Sleep EEG Processing with Wavelets

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Abstract

The EEG is a non-invasive technique to study the brain and very useful in sleep analysis. The classification of the sleep in stages was widely used, but has been limited by its coarse resolution. The sleep EEG microstructure gives attention to the transient EEG phenomena (phasic events) and they could be described in frequency and have short duration. The wavelet packet analysis is used to extract the signal activity in frequency bands for later processing in order to detect those events.

1 Introduction

The EEG is an affordable and non-invasive technique largely used to study the brain and very useful in sleep analysis. The amount of data collected in a normal eight hours sleep night is very high, and techniques to make their automatic analysis are of great importance.

The organization of the sleep in stages was been intensively used. This is commonly expressed as a succession of sleep stages of two types - 4 NREM stages: S1, S2, S3, S4 related with the sleep depth and a special stage REM associated with rapid eye movements. Scoring epochs of several seconds of signal (20s to 30s) are classified at a time [1].

The sleep Electroencephalogram (EEG) microstructure analysis gives attention to the transient EEG phenomena (phasic events) [2], [3]. They last less than the scoring epoch of sleep staging. These events are commonly designated as arousal-related phasic events (ARPE) and are generally associated with a transient lightening of sleep depth and have become very important in sleep study. They could be well described in frequency, but have short duration. The classical Fourier analysis is not well adapted to these situations of short duration. In this work we present the wavelet transforms as a tool to analyze the sleep EEG signal, in the time-frequency domain, to separate the signal power in frequency bands (delta, theta, alpha, sigma and beta) that are standards in sleep EEG studies. The wavelet transform conjugates good discrimination in frequency and in time, and is well adapted to process the sleep EEG signal in order to extract features with good time resolution.

2 Material and Methods

2.1 Wavelet Time-Frequency Analysis

Wavelet transforms are closely related with filter banks. In the wavelet transform the signal is decomposed through a family of functions – translation and dilation of a unique prototype.

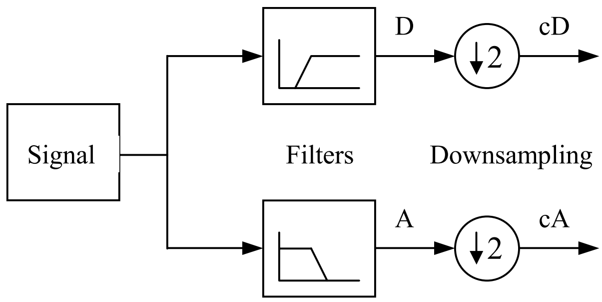

Figure 1 - Schema of one stage filtering - D: Detail; A: Approximation; cD, cA: DWT components.

A fast discrete wavelet transform (DWT) computes coefficients efficiently, applying recursively a pair of half-band mirror filters (approximation and detail), see figure 1. Multi-resolution analysis decomposes the sleep EEG signal in a dyadic time-frequency space [4], [5]. Following the wavelet packet schema we gain flexibility to choose the frequency sub bands adequate to characterize the events. In the wavelet theory, time-scale is the most natural one, but as scale and frequency are closely related we could talk about time-frequency space.

With this structure the frequencies are divided in octave bands: the compression in time by a factor of two means expansion in frequency by the same factor.

$$\left[f(t) \to f(2t)\right] \Leftrightarrow \left[F(w) \to \frac{1}{2}F(\frac{w}{2})\right]$$

To decompose the sleep EEG signal in their relevant EEG signal activity bands for sleep, we built the wavelet packet analysis shown in figure 2.

Table 1 shows in detail the decomposition in frequency for each band, associated with the nodes of the wavelet packet analysis tree. Delta band results from the combination of delta1, delta2 and delta4.

