Butterworth Bandpass and Stationary Wavelet Transform Filter Comparison for Electroencephalography Signal

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***Abstract*—Electroencephalography (EEG) is a non-invasive process that record and capture brain signal. Raw EEG signal contaminated with a lot of noise such as power line interference, muscle movement (electromyography artifacts) and eye blinking (electrooculography artifacts). Removing this types of noise can produce a clean signal. The noise that contaminated with EEG signal will affect the actual result during analyzing stage. This paper aims to shows the comparison when EEG signal filter with 4th order Butterworth bandpass and stationary wavelet transform (SWT). Two parameters are used to compare the effect of filter on EEG signal; that are mean square error (MSE) and peak-to-noise ratio (PSNR). This types of parameter was use because it able to compare the quantitative value for two signals. The result shows that the stationary wavelet transform is more effective in removing the noise without losing the original information.**

Keywords-EEG signal: butterworth bandpass filter; SWT filter; MSE; PSNR

I. Introduction

Electroencephalography is widely used by researchers in order to record the electrical activity of the brain [1]. It is purposely used for educational field or medical field. Generally, the EEG signal has five different types of frequency band; that are delta (0.4-4 Hz), theta (4-8 Hz), alpha (8-13 Hz), beta (13-30 Hz) and gamma (above 30 Hz) [2]. The alpha rhythms represents stability state, the beta rhythm for immersion degree, the gamma wave for tension and active high-degree cognition process and the theta wave represents meditation, activity improvement, enhancement of memorization and reduction of stress [3]. Among the advantages that this modality are low cost, not painful and harmful to people, non-invasive technique and able to record EEG signal in millisecond. However, raw EEG signal commonly is contaminated with various type of artifacts due to it has small amplitude [2]. The source of artifacts can be whether come from the subject or other devices. Removing the artifacts is not an easy task. The filter should has specific requirements in order to maintain the original signal. The filtering process aim to retain the specific frequency of the signal [4]. The information that obtained from the clean EEG signal can be used for clinical purposes; such as detect epilepsy, coma, head injury, brain injury and stroke [4].

Mean square error (MSE) and peak-to-noise ratio (PSNR) is a quantitative parameter that use for determine the quality and fidelity of signal especially in signal processing [5]. The aim of a signal fidelity measure is to compare the original signal with the reconstructed signal by providing a quantitative score that describes the degree of similarity/fidelity or, conversely, the level of error/distortion between them. The MSE between the signals can be defined as

$$\mathrm{MSE}(x, y) = \frac{1}{N}\sum_{i=1}^{N}(xi - yi)^{\wedge}2 \qquad (1)$$

where x and y are two finite length (discrete signals), N is the number of signals samples and xi and yi are the values of the ith samples in x and y [5]. The MSE value usually converted into the PSNR value for determining the quality of image in decibel value. PSNR can be defined as

$$\mathrm{PSNR} = 10 \log_{10}\frac{L^{\wedge}2}{MSE} \qquad (2)$$

where L is the dynamic range of allowable image pixel intensities [5].

II. Methodology

The raw EEG signal data was taken from the experiment that has been conducted in the laboratory. The 22 years old subject was required to memorize the visual task within 2 minutes. The EEG signal was recorded using 10-20 placement electrode system of scalp (see Fig. 1). However, there are only three channels selected for filtering process. These channels were chosen due to it important for analyzing the memorizing process. The channels are Fp1 (attention), Fz (working memory) and Pz (cognitive processing) [6].

