

Decomposition Level Comparison of Stationary Wavelet Transform Filter for Visual Task Electroencephalogram

Syarifah Noor Syakiylla Sayed Daud, Rubita Sudirman*

Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia

Corresponding author: rubita@fke.utm.my

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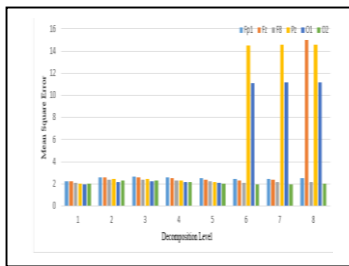
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Graphical abstract



Mean Square Error at different channel and decomposition level

Abstract

There has been a lot of research on the study of the human brain. Many modalities such as medical resonance imaging (MRI), computerized tomography (CT), positron emission tomography (PET), electroencephalography (EEG) and etc. has been invented. However, between this modality the electroencephalography widely chosen by researchers due to it is low cost, non-invasive techniques, and safely use. One of the major problems, the signal is corrupted by artifacts, whether to come from the muscle movement (electromyography artifact), eye blink and movement (electrooculography artifact) and power line interference. Filtering technique is applied to the signal in order to remove these artifacts. Wavelet approach is one of the technique that can filter out the artifact. This paper aim to determine which decomposition level is suitable for filtering EEG signal at channel Fp1, Fz, F8, Pz, O1 and O2 use stationary wavelet transform filter at db3 mother wavelet. Eight different decomposition levels have been selected and analyze based on mean square error (MSE) parameter. The Neurofax 9200 was used to record the brain signal at selected channel. Result shows that the decomposition at level 5 is suitable for filtering process using this stationary wavelet transform approach without losing important information.

Keywords: EEG; stationary wavelet transform filter; mean square error; decomposition level

Abstrak

Banyak kajian telah dilakukan terhadap otak manusia. Pelbagai alatan dicipta seperti *medical resonance imaging (MRI)*, *computerized tomography (CT)*, *positron emission tomography (PET)*, *electroencephalography (EEG)* dan lain-lain. Walau bagaimanapun, berbanding dengan alatan lain mesin *electroencephalography* selalu digunakan oleh para pengkaji berikutan kelebihan yang dapat menjimatkan kos, teknik tidak invasif dan selamat digunakan. Kekurangan menggunakannya ialah isyarat yang dikeluarkan dipengaruhi oleh hingar disebabkan oleh pergerakan otot, pergerakan dan kerdipan mata, dan hingar elektrik. Teknik penapisan akan digunakan untuk membuang hingar-hingar tersebut. Teknik wavelet merupakan salah satu kaedah yang boleh digunakan untuk menapis hingar tersebut. Kertas ini bertujuan untuk menentukan tahap penguraian yang sesuai bagi menapis isyarat EEG pada saluran Fp1, Fz, F8, Pz, O1 dan O2 dengan menggunakan ubahan pegun pada db3 ibu ubahan. Lapan tahap penguraian yang berbeza telah dipilih dan dianalisis berdasarkan parameter ralat min kuasa dua (MSE). Neurofax 9200 telah digunakan untuk merekodkan isyarat otak pada saluran yang dipilih. Hasil kajian menunjukkan bahawa penguraian pada peringkat 5 adalah lebih sesuai untuk proses penapisan yang menggunakan pendekatan mengubah ubahan tidak bergerak ini tanpa kehilangan maklumat penting.

Kata kunci: EEG; penapis ubahan pegun; ralat min kuasa dua; tahap penguraian

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1.0 INTRODUCTION

Memorizing is one of the techniques that student always applies to their study. Facts, human anatomy, math equation and science symbol are the example that needs the ability of students to memorize. Capability of memorizing by person depend on the internal and external factors such as physical state, cognitive factor, emotional factor, task demand and meta-memory [1]. Some people can memorize in a short time but some others may need to repeat a few times. According to Atkinson and Shiffrin

the human memory can be categorized into three that are sensory memory, short-term memory and long-term memory [1]. Mostly, the researchers like to study the factors that affect the short-term memory or working memory [2-4]. Working memory can be defined as the temporary memory that stores and manipulates information in the brain [5]. One of the popular task that researcher use is Sternberg's task, which is a list of the alphabet will be shown to the subject for memorizing in a provided time [6-7]. In this study, we use the visual task (picture with two digit numbers) in order to avoid the effect of language [2].

