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An Algorithm of Wavelets for the Pretreatment of EMG Biomedical Signals

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Abstract

This paper presents a new analytical method for the denoising and the detection of the signal biomedical parameters for Electromyogram signals EMG type.
In practice, the EMG signals are noising, so it is very difficult for the doctor or the specialist to analyze these signals. Thus, in this context, the present work aims to give an algorithm based on the mathematical model of the EMG signals and the wavelets concept, for the denoising and the estimation of the waves present in the EMG studied signals. The choice of the adapted wavelets for the pretreatment of the EMG signals is justified by mathematical proofs.
we have realized, in Matlab, the simulations on academics signals and the numerical results are satisfactory. Our calculation method- ology and an algorithm which facilitate the research of the signal peaks is presented.

Keywords: Electromyogram Signal , Wavelet Transform, Denoising, Departure times, Estimation, Calculation methodology

1 Introduction

The analysis of biomedical signals, in particular the Electromyogram signals (**EMG**) is a recent subject and important because the perfection of these signals is still an open question. Actually, various applications are focused on the study of the EMG signals, in particular, the muscular operating study and the neuromuscular junctions in medical readaptation, the analysis of the physiological work impact and the muscular sports domain (muscle fatigue) [1].

Moreover, in biomedical literature, different analysis methods of EMG signals give the solution to the same problems in various applications. For example, the principal components analysis (PCA) method, the independent components analysis (ICA), the Higher order statistics and the stochastic methods.

The principal object of this article, is to propose by mathematical proof an analytical method based on the Continuous Wavelet Transform (CWT) defined in the Fourier domain for amelioration of the estimation of EMG signal parameters in surface acquisition case with noise, and after to propose an algorithm and a Calculation methodology which automate the analytical method. In fact, it is very important to remark that basing on a simplified mathematical model of EMG signal, the waves form of these signals is similar to the mathematical wavelets, which leads to the fact that the wavelet approach is very adapted to the pretreatment and it is then the favorite candidate for analyzing these signals. We proof under some hypothesis for the analyzing wavelet based on the observation of EMG form and for particular scale factors, that it is possible to choose the adapted and optimally wavelet able to denoising and to analyzing the EMG signals (estimations of parameters).

The paper begin by a presentation of EMG signals and an adopted model. This model can be used for the application of the wavelet transform in second step. By remarking that under some conditions related to the acquisition of data, the departure times of EMG waves are estimated by local maximums of the wavelet transform, and the signal can be automatically denoised in the analyzing phase. For this step, we present a calculation methodology and an algorithm which allow the automation of this task. We terminate by a presentation of some compared results for the academic signals generated under Matlab.

2 The EMG Signal Model

The Electromyogram (EMG) is a signal generated by the electrical activaty of muscles before the mechanic contraction. Generally, there is tow EMG models, since there exist tow types of acquisition methods presented as follow:

- The surface acquisition: The electrodes are directly put in the skin covering the muscle.
- Acquisition by Needles: Neurogenic attack.

In this second case, the obtained signals present some periodicity, but in the acquisition surface, because of the waves interference, it becomes difficult to analyze the signal. During this work we are interesting in this case.

We based our analysis on a mathematical model introduced by Atal and Rende in the context of parol signal context [2]. We suppose that the EMG signal has an additive character, so it can be modeled by a linear system ([3] et [4]):

$$y(t) = \sum_{i=1}^{P} A_i h(t - \tau_i) + \varepsilon(t) \tag{1}$$

with:

- A_i: amplitude of the i^{rd} waveform.
- h : impulsions of the Auto-Regressive (AR) filter estimated on the signal.
- τ_i : departure time of the i^{rd} wave.
- ε : additive noise.

Figure 1 illustrates the stages of the formation of EMG signal.
In this work, the noise is generated especially by cardiac QRS activity and the phasic muscular activity, electrodes movements and electrical parasites [5].

