardening.

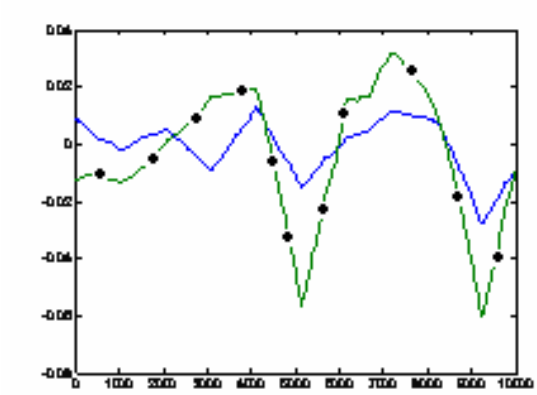

Fig. 2a Case # 2, Comparison of wavelet coefficients at level j = 12 at May 2004

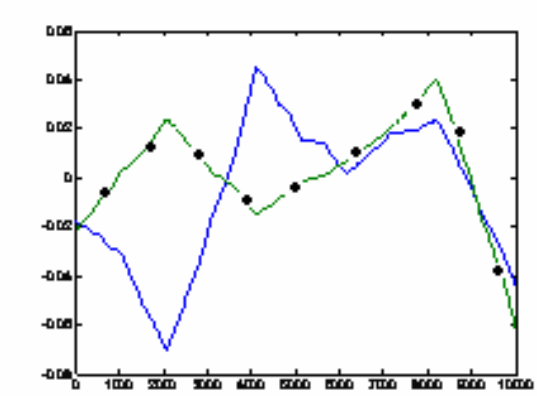

Fig. 2bCase # 2, Comparison of wavelet coefficients at level j = 11 at May 2004

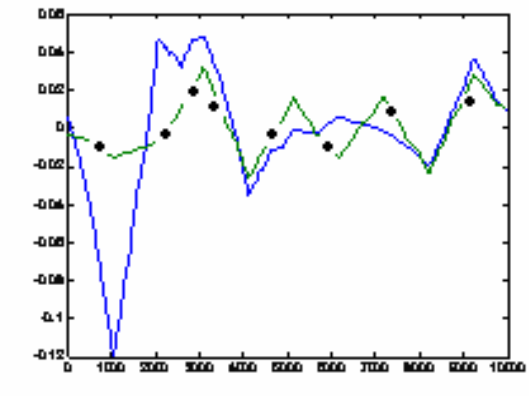

Fig. 3a Case # 2, Comparison of wavelet coefficients at level j = 11 at May 2005

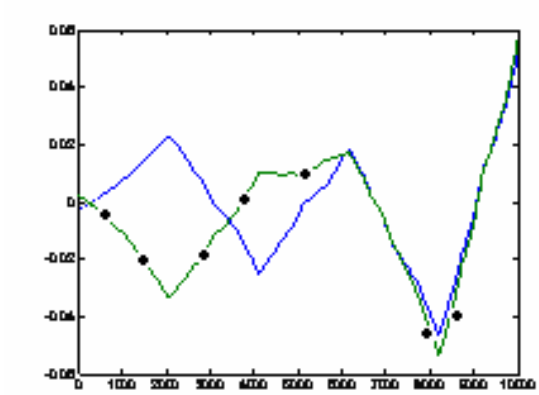

Fig. 3b Case # 2, Comparison of wavelet coefficients at level j = 12 at May 2005

- **Case # 3 (Fig. 4a.b):** Adult (female), 48 years, lose of memory and difficulty of concentration and partial seizures with separation from reality.

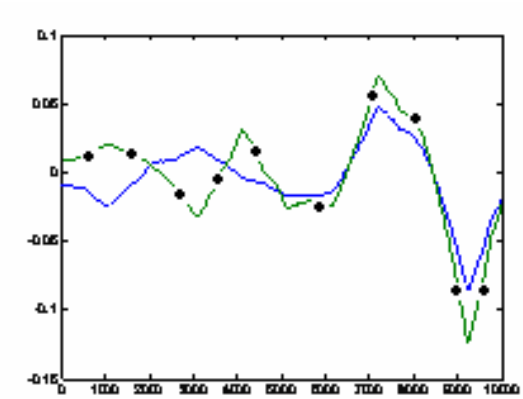

Fig. 4a Case # 3, Comparison of wavelet coefficients at level j = 11

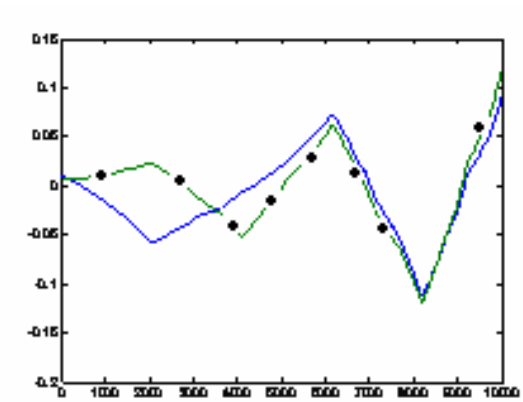

Fig. 4b Case # 3, Comparison of wavelet coefficients at level j = 12

- **Case # 4 (Fig. 5a.b):** Boy 17 years, affected by epilepsy in remission and suspension of the antiepileptic as from approximately two years.

