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WAVELET FREQUENCY ESTIMATION PARAMETER OF ENERGY DISTRIBUTION FOR ELECTROOCULOGRAPH SIGNAL ANALYSIS

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Abstract. The study investigates the electrooculograph (EOG) signals of eye movement patterns. The behaviours of the eye movement signal is described using wavelet method and combined with the energy distribution features. The features are derived from EOG signals of four type eye movement and recorded using the EEG Data Acquisition System Neurofax EEG-9200. The electrodes were attached to the subjects on the forehead and below the eye. The data is acquired from 15 subjects in a quiet room, in which the recorded data is composed by four different eye movements that are upward, downward, towards to left and towards to right. Wavelet scalogram algorithm is used as the tool because of its capable to distribute the EOG signals energy of eye movement with the change of time and frequency. From the results, it indicated that the energy distribution of EOG signals exhibit different patterns in their corresponding movements as follow: level 6 (8-16 Hz) for left eye movement; level 7 (4-8 Hz) for upward; level 8 (2-4 Hz) for right and level 9 (1-2 Hz) for downward.

Keywords: Electro-oculogram; eye movement; signal potentials; wavelet transform; scalogram

Abstrak. Pengajian ini mengkaji *electrooculograph* (EOG) isyarat pola gerakan mata. Perilaku dari isyarat gerakan mata dijelaskan menggunakan kaedah *wavelet* dan digabungkan dengan ciri-ciri pengedaran tenaga. Ciri-ciri yang berasal dari isyarat EOG daripada empat jenis pergerakan mata dan dicatat menggunakan Sistem Akuisisi Data EEG, EEG Neurofax-9200. Elektrod-elektrod tersebut diletakkan di dahi dan di bawah mata. Data diperolehi daripada 15 subjek di dalam bilik yang senyap, di mana data yang tercatat terdiri daripada empat gerakan mata yang berbeza, iaitu pergerakan ke atas, ke bawah, ke kiri dan ke kanan. Algoritma *Wavelet scalogram* digunakan untuk menganalisa isyarat yang direkodkan kerana ia mampu untuk menunjukkan amaun tenaga isyarat EOG pergerakan mata dengan perubahan masa dan frekuensi. Hasil kajian menunjukkan bahawa amaun tenaga isyarat EOG menunjukkan pola yang berbeza dalam gerakan-gerakan berikut: tahap 6 (8-16 Hz) untuk gerakan mata ke kiri; tahap 7 (4-8 Hz) untuk

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gerakan ke atas; tahap 8 (2 – 4 Hz) untuk gerakan ke kanan dan peringkat 9 (1-2 Hz) untuk gerakan ke bawah.

Kata kunci: Electro-oculogram; gerakan mata; tenaga isyarat; transformasi wavelet; scalogram

1.0 INTRODUCTION

The human eye is a spherical structure with a radius of 12 mm. The signals sensed from the movement of the human eyes are 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 is positive and back with globe is negative. This phenomenon was first observed by Emil du Bois-Reymond in 1848 and has been the foundation in electrooculography (Malmivuo and Plonsey, 1995).

EOG is taken using bipolar electrodes besides the eyes. Exact electrode placements vary, but the electrode generally placed on the temples or on the distal ends of the forehead. When the eyes move, it resulted in a differential potential. The magnitudes of the right and left eye movement can be seen between –75 μV to 150 μV respectively. The polarity of movement potentials is dependent on electrode setup since the signal is positive when the eyes are moving toward the positive electrode (Malmivuo and Plonsey, 1995).

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 (Jagla *et al.*, 2007). 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 (Knapp *et al.*, 1993).

EOG signals band is limited in the range of about 1 to 50 Hz. It is essentially non-stationary and time varying and can be analyzed by using Wavelet Transform (Bhandari *et al.*, 2007). In biomedical signal processing, the assessment of vital function of the body is definitely requiring a non-invasive implementation for data acquisition, processing and analysis of physiological signals.