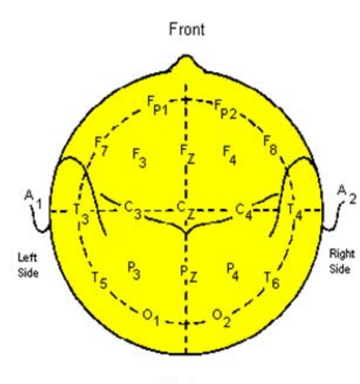

Figure 1. The 10-20 Placement Electrode [7]

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The data has 60 000 data points with 120 seconds duration. The data was save in ASCII file and then converted to the text file. The data frequency sampling is 500 Hz. After that, the raw EEG data were loaded into MATLAB software for filtering process. Firstly, the raw EEG signals implement using simple algorithm in MATLAB. Then, the functions were used to call the three channel. After that, the 4th order of Butterworth bandpass filter was used. This types of filter is chose because it has linear response compare to others. The cutoff frequency was 4 to 40 Hz. The delta frequency (below 4 Hz) is eliminates because it consider as noise whereas 40 Hz is within the gamma frequency ranges that needed for analyzing process and also to remove the power line interference (50 to 60 Hz) [8]. Fig. 2 shows the flow of filtration process for Butterworth bandpass filter.

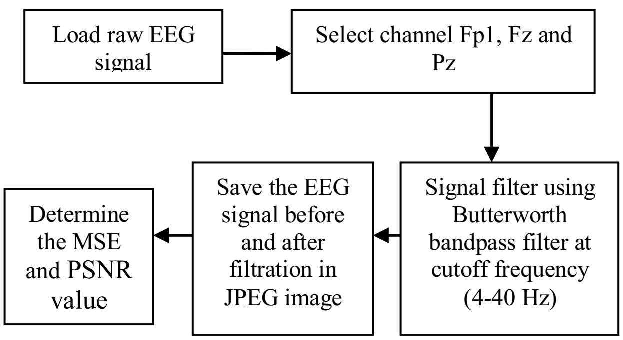


Figure 2. Filtering process for Butterworth bandpass filter

Same process was use for stationary wavelet transform filter. The dB3 wavelet mother with 5 decomposition levels of decomposition is choose for this filter [4]. This wavelet mother chosen because it able to detect and localize the spike in EEG signal [9]. The spike characteristics is consists in electromyography signal (muscle movement) and electrooculography signal (eye blinking). Three steps involve in SWT filter. Firstly, the high frequency noise was eliminate and follow by low frequency noise elimination using soft threshold method and lastly the signal was reconstructed [4]. After obtain a clean signal from this two filter an algorithm use to determine their mean square error (MSE) and peak-to-signal noise ratio (PSNR) value.

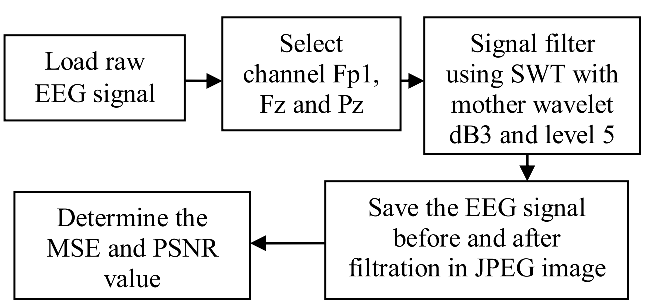
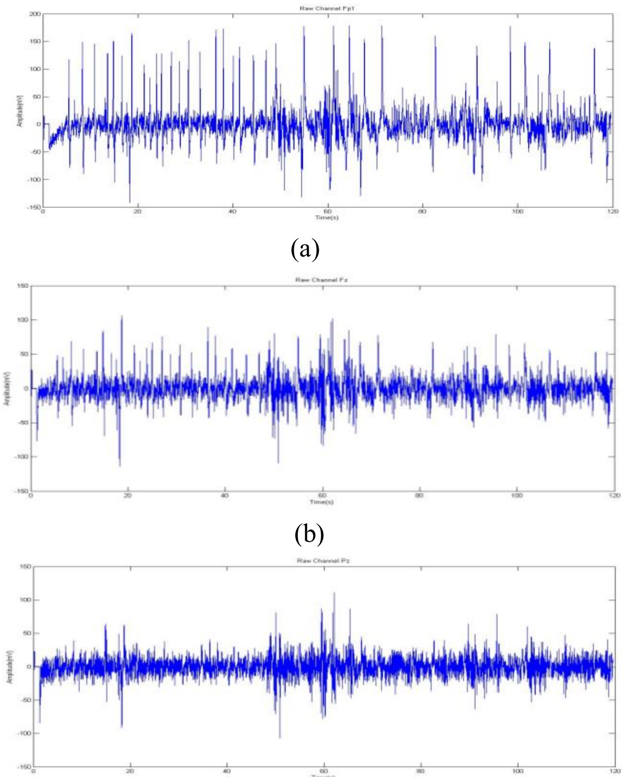


