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Design of Lowpass Filter and Wavelet Analysis for Electroretinogram in Dogs

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Abstract—**In frequency domain, wavelet coefficient is one of the characteristics of ERG signal which is hidden in frequency-domain. This paper aims to develop a tool for analyzing the constituent frequencies and time of interest in the dog's ERG signal using wavelet analysis. We design a lowpass filter to reduce noise during the measurement of ERG response. ERG dataset was obtained for the light intensity series and their constituent frequencies are analyzed by using the continuous wavelet transform (CWT). The results show that, in time-domain, as light intensity increases, both amplitudes of a-wave and b-wave are higher. We can visualize the noise interference in the ERG signals. Then a lowpass filter is designed to attenuate the noise effect. The filtered signals have lower a-, and b-waves' amplitude which affect the important characteristics in time domain. Therefore, we choose to filter signal from 26ms onward, the main components are recovered, and the filtered signal becomes smoother. In frequency-domain, the peak magnitude of wavelet coefficients is increased as light intensity increases.**

Keywords—Electroretinogram, Wavelet Transform, lowpass filter.

I. INTRODUCTION

Electroretinogram is a diagnosis test which measures the electrical activity of the retina in response to light stimulus [1].

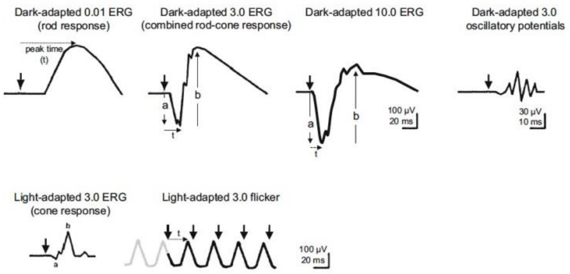

Fig. 1. ERG signal characteristics [2]

The main components of ERG signal are the a-wave, b-wave and others as shown in Fig. 1. They show the response of retina function and are used to determine the abnormal activity in time-domain of cone cell, rod cell, and other cells, respectively [3]. It refers to the changes of important characteristics of ERG signal due to the malfunction of photoreceptors. This fact makes us interested in studying the main components of ERG. In addition, wavelet analysis has been performed to investigate frequency-domain electroretinographic responses in both humans and animals [4]. More information is found by using wavelet analysis method [5]. The objectives of this paper are to develop a tool for analyzing characteristics of ERG signals in dogs and reduce remaining noises in the signals. The constituent frequencies, which are not visualized in the time-domain signal, can be investigated by using wavelet transform. It can lead to better understanding of ERG signal. For good representation, ERG signals at the light intensity based on ISCEV standard is recommended for the function of photoreceptor (rod and cone cell) and combined function [6].

The paper is organized as follows. In the next section, we provide materials and methods. In section III, results and discussion are presented. Lastly, in section IV, we conclude the current research work and suggest the future work.

II. MATERIALS AND METHODS

A. ERG samples

ERG samples were collected from dogs presented at the Ophthalmology Unit, Small Animal Teaching Hospital, Faculty of Veterinary Science, Chulalongkorn University. There were 8 ERG samples of normal dogs' eyes. The study was approved by the Institution of Animal Care and Use Committee, Faculty of Veterinary Science, Chulalongkorn University (Approved ID 2231028). Each sample was recorded at series of light intensity as shown in TABLE I. .

TABLE I. LIGHT INTENSITY OF RECORD.

Test	dB	cds/m^2 (SI Unit)
Rod	-30	0.002
	-25	0.0063
	-20	0.02
	-15	0.063
	-10	0.2
	-5	0.63
Combine Std	0	2
Cone	0	2
	5	6.3

B. Lowpass filter

Lowpass filter is a digital signal processing for rejecting unwanted high frequencies. It allows only low frequencies to pass through. The low pass filter consists of 3 parts as shown in Fig. 2.

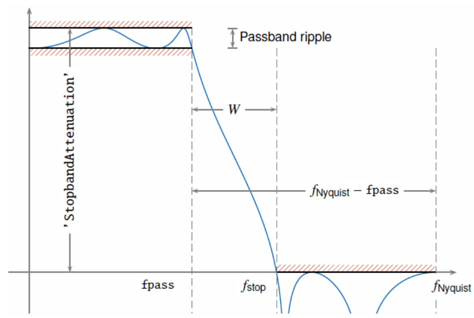

Fig. 2. The design of low-pass filter [7].

1) Passband is a range of frequency that allows the determined frequencies to pass through. It's ideally a constant, but, there is a ripple in practice.

2) Transition band is a center of passband and stopband. It can be described with cutoff frequency.

