Second International Conference on Computational Intelligence, Modelling and Simulation

Wavelet Frequency Energy Distribution of Electrooculogram Potential towards Vertical and Horizontal Movement

W. M. Bukhari W. Daud, R. Sudirman (*IEEE member*)*, Anwar Al Haddad.
Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johore, Malaysia
*Corresponding author: rubita@fke.utm.my

***Abstract*- Wavelet transform is one of the favoured tool for analyzing the biomedical signals. In this paper, we describe the identification of Electro-oculography (EOG) signals of eye movement potentials by using wavelet transform which gives more feature informations than FFT. The capability of wavelet transform is to distribute the signal energy over the change of time in different frequency bands. The EOG signals are captured using electrodes placed on the forehead around the eyes to record the eye movements using the Neurofax EEG-9200. The wavelet features are used to determine the characteristic of eye movement waveform. The recorded data is composed of an eye movement toward vertical, upward and downward and horizontal, left and right movements. From the result, it is proved that different EOG signals exhibit differences in signals energy, in which their corresponding dominant energy are: level 6 (8-16Hz) for left eye movement; level 7 (4-8Hz) for upward; level 8 (2-4Hz) for right and level 9 (1-2Hz) for downward.**

Keywords - Electro-oculogram; Eye Movement; Signal Potentials; Wavelet Transform; Scalogram

I. INTRODUCTION

The human eye is a spherical structure with a radius of 12mm. The signals that can be sense from the movement of the human eyes can be known as Electro-oculography (EOG). The EOG is derived from the Cornea Retinal Potential (CRP) that is generated within the eyeball by the metabolically active retinal epithelium. The production of CRP comes from the hyper-polarization and de-polarizations of the nervous cells in the retina. EOG is the electrical recording corresponding to the eye movement. The eye has a resting electrical potential, with the front of the globe positive and back with globe negative. This phenomenon was first observed by Emil du Bois-Reymond in 1848 and has been the foundation in electrooculography [1].

EOG are taken using bipolar electrodes on the outside of eye. Exact electrode placements vary, but the electrode generally placed on the temples or on the distal ends of the forehead. When the eyes move, a differential potential result will occur. The magnitudes of the right and left eye movement can be seen between -75uV to 150uV respectively. The polarity of movement potentials is dependent on electrode setup since the signal is positive when the eyes are moving toward positive electrode [1].

EOG is a technique for measuring the resting potential of the retina. The resulting signal is called the electro-oculogram. The main applications are in ophthalmological diagnosis and in recording eye movements [2]. The EOG is a potential produced by movement of the eye or eye lid. The generation of the EOG signal can be understood by envisaging dipoles located in the eyes with the cornea having relatively positive potential with respect to the retina [3].

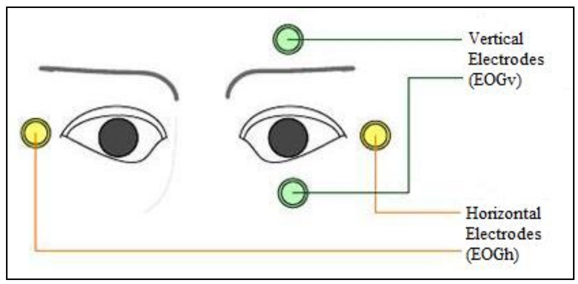

Fig. 1 Position of electrodes

This EOG signal is picked up by a bi-channel signal acquisition system consisting of the Horizontal (H) and Vertical (V) channels. The placement of the electrodes shown in Fig. 1. EOG_h is electrode's placement to measure the horizontal eye movement, while EOG_V is the placement to measure the vertical eye movement.

Numerous other techniques from theory of biomedical signal processing have been used to obtain representations and extract the features of interest for classification purposes. Dinesh Kumar et al. [4] used the EOG signals for determining the angle of eye gaze for controlling a computer while Aysegul Guven and Sadik Kara [5] used the EOG signals for the classification with Artificial Neural Network (ANN) and Rubita Sudirman et al. [6] used the eye movement for the classification by using time frequency analysis. Study done by the A. Bhander et.al [7], used the wavelet scalogram decomposition to determine the most energy in specific frequency bands of vertical eye movement. They found that 90% of the signal energy (90%) is concentrated in the lower or higher scales and signal denoising.

II. WAVELET SCALOGRAM

Wavelet transform is a powerful tool in analyzing signals because of its ability to extract time and frequency domain information. The wavelet transform could be defined as an extension of the classic Fourier transform, except that, instead of working on a single scale (time or frequency), it works on a multi-scale basis [8]. Wavelet functions overcome the limitations of Fourier methods by employing analyzing function that are localized in time and frequency. It has a finite energy function and can be represented on a transient signals. In signal processing, wavelet analysis is mostly used in processing non-stationary signals. The wavelet transform can be interpreted as a decomposition of the original signal into set of independent frequency composition.