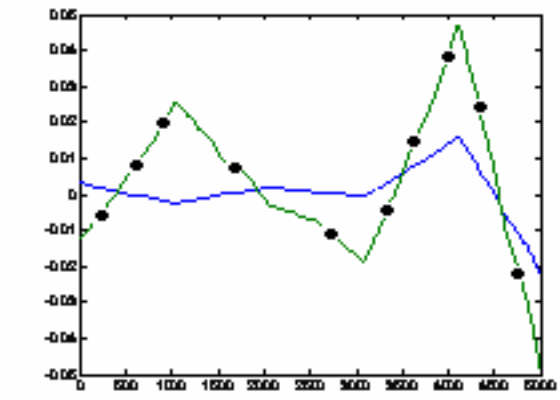

Fig. 5a Case # 4, Comparison of wavelet coefficients at level j = 12 at Nov 2003

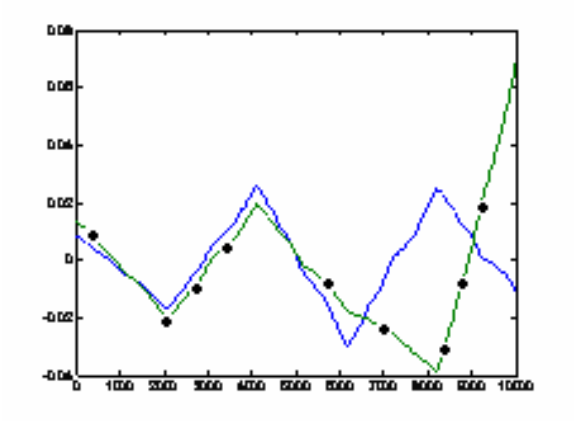

Fig. 5b Case # 4, Comparison of wavelet coefficients at level j = 12 at Jun 2005

Finally, in the Figg. 6 and 7 it is showed the comparison of two subjects: the first one healthy and the second one affected by epilepsy.

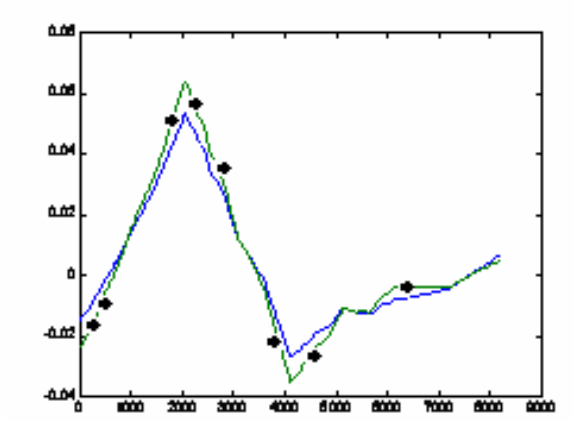

Fig. 6 Comparison of wavelet coefficients at level j = 12, referred to: Male 17 years, healthy

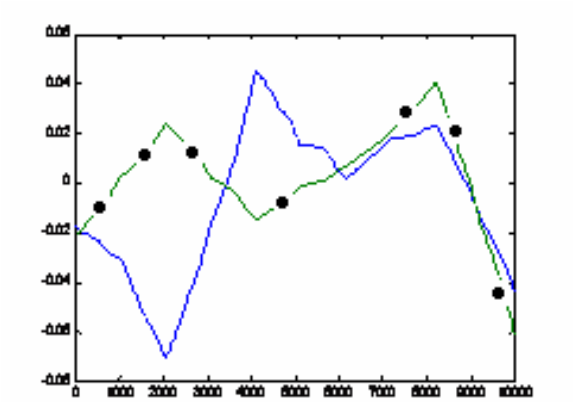

Fig. 7 Comparison of wavelet coefficients at level j = 12, referred to: Boy, 13 years epileptic

4 Discussion and conclusions

The analysis of various scales of resolution level in which the EEG signals were decomposed by wavelet transform if compared to standard EEG confirmed that the subjects were affected by a pathology. That was done by examining only the first 5000 points of multiresolution response. The automatic analysis performed by means of calculating or instruments analyzers purposely constructed would have had to become substitutive regarding the visual evaluation of the standard EEG recordings as far as concerned the basic activity.

Our method appears to be valid, because immediately allows us to point out the existence of an alteration of EEG pattern and through opportune mathematical applications it is possible to quantify their energetic content. In the future by studying a wider case histories we firmly hoping to produce a

graphical response able to eliminate the uncertainty concerning the irritative or suffering activities. Nowadays, this differentiation, is performed by standard EEG, for several specific forms of epilepsy, some neurological pathologies and other important pathologies (i.e., ictus, encephalitis, etc). Referring to our previous work the application of the methodology could be useful for differential diagnosis of convulsions from others paroxysmal disturbs with or without loss of conscience. Nowadays, it can be obtained on clinical basis exclusively even if it is of difficult resolution in the children. In fact, the simple faints with or without ipossic clonic convulsions, nocturnal headache, terrors, myoclonus in the sleep, cardiac disorder and tic disorder are often diagnosed as epilepsy [7]. Moreover, we are confident that the proposed signal processing methodology can also help the decision to suspend the therapy in epileptic subject, not only on what the patient reports (i.e., no seizures from at least one year), but on a border of normality by comparing the energetic content of two symmetrical cerebral regions (see, Figg. 5a and 5b). As well as it will be more stimulating to verify the pharmacological response of a subject affected by epilepsy.

The interpretation of standard EEG signal is burdened to subjective factors. Our method, allowing an immediate comparison, is less susceptible to suggestion and it is also able through specific applications and algorithms to put in evidence *quantitatively* the differences between normal and pathological or abnormal cerebral activity.

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