3) Stopband is a range of frequencies that rejects any high frequencies which are considered noise in this paper.

The design of low-pass filter is needed to assign parameters including cutoff frequency, gain at cutoff frequency, and minimum attenuation or gain at the stopband for estimating the order of the filter [8].

C. Wavelet analysis

Wavelet analysis is one of the tools for analyzing ERG signals in frequency-domain. Unlike Fourier transform, the transient signals in non-stationary signal can be located correctly and precisely due to the different size of window in wavelet transform [9]. By using MATLAB, the result is in the form of scalogram, 3-D graph with time, frequency, and magnitude of wavelet coefficient. Continuous wavelet transform is defined as follows in Eq. 1 [4].

$$W(b,a) = \frac{1}{\sqrt{a}}\int_{-\infty}^{\infty} s(t)g\left(\frac{t-b}{a}\right)dt\,, a > 0 \qquad (1)$$

where s is the ERG signal, g is the mother wavelet, a is the scaling parameter, and b is the shifting parameter.

The mother wavelet is chosen based on the correlation of the ERG signal. There are many mother wavelets for selection which can be discussed in [10]. In this paper, morse wavelet is chosen because its wave form closely assimilates ERG signal.

III. Results and Discussion

A. ERG signals

The original ERG signals of dogs are plotted. The ERG responses show that a-wave and b-wave are found as shown in Fig. 3-7. There are transients at the peak of the b-wave and at the end of the signals. At low light intensity, there is only the component of b-wave. The component of a-wave can be observed at light intensity of -20 dB. As the increase of light intensity, the trend of amplitude of a-wave and b-wave is increasing. However, at light intensity over 0 dB (combine), the result shows that the ERG response was clearly affected by noise.

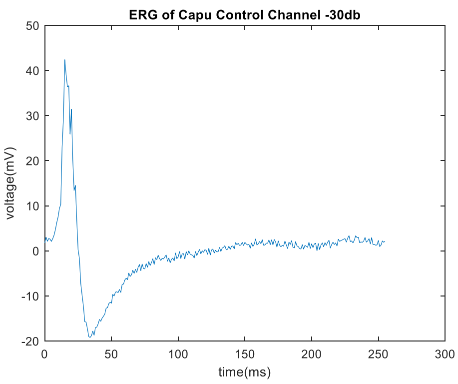

Fig. 3. ERG of control sample at light intensity of -30 dB.

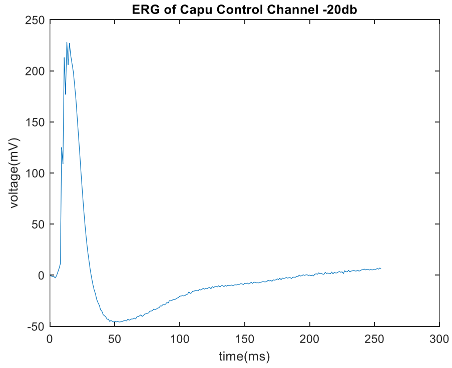

Fig. 4. ERG of control sample at light intensity of -20 dB.

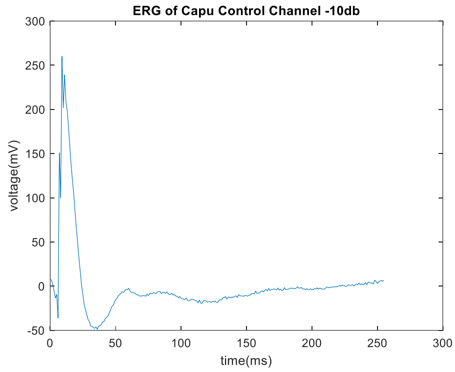

Fig. 5. ERG of control sample at light intensity of -10 dB.

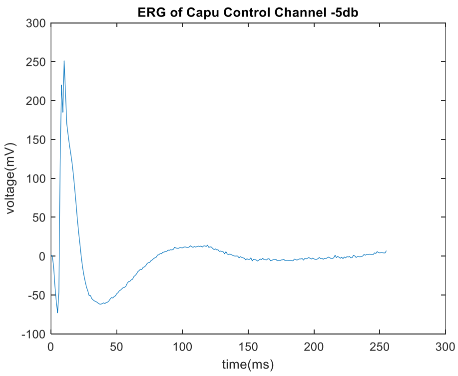

Fig. 6. ERG of control sample at light intensity of 0 dB (combine).