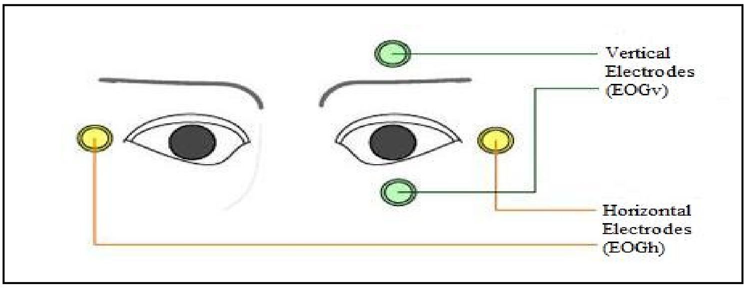


Figure 1 Position of electrodes

This EOG signal is picked up by a bi-channel signal acquisition system consisting of the horizontal and vertical channels. The placement of the electrodes is shown in Figure 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. (Kumar *et al.*, 2002) used the EOG signals for determining the angle of the eye gaze for controlling a computer while (Aysegul and Sadik, 2006) used the EOG signals for the classification with Artificial Neural Network (ANN) and (Sudirman and Bukhari, 2009) used the eye movement for the classification by using time frequency analysis. Study done by the (Bhandari, *et al.*, 2006) 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.

Examples of physiological signals found in biomedicine include the electrical activity of the brain- the encephalogram (EEG), the electrical activity of the heart- the electrocardiogram (ECG), the electrical activity of the eye, i.e electroretinogram (ERG) and electrooculogram (EOG) and speech signals. EOG signals can be used in various aspects of medical and biomedical application beyond diagnostics, for instance, in assisting the disabled (Jagla *et al.*, 2007).

2.0 WAVELET ENERGY

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 (Hazarika *et al.*, 1977). Wavelet functions overcome the limitations of Fourier methods by employing analyzing function that is localized in time and frequency. It has a finite energy function and can be represented on a transient signal. 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 a set of independent frequency composition.

Wavelet transform is the basis of the wavelet function. The wavelet has vanishing moment localized both in frequency and time. Assumption from the study done by (Magosso et al., 2009) has brought us to this solution. In both forms of wavelet analysis (continuous and discrete), the signal is decomposed into scaled and translated versions $\psi_{ab}(t)$ of a single function $\psi(t)$ called mother wavelet:

$$\psi_{ab}(t) \underline{\Delta} \frac{1}{\sqrt{a}} \Psi\left(\frac{t-b}{a}\right) \tag{1}$$

where a and b are the scale and translation parameters respectively, with a, b $\in \Re$ and a $\neq$ 0. The continuous wavelet transform (CWT) of a signal s(t) $\in L^2(\Re)$ (the space of the square integrable functions) is defined as:

$$C_{ab}(t) = \int_{-\infty}^{\infty} s(t) \frac{1}{\sqrt{a}} \Psi^*\left(\frac{t-b}{a}\right) dt = \langle s(t), \psi_{a,b}(t) \rangle, \tag{2}$$

where the symbol * mean complex conjugation and < > the inner product. The discrete wavelet transform (DWT) is obtained by discretizing the parameters *a* and *b*. In its most common form, the DWT employs a dyadic sampling with parameters *a* and *b* based on powers of two: $a = 2^j$; $b = k2^j$, with j, k$\in$Z. By substituting in Eq. (1), we obtain the dyadic wavelets:

$$\psi_{j,k}(t) = 2^{-j/2} \psi(2^{-j} t - k). \tag{3}$$

The DWT can be written as

$$d_{j,k} = \int_{-\infty}^{\infty} s(t) 2^{-j/2} \Psi^*(2^{-j} t - k) dt = \langle s(t), \psi_{j,k}(t) \rangle, \tag{4}$$

By appropriately selecting the mother wavelet $\psi(t)$, the collection of functions {$\psi_{j,k}$(t), j, k $\in$ Z} forms an orthonormal basis for $L^2(\Re)$. The correlated DWT allows the original signal to be reconstructed accurately and efficiently without any redundancy. The orthonormality of the set {$\psi_{j,k}$ (t), j, k$\in$Z} allows the concept of energy within the framework of the discrete wavelet decomposition to be linked with the usual notions derived from the Fourier theory. the energy series associated with coefficient series $d_{j,k}$ is given by

$$E_{j,k} = \left| d_{j,k} \right|^2 \tag{5}$$

and the overall energy at resolution j is

$$E_{j,k} = \sum_{k=0}^{2^{M-j}-1} \left| d_{j,k} \right|^2 \tag{6}$$

Hence, the total energy associated with the entire signal can be obtained as

$$E_{tot} = \sum_{j=1}^{M} \sum_{k=0}^{2^{M-j}-1} \left| d_{j,k} \right|^2 . \tag{7}$$

