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The Wigner Ville Distribution- A Best Tools for Time-Frequency Analysis of Infant Vep

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Abstract: The existant analysis methods, to effect an assessment of non verbal infant visual accuity, aren't adapted to clinical needs: one of the problems encontred is lability of the time of infant attention to the stimulus. The proposed solution, to day, is the frequential analysis of rapidly extration of Visual Evoqued Potentiel. This requires a temporal selectivity and frequential selectivity arbitration. We extracted the instantaneous frequency for electrophysiological signal.This work preposes:- a selection of several analysis methods, based on a Time Frequency signal analysis, allowing a comparative study emphasizing the Wigner Ville avantages for the non stationary signal like the VEP.- the implementation of this analysis for an experimental study of VEP meet's the theoric study and prove the Wigner-Ville advantages.- finally discussing results of analysis methods to find the efficiency analysis of each one as a best investigator for visual system.

Key words: Time Frequency Analysis · Vep · Wigner- Ville · Visual Acuity

INTRODUCTION

Currently, the investigation of visual system in clinical routine poses problems that are not solved. In particular, obtaining Visual Evoked Potentials (VEP) requires an examination time of about one minute. While for newborns, the periods of attention are of the order of a few seconds [1] and current methods do not provide satisfactory answers for the following questions:

- Is there a significant response to the stimulation frequency (5Hz)?
- It is necessary to detect the answer, as small as it is:
- Reduced in time.
- Reduced in energy of the signal / noise ratio.
- How to characterize noise at 5Hz?
- How to characterize the signal?
- Is there retinal stimulation?

Indeed, when the visual system is stimulated at a frequency higher than 5 Hz, a synchronization phenomenon occurs between the stimulation and the bioelectrical response collected on the occipital scalp. This phenomenon is initially described as "photic driving" by physiologists [2]. It corresponds to a training of the electrical activity of the visual system which no longer has the time to return to the state of rest between two successive stimulations.

Electronic techniques [1, 3] have allowed to extract these responses called "Steady state evoked potentials" or "stationary evoked potentials". Their morphology is similar to a sinusoidal wave characterized by its amplitude and phase. There is a complex morphology of the response.

This has led us to a different approach that consists of analyzing the frequency content of the signal, in order to find the component corresponding to the stimulation.

Frequency Analysis by DFT: A first approach was conducted, which consisted in limiting the duration of the examination to 12 s, considering only the part of the signal where the attention period was maximum and this depending on the minimum amplitude and the stability of the phase of input signal at the frequency of stimulation.

Thus a spectral analysis is carried out by Fourier Transformation on digitized data.

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The length of the treated signal is equal to T=NΔt with N samples. The spectral resolution is Δf= 1/T = 1/NΔt.

The discrete Fourier transform is:

$$X(m\Delta F)=\frac{T}{N}\sum_{k=0}^{N-1}x(k\Delta t)e^{(-2j\pi k/N)}\quad 0<m<N-1$$

Or

$$X(mF)=\frac{T}{N}\sum_{k=0}^{N-1}x(k)e^{(-2j\pi k/N)}\quad 0<m<N-1$$

The spectrum analysis is accomplished on a temporal sample chosen by the operator. The selectivity of this frequency analysis depends directly on the length of the analysis sample [4]. The choice of the length of analysis is therefore the result of a compromise. More this length is short, less the filter is selective in frequency field and the less it is able to dissociate the response to visual stimulation from other bioelectrical activities, such as the alpha rhythm of the electroencephalogram, whose frequency band is in the vicinity of the frequency of analysis. More this length is long, less the filter is selective in the temporal field and less he is able to detect the answer during a brief period of attention.

This answer is incomplete, it is often necessary to visualize the spectrum of the signal at different times to judge the validity of the response at 5 Hz compared to those of neighboring frequencies.

