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Wavelet Transform for Rabbit EEG with Vagus Nerve Electric Stimulation

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Abstract**—**Vagus nerve electric stimulation is a new method for preventing and treating epilepsy, pain disorders and depression with a subcutaneous surgically implanted device. The mechanisms of action of implanted stimulation device are still unknown. And the vagus nerve electric stimulator has several operating and stimulation parameters with the programming wand or the magnet. We had finished designing a new vagus nerve electric stimulator for the epilepsy last year. In order to analysis and detect the effects on the brain characteristics with these operation and the electrical activation, the rabbits are implanted the device. Then the EEG is used for recording the brain functional activity of the rabbit with the stimulator. Moreover the wavelet transform is employed to classify and separate the EEG signals into different spectral components. The δ, θ, α and β waves are obtained to better understand the stimulation effects on the brain. The results demonstrated that the new device is safe and has excellent potential role for the epilepsy treatment.

Key words —vagus nerve stimulation, EEG, wavelet transform

I. INTRODUCTION

Vagus nerve electric stimulation as surgical treatment for some neuropsychiatric disorders such as epilepsy, pain disorders and depression is already demonstrating good efficacy, which includes a small pulse generator (usually called stimulator) and electrodes of the bipolar lead [1]. The pulse generator and the lead are implanted subcutaneously through an incision. And the pulse generator sends intermittent electrical impulses to the left cervical vagus nerve for transmission to the brain through the lead.

Last year, we have finished designing a new vagus nerve electric stimulation device for the epilepsy treatment and manufactured the sample. So, the effects on the brain wave of the new device with all kinds of operation are estimated after the implantation procedure by employing male rabbits without epilepsy firstly.

EEG device is used efficiently identifying the physiological situations and the functional activity of the brain [2]. This method is revisited for testing the brain wave with the new device. Many EEG signals of practical interest turn out to be extremely non-stationary processes.

Wavelet transform is capable of providing the time and frequency information simultaneously, hence giving a time-frequency representation of the signal. So wavelet transform is widely used to study various EEG signals in practice [3]. As orthonormal bases of compactly supported wavelets, the db5 wavelet function which decomposes the EEG signals fast and easily is introduced to detect rabbit EEG signals and obtain good results.

II. MATERIAL AND METHOD

A. EEG Measurement System

Firstly, eight male rabbits were implanted the stimulator and the electrodes of the bipolar leads. Two weeks later, the effect on the brain wave with the program, communication and stimulation processes were tested for the rabbits.

The measurement system, which includes the rabbit with the new device, EEG and the computer, is shown in Fig. 1. The Neuroscan SynAmps2 and AC/DC amplifiers are used to record the EEG data to make computer-based analysis. Usually the sample rate was 1000Hz.

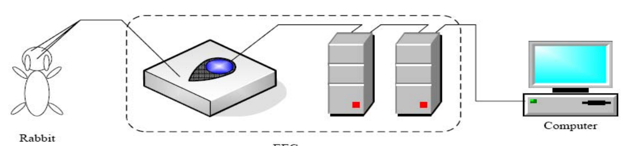

Fig.1 EEG measurement system

B. *Wavelet Transform*

Fourier Transform, in which we analyze signals using sines and cosines functions, applies to the stationary signals without changing much over time easily and good result can be taken. However, a plenty of signals such as EEG signals contain non-stationary or transitory characteristics, and Fourier Transform is not suited properly to analyze the non-stationary signals.

Unlike Fourier analysis, the wavelet is a real function $\psi(x) \in L^2(R)$ (the Fourier transform is $\Psi(\omega)$) with a zero average, which satisfied the condition:

$$C_\psi = \int_{R^*} \frac{|\Psi(\omega)|^2}{|\omega|} \mathrm{d}\omega < \infty \qquad (1)$$

where $R^* = R - \{0\}$. The theorem hypothesis (1) is called the wavelet admissibility condition.

