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Abstract - Currently, digital processing techniques have been applied in the determination of flicker obtained from electroencephalogram (EEG) signals. However, a deterministic comparison in the search for dominant frequencies determining gestural movements has not been proposed.

The purpose of the following study is to determine patterns generated by 6 gestural movements: Opening / Closing - Eye, Opening / Closing - Mouth, Concentration, Meditation, Up / Down Eye Movement and Left / Right Eye Movement recorded on the prefrontal area at N_z , applying nonparametric spectral estimation techniques, using the Fast Fourier Transform (FFT), Barlett's periodogram and Welch's periodogram.

External measurements were performed on 30 subjects in the age range of 18 to 22 years. The results show frequencies in the Delta 0.5-3.5 Hz) and Alpha (4-7 Hz) biosignal range applying the FFT method and Bartlett's periodogram, showing the same result in dominant frequencies and amplitude variations (PSD).
However, it is not recommended to use the Welch periodogram applying a rectangular window larger than 4, generating attenuation in the harmonics.

Keywords: *Delta biosignal, EEG, Nonparametric methods, Prefrontal Surface.*

Abstract -- Currently, digital processing techniques have been applied in determining the flicker obtained from electroencephalogram (EEG) signals. However, a deterministic comparison in the search for dominant frequencies has not been proposed determining gestural movements. The purpose of the following study is to determine patterns generated by 6 gestural movements: Opening / Closing - Eye, Opening / Closing-Mouth, Concentration, Meditation, Eye Movement Up / Down and Left / Right Eye Movement recorded in the prefrontal area in the point N_z , applying nonparametric spectral estimation techniques, using the Fast Fourier Transform (FFT), Barlett's periodogram and Welch's periodogram.
For this purpose, externally measurements were made to 30 subjects in the age range of 18 to 22 years. The results show frequencies in the range of the Delta (0.5-3.5 Hz) and Alfa (4-7 Hz) biosignal applying the FFT method and Bartlett's periodogram showing the same result in dominant frequencies and variations in amplitude (PSD). However, Welch's periodogram is not recommended use by applying a rectangular window greater than 4, generating attenuation in the harmonics.

Key words - *Delta Biosignal, EEG, Nonparametrics methods, Prefrontal surface.*

INTRODUCTION

The analysis of patterns in EEG signals allows the execution of movements in bionic prostheses helping people who have suffered amputations or have a disability. Therefore, it is relevant to have a database to determine by means of a spectral-statistical analysis the biopotential patterns involved in the execution of movements.

Preliminary research has proposed studies on brain signals determining patterns by applying noninvasive methods in capturing brain electrical activity. Li *et al* [1], [2] have proposed spectral techniques that provide better spectrum estimation and resolution.

At present, several studies have compared the FFT [3],[4] Barlett's Periodogram and ARMA (Autoregressive Moving Average Model) [5] in the determination of the flicker, presenting an optimal model in obtaining the spectrum and improving resolution.

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However, a deterministic comparison has not been proposed in the search for dominant frequencies for the determination of gestural movements, such as: Eye Opening/Closing, Mouth Opening/Closing, Concentration, Meditation, Upper/Lower Eye Movement y Movement eye movement Left/Right, These gestural movements are the main cause of errors in clinical studies, due to intrinsic execution by patients.

As a result, the original signal is altered and the study spectrum is modified, generating ambiguity in the determination of diseases such as: dyslexia, epilepsy, psychological alterations, stress tests, wakefulness, among others [6], [7].

The present study and analysis process aims to perform a spectral decomposition by analyzing the dominant frequencies and maximum frequency weights [8], selecting by statistical data the appropriate nonparametric technique in the determination of the 6 gestural patterns, comparing the FFT, Barlett periodogram and Welch periodogram. In addition, the original sampled signal is presented by visualizing electrical characteristics and waveforms [9].

DEVELOPMENT

Materials and methods

We used data from 30 subjects in the range of $18a$ 22 years old, 21 males and 9 females, performing 6 facial movements, capturing 30 sessions by movement in a span of $10s$ per session in a single channel, presenting a total of $300s$ per movement in a single channel. each subject and an analysis time equal to $9000s$ by movement in the 30 subjects.