It is only through continuous analysis that short attention episodes can be detected. Therefore, the best way to detect the evolution of micro-potentials corresponding to the VEP, is to have the maximum energy of the signal and to judge the trace of the instantaneous frequency [5]. Hence the interest of a new analysis methodology which is based on the Time-Frequency representation and which would overcome the compromise between temporal selectivity and frequency selectivity.

New Methodology of Frequency Analysis

Time-Frequency Analysis Principles: The realization of a new frequency analysis of the VEP supposes the extraction of the instantaneous frequency of the electrophysiological signal to be interested in the component corresponding to the stimulation compared to the neighboring frequencies. We will remember that the only way to have a trace of the instantaneous frequency is a 3-dimensional representation (time, frequency and amplitude): this same representation is called the time-frequency representation. There are several types of time-frequency representations [6]. Our interest has focused exclusively on two of them, which are linear "this facilitates the interpretation of the results" and which offers the possibility to visualize the complete spectrum and thus we can quantify the noise generated by the electroencephalogram in the vicinity of 5Hz:

- Complex spectrogram.
- Wigner-Ville Transform

Complex Spectrogram: We define the spectrogram as the module of the short term Fourier transforms [7].

$$S(\tau,\nu)=\left|\int_{-\infty}^{+\infty}f(t)w(t-\tau)e^{(-2i\pi\nu t)}dt\right|$$

f(t)w(t-τ) is the slab of the signal cut up by the window w at instant ô. It is a specter brought forward in time, where the frequency of sampling satisfies on the Nyquist or Shannon condition. Frequency resolution is constant, equal to Δf=1/T. It is a transformation with a bi linear structure and present a terms of correlations between both elements of plan time frequency of the signal. These terms of correlations are eliminated by passage in a complex signal which puts in zero all the party of the specter where frequency is negative. This signal is centered to reduce the energy of the specter to the neighborhood of 0Hz.

Moreover, the correct translation of the law of modulation of the signal depends on the correct choice of the length of the window of analysis, because this transformation introduces a compromise between temporal resolution and frequency resolution [8].

The choice of such analysis window (example: T = 3.2s ==> Δf = 0.3125 Hz) does not give a satisfactory result for all patients.

Therefore it is necessary to reduce the influence of this compromise in our results, and to choose a presentation which is free of any compromise between temporal selectivity and frequency selectivity.

Wigner-Ville Transform: Whereas, The Wigner-Ville transformation is a bi linear structure, which introduce better resolution than the spectrogram [9]. In effect, if the temporal signal is sampled in a step Ät, WVT will be sampled in a step Δt/2. This resolution is said degraded, because it is maximum for the central peak and decrease for neighboring frequencies.

The distribution of Wigner-Ville is the most concentrated distribution in a square module sense of time-frequency presentation; that's mean a distribution which the square module has a minimum booming [9].

The distribution of Wigner-Ville can be defined from the signal f (t) by WV(t, υ):

f(t) : temporal signal, f*(t): conjugate of f(t)

$$WVf(t,\nu) = \int_{-\infty}^{+\infty} f(t+\frac{\tau}{2}) f^*(t-\frac{\tau}{2}) e^{(-2i\pi\nu\tau)} d\tau$$

where also, from the spectrum F (υ) of the signal f (t):

$$WVf(t,\nu) = \int_{\infty} F(\nu+\frac{\eta}{2}) F^*(\nu-\frac{\eta}{2}) e^{(2i\pi\eta t)} d\eta$$

WV(t, υ) exist for all the physical signals of finite energy.

The size of the zone, on which the integration of WVT gives a significant result, is defined by the uncertainty relation of Heisenberg [9]:

T_f. $B_f \geq ½$

↙ ↘

length Spectral band

Combined on the time-frequency plan the uncertainty relation of Heisenberg is translated, for t0 and υ0 giving, by:

$$2\pi \int \left[\frac{(t-t_0)^2}{T} + T(\upsilon-\upsilon_0)^2 \right] w_f(t,\upsilon) dt d\upsilon \geq E$$

We point out that WV (t, υ) introduces a high frequency resolution around t = 0 [9]; and WVT weight more the samples located in the middle of the signal noticed by the analysis window.