Figure 3. Filtering process for Stationary Wavelet Transform filter

III. Result and Discussion

A. Raw Electroencephalography Signal

Fig. 1 shows the EEG signal at channel Fp1, Fz and Pz that contaminated with artifact for 120 second duration. It is derived using MATLAB software.

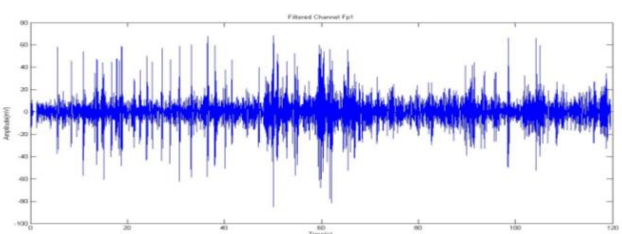


(a) (b) (c)

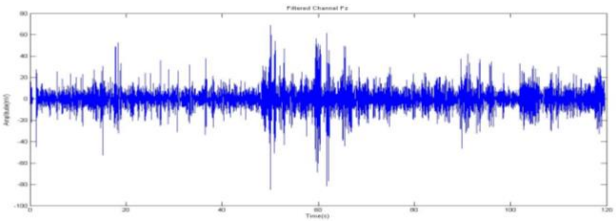
Figure 4. (a) Raw Fp1 signal with artifacts (b) Raw Fz signal with artifacts (c) Raw Pz signal with artifacts

B. Signal after Butterworth Bandpass Filter

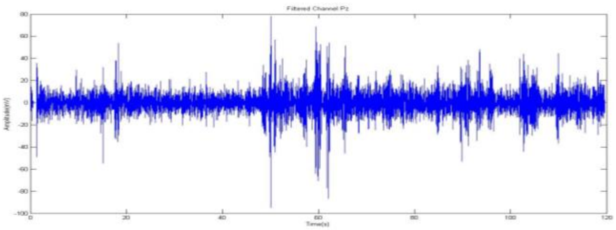
Fig. 2 shows the result when EEG signal at channel Fp1, Fz and Pz are filter by Butterworth bandpass at frequency 4 to 40 Hz. This type of filter does not suitable because some of the original information are loss during the filtration process.



(a)



(b)

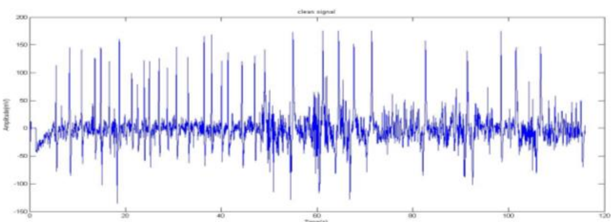


(c)

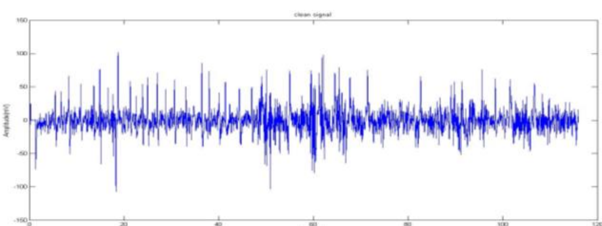
Figure 5. (a) Clean Fp1 signal after Butterworth filter (b) Clean Fz signal after Butterworth filter (c) Clean Pz signal after Butterworth filter

C. *Signal after Stationary wavelet transform filter*

The result in Fig. 3 shows the EEG signal when filtered by stationary wavelet transform. As we can seem, the resulted signal is good because it still can recover the original information although the artifact has cancel out.