3 The Continuous Wavelet Transform

During this work, we consider the Hilbert space (space of the signals of finite energy):

$$L^2(R) = \{f : R \to R / \int_R |f(t)|^2 \, dt < +\infty\}.$$

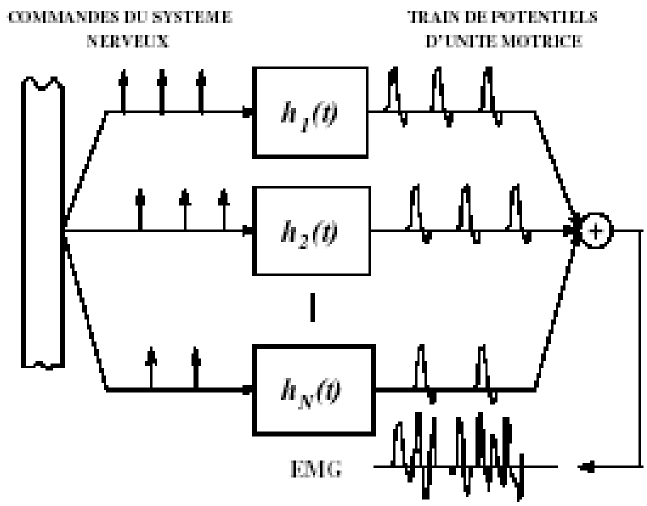

Figure 1: Schema of EMG model

A function $\psi \in L^2(R) \cap L^1(R)$ is a wavelet if she verified the admissibility condition:

$$C_\psi = \int_{-\infty}^{+\infty} \frac{\left|\widehat{\psi}(\xi)\right|^2}{|\xi|} d\xi < \infty$$

ψ is called a analyzing wavelet or admissible.

The Continuous Wavelet Transform (CWT) of the function $f \in L^2(R)$ associated to the the wavelet ψ noted T^ψ is defined by [7]:

$$T^\psi f(a,b) = \frac{1}{\sqrt{C_\psi}} \int_{-\infty}^{+\infty} f(t)\overline{\psi}_{a,b}(t)dt$$

By Parseval equality this formula is equivalent to the CWT formula in Fourier domain:

$$T^\psi f(a,b) = \frac{\sqrt{a}}{\sqrt{2\pi C_\psi}} \int_{-\infty}^{+\infty} e^{i\xi b}\widehat{\overline{\psi}}(a\xi)\widehat{f}(\xi)d\xi \quad (2)$$

A formulation of the Continuous Wavelets Transform in the Fourier domain leads to a calculating algorithm which is less costly (in terms of the number of operations) .

4 Denoising and detection of the departure times of waves

In this section, we expose an analytical method for the estimation of the times τ_i of waves constituting a EMG signal (equation 1). This estimation is a interesting issue in biomedical analysis. In fact, the EMG signals are noising and there is not an efficient physical material for the elimination of noise, thus the interpretation is not possible.

With the proposed method, it will be possible to denoising and to estimate the depart times of the EMG signals. We suppose that the response impulsion of the AR filter verify the following points:

- h is of a compact support : $h(t) = 0,\ \forall t \notin [-T, T]\,,\ T > 0.$
- No Energy loss between the neurological impulsion and the electrodes at the surface. So, we can write: $\int_R h(t)dt = 0.$)))
- The noise is of high frequencies : $\widehat{\varepsilon}(\xi) = 0$ for $|\xi| < \upsilon$.

We set ψ an analyzing wavelet and we suppose that:

- It is of a rapid decrease:

$$\forall \varepsilon > 0, \exists C > 0, \forall t \notin [-C, C]\,,\ \psi(t) < \frac{\varepsilon}{t^2}$$

- it is of a compact support in the Fourier domain:

$$\exists \xi_{\psi,1} > \xi_{\psi,2} > 0, /\ \widehat{\psi}(\xi) = 0,\ \text{for}\ \ |\xi| \notin [\xi_{\psi,1}, \xi_{\psi,2}]$$

The continuous wavelet transform (formula 2) applied to the EMG signal model (equation 1) can be written as follow:

$$T^{\psi}y(a,b) = \frac{\sqrt{a}}{\sqrt{2\pi C_{\psi}}}\left[\sum_{k=1}^{p}\int_{-\infty}^{+\infty} e^{i\xi(b-\tau_k)}\widehat{\overline{\psi}}(a\xi)\widehat{h}(\xi) + \int_{-\infty}^{+\infty} e^{i\xi b}\widehat{\overline{\psi}}(a\xi)\widehat{\varepsilon}(\xi)d\xi\right]$$

For a chosen scale factor a such that $\frac{\xi_{\psi,2}}{\upsilon} \leq a \leq \frac{T}{C}$
We verified that $\widehat{\overline{\psi}}(a\xi)\widehat{\varepsilon}(\xi) = 0,\ \forall \xi$
Thus, the EMG signal is denoised and the CWT of y can be written as follow:

$$T^{\psi}y(a,b) = \frac{\sqrt{a}}{\sqrt{2\pi C_{\psi}}}\sum_{k=1}^{p}\int_{-\infty}^{+\infty} e^{i\xi(b-\tau_k)}\widehat{\overline{\psi}}(a\xi)\widehat{h}(\xi)$$