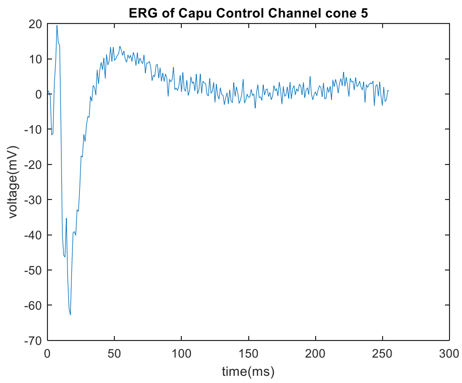

Fig. 7. ERG of control sample at light intensity of 5 dB (cone 5).

B. *Filtered signal, scalogram and contour plot*

The constituent frequencies and occurred times of the wavelet transform are determined. In Fig. 7, the noise of high frequency is clearly observed after the second negative peak. Moreover, the scalograms of some ERG signals contain a light blue band at the frequency of 150 Hz as shown in Fig. 8. To remove the noise, a low-pass filter was designed with the cutoff frequency of 150 Hz and applied to ERG signals. The original and filtered ERG are shown in Fig. 9. By using continuous wavelet transform, the original scalogram and contour plot are shown in Fig. 10-11. Subsequently, three peaks of wavelet coefficient, related to 3 major constituent frequencies in the original ERG signal, are found in the contour plot. After applying low-pass filter, the signal becomes smoother, but the amplitude of a-wave decreases from 42.4 mV to 40.5 mV at light intensity of -30 dB and the peak at high frequency is missing, referred to Fig. 12. To prevent the vanishing information, we design a lowpass filter for the ERG signal only at the time after 26 milliseconds. The partial filtered ERG signal gives the contour plot using continuous wavelet transform as shown in Fig. 13. Next, the filtered signals will be processed to determine the peak WT coefficient magnitude.

It appears to have a relationship between time-domain and frequency-domain characteristics, considering the peaks of WT coefficients magnitude and the important features on the filtered ERG signals. The first peak is located at the time like the position of b-wave. The second peak refers to the a-wave component. The third peak relates to the response before the a-wave. Further study is recommended to identify the relationship of each component in time-domain and each peak in frequency-domain.

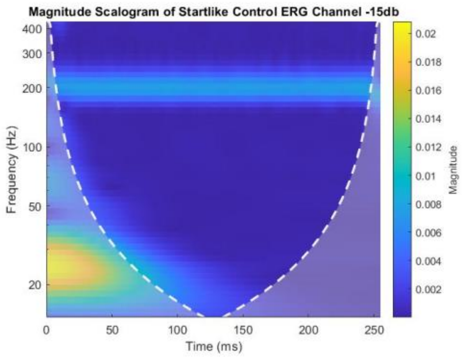

Fig. 8. ERG of original signal at light intensity of -15 dB (cone 5).

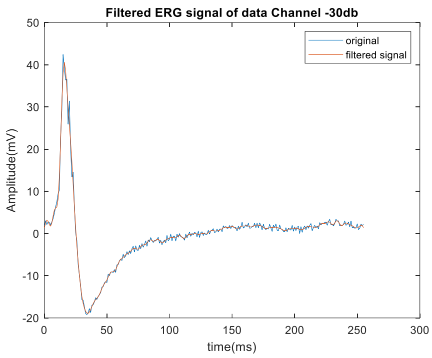

Fig. 9. ERG of original and filtered signal at light intensity of 5 dB (cone 5).

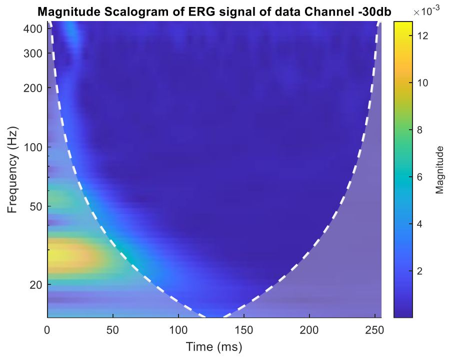

Fig. 10. Scalogram of original signal at light intensity of 5 dB (cone 5).

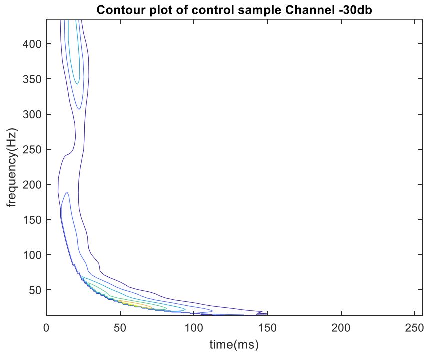

Fig. 11. Contour plot of original signal at light intensity of -30 dB.