(a)



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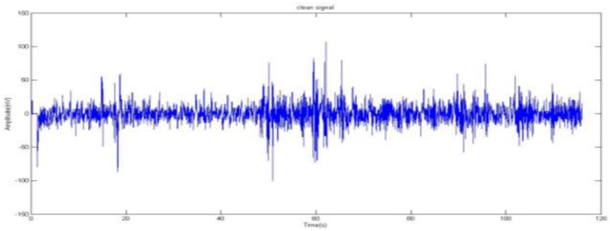

(c)

Figure 6. (a) Clean Fp1 signal after SWT filter (b) Clean Fz signal after SWT filter (c) Clean Pz signal after SWT filter

D. *Mean Square Error and Peak-to-Noise Ratio*

Fig. 7 and Table I shows the mean square error (MSE) for Butterworth bandpass filter and stationary wavelet transform filter (SWT) at channel Fp1, Fz and Pz.

TABLE I. MEAN SQUARE ERROR AT CHANNEL FP1, FZ AND PZ

Filter/Channel	**Fp1**	**Fz**	**Pz**
Butterworth Bandpass	20.42	24.50	30.50
Stationary Wavelet Transform	2.43	2.32	2.01

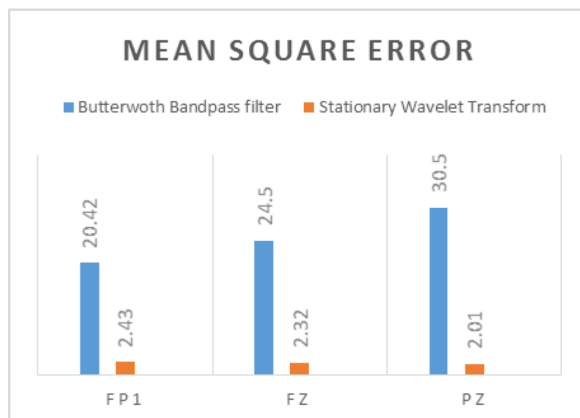

Figure 7. Mean Square Error of the Butterworth bandpass and stationary wavelet transform filter

The stationary wavelet transform have lower MSE value compared to the Butterworth bandpass filter. At channel Fp1, the SWT filter has MSE about 2.43 whereas Butterworth bandpass 20.42. At channel Fz, the MSE value for SWT filter is 2.32 and 24.50 for Butterworth bandpass filter. At channel Pz the MSE value for SWT filter is 2.01 and 30.50 for Butterworth bandpass. The percentage difference between the two filters at channel Fp1 is 88.1% whereas at channel Fz is 90.5% and lastly at channel Pz is about 93.4%.

TABLE II. PEAK-TO-NOISE RATIO AT CHANNEL FP1, FZ AND PZ

Filter/Channel	Fp1	Fz	Pz
Butterworth Bandpass (dB)	35.07	34.27	33.32
Stationary Wavelet Transform (dB)	44.30	44.52	45.12