The equipment used is based on a retractable headband of the brand Neurosky Mindwave MW003, with a sampling frequency (F_s) equal to $512Hz$ and a resolution of $16bits$, capturing 5120 samples on $10s$. We use a dry contact electrode of chloride silver [10] with an accuracy of 95 % with respect to surgical electrodes.

The equipment consists of a Butterworth low-pass filter with a -60 dB with f_c equal to $60Hz$ with a stage of amplification and A/D conversion [11].

The reception and processing of data was performed in the software software Matlab R2015b software. The actions of pairing of the headband with the station of carried out within the first 2 seconds of reception. Frequency overlap was performed. selecting 6 to 7 random spectral responses in each subject for a total of 200 tests to be evaluated.

Discrete Fourier Transform linear transformation

The DFT (Discrete Fourier Transform) is described as:

$$X(\omega) = \sum_{n=-\infty}^{\infty} x(n) e^{-j\omega n} \quad \text{Eq. (1)}$$

Where (ω) represents the vector in frequency bounded in (-∞, ∞) , x(n) is the encephalic signal followed by a preprocessing step. The expression $e^{-j\omega n}$ is replaceable by:

$$e^{-j\alpha} = \cos(\alpha) - j sen(\alpha) \quad \text{Eq. (2)}$$

The model shown in (1) is linearized as:

$$X_k = \sum_{n=0}^{N-1} x(n) W_N^{kn}, \ k = 0,1 \dots, N-1 \quad \text{Eq. (3)}$$

$$W_N = e^{-\frac{j2\pi}{N}} \quad \text{Eq. (4)}$$

Where:

N is the length of the sample vector x(n). W_N is the complex matrix of dimension NxN represented as:

$$W_N = \begin{bmatrix} 1 & 1 & 1 & \dots & 1 \\ 1 & W_N & W_N^2 & \dots & W_N^{N-1} \\ 1 & W_N^2 & W_N^4 & \dots & W_N^{2(N-1)} \\ \vdots & \vdots & \vdots & \dots & \vdots \\ 1 & W_N^{N-1} & W_N^{2(N-1)} & \dots & W_N^{(N-1)(N-1)} \end{bmatrix} \quad \text{Eq. (5)}$$

Equations Eq.(3), Eq.(4) and Eq.(5) can be expanded as follows:

$$\begin{aligned} X(0) &= x(0) e^{\frac{-j2\pi(0)(0)}{N}} + x(N-1) e^{\frac{-j2\pi(N-1)(0)}{N}} \\ X(1) &= x(0) e^{\frac{-j2\pi(0)(1)}{N}} + x(N-1) e^{\frac{-j2\pi(N-1)(1)}{N}} \\ X(2) &= x(0) e^{\frac{-j2\pi(0)(2)}{N}} + x(N-1) e^{\frac{-j2\pi(N-1)(2)}{N}} \\ &\vdots \\ X(N-1) &= x(0) e^{\frac{-j2\pi(0)(N-1)}{N}} + x(N-1) e^{\frac{-j2\pi(N-1)(N-1)}{N}} \end{aligned} \quad \text{Eq. (6)}$$

To implement, a change is made $e^{\frac{-j2\pi nk}{N}} = \cos\left(\frac{-2\pi kk}{N}\right) + j sen\left(\frac{-2\pi nk}{N}\right)$ obtaining the magnitude operation is $|X(k)|$ and spectrum phase $\angle X(k)$.