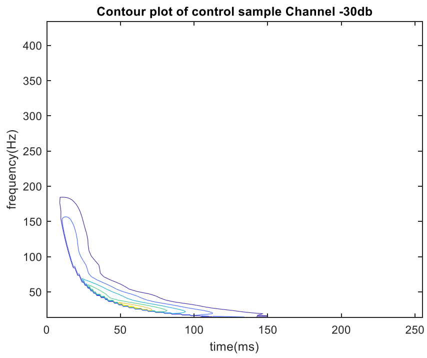

Fig. 12. Contur plot of filtered signal at light intensity of -30 dB.

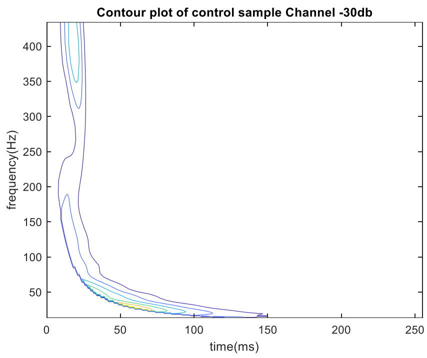

Fig. 13. Contour plot of filtered signal after 26 ms at light intensity of -30 dB.

C. *Peak magnitude of wavelet coefficient with time and frequency occurrence*

To measure the distribution of the maximum magnitude of wavelet coefficients, a box plot is presented. The average and standard deviation of time and frequency occurrence are calculated for the light intensity series.

Fig. 14 and TABLE II. show that as light intensity increases, the average peak magnitude of WT coefficients is higher until the light intensity reaches 0 dB (combine). After that, the peak magnitude drastically decreases due to the response of retina on very high light intensity.

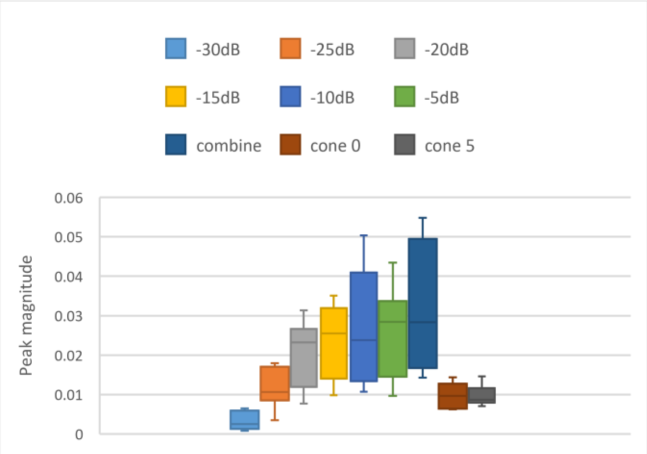

Fig. 14. Box plot of peak magnitude of WT coefficient for light intensity series.

TABLE II. AVERAGE AND SD OF WT COEFFICIENT MAGNITUDE.

Light intensity	Average Mag. (×10^{-3})	SD (×10^{3})	Time (ms)	SD	Freq. (Hz)	SD
-30 dB	3.24	2.28	67.88	23.26	26.72	9.77
-25 dB	11.64	4.97	60.5	20.33	76.19	144.66
-20 dB	20.30	8.47	61.25	5.09	26.74	2.11
-15 dB	23.86	9.27	49.38	17.07	80.69	142.86
-10 dB	26.95	14.35	21.38	15.48	178.31	166.11
-5 dB	25.84	11.48	12.75	4.33	227.06	171.53
0 dB (combine)	32.08	16.23	11.62	4.17	240.56	163.37
0 dB (cone 0)	9.74	3.27	9.75	2.49	186.66	101.36
5 dB (cone 5)	9.59	2.57	26	35.28	150.78	79.51

IV. CONCLUSIONS

Wavelet analysis is one of the tools for finding frequency-domain information in ERG signals. It can be found that, in time-domain, the amplitude of a-wave and b-wave at high intensity of light are higher than that of low intensity. Similarly, the average peak magnitude drastically increases as light intensity becomes higher in frequency-domain. However, at 0 dB (cone 0) and 5 dB (cone 5) which are considered high intensities of light, due to background noise and retina's response, both results in time- and frequency domain are reversed.

For the ongoing work, we aim to analyze noise characteristics measured by ERG signals of the background without objects. This will improve the efficiency of filter design and noise reduction. Moreover, it is recommended to explore other types of mother wavelets and other frequency analysis tools. The relationship between time-domain and frequency-domain is recommended for further study.

ACKNOWLEDGMENTS

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