



Extraction and Localization of Non-contaminated Alpha and Gamma Oscillations from EEG Signal Using Finite Impulse Response, Stationary Wavelet Transform, and Custom FIR

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Abstract. The alpha and gamma oscillations derived from EEG signal are useful tools in recognizing a cognitive state and several cerebral disorders. However, there are undesirable artifacts that exist among the electrophysiological signals which lead to unreliable results in the extraction and localization of these accurate oscillations. We introduced, three filtering techniques based on Finite Impulse Response filters FIR, Stationary Wavelet transform SWT method and custom FIR filter to extract the non-contaminated (pure) oscillations and localize their responsible sources using the Independent Component Analysis ICA technique. In our obtained results, we compared the effectiveness of these filtering techniques in extracting and localizing of non-contaminated alpha and gamma oscillations. We proposed here the accurate technique for the extraction of pure alpha and oscillations. We also presented the accurate cortical region responsible of the generation of these oscillations.

Keywords: EEG signal · Oscillation · FIR · SWT · Custom FIR
Source localization

1 Introduction

In order to study the human brain activity, we relied on analyzing electrophysiological signals; among this recording technique the electroencephalogram EEG signal remains one of the reliable ways to investigate the neurons activity response and their impact on our daily tasks, conscious state and medical disorders. Based on the EEG frequency variation, this physiological signal is generally classified into five waves: delta band (0.5–4 Hz), theta waves (4–7.5 Hz), alpha (8–13 Hz), beta (14–26 Hz) and gamma

(30–45 Hz) [1]. The alpha waves are generally located in the occipital area, considered as the most important cortical waves, it reveals the states of relaxation, awareness and absence of concentration. For the gamma waves they are much more identified as active level of cognition state and mostly used for confirmation of several neurological diseases and malfunctions [2], especially in epilepsy. The extraction of these frequency bands in a pure way was and remains a challenging task notably when the EEG recorded frequencies covers a wide range (from 0.5 Hz up to 45 Hz and above). With a variety of different filtering techniques, [3–6], the consensus filtering method remain in negotiation versus several constraints: the signal to noise ratio, the overlapped level, the width of spikes and oscillations.... An effective separation of cortical frequency band would produce non-contaminated oscillatory activities (neurons generators) with a much better analysis of the responsible sources and generators of these activities.

2 Filtering Techniques

2.1 Finite Impulsive Response (FIR): Kaiser Window

The Finite Impulse Response filter is a classical technique that conservers both the causality and stability aspects. The FIR is preferred then Infinite Impulsive Response IIR (difficult to implement mainly for the instability in higher orders) [7–9].

In fact, the FIR is always applied with windowing method. Hence, we used the Kaiser window to control the passband ripples stability with a smother manner [10]. The Kaiser window (Kaiser function in Matlab), defines the window shape by the β parameter. In our study, we settled the filter order to $N = 100$, the passband frequencies F_{c1} , F_{c2} respectively set to 8 and 12 Hz for the extraction of the alpha wave and for the gamma wave were set to 30 and 46 Hz. (fir1 function in matlab), and the β window parameter to 3.

2.2 A Custom Designed FIR Filter Derived from Parcks-MacClellan Algorithm

The Parcks-MacClellan algorithm is as fundamental way to design Equiripple FIR filters [11], based on the Chebyshev approximation [12].

The main advantage of this filter is its ability to minimize errors both in passband and stopband frequencies [10].

We defined in our study, the filter order to $N = 100$, the stop and pass weights to $W_{stop1} = 100$, $W_{pass} = 80$ and $W_{stop2} = 120$. The passband and stopband frequencies were the same as the FIR filter settings for both alpha and gamma waves extractions.

2.3 Stationary Wavelet Transform (SWT)

The stationary Wavelet Transform SWT is a wavelet transform filter based on the Discrete Wavelet Transform (DWT) with the advantage, of surpassing binary decimation step, of the wavelet transform [3, 13] that allows a retention of the real signal

properties. The SWT also has a better performance than the Classical Wavelet Transform (CWT) by overcoming the frequency bands overlapping. The SWT has been also proven very useful in EEG signal analysis [3, 14]. In fact, this technique, decomposes a signal $s(t)$ at each scale j and step k , then project it on the mother wavelet function ϕ by the Eq. (1):

$$\phi_{j,k(t)} = 2^{-j}\phi(2^{-j}(t - k)), C_{j,k} = \langle s(t), \phi_{j,k(t)} \rangle \quad (1)$$

with $C_{j,k}$ is the value of the approximated or detailed coefficients at level j decomposition depending on the reconstruction.