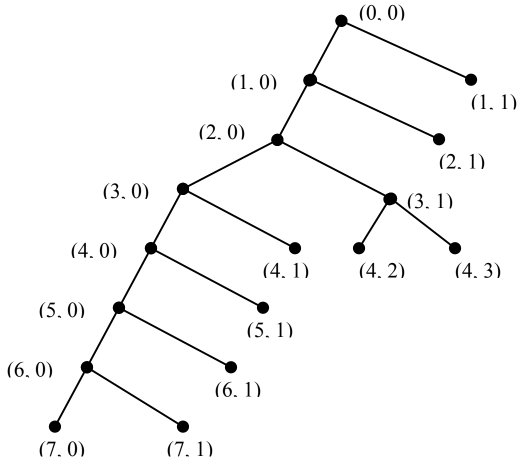

Figure 2 - Wavelet packet analysis tree.

This structure is optimized to the standard frequency bands used in the sleep EEG analysis. This

Table 1 - Wavelet packet analysis frequency bands (Sampling=128Hz; Time in seconds; Freq. in Hz)

Node	Level	Freq. (Hz)	Bands		Δ_Freq	Δ_Time
1.1	1	32 – 64	Residual		32	0.016
2.1	2	16 – 32	Beta		16	0.031
3.1	3	8 – 16	Alpha/Sigma		8	0.063
4.3	3.1	8 – 12	Alpha		4	0.125
4.2	3.1	12 – 16	Sigma		4	0.125
4.1	4	4 – 8	Theta		4	0.125
5.1	5	2 – 4	Delta4	Delta	2	0.25
6.1	6	1 – 2	Delta2		1	0.5
7.1	7	0.5 – 1	Delta1		0.5	1
7.0	7	0 - 0.5	Slow Delta		0.5	1

method results in different time discrimination for each band. Later processing over these data is easier if all frequency bands have the same time discrimination. Moreover, files of results become shorter. To get this, all the bands are adjusted to a common fine time resolution using moving average over the wave packet coefficients.

2.2 Wavepacket Calculation

The calculation of the wavelet packet decomposition coefficients is made using an overlapped sliding window that pass over the EEG signal. The powers of the coefficients in the overlapped zone are averaged to get a better estimate of the signal activity. This is represented in the diagram of the figure 3.

The wavelet basis could be chosen from a family of wavelets. The implementation of the wavelet filter was made in a pre-programmed library.

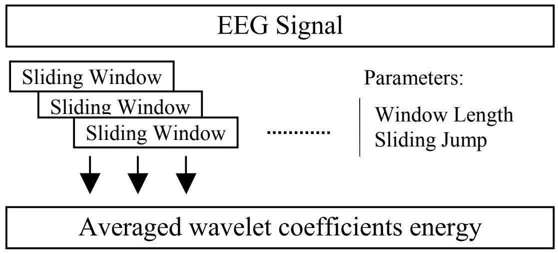

Figure 3 – Wavelet coefficients calculation

3 Results

The application to the EEG signal was made over full 8 hours sleep nights; in one channel derivation (more than one channel could be used).

All the results shown below were calculated using a Daubechies order 6 wavelet (DB6). The time resolution in all bands was adjusted to 0.25s, that is small enough to detect the beginning and the end of events presents in the sleep EEG signal.

3.1 Detailed Examples

The graphics in figure 4 represent 30 seconds of sleep EEG and the activity separated by frequency bands as defined in table 1. The time discrimination for each band is the maximum associated with each level.

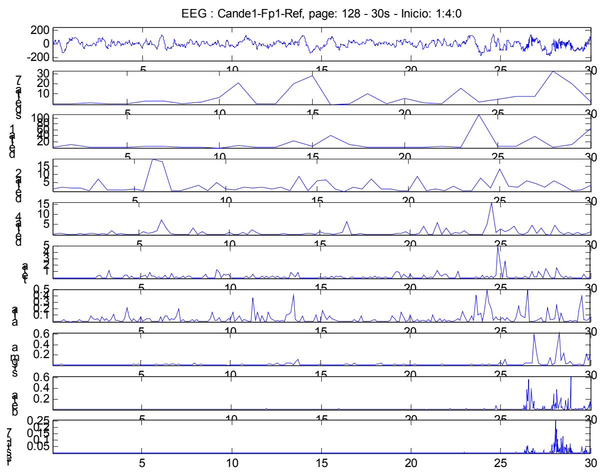

Figure 4 – EEG and activities in bands for 30s of sleep .The first graph is the EEG signal and the others are the energy of the wavepacket coefficients.