1.1 Electroencephalography (EEG)

Among the modalities that has been invented the electroencephalography is widely used compared to others. It able to detect the brain signal in a short time, low cost, non-invasive technique and painless/harmless to human [8]. Electroencephalography is a technique that use to record the human brain signal by placing scalp or electrode on the human head. Hans Berger is the first person that record the human brain signal using EEG in the early 1920s [8]. EEG widely uses in the medical field for determining the brain problem. Its use for detecting coma, brain death, epilepsy, head injury, stroke and tumor. There are four techniques involve in recording the signal.

Firstly, the bio potential will be picked up from the cerebral surface of transducer electrodes. Then, the signal is amplified and filter to remove any artifact before record and display on graphic recorder. The last process is the signal analyze and interpret by visual or computer. The amplitude of EEG signal is in microvolts and within 0.1 to 100 Hz frequency [8]. Due to small amplitude, it easily to be corrupted by artifact/noise. It easily corrupted by muscle movement (electromyography noise), eye movement and blink (electrooculography noise) and power line interference (50-60 Hz) [9]. This type of noise will affect the real result if does not remove from the signal.

In 1958, International Federation in Electroencephalography and Clinical Neurophysiology adopted standardization for electrode placement known as 10-20 placement electrode system [9]. Figure 1 shows the illustration of the electrode placement.

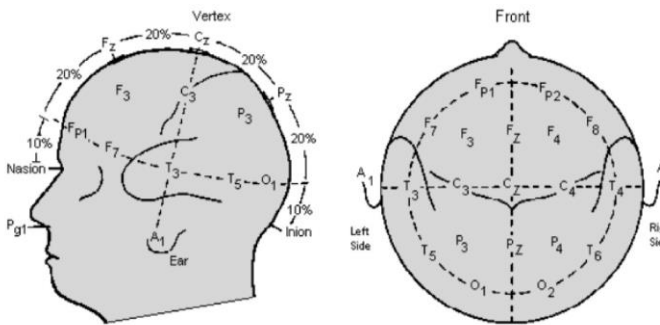


Figure 1 International 10-20 Placement Electrode [10]

It has standardized the placement of electrodes on the scalp based on the brain regions. Generally, the human brain has four different regions that are frontal (F), parietal (P), occipital (O), and temporal (T). The electrodes naming according to the brain regions that are Fp1, Fp2, F7, F3, Fz, F4, F8, T3, T4, T5, C3, Cz, C4, P3, Pz, P4, T6, O1, Oz and O2. Each of the electrode placement represents their own roles (see Table 1).

1.2 Stationary Wavelet Transform

Many techniques are introduced to remove EEG artifacts such as adaptive filter, frequency domain regression technique, wiener filter technique, FIR filter, independent component analysis (ICA), and discrete wavelet transform (DWT) [12]. However, the result shows that the wavelet is more effective to remove EEG artifacts [13]. The idea of wavelet transform has been introduced by Jean Morlet in 1982. He has provided a new mathematical tool

for seismic wave analysis [13]. This type of analysis has emerged as one of the superior techniques in analyzing non-stationary signals like EEG [5]. The raw EEG signal in time domain needs to be processed in order to obtain more information for clinical or education purposes. Fourier transform is one of the techniques that can transform the signal from time domain to frequency domain. However, this technique is not suitable for non-stationary signal because the time-domain information will lost [13]. Wavelet is an approach that can transform the EEG signal from time domain into time and frequency localization without losing the signal information. Among the advantages of wavelet are; it's able to perform a different time and scale resolution, able to localize the area of larger signal, able to disclose information contain of the signals and able to filter the artifacts as well as classify the signal [13]. There are two types of wavelet transform that widely uses for filtering EEG signal; that are discrete wavelet transform (DWT) and stationary wavelet transform (SWT).