In our case, we applied the SWT to extract the alpha using 7 levels of decomposition while the gamma rhythms require only a decomposition of 6-levels (the decomposition level increases when the selected frequency band decreases). We applied, in this study, the wavelet family symlets 4 and the SWT Matlab function for the decomposition with the iswt functions of Matlab for the reconstruction of pure alpha and gamma oscillations.

3 Database

Our real EEG signal used in this work is a registration of one subject, the acquisition and preprocessing phases were applied in the Clinical Neurophysiology Department of ‘La Timone hospital’ in Marseille as in Jmail and colleagues [6] and validated by an expert neurologist. This particular EEG recording was chosen because it presented clear alpha and gamma patterns with regular spiking and visible epileptic oscillations as validated by the expert. The EEG data was recorded on a Deltamed System, sampled at 2500 Hz, with anti-aliasing low-pass analog filter set to 100 Hz. Our dataset is composed of 74 epochs each with 6 s duration, 62 channels and 148 events.

4 Results

4.1 Extraction of Alpha and Gamma Rhythms for Real EEG Signal

In Fig. 1, we depicted the three-filtering methods response for the reconstruction of the alpha rhythm against the EEG signal. It is noticeable that the FIR and the SWT methods have a relatively similar result with a visually confirmed proof of match to the ideal alpha wave, while the Custom FIR could not dispose the higher frequency oscillations which leads to a contaminated signal more related to the real EEG signal.

In Fig. 2, we compared the robustness of our adopted filtering methods versus the real EEG signal. Similar to the alpha case, it is perceptible that the FIR and SWT methods are relatively similar results in the extraction of the gamma band, however the Custom FIR still present a corrupted oscillation.

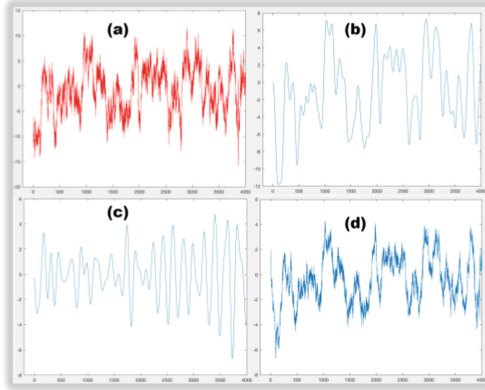


Fig. 1. A comparison of (a) original EEG dataset, with the extracted alpha band by (b) FIR (c) SWT (d) Custom FIR.

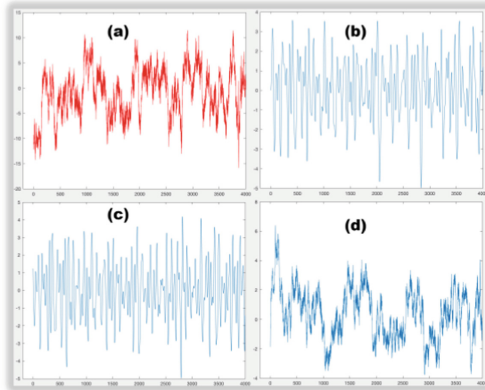


Fig. 2. A comparison of (a) original EEG dataset, with the extracted gamma band by (b) FIR (c) SWT (d) Custom FIR.

4.2 Evaluation of the Three Extraction Methods

The GOF for the Extraction of Pure Alpha and Gamma Rhythm

The reconstructed simulated signals using three filtering techniques were compared to the simulated signals. See Eq. (2):

$$GOF = 1 - \left(\frac{\sum_{t=1}^r (s(t) - s_f(t))^2}{\sum_{t=1}^r s(t)^2} \right) \tag{2}$$

With $s(t)$ is the theoretical power and $S_f(t)$ is the power of the filtered signal that depends on the adopted filtering technique (FIR, SWT, Custom designed FIR).

The GOF value for these different SNR measurements is gathered in the Fig. 3.

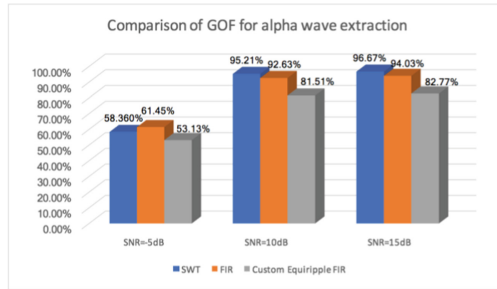


Fig. 3. Comparison of GOF values for the recovered alpha simulated signal by SWT, FIR and custom FIR.