Wavelet transform decomposes a signal onto a set of basic function $\psi(x)$. Wavelet transform should be separated as continuous wavelet transform (CWT) and discrete wavelet transform (DWT). Continuous wavelet transform of an analog signal $f(x)$ is expressed as in (2):

$$W_f(a,b) = \int_R f(x)\, \overline{\psi}_{(a,b)}(x)\, \mathrm{d}x = \frac{1}{\sqrt{|a|}} \int_R f(x)\, \overline{\psi}\left(\frac{x-b}{a}\right) \mathrm{d}x \quad (2)$$

with

$$\psi_{(a,b)}(x) = \frac{1}{\sqrt{|a|}} \psi\left(\frac{x-b}{a}\right)$$

where $a \in R$ represents the scale parameter, $b \in R^+$ represents the translation.

CWT is complicated by the redundancy in time and scale. Generally dyadic wavelet transform (which has an orthogonal basis) is used in wavelet application. The dyadic scales $a_k = 2^{-k}, b_{k,j} = j2^k$ are chosen as the mother wavelet function. The mother wavelet is (3):

$$\left\{ \psi_{k,j}(x) = 2^{\frac{k}{2}} \psi\left(2^k x - j\right);\ (k,j) \in Z \times Z \right\} \qquad (3)$$

where $\{\psi_{k,j}(x)\ j,k \in Z\}$ for $L^2(R)$.

According to the Mallat algorithm [4], the low and high pass filter coefficients are (4):

$$h_l = \int_R \varphi(t)\, \overline{\varphi}_{1,l}(x)\, \mathrm{d}x,\ \ g_l = \int_R \psi(x)\, \overline{\varphi}_{1,l}(x)\, \mathrm{d}x \qquad (4)$$

where the $\phi(x)$ is scaling function.

Ingrid Daubechies had constructed a series of compactly supported wavelet functions usually called dbN wavelet in 1988 [5]. N is the order of the db wavelet function. The db5 means there are five low filter pass coefficients of the db wavelet function family. Fig. 2 shows the db5 wavelet function and scaling function.

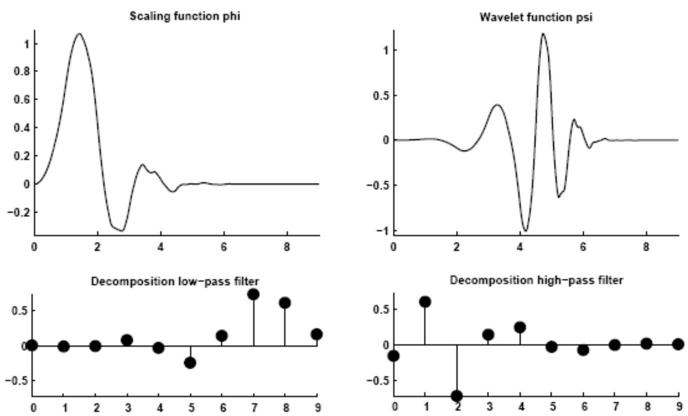

Fig. 2 Db5 scaling function and wavelet function

The way of wavelet transform is called DWT. For a given signal $f(x)$ initially represented by means of its coefficients at some levels of details, the wavelet decomposition can be written as follows:

$$f(x) = \sum_{l \in Z} c_{j+1,l}\varphi_{j+1,l}(x) = \sum_{k \in Z} c_{j,k}\varphi_{j,k}(x) + \sum_{k \in Z} d_{j,k}\psi_{j,k}(x) \quad (4)$$

where

$$c_{j,n} = \sum_{m \in Z} \overline{h}_{m-2n} c_{j+1,m},\ \ d_{j,n} = \sum_{m \in Z} \overline{g}_{m-2n} c_{j+1,m}$$

are the wavelet transform coefficients of the $f(x)$.

III. Result

According to the international 10-20 system, the rabbit EEG data have been measured with the electrodes placed on the scalp with both earlobes chosen as common referential electrodes. The db5 wavelet function was used as analyzing wavelet base to decompose all signals obtained in the test. With the decreasing of resolution, the details of rabbit brain EEG signals disappear gradually. Moreover some frequency components were ignored in these transform.