In figure 5 is shown the same data of figure 4 but with the same time resolution for all bands (0.25s). Compared with the results in figure 4, we can see that the time discrimination is appropriate to detect the beginning and end of the events.

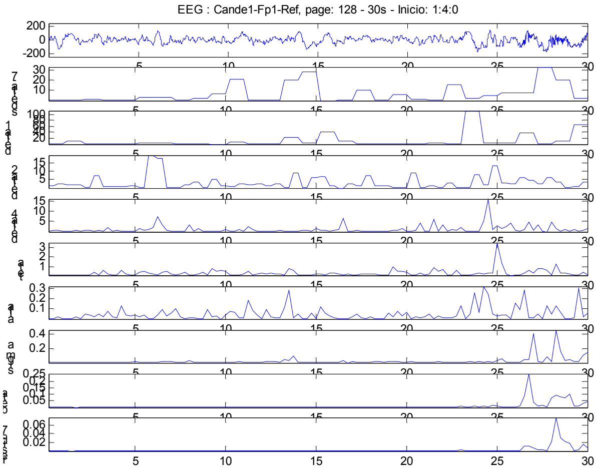

Figure 5 – EEG activities in bands for 30s of sleep. The presence of activity in EEG frequency bands is clearly detected. Time resolution adjusted to 0.25s.

Figure 6 shows EEG in stage 2NREM with the presence of a vertex wave at 5s (theta activity), and a K-complex with spindle at 22-25s (delta: d124, and sigma activity).

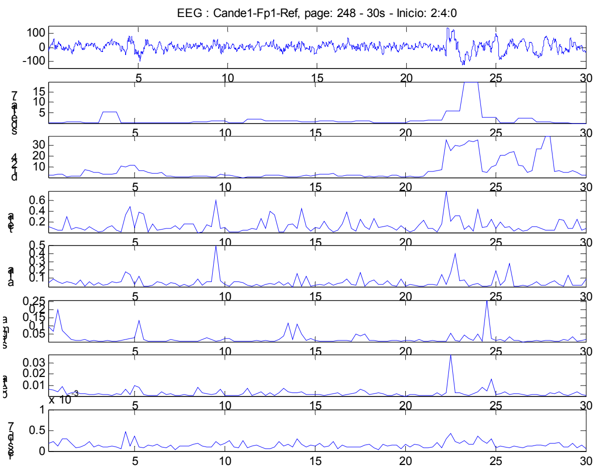

Figure 6 – EEG stage 2NREM with a vertex wave (5s-predominant theta), and a K-complex with spindle (22-25s – delta: d124, and sigma activity).

Figure 7 shows EEG in stage REM with a wakening beginning at 70s with the presence of alpha activity, followed by activity in all bands, maybe related with body movement. The activity in slow delta: "sdelta7" band (0-0,5hz), in this case, is related with this movement. (Certainty only could be done by a muscle activity recording).

Figure 8 shows 60 seconds of EEG in stage 4NREM with two delta bursts with spindles (8-17s and 50-58s) that can be seen in sustained delta activity and sigma activity.

