EEG Signal Analysis and Artifact Removal by Wavelet Transform

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Abstract— **Electroencephalogram (EEG) is a non-invasive method to collect brain signals from human's scalp. EEG signals are located in low frequency range and relatively small. The amplitude of these signals are approximately 50µV with the maximum amplitude is about 100µV. Therefore, there are number of sources such as power line, EOG or ECG can extremely interfere EEG signals. Detection and elimination of artifacts plays an important role to acquire clean EEG signals to analyze and detect brain activities. Besides, the extraction of important components in recorded EEG required fast and reliable algorithm to process mix of data set. In this paper, we will demonstrate EEG acquisition from EEG Exea Ultra system of Bitmed, analyze and compare signals from volunteers in relaxation mode and contaminated EEG signals with eye blinks. We then design filters to remove powerlines and baseline noise from acquired signals. With the aim to assess the feasibility of Wavelet transform technique to identify feature in recorded EEG signals, we carried out Wavelet transform and applied threshold method to detect and remove artifacts in EEG signals with eye blinks. We achieved PSNR of original signals and wavelet filtered signal that approximately 17,7810 dB. Our preliminary results show that wavelet can be utilized as automatically detection tools for artifacts and event-related potentials and in applications require real-time processing of EEG signals.**

Keywords— **EEG, signal analysis, feature extraction, Wavelet transform, de-noise, ocular artifact, rehabilitation.**

I. INTRODUCTION

Analyzing brain wave activities plays an important role in neurosciences. Brain signals carry information allows us to identify activities of brain as well as abnormalities. In combination with other imaging techniques such as MRI, we can create an useful tools for doctors and therapeutic physicians [1,2]. Brain signals are components of recorded electroencephalogram called EEG. There are different forms of brain waves according to ages, stimulation, brain diseases or physiology conditions [3]. Components or event-related evokes can be extracted from EEG data that help doctors in diagnostic and treatment. That can be a event – related potentials happened in transient specified time or emergence in specific area in human scalp (localized in space). In our research direction, we are researching the changes of EEG signals that controlling movement statement. Frequencies range of EEG signals related to motor function are from 0,5 Hz to 30Hz [4,5]. The advantages of EEG method are non-invasive measurement and high time resolution. Therefore, this technique can be used in real-time monitoring changes of motor activities. (The time resolution is approximately 1ms). The extraction of important components in recorded EEG required fast and reliable algorithm to process mix of data set [6, 7]. However EEG signals are complex and hard to identified. Recorded signals from scalp are embedded with sources of noises that can causes problems when analyze, display and restore motor – related EEG signals. The present of noise produces spikes lead to misinterpretation of brain signals. Therefore, elimination or attenuation noises from EEG signals to improve the accuracy of diagnostic and analysis brain activities must be carried out. Eye movement is one of sources that contaminated recorded EEG. Author Senthil [8] had demonstrated the use of Wavelet transformation to canceled eye blinks without EOG references channel. V.Krishnaveni proposed method to detect eye blinks area and apply adaptive threshold algorithm based on Wavelet that allow us to keep necessary information. In this methods, author used Haar Wavelet function to detect eye blinks and eliminate them afterward using SWT with Coif3 as basic function [9,10]. Other method is use ICA independent component analysis. This is blind source separation techniques that linearly decompose EEG signals into independent sources component [11].

Fig. 1 EEG measurement from volunteer using EEG electrode cap following international standard 10/20.

This technique can eliminate noises by apply reconstructed algorithm without noise sources. But the

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process still requires manual rejection through visual inspection on graphic interfaces [12]. In this paper, we describe EEG acquisition method from 25 channels EEG Exea Ultra of Bitmed. EEG signals are recorded from volunteers in relaxation state and with natural eye blinks to monitor and analysis. Acquired signals are preprocessed with band pass filter (FIR). Then, with the aim to assess the feasibility of Wavelet transform technique to identify feature in recorded EEG signals, we applied Wavelet transform to detect and remove eye blink by applied hard threshold and evaluate output results.