Wavelet scalograms (refer to Fig.3 and Fig.4) represent the time frequency localization property of the discrete wavelet transform. In this plot each detail coefficient is plotted as a filled rectangle whose color corresponds to the magnitude of the coefficient. The location and size of the rectangle are related to the time interval and the frequency range for this coefficient. Coefficients at low levels are plotted as wide and short rectangles to indicate that they localize a wide time interval but a narrow range of frequencies in the data. In contrast, rectangles for coefficients at high levels are plotted thin and tall to indicate that they localize small time ranges but large frequency ranges in the data. The heights of the rectangles grow as a power of 2 as the level increases. The bar shown on the scalogram plot, which indicates the range of energy for each level. This energy is defined as the sum of the squares of the detail coefficient for each levels. By the scalograms, it reveals that most of the energy of the signals in the data is captured in the details coefficient.

III. METHODOLOGY

This system setting includes the EEG data acquisition system; Neurofax EEG-9100 software [9] with EOG electrodes set and the sampling interval is 1ms. The EEG data acquisition system is used to record EOG signals from the subjects. Independent measurements can be obtained from both eyes, but as both eyes move in the vertical direction, it is sufficient to measure the vertical motion of only one eye together with the horizontal motion of both eyes. *Ag/AgCl electrodes* are chosen as their half cell potential is closer to zero compared to other types such as silicon rubber electrodes. This process was done in a quiet room to minimize the noise and hence get better recorded signals as shown in Fig. 2. Subjects were seated on a chair and supervised by an instructor who gave instructions on how to move their eyes. The instruction composed of four movements that are upward, downward, left and right. The recording was done in four successive eye movements for 10 subjects and each subject repeated for three times. Initially, EOG was recorded for 20 to 30 seconds for each eyes movement. Unfortunately, since the subjects were showing signs of tiredness, the recording duration has been reduced to 10 seconds which was free from artefacts observed in longer traces by visual inspection.

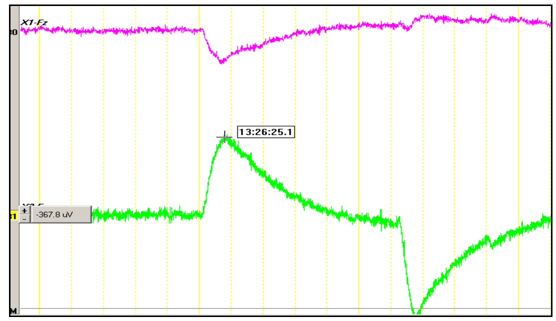

Fig. 2 Horizontal EOG signal (green line) display from data acquisiton system

The eyeball moved to the desired direction and the centre or static eye becomes the reference point. Furthermore, subjects were also asked to avoid blinking, body movements and any disturbances during the recording to minimize the unwanted artefacts. EOG signal captured was then analyzed by using wavelet analysis from MATLAB software and toolbox application. It was then uploaded into a program that runs a wavelet scalogram in order to present the signal in the wavelet coefficient energy in scale and space or time. The signals is decomposed down to 10 level of details using Daubechies order 4 (db4) as a mother wavelet. The db4 has been chosen because it has two vanishing moment i.e constant and linear component. The numbers of level decomposition strictly depend on the sample rate of original signal [10].

IV. RESULT AND DISCUSSION

When we come to the time frequency analysis in wavelet transform, we want to know the distribution of signal energy of wavelet details coefficient with the change of time. Hence, we plotted a scalogram for each movement in order to identify the dominant scales over maximum wavelet energy coefficient for the signal. Scalogram is used because it represents the time frequency localization property of wavelet transform. In this plot, each details coefficient is plotted as a filled rectangle whose colors correspond to the magnitude of the coefficient. The bar on the scalogram plot indicates the range of energy for each level. This energy is defined as the sum of the squares of the details coefficient for each level. Fig. 3 and Fig. 4 show the scalogram of signals of four different movements from a subject; left, right, downward and upward.