Table 1 Electrode placement and function [11]

Brain Region	Electrode	Function
Frontal	Fp1	Attention
	Fp2	Judgment, restrain of impulses
	F7	Verbal expression
	F3	Motor planning
	F4	Motor planning for left upper extremity "integration midline left side"
	F8	Emotional expression
Temporal	T3	Verbal memory
	T4	Emotional memory
	T5	Verbal understanding
	T6	Emotional understanding and motivation
Central	C3	Sensorimotor integration (right)
	Cz	Sensorimotor integration (midline)
	C4	Sensorimotor integration (left)
Parietal	P3	Cognitive processing special temporal info. "verbal reasoning"
	Pz	Cognitive processing
	P4	Cognitive processing special temporal info. "Math word problems", "non-verbal reasoning"
Occipital	O1	Visual processing
	Oz	Incontinence
	O2	Visual processing

According to the researcher the DWT method is not suitable for signal processing because it involved the down-sampling method which the frequency sampling reduce to half after decomposition [13]. This situation may cause lose the time invariant property [13]. The time invariant property is important because it able to identify and detect the changes or transient characteristics of EEG signal. SWT technique able to maintain the time invariant property and improve the power of the signal denoising because it process does not reduce the original signal length [13]. This research aims to use dB3 mother wavelet of SWT technique for filtering the artifact in EEG signal. The reason uses the dB3 mother wavelet because it is capable to detect and localize the spike in the EEG signal [13]. The EOG and EMG has the spiky characteristic; so this type of mother wavelet is suitable to denoise it. The Daubechies wavelet order 4 or higher is not

suitable because it more stretched in time axis and mother wavelet is more sinusoidal like [15]. There are four steps involved in this filtering process in order to remove the artifact. Firstly the signal decomposed into two parts which is an approximation and details by passing through a low pass filter and a high pass filter (see Figure 2).

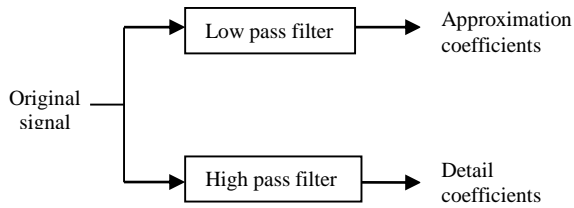


Figure 2 Stationary Wavelet Transform decomposition

The approximation and detail coefficient have the same length with the original signal. The decomposition of the SWT can be computed by [15]:

$$cA_{j,k}^{SWT} = \sum_n cA_{j-1,k+2^j(n)}^{SWT} g(n) \tag{1}$$

$$cD_{j,k}^{SWT} = \sum_n cD_{j-1,k+2^j(n)}^{SWT} h(n) \tag{2}$$

where $cA_{j,k}^{SWT}$ is the approximation coefficient of SWT, $cD_{j,k}^{SWT}$ is the details of SWT, j, k is the number of level decomposition and the position, $g(n)$ is stands for low pass filter and $h(n)$ stands for high pass filter [15]. The decomposition process can be seen in Figure 2. The second step is to eliminate the EMG artifact considers as a high frequency component and the signal is reconstructed again. Lastly, the threshold method is applied in order to remove the EOG artifact before obtain the clean signal.

1.3 Mean Square Error

Mean square error is a quantitative parameter that used to determine the effect on the original signal after filter process [16]. The aim of this parameter is to compare the original signal with the reconstructed signal by providing a quantitative score that describes the level of error or distortion between them. MSE can be defined as

$$MSE(x, y) = \frac{1}{N} \sum_{i=1}^N (x_i - y_i)^2 \tag{3}$$

where x and y are two finite length in discrete signal, N is the number of signal samples and x_i and y_i are the values of the i^{th} samples in x and y [16].

The lower the MSE is the better because more artefact have filtered out. However, in some cases, although the reconstructed signal has lower MSE but some important information may lose. So, to avoid this case happen the type of filter must be carefully chosen. MSE value can be converted into decibels known as peak-to-noise ratio (PSNR). It can be defined as equation (4).

$$PSNR = 10 \log_{10} \frac{L^2}{MSE} \tag{4}$$

where L is the dynamic range of allowable image pixel intensities [16].

1.3 Related Works

Previous studies had shown that the wavelet approach able to remove the artifact in image and signal effectively. There are three types of wavelet approach; that is continuous, discrete and stationary wavelet transform. Each of them has their own advantages in preprocessing the signal or image. According to Palendeng [13] the stationary wavelet transform is the best selection wavelet approach because it's able to maintain the frequency sampling of the image or signal [13]. However, in discrete wavelet transform approach the frequency will be down-sampled whereas for continuous wavelet transform the frequency of the signal or image will be oversampling.