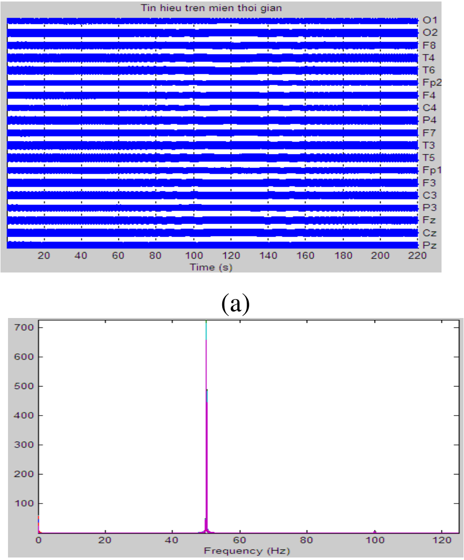
II. MEASUREMENT METHODS

EEG signals are recorded from 25 channels EXEA Ultra devices. Volunteers are sat comfortable and still to elimination movement interference to the signals. Time duration for each trial is 4 minutes. The volunteers are then required to perform followings states: Free stage with eye close and relaxation; Eye blinks state with natural eye blinks. Recorded channels are O1, O2, F8, T4, T6, Fp2, F4, C4, P4, F7, T3, T6, Fp1, F3, C3, P3, Fz, Cz, Pz. Electrode montage follows 10/20 international system for electrode placement [17]. Gels are then injected to each electrode to increase electric conduction. For good EEG recordings, electrode impedance is kept below 5KΩ. Signals are then amplified and sampled at 200Hz. In this paper, to investigate the EEG feature identification and artifacts reduction of wavelet transform technique, we used data from channel Fp1, Fp2 that located in frontal lobe. The electrodes in this area are much interfered by eye movement. Figure 1 demonstrates settings and EEG measurement from volunteers.

III. POWER LINE AND BASELINE ARTIFACT REMOVAL

Recorded signals from 19 channels are shown in Figure 2a. The power line noise can be seen relatively high, hence, covered acquired signals. Figure 2b shows power line spectrum has dominant power in 50Hz frequency. As the result, objective of this process is to minimize this line-frequency artifact. To get this goal, we use low pass filter that have cut-off frequency of 40Hz.

Still, we can observe that the signal is strongly affected by baseline noise which has the low frequency and high amplitude causing a fluctuation of amplitude in received signal. The period estimation of baseline noise is 5 to 10 second (0.1 to 0.2 Hz) and amplitude is about 150 uV.



(a)

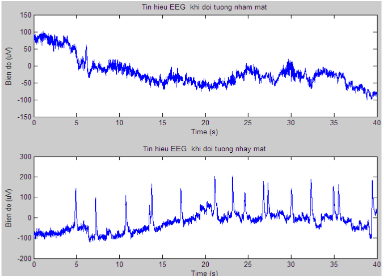
(b)

Fig. 2 Recorded signals in 19 channels (a) and spectrum magnitude of EEG with household line frequency at 50Hz (b).

We then move signals forward to high pass frequency with cut-off frequency is 0,5Hz. Figure 3 demonstrates signals before and after baseline artifact removal.

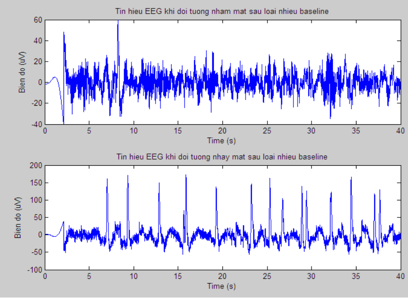
IV. EYE BLINKS REMOVAL FROM RECORDED SIGNALS USING WAVELET TRANSFORMS

After initial preprocessing stage, EEG signals are forwarded to eye blinks detection and elimination stage. As usual, conventional FFT transform can reveals spectrum component but can not identify the time when it happened. Meanwhile, EEG signals has unstable characteristic that causes frequency changes. Wavelet transform had been investigated to use for EEG signals in many researches [13,14].



(a)

Fig. 3 (a) EEG signals when the volunteers close eyes (above) and open eyes with natural eye blinks (below) before baseline artifact removal. (b) EEG signals when the volunteers close eyes (above) and open eyes with natural eye blinks (below) before baseline artifact removal.



