ABSTRACT

The Brain Computer Interface technology allows the communication between people and mechanical devices controlled by microprocessors [1] [8]. It translates the human mental activity into device commands. The kernel of this technology is an algorithm that takes samples, filters and classifies the electro-encephalographic signal [2] [3] [4] [5].

In this paper, different types of filtering windows are considered, the main objective is to determine the type of window with best results in the discrimination stage, when the user is thinking about different activities; as secondary result the most relevant features are extracted.

With an earlier and better discrimination the classifier would be easier to implement, faster and more reliable[14].

KEY WORDS


1. Introduction

This article is focused on the applicability of Brain Computer Interface technology[1]. BCI is aimed to communicate human beings with computers, or other kind of devices controlled by microprocessors, using the electro-encephalographic signal as a source of commands to the external elements [2-5].

This new technology is useful for people with some type of motor disability; it does not need to perform any kind of movement, it is also useful in those cases when the operator is handling another devices and he has not got any other way to communicate the response.[5][8][9]

In order to obtain this objective it is necessary to associate some mental patterns with commands on the external device, so an algorithm that detects, acquires, filters and classifies the human electro-encephalographic signal is required.[1-5]

Different kind of algorithms have been proposed based on: neural networks[2-5,7], Bayesian classification [6], stochastic complexity measures[8], etc. In all of them a first pre-process stage is considered. In this stage the signal is amplified and filtered in the time domain, after that, the signal is sampled and quantified, these samples are bundled in packages of fixed size. These packages are analyzed to extract features that allow both the identification and the classification of the original mental pattern.

Generally all samples of the package are equally weighted, this process is equivalent to the convolution of the signal with a rectangular window.

In most of the cases the identification of the mental pattern is done using the frequency components of the signal[4-8], so it is necessary to take in consideration the effect of the window in the convolution with the signal, and if it is possible to choose the window which offers the best results.

In this article are described seven different types of windows: rectangular, triangular, Hamming, Hanning, Blackman, Kaiser and Tukey. It is studied the effect over the pattern identification and classification; in the same way the experimental process, equipment and methodology is briefly explained[12]. This paper emphasizes the importance of the pre-process signal stage in the rest of the phases of a BCI algorithm. With the use of a window which gets good separability between mental patterns, the classifier will be easier, faster and the results more reliable.[14]

2. Experimental procedure

The tests described below were carry out with a trained subject, under controlled conditions to avoid distractions, between 10:00 a.m. and 14:00 p.m. The subject was sat-down in front of the acquisition system monitor, at 50 cm from the screen, their hands were in a visible position, the supervisor of the experiment controlled the correct development of it. To minimize interferences, the neighbour equipments were switched off.[13]
2.1 Methodology and equipment

The experimental process is showed on figure 1.

**Test of system devices.** Checks the correct level of battery, and the physical state of the electrodes: active surface and connection plugs.

**System assembly.** Device connections: electrodes, battery, bio-amplifier, acquisition signal card, computer.

**System test.** Verification of the correct operation of the whole system. To minimize noise from the electrical network the Notch filter (50Hz) of the bio-amplifier is switched on.

**Subject preparation for the experiment.** The electrodes are applied to the subject’s head. The electrode zones were previously cleaned and conductive gel was applied in them. After the electrodes were fixed an impedance test was carried out to confirm a good conductivity, the impedance must be less than 4 KOhms.

**System initialization and setup.** Verification of the data register. The temporal signal evolution is monitored, in the spectrogram should appear a very low 50 Hz component.

**Experiment setup.** The supervisor of the experiment sets-up the number of replications and the quantity of different mental activities. The duration of each trial is \( t = 7 \) s, the acquisition frequency is \( f_s = 384 \) Hz. The system suggests to the subject to think about the proposed mental activity. A short relax is allowed at the end of each trial; between replications the relax time is \( t = 7 \) s.

The equipment used in the experiment was:
- Superficial electrodes. Grass Au-Cu.
- Bio-amplifier. Made by: g.tec. Model: g.BSamp.
- Computer. Pentium II. 166 MHz. 64 MB. Matrox G-200.

2.2 Position of the electrodes

The electrodes were placed in the central zone of the skull, next to C3 and C4[13]\(^4\), two pairs of electrodes were placed in front of and behind Rolandic sulcus, this is one of the zones with highest discriminant power, it takes signal from the motor and sensory areas of the brain [2-10]. The reference electrode is placed over right mastoid, and two more electrodes are placed near to the corner of the eyes to register blinking or any other muscular activity on the eye zone. The location of the electrodes are shown on the next photographs.