Fig. 3 shows the EEG signals of rabbit implanted the new device without stimulation. Normal rabbit EEG data have been measured at a sampling frequency of l000Hz.The signal (s) were decomposed into different scale: d_6 level (15.6-31.5Hz) including β wave, d_7 level (7.8-15.6Hz) including α wave, d_8 level (3.9-7.8Hz) including θ wave, a_8 level (0-3.9Hz) including δ wave. The other levels are paid no attention for the test.

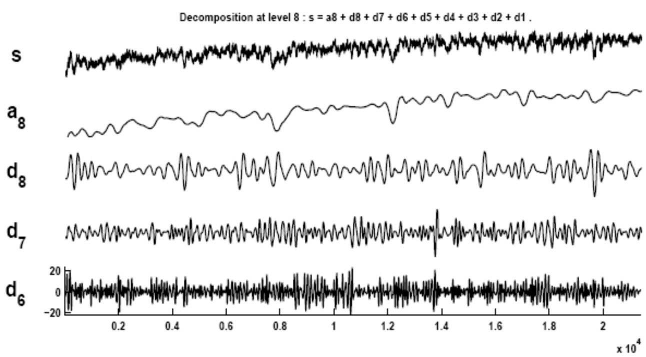

Fig.3 Wavelet decomposition for the rabbit EEG without stimulation

The stimulator waits for the communication signal and implements interrogations including testing the device states, setting the parameters, and inquiring for the device history. In addition, the inner information of the stimulator is transformed to the programming wand and saved to databases. The procedure may take most 10 seconds.

Fig. 4 shows the wavelet decomposition of rabbit EEG data in the course of the communication of the programming wand with stimulator. In order to test the uncertain signal frequency, the highest sampling frequency 20000Hz of the EEG device is used in the procedure. So the signal of the rabbit EEG needs to transformed to 12 levels for the brain waves. From the d_4 level, the period of communication is determined accurately and the β, α, θ, and δ wave are analyzed from the level d_{10}, d_{11}, d_{12} and a_{12} respectively. The brain waves show us the communication procedure is safe for the new stimulation device.

Two type of stimulation, which are independent of each other by initiated the program are normal mode and magnet

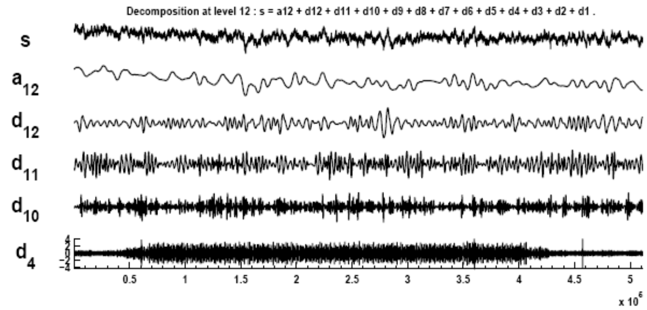

Fig. 4 Wavelet decomposition for the rabbit EEG in communication

mode. The normal mode stimulation has been set the output current 0.25mA, the pulse width 130 μs , the signal frequency 30Hz, and stimulation time 12s with 5 seconds. The sampling frequency is the same with the communication analysis.

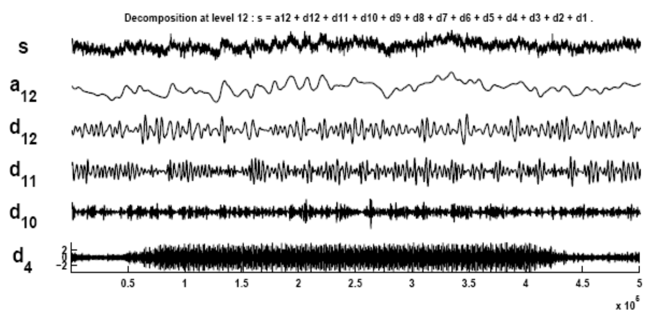

Fig. 5 Wavelet decomposition for the rabbit EEG with normal mode

Fig. 5 shows wavelet transform coefficients of the rabbit EEG in the period of normal mode stimulation. Because of the less stimulation current, the brain waves show normal β, α, θ, and δ wave.