(b)

Fig. 3 (*continued*)

The most benefit of wavelet transform is that it is localized in both time and frequency. Wavelet transform are used to convert EEG signal into a series of wavelet which are shifted and scaled version of mother wavelet. Therefore, Wavelet can be suitable with hidden event that can help to detect exact frequency and location of the event in time scale. Moreover, wavelet can be suitable with abnormal event due to special shape. Wavelet transform utilizes different window sizes for each range of frequencies. Longer window for lower frequencies range and shorter window for higher frequencies range. This technique is differs from sTFT techniques as sTFT use fixed window dimension to compute transformation [15]. The fixed size window can cause drawbacks as we have the same resolution in time and frequency domain.

We can define Wavelet transform as general as following

$$\boldsymbol{C(scale, position)} = \int_{-\infty}^{\infty} \mathbf{s(t)\Psi(scale, position, t)dt} \quad (1)$$

Where C is the coefficients of Wavelet Transform, s(t) is the signal needed to be transformed, $\Psi(\text{scale}, \text{position}, \text{t})$ is the Wavelet transform function.

Continuous Wavelet Transform formula:

$$\boldsymbol{C(a,b) = \int_R s(t)\frac{1}{\sqrt{a}}\Psi\left(\frac{t-b}{a}\right)dt} \quad (2)$$

In the Discrete Wavelet Transform (DWT, SWT) the parameter scale $\boldsymbol{a = 2^{-j}}$ and position $\boldsymbol{b = k2^{-j}, (j,k)\epsilon Z^2}$

And the inversed function in the cases of DWT and SWT:

$$\boldsymbol{s(t) = \sum_{j\in Z}\sum_{k\in Z} C(j,k)\Psi_{j,k}(t).} \quad (3)$$

Where a is scale, j is called level and b, k are shift coefficients.

DWT allows choose scale j and position k for function ψ (t) with:

$$\boldsymbol{\psi_{j,k}(t) = 2^{\frac{j}{2}}\psi(2^j t - k)} \quad (4)$$

By stretching ψ (t) with the coefficients 2^j and compressing with the coefficients 2^{-j}, we can build a wavelet for any function. Compressed version of wavelet function is suitable with high frequencies components and stretched version is for low frequency components of signals. Wavelet transform can eliminate frequencies component at specific time in the EEG recordings [16]. Therefore, cancellation of bad signals and keep good ones is possible. Figure 4 presents the proposed wavelet function Sym3 [8] that have similar shape with eye blinks EEG patterns.

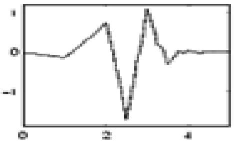
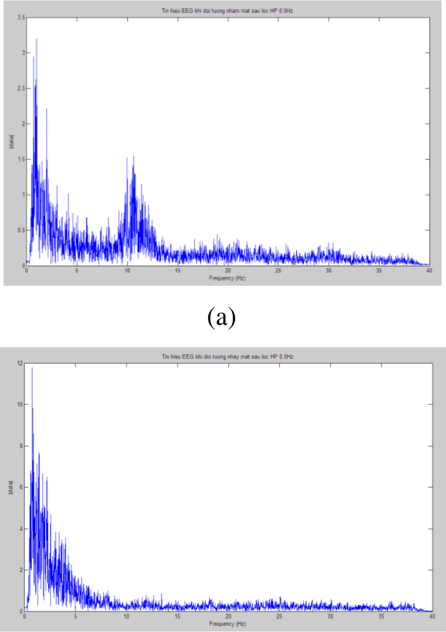


Fig. 4 Sym3 Wavelet function

It is observed that spikes (Figure 3b) have high amplitude in acquired signal because of the present of eye blinks artifact. In relaxation state, when the participant close eyes, alpha rhythm which have frequency range of 8-13Hz is prominent in EEG signal with the center frequency of approximately 10Hz. We could view it clearly on Figure 5a. In figure 5b where the spectrum of signal with eye-blinks is showed, alpha rhythm is no longer prominent.