Fast Fourier Transform

Applying the base algorithm 2 shown in [12], [13], [14] where N is the number of samples equal to 5120.

$$X_k=\sum_{n=0}^{N-1} x(n)W_N^{kn},\ k=0,1,\dots,N-1 \quad \text{Eq. (7)}$$

$$X(k)=\sum_{n\,par} x(n)W_N^{kn}+\sum_{n\,impar} x(n)W_N^{kn} \quad \text{Eq. (8)}$$

$$X(k)=\sum_{m=0}^{(\frac{N}{2})-1} x(2m)W_N^{2mk}+\sum_{m=0}^{(\frac{N}{2})-1} x(2m+1)W_N^{k(2m+1)} \quad \text{Eq. (9)}$$

Eq.(8) divides two subsets with N/2, where $F_1(k)$ and $F_2(k)$ expresses the even and odd series. The equation Eq.(6) implies the symmetry property $W_N^2=W_{N/2}$. The equation Eq.(9) can be expressed as:

$$X(k)=\sum_{m=0}^{(\frac{N}{2})-1} f_1(m)W_{\frac{N}{2}}^{km}+W_N^k\sum_{m=0}^{(\frac{N}{2})-1} f_2(m)W_{\frac{N}{2}}^{km} \quad \text{Eq. (10)}$$

$$F_1(k)+W_N^kF_2(k),\quad k=0,1,\dots,N-1 \quad \text{Eq. (11)}$$

The length of the vector is transformed into two vectors of data $f_1(m)$ and $f_2(m)$ obtaining two *DFTs* reducing the processing time $0 \leq m \leq N/2$.

$$X(k)=F_1(k)+W_N^kF_2(k),\ k=0,1,\dots,\frac{N}{2}-1 \quad \text{Eq. (12)}$$

$$X\left(k+\frac{N}{2}\right)=F_1(k)-W_N^kF_2(k),\ k=0,1,\dots,\frac{N}{2}-1 \quad \text{Eq. (13)}$$

Spectral Power Density

The *PSD* (Power Spectral Density) is analyzed from the expression of the energy as:

$$E=\int_{-\infty}^{\infty}|X_a(t)|^2dt<\infty \quad \text{Eq. (14)}$$

E represents the energy, $X(t)$ the function in the time, contemplates the area under the curve of the function. The signal sampling modifies the expression

$$X_a(F)=\int_{-\infty}^{\infty} x_a(t)e^{(-j2\pi Ft)}dt \quad \text{Eq. (15)}$$

In equation Eq.(15) $X_a(F)$ represents the vector in frequency. Applying Parserval's Theorem, the power of the signals is corroborated to be equal to the sum of its components.

$$E=\int_{-\infty}^{\infty}|x_a|^2dt=\int_{-\infty}^{\infty}|X_a(F)|^2dF \quad \text{Eq. (16)}$$

$$S_{xx}(F)=|X_a(F)|^2 \quad \text{Eq. (17)}$$

Where $S_{xx}(F)$ represents the sum of the harmonics expressed in spectral power and $|X_a(F)|^2$ is the squared modulus of the Fourier transform of the vector $x_a(t)$. The autocorrelation $R_{xx}(\tau)$, obtained by the multiplication of two functions where $x_a(t+\tau)$ represents the displacement in τ of the sampled vector by evaluating it in the interval $(-\infty,\infty)$.

$$R_{xx}(\tau)=\int_{-\infty}^{\infty} x_a^*(t)x_a(t+\tau)dt \quad \text{Eq. (18)}$$

$$S_{xx}(F)=|X_a(F)|^2=\int_{-\infty}^{\infty} R_{xx}(\tau)e^{-j2\pi F\tau}d\tau \quad \text{Eq. (19)}$$

Bartlett Periodogram

The variance reduction is based on subdividing the data sequences $x(n)$ in a number of non-overlapping windows M by overlapping the windows when applying the DFT.

$$P_{xx}^{(i)}(f)=\frac{1}{M}\left|\sum_{n=0}^{M-1}x_i(n)e^{-j2\pi fn}\right|^2\quad i=0,1,\dots,K-1 \quad \text{Eq. (20)}$$

$$P_{xx}^B(f)=\frac{1}{K}\sum_{i=0}^{K-1}P_{xx}^{(i)}(f) \quad \text{Eq. (21)}$$

The periodogram by segments is expressed in Eq.(20), where $P_{xx}^{(i)}(f)$ represents the PSD in each segment of length M, the DFT is denoted by $x_i(n)e^{(-j2\pi fnfn)}$. The Barlett periodogram is expressed in equation Eq.(21) representing $P_{xx}^B(f)$ as the average of each segment i from $0 \leq i \leq$ K-1 for all M windows.