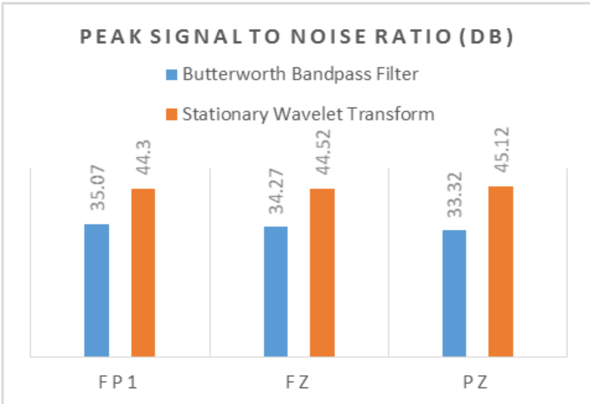

Figure 8. Peak-to-Noise Ratio of the Butterworth bandpass and stationary wavelet transform filter

Based on the Table II and Fig. 8, it shows that the stationary wavelet transform has bigger PSNR value at the three channels compares to the Butterworth bandpass filter. It means more noise is filter out. At channel Fp1, the PSNR is 35.07 dB for Butterworth bandpass filter while for SWT filter is 44.30 dB. The percentage difference is 20.9%. At Channel Fz, PSNR for Butterworth bandpass filter is 34.27 dB whereas SWT filter is 44.52 dB. The percentage difference is about 23.0%. At channel Pz, the PSNR for SWT filter is 45.12 dB whereas Butterworth bandpass filter is 33.32 dB.

Based from the MSE and PSNR values, it shows that the stationary wavelet transform filter with dB3 mother wavelet and 5 decomposition level is able to filter out more noise compare to 4^{th} order Butterworth bandpass filter at cutoff frequency 4 to 40 Hz. Besides that, the original information does not loss for SWT technique.

IV. CONCLUSION

Filtering the artifact is an important technique before analyzing the data. EEG signal are affected by various artifacts. In this paper, two different filter has been introduced to determine their effect in removing the noise. The MSE and PSNR is a popular parameter to determine the quality of signal after filtering. SWT filter able to remove electromyography and electrooculography artifacts while the Butterworth bandpass filter does not able to remove all of artifact. The stationary wavelet transform is better in removing the noise compare to Butterworth bandpass filter.

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REFERENCES

[1] E. Niedermeyer and F. L. da Silva, Electroencephalography: basic principles, clinical applications, and related fields, 5th ed. New York: Lippincott Williams & Wilkins, 2005.

[2] M. Sheoran, S. Kumar, and A. Kumar, "Wavelet-ICA based denoising of electroencephalogram signal," International Journal of Information and Computation Technology, vol. 4, pp. 1205-1210, 2014.

[3] K. S. Park, H. Choi, K. J. Lee, J. Y. Lee, K. O. An, and E. J. Kim, "Patterns of electroencephalography (EEG) change against stress through noise and memorization test," International Journal of Medicine and Medical Sciences, vol. 3, pp. 381-389, 2011.

[4] M. E. Palendeng. "Removing noise from electroencephalography signals for BIS based depth of anaesthesia monitors." M. E. thesis, University of Southern Queensland Toowoomba, Australia, 2011.

[5] Z. Wang and A. C. Bovik, "Mean squared error: love it or leave it? A new look at signal fidelity measures," Signal Processing Magazine, IEEE, vol. 26, pp. 98-117, 2009.

[6] J. R. Walker. "Brain task map." Internet: http://www.soft-dynamics.com/, 2007 [Feb. 15, 2014].

[7] B. Geethanjali, K. Adalarasu, and R. Rajsekaran, "Impact of music on brain function during mental task using electroencephalography," World Academy of Science, Engineering and Technology, vol. 66, pp. 883-887, 2012.

[8] K. S. Park, H. Choi, K. J. Lee, J. Y. Lee, K. O. An, and E. J. Kim, "Patterns of electroencephalography (EEG) change against stress through noise and memorization test," International Journal of Medicine and Medical Sciences, vol. 3, pp. 381-389, 2011.

[9] P. Jain and P. K. Govindaiah. "Removal artifacts and analysis of EEG signal using data driven parameters," in Proc. IEEE TechSym Satellite Conference, 2014, pp. 3-4.