(a)

(b)

Fig. 5 EEG spectrum when volunteers close eyes (a) natural eye blinks (b) after preprocessing stage

There are other waves with frequency below 5Hz and high amplitude. When volunteers open eyes and perform natural eye blinks, these frequencies range are almost attenuation. Therefore, eye blinks has spectral components located in low frequencies range. To eliminate eye blinks components, we implemented undecimated discrete wavelet transform 8 level SWT. Wavelet Sym3 that have high correlation with eye blink artifacts is proposed to use for noise cancellation algorithm. The algorithm presents in Figure 7 has been applied for analysis recorded EEG signals. Frequencies band after decomposed by SWT has been illustrated in Table 1.

Table 1 Decomposition of acquired EEG signals after SWT 8 level wavelet transform

Frequencies band (Hz)	Decompose level	Frequencies band	Frequencies bandwidth (Hz)
62.5 – 125	D1	Noise	62.5
31.25 – 62.5	D2	Gama	31.25
15.625 – 31.25	D3	Beta	15.625
7.8 – 15.625	D4	Alpha	7.8125
3.9 – 7.8	D5	Theta	3.9
1.95 – 3.9	D6	Delta	1.95
0.98 – 1.95	D7	Delta	0.98
0.49 – 0.98	D8	Noise	0.49
0 – 0.49	A8	Noise	0.49

Figure 6 below illustrated signals with eye blink artifacts in FP1 channel and decomposition level of signals (D1-D8 and A8). Detail coefficients D1, D8 and A8 are artifact components is then removed from signals. The red pipe located in eye blinks area that has been detected in detail coefficients.

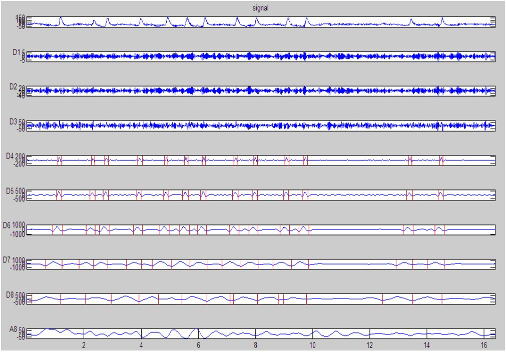


Fig. 6 EEG signal decomposition in 8 level and eye blinks area detection.

The data before and after eye blink cancellation by apply threshold level and wavelet function sym3 show in Figure 8. The received outputs are depending on wavelet function selection that has similar shape with eye blink pattern. Higher coefficients than threshold were set to zero.

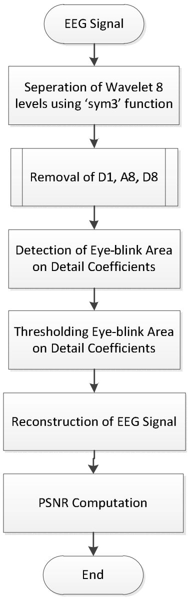


Fig. 7 Flow chart of EEG signal processing using wavelet transforms.

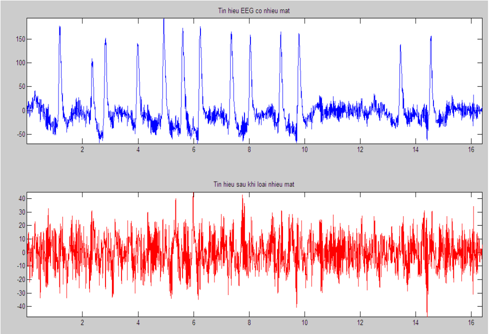


Fig. 8 EEG signal with eye blink rejection (red waves) using wavelet transform.

V. DISCUSSION

To compare and measure the quality of removing noise, the Peak Signal to Noise Ratio (PSNR) is computed between the original signal $f(k)$ and the denoised signal $f_d(k)$, given by:

$$\mathrm{PSNR} = 10\log\left(\frac{f_{max}^{2}}{\mathrm{MSE}}\right) \tag{5}$$

Where f_{max} is the maximum value of signal given by:

$$f_{max} = \max\big(\max(f(k)), \max(f_d(k))\big) \tag{6}$$

With the sampled EEG data from our recordings, we can achieved PSNR = 17.7810 (dB)