$$E[P_{xx}^B(f)]=\frac{1}{K}\sum_{i=0}^{K-1}E[P_{xx}^{(i)}(f)]=E[P_{xx}^{(i)}(f)] \quad \text{Eq. (22)}$$

Welch's Periodogram

Starting from Eq.(22) the Welch periodogram is represented as:

$$P^{(i)}_{xx}(f) = \frac{1}{MU}\left|\sum_{n=0}^{M-1} x_i(n)\,w(n)\,e^{(-j2\pi f n)}\right|^2$$

$i = 0,1,\dots,L-1$ Eq. (23)

Where $P^{(i)}_{xx}(f)$ defines the modified periodogram, M the segment window length, U the normalization for $w(n)$. The constant U can be calculated as:

$$U = \frac{1}{M}\sum_{n=0}^{M-1} w^2(n) \quad \text{Eq. (24)}$$

$$P^{W}_{xx}(f) = \frac{1}{L}\sum_{i=0}^{L-1} \tilde{P}^{(i)}_{xx}(f) \quad \text{Eq. (25)}$$

The term of Eq.(25) where $(P^{W}_{xx}f)$ is the result of Welch's periodogram in PSD estimating the harmonics present in the spectrum. The expanded equation of the periodogram is specified in Eq.(26).

$$E[P^{(i)}_{xx}(f)] = \frac{1}{MU}\sum_{n=0}^{M-1}\sum_{m=0}^{M-1} w(n)\,w(m)\,E[x_i(n)\,x_i^{*}(m)]\,e^{-j2\pi f(n-m)} \quad \text{Eq. (26)}$$

DISCUSSION AND ANALYSIS OF RESULTS

Original signal and FFT processing

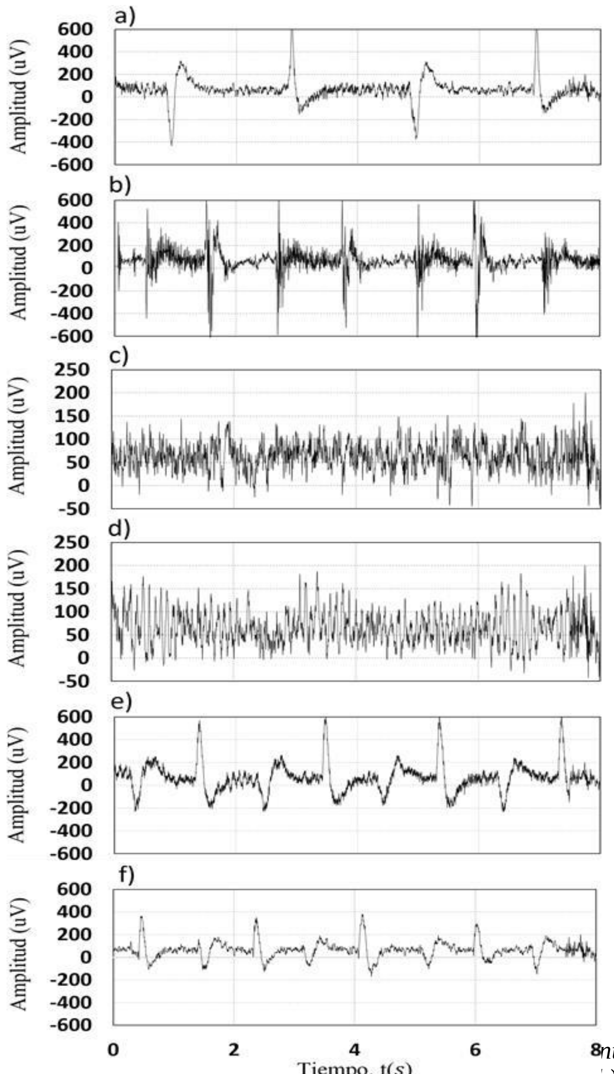
Figure 1 shows the original EEG signals sampled at the time span of 0 < t < 8s, representing their waveform, µV magnitude and time.