It is clear that the SWT provides the best result in the extraction of alpha wave for different SNR values. Hence the SWT is the accurate filtering technique for the recovery of pure alpha signal even in a noisy signal.

We depicted in Fig. 4 the GOF results for the recovery of gamma wave.

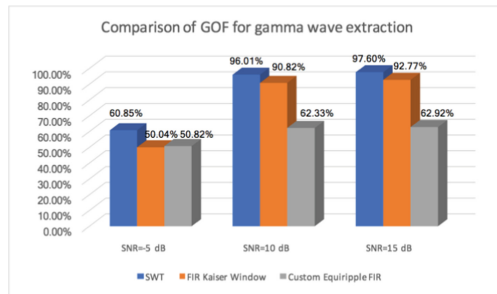


Fig. 4. Comparison of GOF values for the recovered gamma simulated signal by SWT, FIR and custom FIR.

We have similar results as the alpha extraction values, furthermore the GOF values has been widened between the filtering techniques in high SNR values.

The Topographies and DSP for the Extraction of Pure Alpha and Gamma Rhythms.

The topographies and power spectral density (PSD) mapping for the alpha rhythm extraction versus the real EEG signal was depicted in Figure [15] (Fig. 5).

The FIR filter improves the scalp map depolarization, compared to real EEG map, in fact the recovered alpha has a clearer dipolar topography. The SWT shows a much more dipolar and clearer results than the FIR and the original signal. For the Custom FIR has slightly depolarized the scalp map topography.

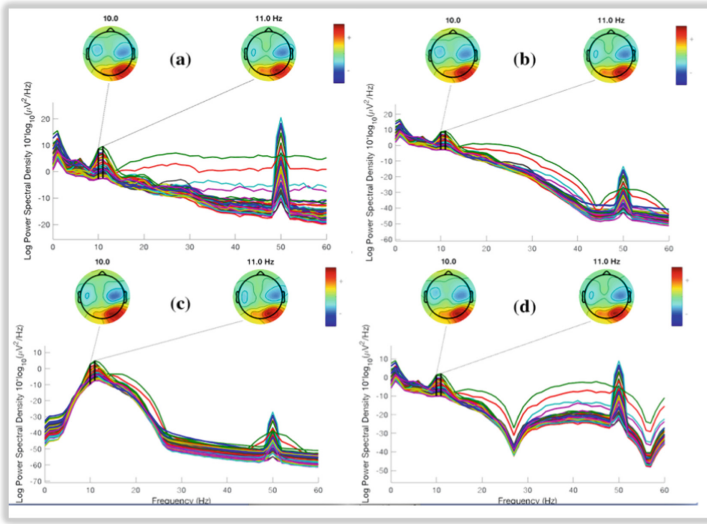


Fig. 5. Comparison of the Topographies and PDS of (a) real EEG signal and the extracted alpha signal by (b) FIR (c) SWT (d) Custom FIR.

There are two clear activities: a parietal and an occipital one, a typical location of alpha rhythms, in fact these dipolar activities are much clear and pure by the SWT filtering technique.

All the adopted filtering techniques: FIR, SWT and custom FIR, have been able to bring out the alpha rhythm since they did valorize the spectral density energies.

For the gamma rhythm extraction, the topographies and PSD evaluation are depicted in Fig. 6. There is no clear difference between the topographies of original and extracted gamma by FIR and costumed FIR, however the SWT topography showed a slight improvement in the depolarization map (a clear dipolar mapping that reflect a physiological activity). The PSD results are increasingly improved (Custom FIR then FIR and finally SWT) in terms of valorizing the gamma band.

The Source Localization of the Pure Alpha and Gamma Rhythm.

To define the accurate sources responsible of the generation of alpha and gamma band, we resolved the forward and inverse problem, using the EEGLAB [15] and the fieldtrip toolbox.

For the resolution of the source localization, we used in this work the BEM technique as a solution for the Forward problem, and the ECD technique (simple in implementation with good results in estimation of the responsible sources) as a solution for the inverse problem. We also set the Residue Variance to $RV = 15\%$ (to reduce the low sources effect on the high sources).