Energy coefficients as computed by Eq. (7) have different localization and density over different frequency band depending on the scale. Therefore, in order to study and compare the different movement of energy at different scales, it is necessary to compensate for the halved time resolution at each scale due to the down sampling operation. These methods have been applied to the analysis of the EOG signals.

3.0 METHODOLOGY AND SYSTEM SETTING

This system setting includes the EEG data acquisition system; Neurofax EEG-9100 software (Sudirman et al., 2010) with EOG electrodes set and the sampling interval is 1 ms. The EEG data acquisition system Neurofax EEG-9200 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.

Subjects were seated on a chair and supervised by an instructor who gave instructions on how to move their eyes shown in Figure 2. The instruction composed of four movements that are upward, downward, towards to left and towards to right. The recording was done in four successive eye movements for 15 subjects and each subject repeated for three times. Initially, EOG was recorded for 20 to 30 seconds for each eye 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.

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.

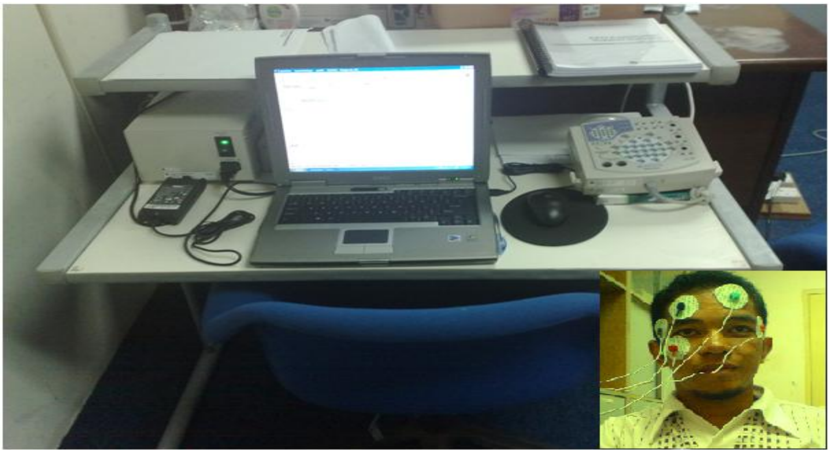


Figure 2 Subject and the data acquisition system

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 are decomposed down to 10 levels 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.

4.0 RESULT AND DISCUSSION

Firstly, in order to determine the useful bandwidth of EOG signals, the power spectral densities of several movements of EOG signal are used. From Figure 3, it shows that the band frequencies from 1 Hz to 15 Hz contain almost 90 percent of the signal energy for each movement.

Hence, the scalogram is plotted for each movement in order to identify the dominant scales over a 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 colours 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. Figure 4, Figure 5, Figure 6 and Figure 7 show the scalogram of signals of four different movements from a subject; towards to the left, towards to the right, downward and upward