(s) applying 6 movements: Eye Opening/Closing (Φ), Mouth Opening/Closing (Ψ), Concentration (Ω), Meditation (Ξ), Upper/Lower Eye Movement (Θ) and Left/Right Eye Movement (Γ) (**8**).

The tests in Figures a), b), e) and f) show a range (Vmax - Vmin) in amplitude of ±600 µV in all 30 subjects. The decrease in magnitude was considered in Figure 1(c) and (d) limiting the range in 250 to - 50 µV.

It is worth noting that the patterns visualized in the 30 subjects in each test present a similar response.

Figure 2 shows the spectral responses performed on the 30 subjects applying 200 trials on each plotted movement, showing the evolutions and overlapping harmonics by observing the effect of the mean (PSD) in all sessions in Delta. The dashed gray line specifies the average of the test set. The resolution computed by the Fs and N allows to decompose the vector x(n) at frequencies higher than 0.1 Hz.



...nts captured in subject 1: a) Eye Opening/Closing (Φ), b) Mouth Opening/Closing (Ψ), c) Concentration (Ω), d) Meditation (Ξ), e) Movement Superior/Inferior ocular movement (Θ) and f) Left/Right ocular movement (Γ).

Figure 2(a) shows 4 weighted frequencies found in $\Phi_f = 0.2$ Hz, $\Phi_2 = 0.7$ Hz, $\Phi_3 = 1.2$ Hz and $\Phi_4 = 1.7$ Hz in the frequency range of 0.5 to 2 Hz, similarity throughout the course in frequency $X(\omega)$, at higher frequencies random encephalic activity (concentration) variations are obtained, as mentioned in [15]. Figure 2(b) presents abrupt variations at $\Psi_1 = 0.9$ Hz, $\Psi_2 = 1.8$ Hz, and $\Psi_3 = 2.7$ Hz. Fig. 2(c) contains encephalic activity. random. Figure. 2(d) locates harmonics in the Alpha(**12**) range, obtaining variations in frequency in the interval ΔΞ= 9.6 - 11.6 Hz, presents harmonics at $f_{\Theta(1)}$ = 0.5 Hz, f_2 = 1.5 Hz and f_3 = 2.5 Hz frequencies higher than 11.6 Hz decrease in magnitude, lower than

9.6 Hz remain constant. Figure 2(e) present harmonics f_1 = 0.5 Hz, f_2 = 1.5 Hz and f_3 = 2.5 Hz shown in the averaged signal, the weightings show an increase of 1 Hz in each interval, noting a multiple in frequency [16], the PSD (dB) is within the range of 18.4 to - 10 dB, the harmonics are found in the Delta biosignal. Figure 2(f), does not present defined harmonics in the signal.

average.

Choice of window in Welch's periodogram

Technique selection was performed by overlapping 200 frequency responses for the Eye Opening/Closing movement, showing the working range of the Delta biopotential. Figure 3(a) and (b) shows the average frequency response of each processing technique evaluated in the 30 subjects. Figure 3(a) compares the rectangular w(n) window applying a number of segments 2,4,8,16 and 32. The magnitude S (*F*) exhibits characteristics of its own in $E[P^{B}_{xx}(f)]$ as mentioned in [17], the window

rectangular in $E[P_{xx}(f)]$ attenuates the frequency response w(n) = 8 and w(n) = 32 deforms the frequency response w(n) = 8 and w(n) = 32.

frequency given the overlap. Figure 3(b) shows the processing of the Welch periodogram by applying a Hanning window.