When increasing the output current to 1mA, the rabbit EEG signal responds to the electrical stimulation. Fig. 6 shows the wavelet transform with the 1000Hz sampling frequency rate. The stimulation duration is confirmed from the level d_3 and the brain wave characteristics are identified from the decomposition coefficients. From the d_6 level (15.6-31.5Hz), β wave is restrained obviously during the stimulation procedure with 1mA current.

The magnet mode stimulation, which has been set the same parameters with the normal mode, is used to activate stimulation during an aura or at the start of a seizure. Fig. 7 shows the wavelet transform of the rabbit EEG in the period of magnet mode. Like the normal mode stimulation signal

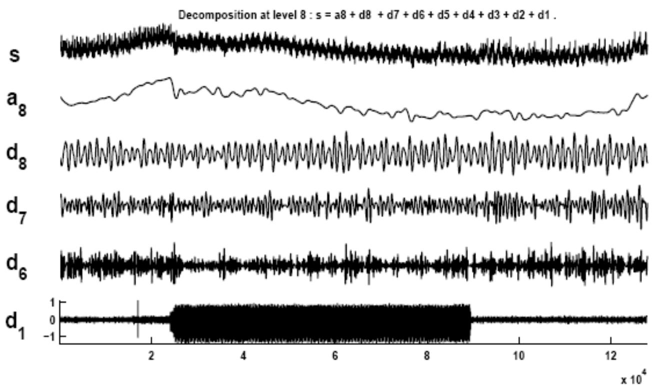

Fig. 6 Wavelet decomposition for the rabbit EEG with 1mA stimulation

decomposition, the on and off time of the stimulation can be test from the level d_1. With the same reason, the brain wave show the 0.25mA is used safely at a low current setting and increased gradually.

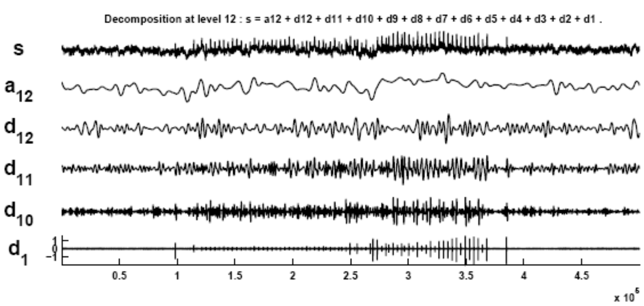

Fig. 7 Wavelet decomposition for the rabbit EEG with magnet mode

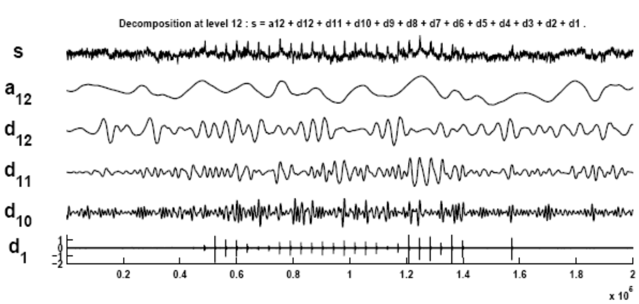

Fig. 8 Wavelet decomposition for the rabbit EEG with programming

According to the patient status, the different parameters are chose to programming into the stimulator. In the period of programming setting, the EEG data are recorded for estimating the effect on the brain wave. Fig. 8 shows the wavelet decomposition results. The results show the programming procedure is safe for the new electric stimulation device.

IV. DISSCUSION

As we have been able to design and manufacture a new electric stimulation device we have measured the effects of the operation procedure on the rabbit brain characteristic by using the EEG monitor.

From the results, the db5 wavelet function is effective for decomposing the EEG signal into the β, α, θ, and δ brain wave of the rabbit to obtain the characteristics of the brain easily and quickly. At the same time, the wavelet function of compactly supported and the orthogonality characteristics are confirmed to be very importance for the EEG signals in practice.

Obviously, there are no adequate experiments for the new device to optimize all kinds of parameters. Research on clinical experimentation for the new device is our further work. The epilepsy modes of the rabbit, which plays a decisive role for examining the function of the new device, are needed. Moreover the db family wavelets functions are employed to detect and predict the epileptic seizures.

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