In practice, the length of observation is often smaller than the complete length of the signal. To face up this problem, an advanced version of WVT, called Pseudo-Wigner-Ville transformation (PWVT) was offered; she allows to apply WVT to a section of the signal f (t) cut up by a window of observation w (t). It is defined by:

$$PWV_f(t,\nu) = WV_{ft}(t,\nu)$$

With $f_t(\tau) = f(\tau)\ w(t-\tau)$

The PWVT returns therefore in:

- The convolution of WVT in relation to frequency. More precisely, we have:

$$PWV_f(t,\nu) = \int_{-\infty}^{+\infty} WV_f(t,\xi)\, WV_w(0,\nu-\xi)\, d\xi$$

where the frequency function W (0, υ) is the WVT at instant t =0 of the window w (t).

- The use of a weighting window w (t).

We choose the window of Kaiser because she answers better demands of the Wigner-Ville transformation and allows having a broad main lobe and a quicker reduction of secondary lobes in μV / Hz.

So PWVT is a WVT smoothed version in the (υ) direction of (t-υ) plan. This has as consequences that:

- Small parasitic waves (term of correlation owed to the structure of the signal) in the frequency direction, presents in simple WVT, are attenuated by the window of Kaiser;
- PWVT introduces a shaded frequency resolution, in comparison with simple WVT, but keep always the same temporal resolution, since operation of convolution acts only on the direction of frequency. This is interesting in comparison with the spectrogram which provides a presentation in which frequency and temporal resolutions are always linked.

As it saw above, the PWVT has the effect of reducing the small parasitic ondulation present in the frequencies direction. However, the parasitic ondulation appearing in the PWVT can be reduced again while smoothing the PWVT, in the direction of time of the plan (t, f), from where the temporal convolution mono dimensional:

$$SPWVT_f(t,\nu) = \int_{-\infty}^{+\infty} p(t') PWV_f(t-t',\nu) dt'$$

where p(t) is a rectangular temporal window.

This Smoothed Pseudo Wigner – Ville transformation (SPWVT), can also be written under this shape:

$$SPWV_f(t,\nu) = \int_{\mathfrak{R}} q(\tau) \left\{ \int_{\mathfrak{R}} p(t-t') f(t+\tau/2) \times f^*(t'-\tau/2)\, d(t') \right\} e^{(-2i\pi\nu\tau)} d\tau$$

$q(\tau) = w(\tau/2)\ w^*(-\tau/2)$

The SPWV smoothed comes back to do a smoothing in the plan (t - f) separable in time and in frequency. We can permute the order of smoothing therefore and can proceed two ways:

- To smooth in the first the signal product rt(τ)=f(t+τ/2)xf*(t-τ/2) then make the PWVT of the product smoothed.
- To calculate the PWVT first and then do a temporal smoothing of the PWVT.

An adequate choice of the type and the size of each windows p(t) and q(t) permits to attenuate the parasitic ondulation distinctly often present in the simple WVT without destroying the structure of the signal [9]. This operation of time - frequencies filtering of the SPWVT is a means to make it positive in all point. It facilitates its interpretation like an energizing distribution.

Of this fact the WVT yields the place to the smoothed PWVT:

$$PWVL(n,k) = \frac{N-1}{n=0}\left\{\sum_{k'=0}^{M-1} w(n',k')H(n-n',k-k')\right\}$$

To get a SPWVT not enduring a recovery, we choose on the one hand the use a weighting window w(m) and on the other hand the passage to the analytic signal.

The analytic signal can be gotten:

- Either in the temporal domain (while doing a transformation of Hilbert of the signal).
- Rither in the frequency domain while putting to zero the values of the specter corresponding to the negative frequencies.