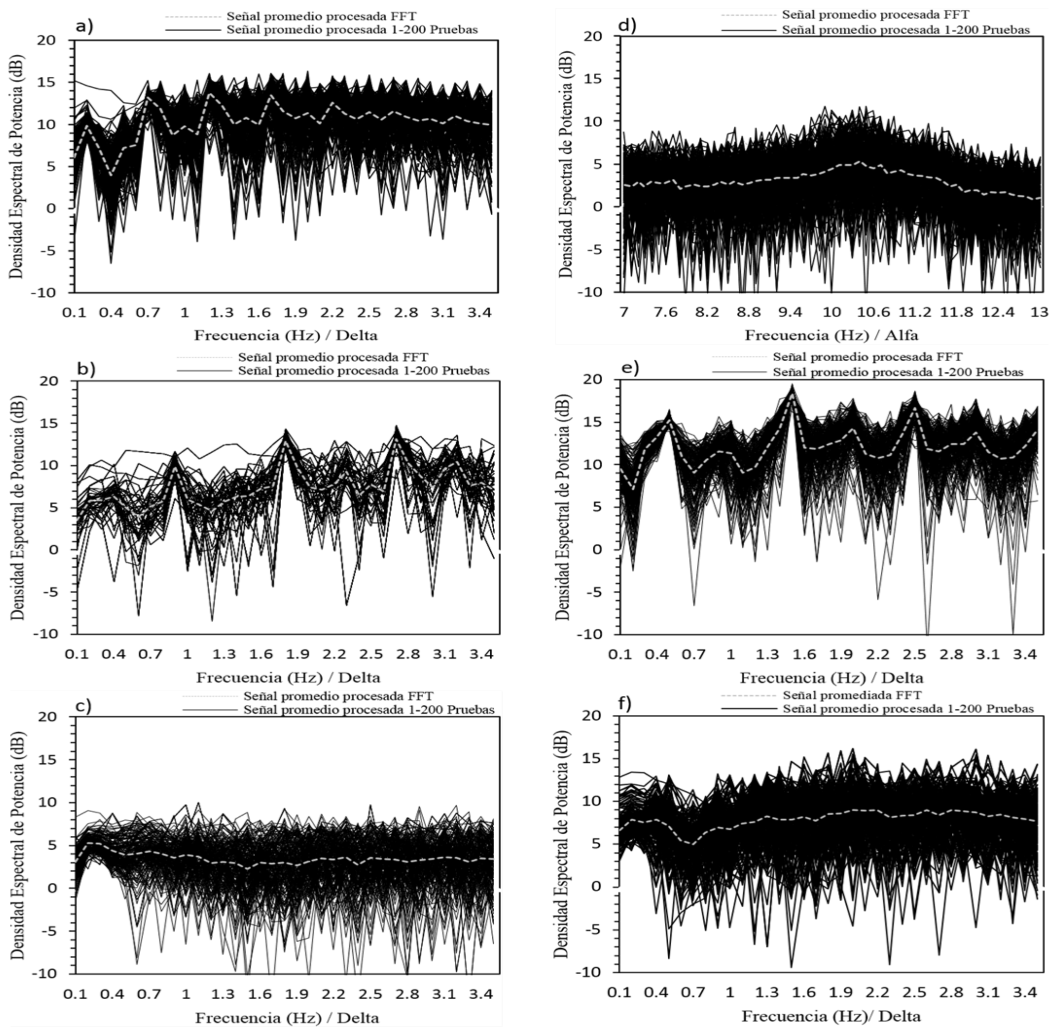


Figure 2: Processing applying Fast Fourier Transform on 6 movements considering 200 trials in 10 s, at the intervals (N=5120, 0.5≤ Δ≤ 3.5 Hz, 7≤ α≤ 13 Hz-Meditation): a) Eye Opening/Closing (Φ), b) Mouth Opening/Closing (T), c) Concentration ( ), d) Meditation ( ), e) Upper/Lower eye movement (ϑ) and f) Left/Right eye movement ( ).Γ

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The comparison in the results shown Figure 3(a) and 3(b) present a better spectral estimation in the rectangular window with w(n) = 4.