By hypothesis, the impulsion response of the filter h verifying $\int_R h(t)dt = 0$, we can demonstrate that h is a wavelet (verifying the admissibility condition). For the choice of wavelet $\psi \approx h$ and for a scale factors $a \sim O(1)$ (generally $1 \leq a \leq \frac{T}{C}$), we have the following estimation [6]:

$$T^{\psi}y(a,b) \approx \frac{\sqrt{a}}{\sqrt{2\pi C_{\psi}}} \sum_{k=1}^{p} \int_{-\infty}^{+\infty} e^{i\xi(b-\tau_k)} \widehat{\psi}^2(\xi) d\xi$$

Consequently, the local maximums of continuous wavelet transform module $\left|T^{\psi}y(a,b)\right|$ is attained for the values $b = \tau_k$.

Figure 2 and Figure 3 bellow show respectively our methodology of calculation and give the illustration of a proposed algorithm which automate and allow the calculation of the local maximums.

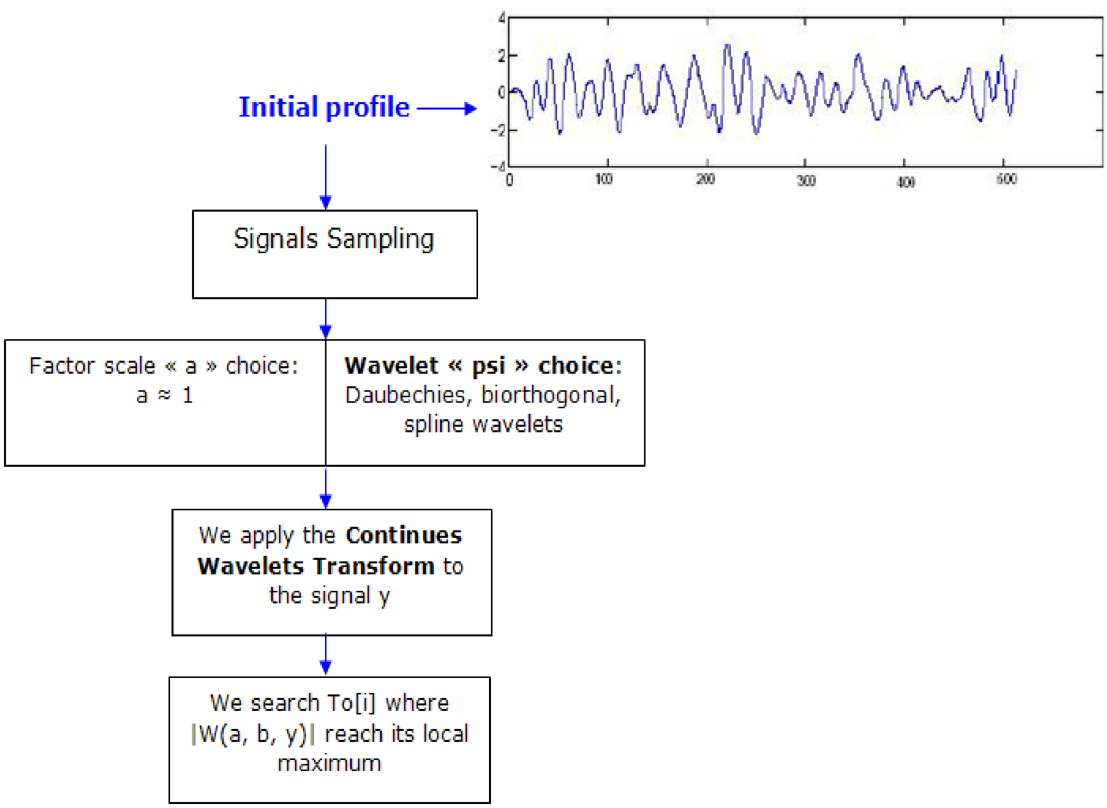

Figure 2: Calculation Methodology

```
/* The Continues Wavelets Transform definition */
a ≈ 1;
integer i;
/* we choose psi wavelet to use by the Transform to be able to eliminate */
/* the noise; (Daubechies for N=2; Biorthognal or spline wavelets).       */

/* We apply the Continues Wavelets Transform to the signal y              */
/* And we search To[i] where |W(a, b, y)| reach its local maximums       */
Wy := W(a, b, y) ;

/* Local maximum research of |W(a, b, y| */

i = 0;
r=0;
While signal still exists, do:
{
        If (|W(a, b[r+1], y)| > |W(a, b[r], y)|)
                {
                        To[i] = b[r+1] ;
                        r = r+1;
                }
        Else
                {
                        To[i] = b[r];
                        i = i+1;
                        r = r+1;
                }
}
```