**Figure 2. Electrode placement.**

2.3 Description of the mental activities

The supervisor of the experiment asks to the subject to figure out the following mental activities, these activities will be the cerebral patterns to differentiate among them[6][9].

**Activity A. Mathematical task.** Recursive subtraction of a prime number, i.e. 7, from a big quantity, i.e. 3,000,000.

**Activity B. Movement task.** This task is subdivided in:

- **B-1 Movement imagination.** The subject is instructed to figure out that their limbs or hands are being moved, but without the materialization of the movement.

- **B-2 Movement realization.** The subject is able to move their hands.

**Activity C. Relax.** The subject is relaxed, thinking in nothing.

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\(^{1}\) \(N_{rep} = 10\)
\(^{2}\) See section 4.3

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\(^{3}\) Terminology of the International 10-20 System

\(^{4}\) The two differential electrodes placed in front of and behind C3 make up channel one, meanwhile the other two electrodes placed in front of and behind C4 constitute channel two.

\(^{5}\) This task is only to check the operation of the system.

\(^{6}\) This task registers the basal line of the subject.
3. Algorithm

The steps followed to study the effect of the filtering window on the separability of cerebral patterns are shown in the figure 3.

![Algorithm](image)

3.1 Window analysis generator

In this block the registered signal is chopped in packages of samples, similar to the bundles of samples obtained from an acquisition card in an on-line BCI application.

The number of samples in each package is a compromise between the goodness of the classification and the amount of time taken by this classification. An algorithm with very good classification and low number of mistakes will take a very big package, so the time between classifications will be also very big, it will do the algorithm useless for a real on-line BCI system, neither a very fast algorithm with small packages of samples but with a high number of mistakes will be useful.

In this work we have considered packages of 128 samples, the sample frequency is $F_s = 384\text{Hz}$, and the classification latency is $t = \frac{1}{3}\text{s}$.

The duration of each activity is 7s, so there will be 21 classifications obtained from each register, no overlap between windows have been considered.

3.2 Standardization

To compare the signal of different sessions is necessary to standardize the samples, avoiding for example that variations in the impedance of the electrodes changes the classification result.

The standardization of each analysis window consists in the subtraction of the average value and the division by the standard deviation.

$$
\mu = \frac{\sum_{i=1}^{N} x_i}{N}, \quad \sigma^2 = \frac{(x - \mu)^2}{N}
$$

$$
x' = \frac{x - \mu}{\sigma}
$$

3.3 Windowing

In this block different kind of windows are convoluted with the standardize signal.

The frequency leakage effect occurs when signals with low frequency components are chopped or convoluted with windows with sharp edges, in this cases in the spectrogram appears high frequency components.[12]

![Leakage effect](image)

In figure 4 is displayed, in the frequency domain, the influence of the convolution of a rectangular window with the signal to process, to minimize this effect different types of windows, with softer edges, have been proposed.

**Rectangular window.**

$$
h(n) = 1, \quad 0 \leq n \leq M - 1.
$$

**Triangular or Bartlett’s window.**

$$
h(n) = \frac{2n - M - 1}{M - 1}, \quad 0 \leq n \leq M - 1.
$$

**Hanning’s window.**

$$
h(n) = 0.54 - 0.46\cos\left(\frac{2\pi n}{M - 1}\right), \quad 0 \leq n \leq M - 1.
$$

**Blackman’s window.**

$$
h(n) = 0.42 - 0.5\cos\left(\frac{2\pi n}{M - 1}\right) + 0.08\cos\left(\frac{4\pi n}{M - 1}\right), \quad 0 \leq n \leq M - 1.
$$

**Kaiser’s window.**

$$
h(n) = I_0\left[\frac{\alpha}{2\sqrt{(M - 1)^2 - (n - M - 1)^2}}\right], \quad 0 \leq |n - \frac{M - 1}{2}| \leq \frac{M - 1}{2}.
$$

**Tukey’s window.**

$$
h(n) = \frac{1}{2}\left[1 + \cos\left(\frac{n - (1 + \alpha)(M - 1)/2}{M/2}\right)\right], \quad \alpha(M - 1)/2 \leq |n - \frac{M - 1}{2}| \leq \frac{M - 1}{2}.
$$

![Rectangular and Triangular windows](image)

![Hamming’s Hanning’s and Blackman’s windows](image)

$^7M = \text{length of the filtering window}$
3.4 FFT

The cerebral activity becomes apparent mainly through the frequency components of the electro-encephalographic signal. Different kinds of mental activities have different frequency components[13]. For this reason it is necessary to transform the sampled time domain signal to frequency domain, to do this a Fast Fourier Transform of 2\(^7\) is used.