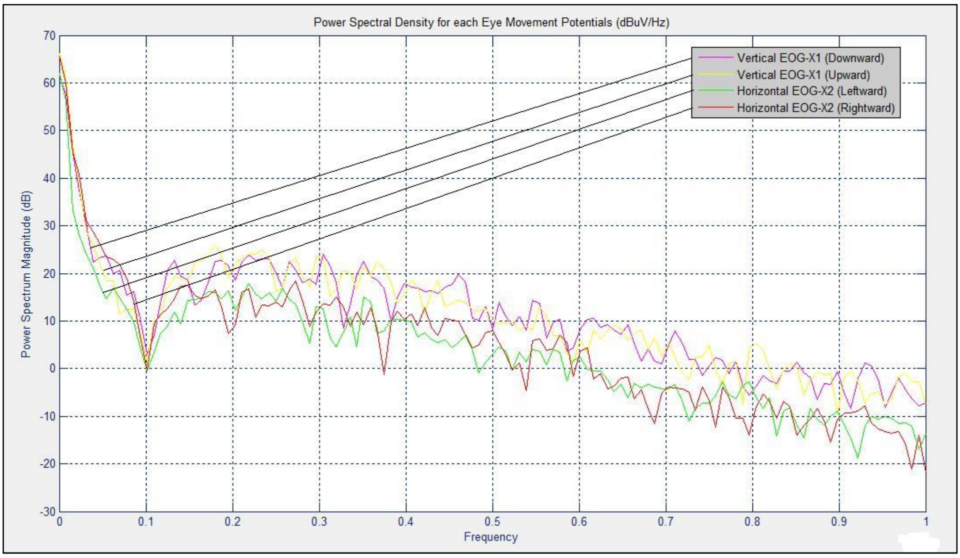
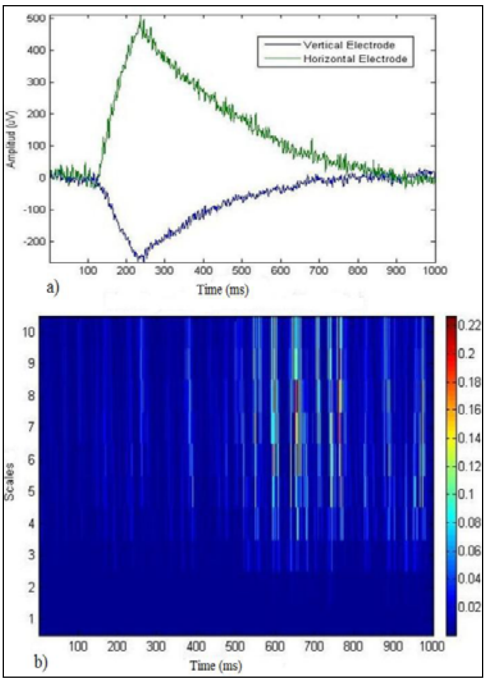