Figure 3: Local maximums Calculation Algorithm

5 Simulation on academic EMG signals

In the previous section, we demonstrate that in order to denoise a EMG signal and estimate the departure times of the different waves, we must choose The wavelet to a compact support in the Fourier domain and a rapid decrease in temporal domain, and with a similar form of the impulsion, the scale factor is in the vicinity of 1. We have proofed that the estimation of departure time is equivalent to the calculation of the local maximums of the wavelets Transform module.

To validate this choice in practice, we have tested few analyzing some wavelets whose forms close to those of the Impulse response filter AR. We have realized these tests by the Daubechies's wavelet [7] for N = 2, N = 4, N = 6 And N = 8 and by B-spline.

Figure 4 presents two synthetic signals of type EMG noising by a high frequency Gaussian noise ([-10dB,-20dB]), the two EMG signals have a different regularity.

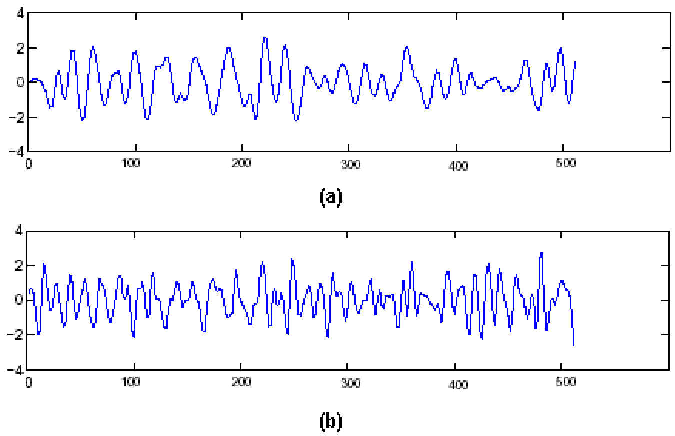

Figure 4: tow synthetics EMG signals (with different regularity

Figure 5 illustrates the obtained results for the quadratic average errors on the departure time of waves for the synthetic EMG signal with the noise (-10db) in this case.

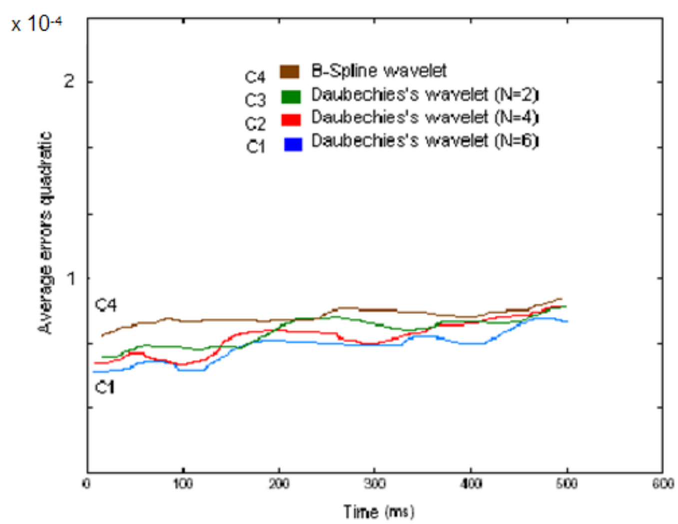

Figure 5: Average errors quadratic of departure times (SRN=-10dB)

6 Conclusion

As a conclusion, we remark that during the realized tests, more the signal EMG present a regularity, more it is interesting to choose the analyzing wavelet of a higher number of vanishing moment. For example the Daubechies's wavelet (N=6 or N=8): more the analyzing wavelet is regular. The analyzing wavelet choice depends on which one is the close form of EMG signal (Impulse response filter) in the regularity context.

Furthermore, in this article, we propose a method based on the Wavelets for denoising and estimating the departure times of EMG signal. This task is a "fundamental" step in the pretreatment of biomedical signals.

We have proofed also that the choice of the adapted wavelet must depend on the observations of the form of impulse response filter signal (regularity, temporary support,...). It will be interesting to estimate correctly the response impulse filter from the detected EMG signal in order to determine the wavelet which will be the "Best" candidate for the pretreatment and analysis of the EMG signal.

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