Having in mind that the sample frequency is 384Hz, the frequency resolution is:

\[
\Delta f = \frac{384Hz}{128} = 3Hz.
\]

In this application the useful information is in the amplitude of the frequency components, so the phases are discarded, we focus our attention on the spectrograms of each of the analysis windows.

Considering the properties of the Fourier Transform and having in mind that the signal in the time domain only have real components, in the Nyquist frequency is produced the reflection effect, so the signal information is in the first halve of the components[13].

3.5 Feature selection

A vector of features is extracted from each signal analysis window. This vector[11] is made up by the mean of the coefficients of the frequency bands considered as follows:\(^8\)

Owing to the frequency of normal human brain is under 40-50Hz only frequencies between 6 and 38Hz have been considered.

3.6 Statistical analysis

Bilateral contrasts between two population are used to determine if there is evidence of statistical difference between the population of features obtained from each mental activity. Each component of the vector is considered to determine its significance and separability power.

These contrasts were done once for each type of window.

To apply the bilateral contrast of two populations is necessary to test the equality of their variance; if the two populations have different variance, it is necessary to apply a correction factor in the degrees of freedom.

- **Bilateral contrast to the variance ratio.**\(^9\)\(^10\)

  Null hypothesis \(H_o\) vs. alternative hypothesis \(H_1\).

  \[ H_o : \frac{(\sigma_1)^2}{(\sigma_2)^2} = R \quad vs. \quad H_1 : \frac{(\sigma_1)^2}{(\sigma_2)^2} \neq R \]

  Considering that:
  
  \[
  \frac{(n_1 - 1)S_1^2}{\sigma_1^2} \sim \chi^2_{n_1-1} \quad y \quad \frac{(n_2 - 1)S_2^2}{\sigma_2^2} \sim \chi^2_{n_2-1}
  \]

  \[
  \frac{1}{n_1 - 1} \frac{(n_1 - 1)S_1^2}{\sigma_1^2} = \frac{\sigma_1^2}{\sigma_2^2} \sim F_{n_1-1,n_2-1}
  \]

  Therefore under the fulfillment of the null hypothesis:
  
  \[
  F_{Exp} = \frac{1}{R} \frac{S_1^2}{S_2^2} \sim F_{n_1-1,n_2-1}
  \]

  The zone of \(H_o\) acceptance is:

  \[ a_{teo} = F_{(n_1-1,n_2-1,1-\alpha)} \]

  \[ b_{teo} = F_{(n_1-1,n_2-1,1-\alpha)} \]

  \[ a_{teo} \leq F_{Exp} \leq b_{teo} \]

- **Bilateral contrast of two independent normal and homocedastic populations.** Null hypothesis \(H_o\) vs. alternative hypothesis \(H_1\).

  \[ H_o : \mu_1 - \mu_2 = \Delta \quad vs. \quad H_1 : \mu_1 - \mu_2 \neq \Delta \]

  The variances of the both population are equal but unknown.

  \[
  T_{Exp} = \frac{(\bar{X}_1 - \bar{X}_2) - (\mu_1 - \mu_2)}{\hat{S} \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}
  \]

\(^9\)The equality of variances is obtained with \(R = 1\).

\(^10\)\(n_1\) = sample size of the first population.

\(n_2\) = sample size of the second population.

\(\hat{S}_1\) = standard deviation of the first population.

\(\hat{S}_2\) = standard deviation of the second population.

\(F\) = Fisher distribution.

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Table 1. Feature vector.

<table>
<thead>
<tr>
<th>FFT index</th>
<th>Frequency.</th>
<th>Denomination.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0 - 2</td>
<td>Not considered</td>
</tr>
<tr>
<td>2</td>
<td>3 - 5</td>
<td>Not considered</td>
</tr>
<tr>
<td>3</td>
<td>6 - 8</td>
<td>(\theta)</td>
</tr>
<tr>
<td>4</td>
<td>9 - 11</td>
<td>(\alpha_1)</td>
</tr>
<tr>
<td>5</td>
<td>12 - 14</td>
<td>(\alpha_2)</td>
</tr>
<tr>
<td>6 - 7</td>
<td>15 - 20</td>
<td>(\beta_1)</td>
</tr>
<tr>
<td>8 - 10</td>
<td>21 - 29</td>
<td>(\beta_2)</td>
</tr>
<tr>
<td>11 - 13</td>
<td>30 - 38</td>
<td>(\beta_3)</td>
</tr>
<tr>
<td>14 - 64</td>
<td>39 - 192</td>
<td>Not considered</td>
</tr>
</tbody>
</table>