Figure 3 Power spectral densities of EOG signals captured



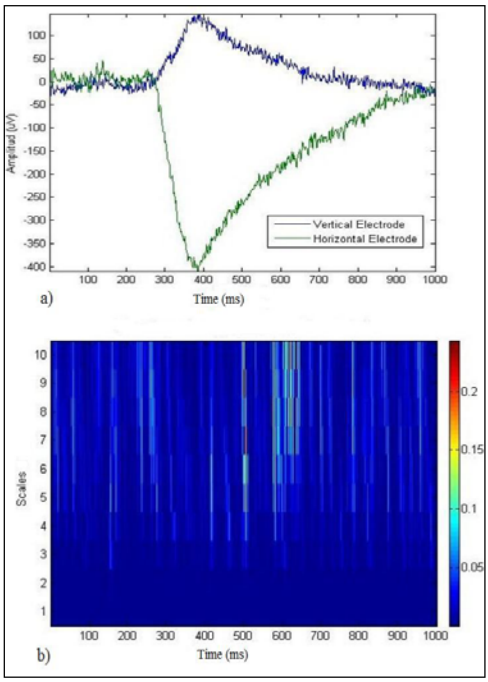


Figure 4 a) Left EOG signal, b) Wavelet scalogram of left EOG signal

Figure 5 a) Right EOG signal, b) Wavelet scalogram of right EOG signal

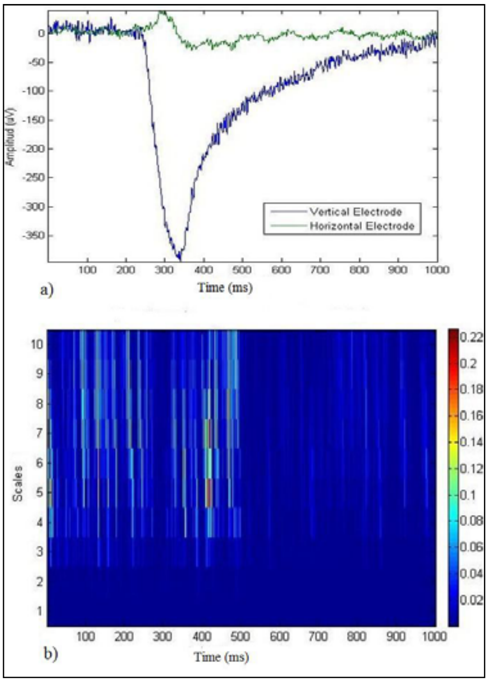


Figure 6 a) Upward EOG signal, b) Wavelet scalogram of upward EOG signal

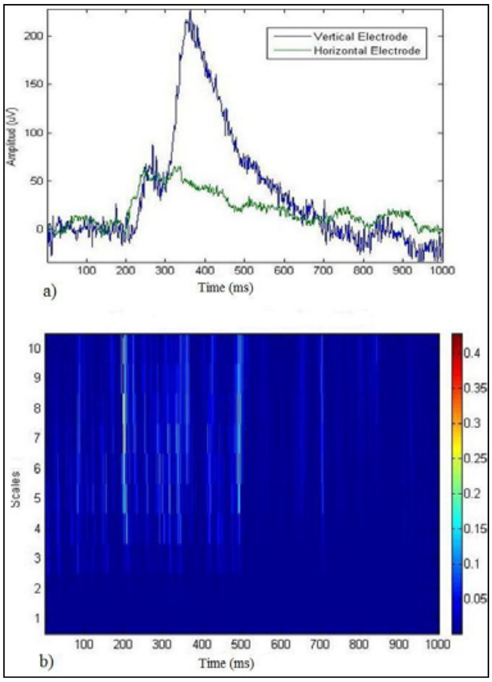


Figure 7 a) Downward EOG signal, b) Wavelet scalogram of downward signal

From the figures of the wavelet scalogram (Figure 4, 5, 6, 7), we could see the different between each signals of eye movement whereas it shown the different in the level of the decomposition and it reveals that highest energy of the signals is captured in 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 1).

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 Figure 8. From Figure8, 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 1 Frequency content of 10 Level decomposition

Level	Frequency (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

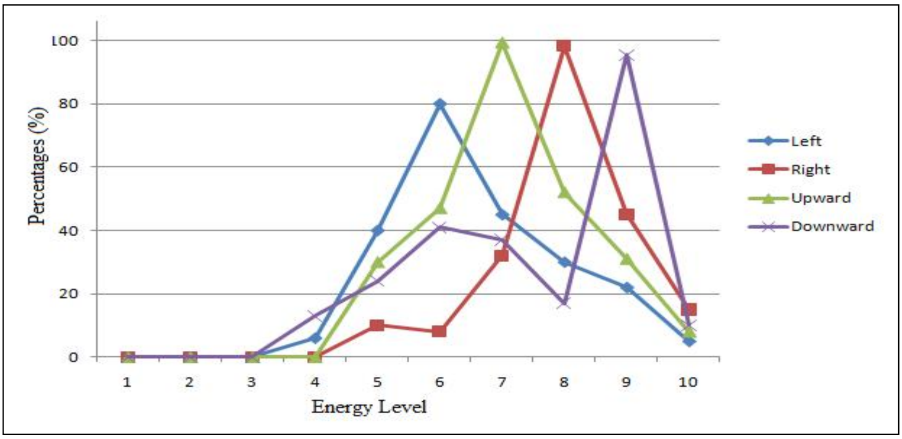


Figure 8 Average percentages of energy level for 15 data of vertical and horizontal eye movements

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.

The percentage of each detail coefficient of four eye movements is illustrated in Table 2 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 2.

Table 2 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

5.0 CONCLUSION

The wavelet transform is a key time-frequency analysis and coding tool for biomedical signals. It acts like mathematical microscope, zooming into small scales to reveal compactly time-spaced events. This kind of approach offers a lot of advantages in detecting transient features of physiological or clinical significance from bio-signals, that cannot be seen by using traditional methods such as FFT. The energetic approach built within the multiresolution decomposition and associated with a suitable chosen mother wavelet and the number of details level, is a powerful tool for investigation and identification of the characteristic in the bio-signals such as EOG.

In conclusion, the proposed study method could be used for developing a system for the EOG signals interpretation using the signals energy distribution of wavelet coefficient. This paper enhances the analysis of the EOG signals in giving the details of how each frequency band rely on each signal involved. The benefit of using signal energy of wavelet details coefficient is to make a precise decision in EOG signals identification for future enhancement.

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