The study by [17], when denoising the image from white Gaussian noise, it shows that the stationary wavelet transform is more suitable compare to discrete wavelet transform [17]. Meanwhile, it is also discovered that the stationary wavelet transform is suitable in removing the muscle and eye artifact in electroencephalography signal [13]. A study by Yasoda and Shanmugan [18], also prefer stationary wavelet transform to detect the electroencephalography artifact compare to discrete wavelet transform [18]. The result on the [19] shows that the stationary wavelet transform filter able to maintain the time invariance property and has superior performance for denoising microarray image compare with adaptive wiener filter and discrete wavelet transform. Based on the previous research result that the stationary wavelet transform is suitable in denoising the signal without losing the time invariance property so this study aim to determine the suitable decomposition level of SWT technique for electroencephalography signal.

2.0 METHODOLOGY

The raw EEG data obtain from the memorizing visual task experiment that has been conducted in the laboratory. Subject need to memorize the number with the picture in two minutes (see Figure 3). The subject was female aged 24 years old with no vision problem. She had given 5 minutes rest after entering laboratory room before the assessment started.

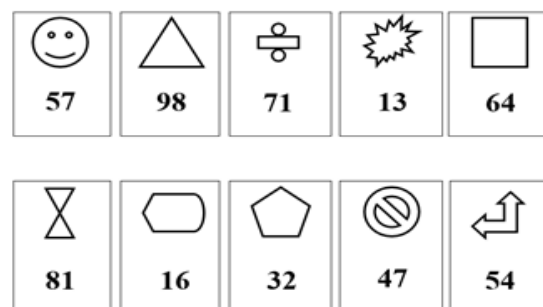


Figure 3 Stimuli for memorizing task [2]

During the memorizing period the brain signal has been recorded using 10-20 placement electrode system of EEG machine (Neurofax 9200). The raw EEG signal saved in ASCII files and then converted into text files. The EEG signal has been sampled at 500 Hz with 60000 data points. After that the raw data loaded into MATLAB software. Six out of twenty channels has been selected that relate to working memory process. The channels are Fp1, Fz, F8, Pz, O1 and O2. Next, our aim is to remove the artifact in this selected channel using stationary wavelet transform approach. It can be done whether using a

wavelet toolbox or a wavelet algorithm coding. In this research, we chose coding for implementing the signal. Seven SWT decomposition level chose to determine which level is the best for filtering process with db3 mother wavelet. The original and reconstructed signal save into JPEG file before determining their MSE and PSNR value. Based on the average MSE and PSNR value the best decomposition level will chose. Figure 4 shows the workflow of this study.

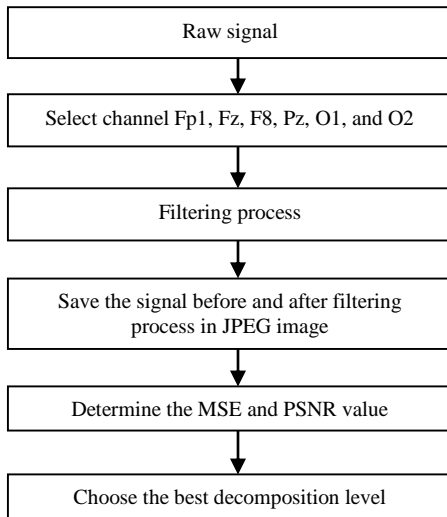


Figure 4 Study workflow

3.0 RESULT AND DISCUSSION

In this study, we aim to determine the stationary wavelet transform decomposition level of db3 mother that suitable for EEG denoising based on the parameter mean square error and peak-to-signal noise ratio. The level of decomposition is chosen in 2 to 8 level exclude the level 1 because it is does not suitable for denoising the EEG signal. Table 2 and 3 shows the mean square error and peak-to-signal noise ratio value at a different decomposition level using stationary wavelet transform approach for 6 channels of EEG signal. The good resulted of mean square error value is the lowest, whereas for the peak-to-signal noise ratio is the higher one. It means that the filter is more effective in removing the artifact.