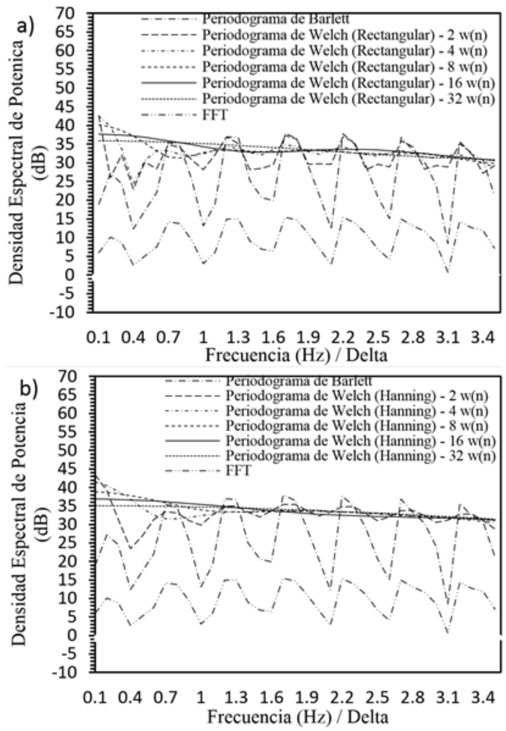

Figure 3: Average signals (frequency overlap): a) FFT, Barlett's periodogram, Welch's periodogram with rectangular enveloping and b) FFT, Barlett's periodogram, Welch's periodogram with hanning enveloping. Application of 2-4-8-16 and 32 segments.

Maximum weighted frequencies

Figure 4 shows the evolution over time of the maximum amplitude values in frequency corresponding to 2000 seconds in the 30 subjects evaluated. The Figure 4(a) exposes major concentration at $\Delta\bar{\Phi}$ = 1.2 and 1.7 Hz in FFT [17] and Barlett's periodogram, Welch's technique obtains at $\Delta\bar{\Phi}$ = 0.8 and 1.3 Hz. Figure 4(b) exhibits the harmonics $\bar{\Psi}$ =2.7 Hz in FFT and Barlett periodogram. However, Welch's technique exhibits frequencies at $\bar{\Psi}$ = 2.3 Hz. Figure 4(c) exhibits a spread in the spectrum, it does not show significant weightings. Figure 4(d) exhibits 1 harmonic at 0.1 Hz resulting from FFT, Bartlett and Welch processing.

The comparison in the results shown in Figure 3(a) and 3(b) present a better spectral estimation in the rectangular window with w(n) = 4.

Figure 4(e) presents a frequency weighted at 1.3 Hz in the application of the FFT and Barlett, the Welch periodogram technique obtained as a result a harmonic at 1.1 Hz. Figure 4(f) presents an unrelated spread with a constant pattern around a reference frequency in the FFT and Barlett technique, the Welch technique presents a 0.1 Hz frequency component similar to Figure 4(c).

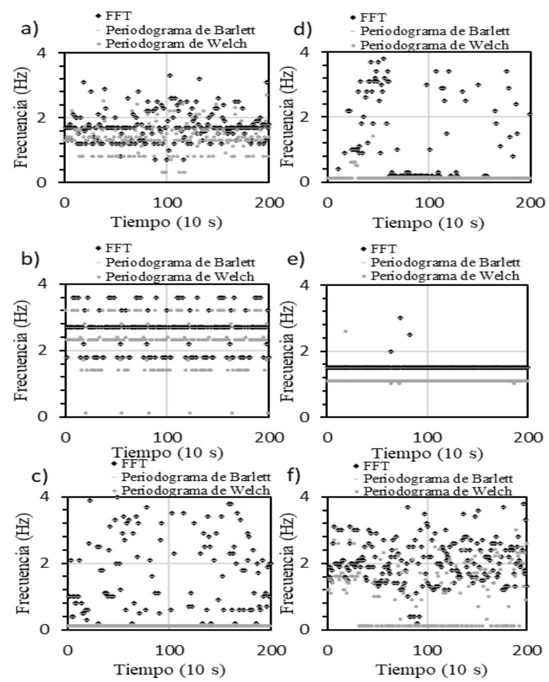

Figure 4: Variation of maximum frequencies. A) Eye Opening/Closing ($\bar{\Phi}$), B) Mouth Opening/Closing ($\bar{\Psi}$), C) Concentration ($\bar{\Omega}$), D) Meditation ($\bar{\Xi}$), E) Eye Movement.