In this paper, we demonstrated EEG acquisition method from volunteers. The dataset is sampled at 200Hz included both clean and eye blinks contaminated EEG signals. Preprocessing signals was initially applied with bandpass filter (fc1= 0,5Hz and fc2=40hz). As the result, the filters have successfully remove line-frequency and baseline noise. However, conventional filter cannot eliminate eye blinks noise due to overlapping spectral between EEG signals and noises. Wavelet transform uses flexible window width that can deliver good signal resolution in both frequencies and time domain. Hence, using suitable wavelet can help us to identified special pattern embedded in EEG signals. The more similarities of the wavelet to the pattern of EEG signal the more possibility to analysis event of interest and the interpretation of EEG recordings. We applied threshold on details coefficients at the area of detected eye blink without distorting portions of EEG data. Application of Wavelet transforms give us an effective tool for analyzing and EEG signal processing, especially with eye blink – that have high amplitude and have spectral overlapping with EEG signals. Our preliminary results show that wavelet can be utilized as automatically detection tools for artifacts and event-related potentials and in application requires real-time processing of EEG signals.

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REFERENCES

1. Gotman J. Epileptic networks studied with EEG-fMRI. Epilepsia 49. Suppl 3:42–51. 2008.
2. Walker MC, Chaudhary UJ, Lemieux L. EEG-fMRI in adults with focal epilepsy. Springer, Heidelberg, pp. 308–331, 2010.
3. M. Teplan Fundamentals of EEG measurement – Measurement science review, Volume 2, Section 2, 2002.
4. Waldert S, Preissl H, Demandt E, Braun C, Birbaumer N, Aertsen A, Mehring C: Hand movement direction decoded from MEG and EEG. J Neurosci, 28:1000-1008, 2008.
5. Pfurtscheller G, Lopes da Silva FH: Event-related EEG/MEG synchronization and desynchronization: Basic principles. Clin Neurophysiol,110:1842-1857,1999.
6. Saeid Sanei and J. A. Chambers, EEG Signal Processing, Wiley-Interscience, 2007.
7. M. Nixon and A. Aguado, Feature Extraction & Image Processing,Elsevier, Amsterdam, 2004.
8. P. S. Kumar, 1, R. A. , 1, K. S. , 2, et al., “Removal of Ocular Artifacts in the EEG through Wavelet Transform without using an EOG Reference Channel” Int. J. Open ProblemsCompt. Math vol. 1, December, 2008.
9. V. Krishnaveni, S. Jayaraman, S. Aravind, V. Hariharasudhan, K. Ramadoss,“Automatic identification and Removal of ocular artifacts from EEG using Wavelet transform”, Measurement Science Review, Vol. 6, No.4, pp.45-57,2006.
10. V. Krishnaveni, S. Jayaraman, L. Anitha, K. Ramadoss, “Removal of Ocular Artifacts from EEG using Adaptive thresholding of Wavelet coefficients”, Journal of Neural Engineering, Vol.3, pp.338-346, 2006.
11. Comon P. “Independent Component Analysis, A new concept”, Signal Processing 36(3), pp 287-314, 1994.
12. Delorme.A, Makeig.S & Sejnowski T. “Automatic artifact rejection for EEG data using high-order statistics and independent component analysis”, Proceedings of the Third International ICA Conference, pp 9-12, 2001.
13. M. Akay, “Time Frequency and Wavelets in Biomedical Signal Processing” IEEE Press series in Biomedical Engineering, 1998.
14. R. A. G. a. H. G. C. Sidney Burrus, “Introduction to Wavelets and Wavelet Transforms” 1998.
15. R. Saab. Wavelet Based Approach for the Detection of Coupling in EEG Signals.
16. D.Lee Fugal. Conceptual Wavelets in Digital signal processing 2012.
17. C.R.Hema,M.P.Paulraj,S.Yaacob,A.H.Adom and R.Nagarajan “An Analysis of the effect of EEG Frequency Bands on the Classification of Motor Imagery Signals”,Biomedical Soft Computing and Human Sciences,Vol 16,pp.121-126,1995.
18. Mattingly J. D. Elements of gas turbine propulsion. McGraw-Hill, Inc. International Editions, US, 1996.

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