Table 2 MSE value of different decomposition level for Channel Fp1, Fz, F8, Pz, O1 and O2

Level	Channel						Average
	Fp1	Fz	F8	Pz	O1	O2	
2	2.55	2.55	2.39	2.46	2.18	2.27	2.40
3	2.63	2.56	2.39	2.41	2.22	2.27	2.41
4	2.59	2.51	2.29	2.30	2.16	2.16	2.34
5	2.50	2.40	2.21	2.15	2.07	2.04	2.23
6	2.41	2.31	2.21	14.50	11.08	1.92	5.74
7	2.46	2.35	2.17	14.56	11.17	1.93	5.77
8	2.49	15.03	2.16	14.59	11.17	1.98	7.90

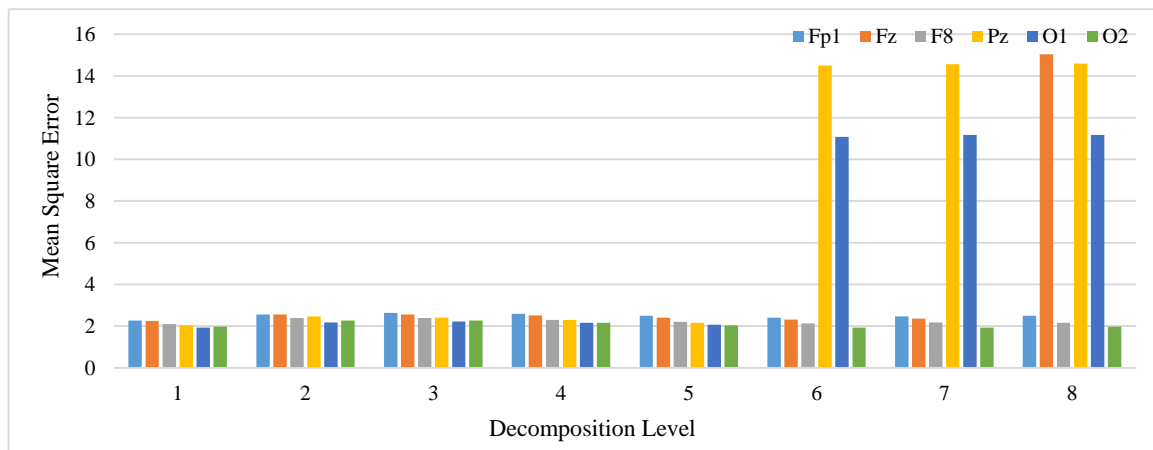


Figure 5 Mean Square Error at different channel and decomposition level

Based on Table 2 and Figure 5, at channel Fp1 (MSE = 2.41), Fz (MSE = 2.31) and O2 (MSE = 1.92) the decomposition at level 6 has the lowest mean square error value, whereas at channel Pz (MSE = 2.15) and O1 (MSE = 2.07) the decomposition at level 5 gives the lowest mean square error. Only F8 (MSE = 2.16) gives the lowest mean square error value at decomposition level 8. In Table 3 the Fp1 (PSNR = 44.34 dB), Fz (PSNR = 44.52 dB) and O2 (PSNR = 45.34 dB) shows the highest peak-to-signal ratio at decomposition level 6 whereas Pz (PSNR = 44.85 dB) and O1 (PSNR = 45.01 dB) is highest peak-

to-signal noise ratio at decomposition level 5. At decomposition level 8, it gives the highest peak-to-signal ratio at channel F8 (PSNR = 44.82 dB).

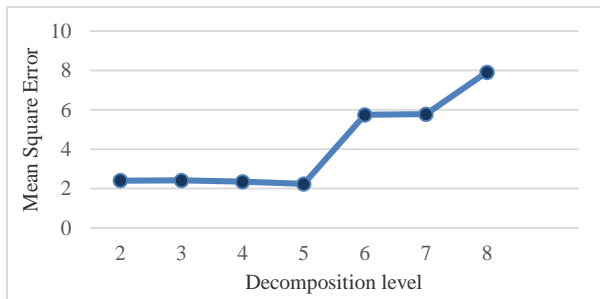


Figure 6 Graph of average mean square error

Table 3 PSNR value of different decomposition level for channel Fp1, Fz, F8, Pz, O1 and O2

Level	Channel						Average
	Fp1	Fz	F8	Pz	O1	O2	
2	44.10	44.11	44.38	44.26	44.78	44.60	44.37
3	43.96	44.09	44.39	44.34	44.70	44.60	44.35
4	44.04	44.17	44.56	44.55	44.83	44.81	44.49
5	44.18	44.36	44.71	44.85	45.01	45.07	44.70
6	44.34	44.52	44.91	36.55	37.72	45.34	42.23
7	44.25	44.45	44.80	36.53	37.68	45.32	42.17
8	44.20	36.39	44.82	36.52	37.68	45.20	40.80