Furthermore, we computed the Independent Component Analysis (ICA) for our original signal to keep only one generator per activity (one with 10 Hz for alpha and one with 45 Hz for gamma). We set the number of component equal to the number of channels (captors) to emphasis the number of independent components. We used the

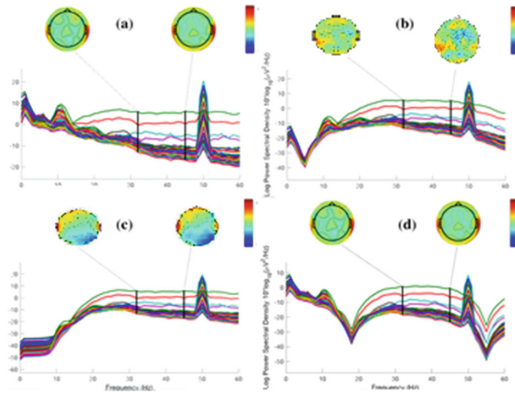


Fig. 6. Comparison of the Topographies and DSP of the (a) real EEG signal and extracted gamma by (b) FIR (c) SWT (d) Custom FIR.

ICA function on Matlab implemented in the EEGLAB toolbox for each filtered dataset (pure alpha/gamma by FIR, pure alpha/gamma by SWT, pure alpha/gamma by custom FIR). Finally, we applied the source localization algorithms on the ICA component depicting a pure alpha oscillator then a pure gamma oscillator.

The choice of the involved components to be localized was based on the topographies results (studied in the previous section). In fact, we selected the components 6 and 8, (dipolar map) for alpha band and the components 13 and 14 for gamma activities.

Figure 7 illustrates the source localization of the involved alpha components 6,8 by our proposed filtering technique (FIR, SWT, custom FIR) versus our real EEG signal.

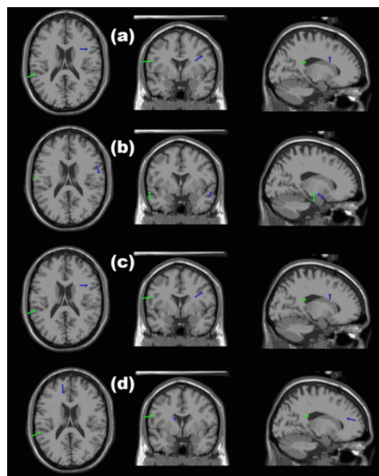


Fig. 7. Source localization of component 6 and 8 for (a) real EEG signal and pure alpha signal using (b) FIR (c) SWT (d) Custom FIR.

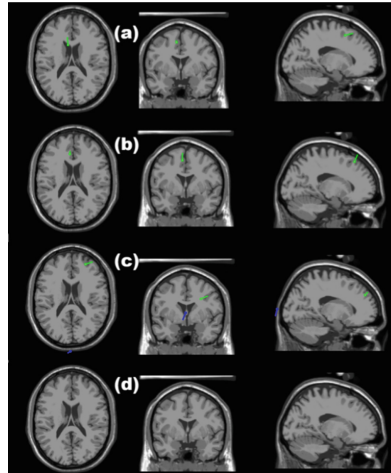


Fig. 8. Source localization of component 13 and 14 for (a) real EEG signal and extracted gamma by (b) FIR (c) SWT (d) Custom FIR.

In Fig. 8 we compared the source localization results as in the Fig. 7 for the gamma rhythms.

The Residual Values RV after localization for all the components are gathered in Table 1, the more the RV value is lower the more the results are accurate.

Table 1. Components RV values for the real EEG signal, FIR, SWT and Custom FIR.

	Component 6 RV%	Component 8 RV%	Component 13 RV%	Component 14 RV%
Real EEG signal	2.45%	6.61%	7.40%	>15%
FIR	7.31%	14.52%	>15%	14.22%
SWT	2.45%	6.61%	1.98%	3.99%
Custom FIR	2.46%	12.26%	>15%	>15%

The RV value indicates that SWT is the efficient filtering method for the extraction of non-contaminated alpha and gamma rhythms.

5 Discussion

In this study, we compared the performance of three filtering methods (FIR, custom FIR and SWT) in the extraction of two frequency bands (the alpha and the gamma wave) among a real EEG signal. In fact, these activities (alpha and gamma) are very important in the analysis of cognitive task and also for the diagnosis of neurological disease as epilepsy. Hence, we proposed to define the best filtering method to recover

in a resalable way a pure alpha and gamma activity in order to locate their responsible sources. These productions are useful to help different neurological decisions for both normal and epileptic cases.

We also evaluated the robustness of our adopted filtering methods against the noise and we proved that the SWT technique is the best method for the extraction of both alpha and gamma waves. Furthermore, the SWT has shown its efficiency in the topographic mapping especially for the alpha band and for the source localization of the gamma extracted signal. In order to help neurologist during the analysis and diagnosis of electrophysiological signal, we propose in the further work to embed our processing chain as a monitoring and neurofeedback system.

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