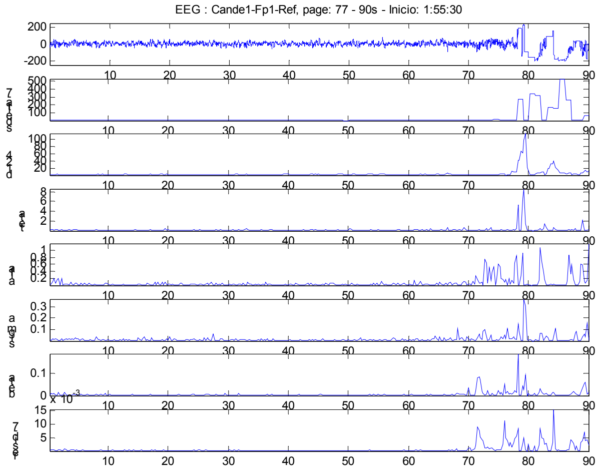

Figure 7 – EEG stage REM with a wakening starting at 70s – activity in alpha band, followed by activity in all bands. The activity in slow delta: "sdelta7" (0-0,5hz) is an indication of possible body movement.

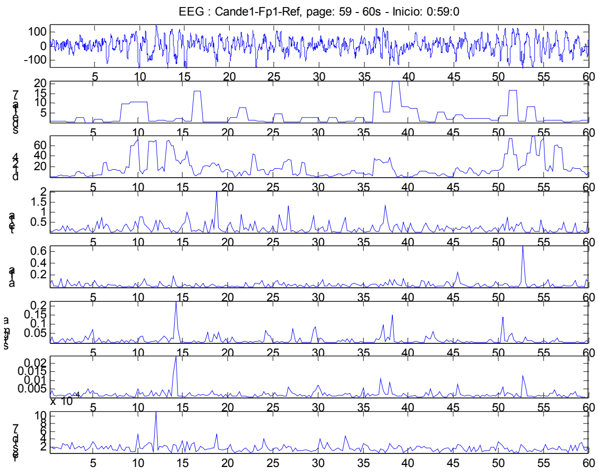

Figure 8 – EEG stage 4NREM with 2 delta bursts with spindles (8-17s and 50-58s) sustained delta: d124 activity and sigma activity.

3.2 All Night Example

The results of processing one EEG channel signal of 8 hours of sleep, sampled with a frequency of 128Hz, are shown in the figure 9. It takes about 10 minutes to be processed in a Pentium IV / 1700 MHz. The top graph is a sleep staging made visually with the stages (Wake; REM; 1,2,3,4NREM) marked from the top to bottom.

The examples shown in the above figures 4 to 8 could be compared with global night. All graphs were made with automatic vertical scale. In same situation the scale value must be verified because very low activity seems to be relevant, but the scale is very small.

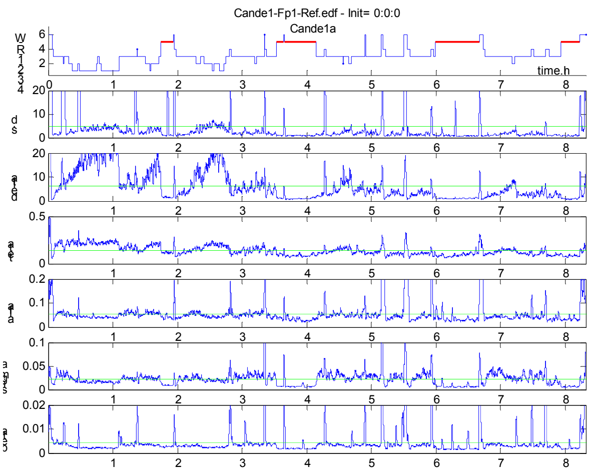

Figure 9 – EEG activities in bands for 8h of sleep, one channel. The first graphic is the sleep staging made visually. Each band has time discrimination of 0.25s.

4 Discussion and Conclusions

The application examples shown in figures 4 to 9 are indicative of the capacity of this method to detect and separate the EEG activity in frequency bands using wavelet packing analysis. To extract the phasic events, more work must be done to build algorithm detectors using the frequency band activities.

The wavelet packet analysis is a powefull and efficient method to process the EEG signal to exctract feactures that allow the caracterization of the activity frequency bands.

The most remarcable advantages are their good beavior in time-frequency space, wich make it well adaptated to be used in the situations of non stationarities and in the presence of short duration events.

References

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