Either z(t), an analytic signal associated to f(t) [9]:

z(t) = f(t) + i Hf(t)

$$H_f(t) = \frac{1}{\pi} vp \int_{-\infty}^{+\infty} \frac{f(\tau}{t-\tau} dt$$

vp: main value to the sense of Cauchy.

The specter Z (υ) is given by Yue min Zhu, Francoise Peyrin and Goutte Robert [9]:

$$Z(\upsilon) = \begin{cases} 2\,F(\upsilon) \text{ si } \upsilon > 0 \\ F(\upsilon) \text{ si } \upsilon = 0 \\ F(\upsilon) \text{ si } \upsilon < 0 \end{cases}$$

We choose the discreet analytic signal calculated in the frequency domain as taking the TFD inverse of the specter defined by:

$$Z(k) = \begin{cases} 2\,F(k) \text{ for } k = 1, \ldots\ldots, M/2 - 1. \\ F(k) \text{ for } k = 0 \text{ ou } k = M/2. \\ 0 \text{ for } k = M/2+1, \ldots., M-1. \end{cases}$$

Otherwise the utilization of weighting window w (m) allows:

- The reduction of the amplitude of secondary lobes.
- The alteration of the breadth of the main lobe.
- The acceleration of the reduction of swing.
- The displacement of the frequency values for which W (m) =0.

The appropriate choice of the window is defined further to a certain number of parameters that they call face of deserve of the window and which are characterized by:

- A broad main lobe.
- A reduction of secondary lobes in μV/Hz.

Moreover, after comparison of different types of weighting window, we kept the window of Kaiser because she answers much sought-after demands.

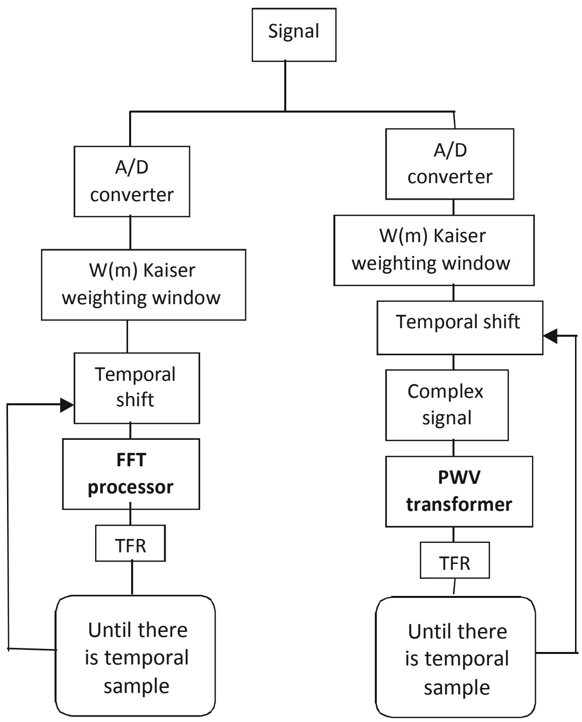
Moreover, we consider a centered signal and a kaiser window of period Tf = 3.2 s. Indeed, if we fix Tf = 1.6 s, the uncertainty relation of Heisenberg (Tf.Bf ≥ ½) is no longer satisfied and the result of the PWVT is erroneous. Finally, a temporal smoothing of 0.4 s is performed to attenuate periodic oscillations in the time domain.

The purpose of our work is to provide an additional tool for the study of visual bioelectrical signals and to allow a better investigation of the visual system. This will allow physiologists a better understanding of the mechanisms and structures of vision-specific nerve functions

MATERIALS AND METHODS

Visual evoked potentials (VEP) were measured for stimulation; by checkered reversal (30'), modulated at 5 Hz on a cathodic screen of luminance 35 cd / m2. Temporal responses are recorded continuously for 12.8s. Those are non-stationary low dynamic signals of about 10µV. They correspond to the acquisition of 2048 16-bit words, ie 8 K bytes of data for two collection channels (right and left Lobe). This time signal is sampled at a frequency equal to 160 Hz so a sampling rate Δt = 6.25 ms and the stimulation frequency is 5 Hz.