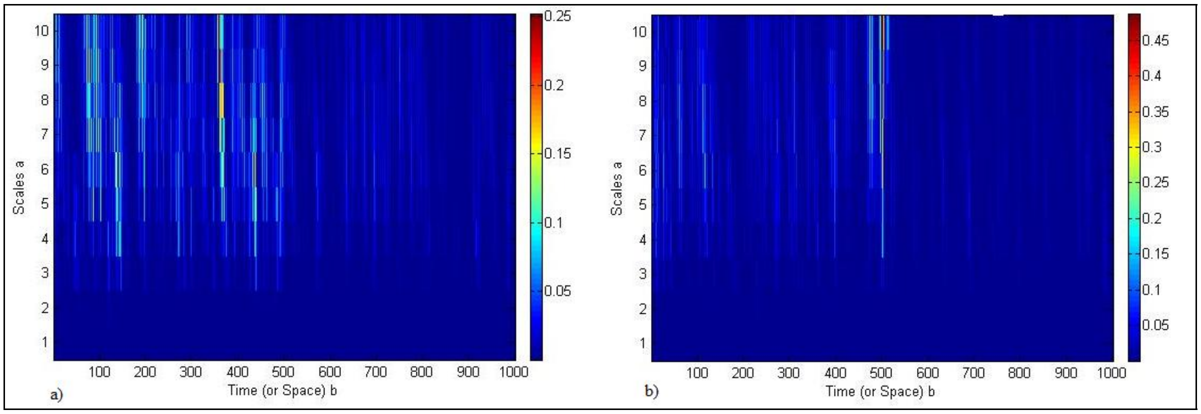

Fig. 3 Scalogram of horizontal eye movements ; a) Left eye Movement, b) Right eye Movement

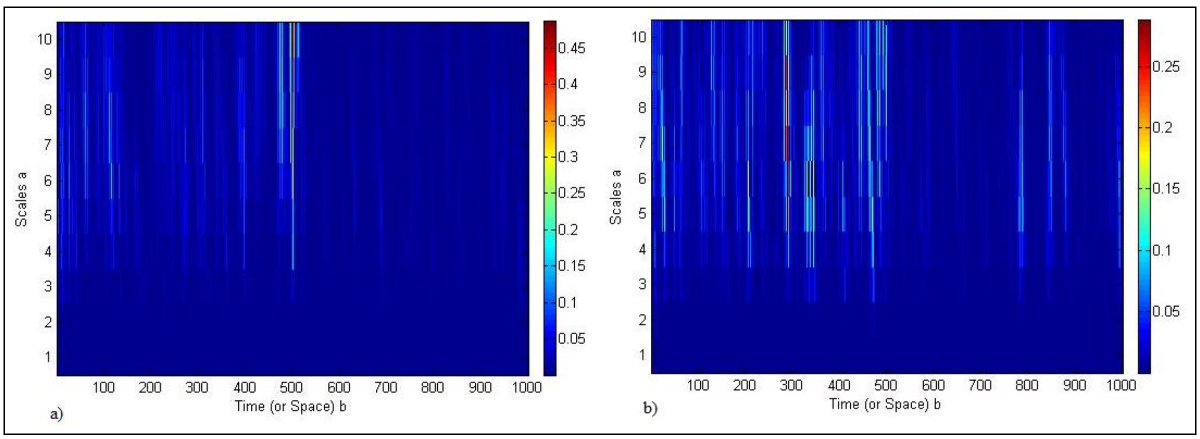

Fig. 4 Scalogram of vertical eye movements ; a) Upward eye Movement, b) Downward eye Movement

From the scalogram, it reveals that highest energy of the signals is captured in the different level of details coefficient for different EOG signals. Frequency component extracted by details move from high frequencies to low frequencies as scale of wavelet coefficient increases from 1 to 10, with frequency content being halved at each increment in accordance to the sampling rate which is 1000 Hz (refer Table I).

About 15 data for each eye movements have been analyzed by using wavelet scalogram in order to extract the most dominant energy details coefficient and it frequencies. The number of extracted detail coefficients from each level is calculated and plotted as shown in Fig. 5. From Fig. 5, it is noticed that average percentage for each movement data is slightly different from their energy level. This means that different eye movements are associated with different frequency bands.

TABLE **I** FREQUENCY CONTENT 10 OF LEVEL DECOMPOSITION

LEVEL / SCALE	FREQUENCY RANGE (Hz)
1	250-500
2	125-250
3	62.5-125
4	31.25-62.5
5	15.6-31.3
6	7.8-15.6
7	3.9-7.8
8	1.9-3.9
9	0.9-1.9
10	0.5-1.0