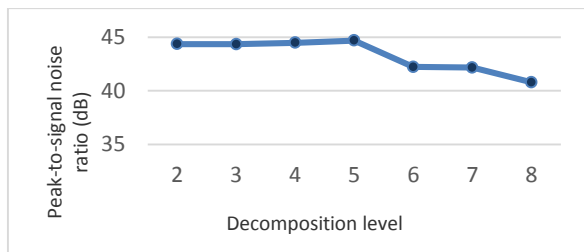


Figure 7 Graph of average peak-to-signal noise ratio

It is difficult to conclude the result based on the mean square error and peak-to-noise ratio parameter due to each channel has different effects at different decomposition levels. The best solution is by averaging the MSE and PSNR value at selected channel to obtain the lowest mean square error and the highest peak-to-signal noise ratio. Based on the average mean square error and peak-to-signal noise ratio the decomposition at level 5 has the lowest mean square error (MSE = 2.23) and the highest peak-to-signal noise ratio (PSNR = 44.70 dB) (see Figure 6 and Figure 7). Thus, in this study, we found that the decomposition at level 5 is suitable for EEG signal denoising.

Stationary wavelet transform approach is selected in this study due to it able to maintain the actual frequency sampling of the original signal, thus the time invariant property of the signal is not lose. Besides that, it also improves the power of the signal denoising. The resulted signal after pass through this filter has the same frequency sampling as the original signal. This criteria is important due to it can preserve the information of the original signal although the artifact has been removed.

3.3 EEG Signal Before and After Filtration

Figure 8 shows the raw EEG signal that contaminated with noise whereas Figure 9 shows the signal after filtering process using stationary wavelet transform technique with db3 mother wavelet at decomposition level 5 for channel Fp1, Fz, F8, Pz, O1 and O2.

4.0 CONCLUSION

The outcome from the EEG processing and analysis is important, especially in medical area which is the clinicians or researcher able to define the condition of the person's brain. However, to achieve this aim is not an easier thing. EEG signal always corrupted by many noises, especially from EOG and EMG artifacts. Suitable filter should be used to remove the artifacts without losing the information. In this study, we choose stationary wavelet transform filter which able to remove the noise without losing the time invariance property. The time invariance property is important to determine the characteristics of the EEG signal. The db3 mother wavelet consists the spiky characteristics which able to filter the EOG and EMG noise. Seven different decomposition levels have been chosen to determine which is can give the best result based on MSE and PSNR parameter. The decomposition at level 1 is not suitable for signal denoising because the difference between original and reconstructed signal is a bit different that might cause loss of information.