Top/Bottom ($\bar{\Theta}$) and F) Eye movement Left/Right ($\bar{\Gamma}$).

Statistical analysis

The FFT shows less deviation in the set of processed sessions, the Barlett periodogram shows a higher mean in PSD with variations close to 2 times the FFT, the Welch periodogram with rectangular window shows less variation compared to Barlett (Table 1). The maximum spectra in the FFT and Barlett's periodogram show identical results. The Welch periodogram shows variations in maximum frequencies (Table 2). Eye movements exhibit less deviation.

❖ Table 1. *Overall analysis of the statistical result in PSD, (mean± standard deviation)* *applied to the 200 sessions in FFT, Barlett's Periodogram and Welch's Periodogram.*

	Φ	¯Ψ	Ω	¯Ξ	¯Θ	Γ
FFT	10.291 ± 1.420	7.378 ± 1.689	3.486 ± 0.461	3.036 ± 0.856	12.075 ± 1.556	7.896 ± 0.704
Barlett	27.571 ± 2.841	21.549 ± 3.559	13.961 ± 0.923	13.061 ± 1.713	31.140 ± 3.113	22.782 ± 1.409
Welch	30.835 ± 1.945	18.323 ± 4.109	24.910 ± 3.536	14.704 ± 1.634	26.181 ± 1.783	34.090 ± 2.606

❖ Table 2. Overall analysis of the statistical result of the maximum peaks in frequency (Hz), (mean± standard deviation) in the application of FFT, Barlett's Periodogram and Welch's Periodogram.

	Φ	¯Ψ	Ω	¯Ξ	¯Θ	Γ
FFT	1.733 ± 0.329	2.684 ± 0.391	3.930 ± 2.554	6.059 ± 4.298	1.515 ± 0.029	2.053 ± 0.506
Barlett	1.733 ± 0.329	2.684 ± 0.391	3.930 ± 2.554	6.059 ± 4.298	1.515 ± 0.029	2.053 ± 0.506
Welch	1.332 ± 0.298	2.160 ± 0.493	0.1 ± 6x10-9	0.314 ± 0.404	1.106 ± 0.014	0.953 ± 0.791

CONCLUSIONS

This study has proposed a spectral analysis applied to EEG signals for the determination of gestural movements using a single measurement channel. In the analysis it was found that the FFT and Barlett's periodogram are functional nonparametric techniques in the determination of the spectrum.

The distribution of dominant frequencies (Hz) leads to an equivalent statistical result presenting differences in amplitude (PSD). However, the Welch periodogram does not show a favorable result, the averaging performed by the method generates frequency distortion altering the maximum weightings. Therefore, it is not recommended in the study of EEG signals.

Gestural movements exhibit unique frequency weightings in Delta and Alpha biopotentials. The application of non-parametric digital processing techniques in determining the frequency spectrum The interacting showed a good contrast with regard to measurements at N_z . The frequencies present at 0.8, 1.7. 2.6 Hz in Opening/Closing of 0.5, 1.5 and 2.5 Hz viewed in Mouth Opening/Closing and 0.7, 1.2, .7 Hz viewed in Upper/Lower Eye Movement present higher magnitude giving the possibility to design digital or analog filters for the purpose of attenuate unwanted harmonics, allowing medical studies to be performed without disturbance or incident noise in the encephalic electrical signal.

FUTURE JOBS

Future work is focused on the use of the described method in a system based on an upper limb prosthesis and a single electrode headband. Having identified the gesticular movements through the devices mentioned above, it is intended to open and close a prosthesis of a hand instantaneously without having to concentrate to achieve it. With the purpose of not having to spend much time in the training process that is normally done in most projects of this type, having to concentrate to be able to perform a movement of the prosthesis, which in certain cases makes it desperate for the user.

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