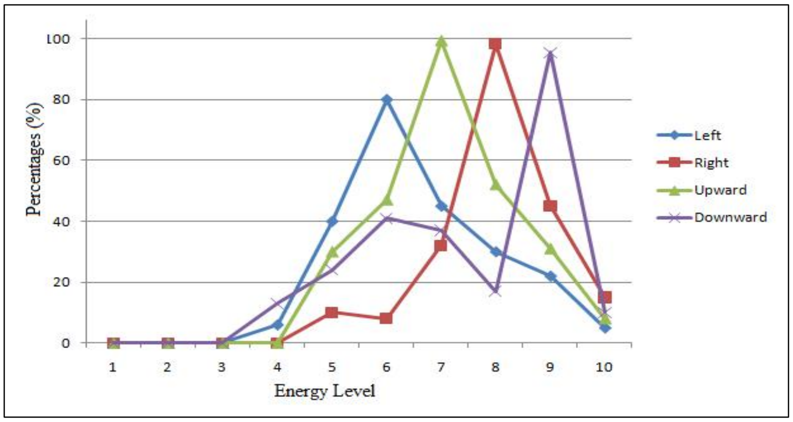

Fig. 5 Average percentages of energy level for 15 data of vertical and horizontal eye movements.

The percentage of each detail coefficient of four eye movements is illustrated in Fig. 5. Statistically, the dominant energy are: level 6 for left eye movement; level 7 for upward; level 8 for right and level 9 for downward. They are summarized as in Table II.

TABLE **II** DOMINANT ENERGY LEVEL FOR 15 EOG DATA

EOG Signals	**Dominant Energy Level**	**Average Percentage (%)**	**Estimated Frequency**
Left	Level 6	80.0	~ 8-16 Hz
Right	Level 8	98.2	~ 2-4 Hz
Up	Level 7	99.2	~ 1-2 Hz
Down	Level 9	95.4	~ 4-8 Hz

Dominant energy level means the maximum details coefficient energy that can be derived by scalogram for each signal. We used this parameter as the benchmark to classify the different movement of EOG signals.

V. CONCLUSION AND FUTURE RECOMMENDATION

This study has classified each EOG signals movement based on its estimated frequency using wavelet scalogram decomposition. Different with the previous study, they only focused on the overall wavelet decomposition and not specifically into the details of each EOG signals of each frequency bands. Hence, this paper is proposed and targets the researchers to look in details of the energy and frequency bands distribution within four eye movement signals for better interpretation of EOG signals analysis by using wavelet scalogram. Result obtained indicates that each eye movement has different frequency bands and could be integrated to design a support machine for paralyzed people to move their wheelchair by using eye movements.

ACKNOWLEDGEMENT

The authors are so indebted and would like to express our thanks to Universiti Teknologi Malaysia and Ministry of Science and Innovation Malaysia for supporting and funding this study. Our appreciation also goes to the Biomedical Intrumentation and Electronics Research Group (BMIE) for their ideas and comments to improve this paper.

REFERENCES

[1] J. Malmivuo, R. Plonsey, *Bioelectromagnetism: Principles and Application of Bioelectric and Biomagnetic Fields*. New York: Oxford University Press, New York, 1995,ch. 28.

[2] F. Jagla, M. Jergelova, I. Riecansky, 2007. Saccadic Eye Movement Related Potentials. Institute of Normal and Pathological Physiology, Center of Excellence for Cardiovascular Research, Slovak Academy of Sciences, Bratislava, Slovakia.

[3] R.B Knapp, H. Lusted, 1993. Biological Signal processing in Virtual Reality Applications, Proc. Virtual Reality and Persons with Disabilities.

[4] D. Kumar, E. Poole, 2002. Classification of EOG for Human Computer Interface, Proceedings of the Second Joint EMBS/BMES Conference Houston, TX, USA, October 23-26.

[5] G. Aysegul, K. Sadik, 2006. Classification of electro-oculogram signals using artificial neural network. Expert System with Applications 31, 199-205.

[6] R. Sudirman, W.M. Bukhari, 2009. Classification of Eye Movement Potentials Using Time Frequency Analysis, Proceedings of the IASTED International Conference on Applied Simulation and Modelling, ASM 2009. 131-135.

[7] A. Bhandari, V. Khare, M. Trikha, A. Anand. 2006. Wavelet Based Novel Technique for Signal Conditioning of Electro-Oculogram Signals. Annual Indian Conference INDICON.

[8] N. Hazarika, J. Z. Chen, C. Tsoi, A. Sergejew, 1977. Classification of EEG Signals Using the Wavelet Transform. IEEE Trans. Signal Processing. 51, Issue 1. 61-72.

[9] R. Sudirman, A.C. Koh, N.M. Safri, W.B. Daud, N.H. Mahmood, 2010. " EEG Different Frequency Sound Response Identification using Neural Network and Fuzzy Techniques" Proc. IEEE 6th. International Colloquium on Signal Processing and its Application (CSPA 2010).

[10] E. Magosso, M. Ursino, A. Zaniboni, E. Gardella " *A Wavelet Based Energetic Approach for the Biomedical Signals: Application to the EEG and EOG*" Applied Mathematics and Computation 207 (2009) 42-62.