\(^8\)The denomination of the bands follow the neurological standard.
In which $\hat{S}^2$ is the pseudo-variance of $\hat{S}_1^2$ and $\hat{S}_2^2$

$$\hat{S}^2 = \frac{(n_1 - 1) \cdot \hat{S}_1^2 + (n_2 - 1) \cdot \hat{S}_2^2}{n_1 + n_2 - 2}$$

The zone of $H_0$ acceptance is:

$$T_{Teo} = t_{(n_1+n_2-2,1-\alpha)}$$

If $|T_{Exp}| \leq T_{Teo}$ then $H_0$ is accepted, on the contrary $H_1$ is accepted and $H_0$ is rejected.

• Bilateral contrast of two independent normal and heterocedastic populations. The null hypothesis $H_0$ and alternative hypothesis are similar to the previous ones, the statistical measure is:

$$T_{Exp} = \frac{(\bar{X}_1 - \bar{X}_2) - (\mu_1 - \mu_2)}{\sqrt{\frac{\hat{S}_1^2}{n_1} + \frac{\hat{S}_2^2}{n_2}}}, \sim t_f$$

In which $f$ is the number of degrees of freedom calculated with the Welch’s formula:

$$f = \frac{(\frac{\hat{S}_1^2}{n_1} + \frac{\hat{S}_2^2}{n_2})^2}{\frac{1}{n_1+1} \cdot (\frac{\hat{S}_1^2}{n_1})^2 + \frac{1}{n_2+1} \cdot (\frac{\hat{S}_2^2}{n_2})^2 - 2}$$

In this case the zone of $H_0$ acceptance is:

$$T_{Teo} = t_{(f,1-\alpha)}$$

If $|T_{Exp}| \leq T_{Teo}$ then $H_0$ is accepted, on the contrary is assumed that the populations are different.

4. Results

The following figures summarize the results of the former tests.

The contrasts between mental activities are shown on the horizontal axis. Figures 8 and 10 show the results of the comparison between activity A-Mathematical Task against: B-1 Movement imagination, B-2 Movement realization and C-Relax.

Figures 9 and 11 show the comparison of B-1 against C and B-2; a comparison between Relax activities is also considered.

All the seven types of windows have been applied to each comparison. In the top of each figure appears both the type of window and a number. This number indicates the average of significant features obtained with this window, it is the total of the features that showed statistical evidence of difference, $p < 0.05$, divided by the number of times the experiment has been replicated.

Finally in the bars are the significant features for each kind of window, in the vertical axis is the percentage of times that this feature has been significant.

Making a comparison between mathematical activity and movement imagination the result is, that among all...
windows, the Tukey’s and Kaiser’s windows are the ones with more significant features. Among features, the most significant are $\alpha_1$ and $\beta_2$ for all kind of windows.

In the comparison between mathematical activity and movement realization the result is that the most significant windows are Hanning’s, Tukey’s and Blackman’s, and the most significant features are $\alpha_1$ and $\alpha_2$.

Taking mathematical activity versus relax, the result is that the rectangular and Tukey’s windows are the most significant. The component of the feature vector with more discriminating power is $\beta_1$ followed by $\beta_2$ and $\beta_3$.

Comparing movement imagination and relax, the obtained result is that the rectangular window is the most significant. The features with more significant power are $\alpha_1$ $\beta_1$ $\beta_2$. Movement imagination versus movement realization are the two mental activities with more discriminating power. The most important features are $\theta$ $\alpha_1$ $\alpha_2$ $\beta_1$. All types of windows obtain a very good result.

Making the comparison between relax activities appears significant difference between populations in the features $\alpha_2$ and $\beta_2$ of the channel 2, and $\beta_1$ $\beta_2$ of channel 1. It is a case of false positive identification due to the noise in the signal, for this reason the window with better behavior is the Tukeys one, it only detect a false positive in $\alpha_2$.

5. Conclusion

A classifier which discriminates between mathematical activity and movement imagination should consider the Tukeys window as filtering window, and the features $\alpha_1$, $\beta_1$ and $\beta_2$.

It is important to note that the Tukey’s window minimizes false positive, so it is more reliable than the others type of window.

In these test the channel two (C4) is more significant than channel one(C3), it is probably due to the subject dexterity, more tests should be realized with left-handed and right-handed subjects to determine the influence of it.

References