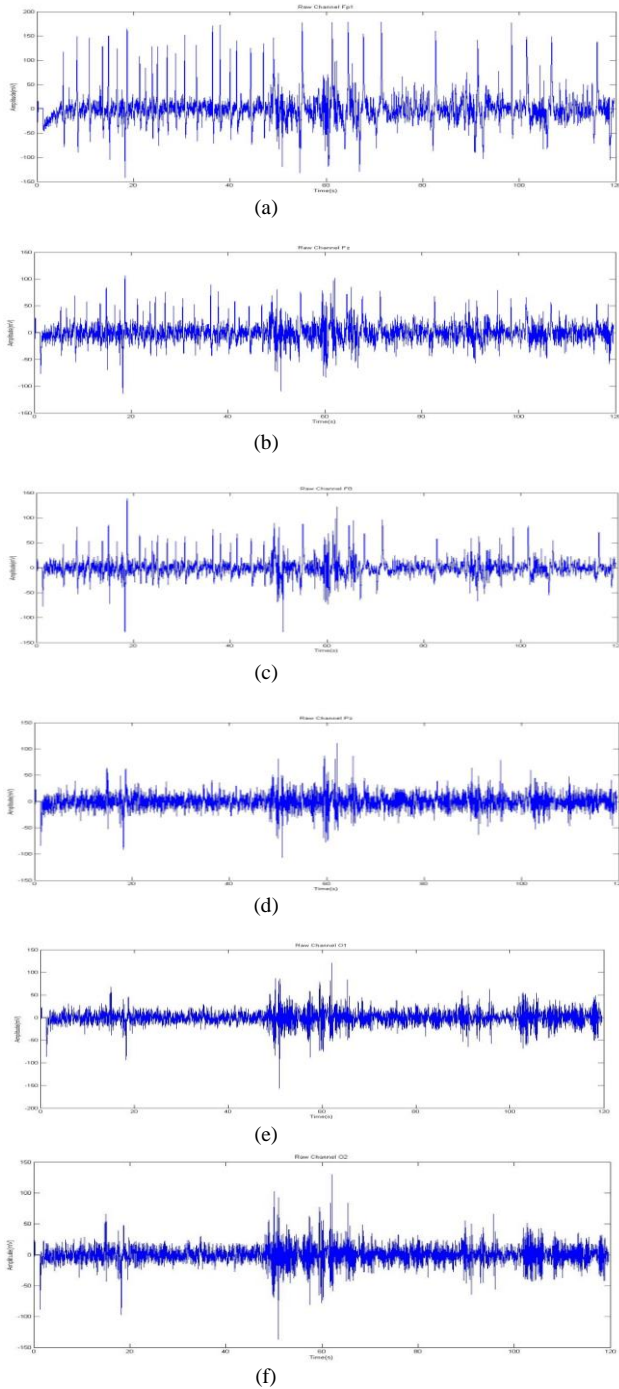


Figure 8 Raw signal : (a) Channel Fp1, (b) Channel Fz, (c) Channel F8, (d) Channel Pz, (e) Channel O1 and (f) Channel O2. The MSE value becomes not stable when the decomposition level increased, especially at certain channel (Fz, Pz and O1). Based from the 7 decomposition level the most better one is at level 5. The MSE result is uniform at channel Fp1, Fz, F8, Pz, O1 and O2 which gives the lowest average MSE value and higher average PSNR value.

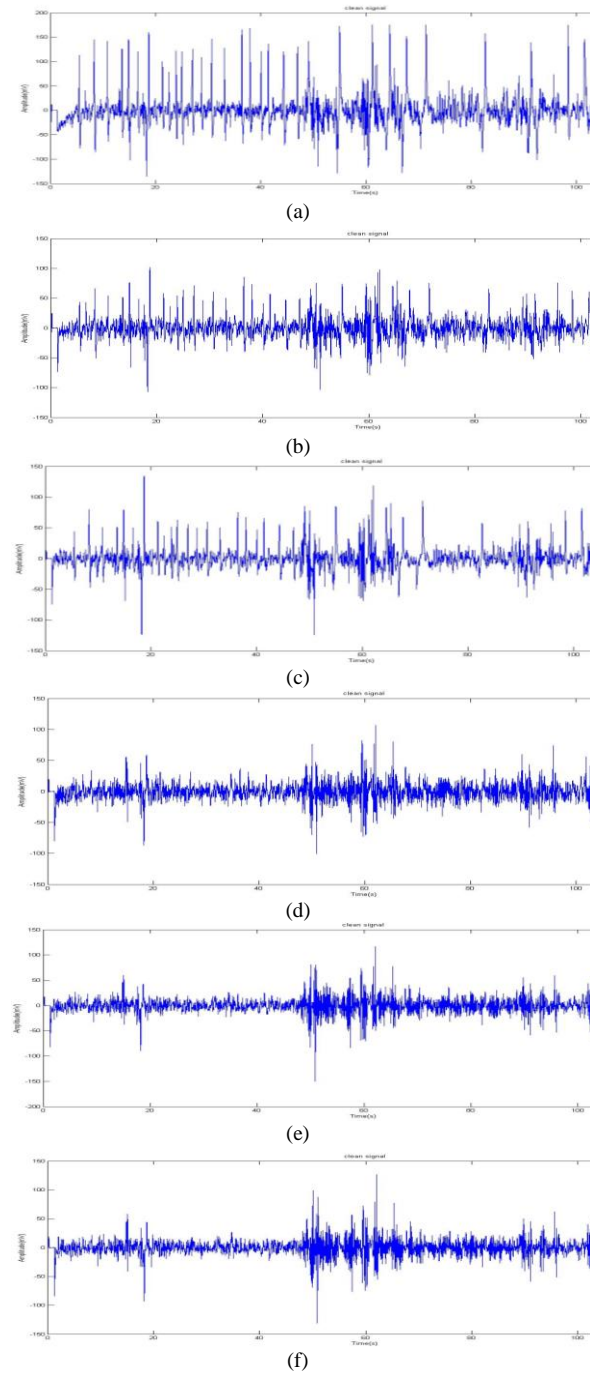


Figure 9 Filtered signal: (a) Channel Fp1, (b) Channel Fz, (c) Channel F8, (d) Channel Pz, (e) Channel O1 and (f) Channel O2

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