A feasibility study was first developed on non-real-time VEPs through the use of a microprocessor (Intel Core i3 CPU 2.53 GHz). These new methods of analysis require a large calculation volume that prompted us to implement them on a test bench equipped with a Digital Signal Processor (TMS320C30).



RESULTS

We can now appreciate the results of a comparison of two methods of analysis which each provide a complete time-frequency representation of visual evoked potential. on the one hand, the spectrogram defined by a fourier transform of a sliding analysis window on an analytical signal and which requires a compromise between time selectivity and frequency selectivity. this compromise is based on experimental data (attention period, noise level, signal level). on the other hand, the wigner-ville spectrum results from a product of convolution of an analysis window and its return, sliding on an analytical signal and which is freed from any compromise. the chosen analysis window is 6.4 s.

These results are stored in files in matrix form (m, p): m columns and p lines, each cell expresses energy at the I th second and J th frequencies of the initial signal; of the order of $10^5 \mu V$ / Hz for the Wigner-Ville spectrum and $10^4 \mu V$ / Hz for the spectrogram.

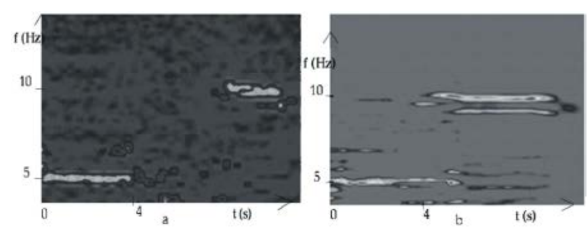
We can stop at the level of the spectrogram but it should be known that this method of analysis lends itself better for transient signals and not to non-stationary signals; it is necessary moreover that the duration of the signal is less than the duration of the window.

DISCUSSION

The results presented in this section were obtained in a normal and cooperating subject. The responses of both eyes were recorded at the same time using Glue Cupule electrodes for the active and reference electrodes. The subject was asked to close their eyes after 4 seconds of stimulation.

The sampling frequency of the temporel signal is 160 Hz, according to a step Δt, so the upper limit of frequency analysis of the signal can not exceed (40 Hz): fmax = 1 / (4Δt) (Frequency of Nyquist or Shannon and uncertainty of Heisenberg) [9].

Knowing that the electrophysiological response of the visual and encephalic system, for a normal subject, is located in a frequency band between 2.5 Hz and 12.5 Hz and that the stimulation frequency is 5 Hz [10], we chose to present the results analyzes on images (2.5: 12.5 Hz, 0: 12.8 s).



Results of a recording where the patient is very cooperative, the eyes are closed after 4 seconds of attention: a) Spectrum Wigner-Ville on time analysis window 6.4 s.
b) Spectrogram on time analysis window 6.4 s.

The analysis results show a better temporal resolution of the Wigner-Ville spectrum for a frequency resolution identical to both representations.

CONCLUSION

For a signal embedded in noise, interference, result of time-frequency analysis, is more important than the significant response. To overcome this problem, we consider the maximum energy and we take a very important analysis window. But the temporal resolution is affected and becomes very weak. As the PWVT has a temporal resolution twice as fine as the spectrogram, we choose a very important analysis window. Thus we have a good frequency resolution which allows to observe clearly the evolution over time of the significant frequencies while ensuring a clear attenuation of the neighboring frequencies.

As a result, the Pseudo-Wigner-Ville transform can be used to characterize the transfer and modulation function of the visual system from the VEP.

Indeed, the PWVT allows a better attenuation of the parasite and gives a very significant evolution of the energy conveyed by the signal; such small changes are reduced in time and amplitude.

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