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Research Article

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Eyes' movement signal processing and analysis

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ABSTRACT

The paper introduces a novel algorithm for brain wave processing and analysis, especial for eyes' movement and hands' movement brain signals with wavelet transform. It first introduces the advantages for wavelet transform and the basic theory for wavelet transform. Then it describes the steps for brain signal processing with wavelet transform. It does simulation with eyes' movements and gets the exact time when the eye moving through analyzing.

Keywords: wavelet transform; brain signal; signal processing; non-stationary random signal; threshold disposal

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INTRODUCTION

When a kind of biological electric current goes through the magnetic field, it takes some information which we called "brain wave". The human brain has many cells in the neural activity, and changes in electrical resistance. That is to say, there are electrical appliances of swing. This swing looks like a wave in scientific instruments. Brain electrical vibration is known as brain waves. Use a word to explain brain, perhaps can say it is by brain cells that generate biological energy, or brain cell activity rhythm[1-2].

The brain wave contains all information of human, such as its health condition, its movement, and its thinking. This paper tries to find a way to analyze the brain wave signals, to know which part of brain wave contains the information of eyes movement.

In 1828, Fourier applied the method which has come to bear his name, of approximating arbitrary function segments by sums of sine waves. In 1870, Richard Caton described the electrical activity of the exposed brain of a dog, and mentioned that even in the absence of stimulation, the electrometer showed a rather unquiet baseline[3]. Recently wavelet transform theory is very popular for dealing with non-stationary signals. The recent confluence of these two branches of science, in the statistical analysis of brain waves, is the basis of much recent work; this paper is a contribution to that field.

In this paper, we use wavelet theory to deal with the signals to get the wavelet coefficients, then we use soft threshold to remove some coefficients that didn't reflect the change of the signals. At last we reconstruct the signals with left coefficients to see when the eyes' movement. In this way we get a new method to know the eyes' movement through brain wave signals.

EXPERIMENT SECTION

Wavelet transform theory and its application to multi-resolution signal decomposition has been thoroughly developed and well documented over the past decade. We will summarize the results of that work for the dyadic case here for use later in the paper[4-5].

$$f(x)=\sum_{j=0}^{\infty} g_j(x) \quad (1)$$

The first level decomposition is done by projecting $f(x)$ onto two orthogonal subspaces, V_0 and W_0, where $V=V_0 \oplus W_0$, and "$\oplus$" is the direct sum operator. The projection produces $f_0(x)\in V_0$, a low resolution approximation of $f(x)$, and $g_0(x)\in W_0$, the detail lost in going from $f(x)$ to $f_0(x)$. The decomposition continues by projecting $f_0(x)$ onto V_1 and W_1 and goes on. The orthonormal bases of V_j and W_j are given by

$$\begin{aligned}\psi_{j,k} &= 2^{-j/2}\psi(2^{-j}x-k)\\ \phi_{j,k} &= 2^{-j/2}\phi(2^{-j}x-k)\end{aligned} \quad (2)$$

where $\psi(x)$ is the mother wavelet and $\phi(x)$ is the scaling function,

$$\begin{aligned}&\int \psi(x)dx=0 \Leftrightarrow \Psi(0)=0\\ &\int \phi(x)dx=0 \Leftrightarrow \Phi(0)=1\end{aligned} \quad (3)$$

where and $\Psi(x)$ and $\Phi(x)$ are the Fourier Transform of $\psi(x)$ and $\phi(x)$, respectively. The projection equations are

$$\begin{aligned}g_j(x) &= \sum_{k=-\infty}^{\infty} d_k^j 2^{-(j/2)}\psi(2^{-j}x-k)\\ d_k^j &= \left\langle f_{j-1}(x),\psi_{j,k}\right\rangle\end{aligned} \quad (4)$$

$$\begin{aligned}f_j(x) &= \sum_{k=-\infty}^{\infty} c_k^j 2^{-(j/2)}\phi(2^{-j}x-k)\\ c_k^j &= \left\langle f_{j-1}(x),\phi_{j,k}\right\rangle\end{aligned} \quad (5)$$

where d_k^j and c_k^j are the projection coefficients and $\langle . \ , \ . \rangle$ is the L^2 inner product. The nested sequence of subspaces, $\{V_j\}$, constitutes the multi-resolution analysis. For the MRA to be orthonormal $\psi_{j,k}$ and $\phi_{j,k}$ must be orthonormal bases of W_j and V_j, respectively, and $W_j \perp W_k$, for $j\neq k$; and $W_j \perp V$, which leads to the following conditions on ϕ and ψ

$$\left\langle \phi_{j,k}, \phi_{j,m}\right\rangle = \delta_{k,m} \quad (6)$$

$$\left\langle \phi_{j,k}, \psi_{j,m}\right\rangle = 0 \quad (7)$$

$$\left\langle \phi_{j,k}, \psi_{l,m}\right\rangle = \delta_{j,l}\bullet\delta_{k,m} \quad (8)$$

The Fourier transform of Eq.(6) gives the Poisson summation, which is for all

$$\sum_{m=-\infty}^{\infty} \left|\Phi(\omega + 2\pi m)\right|^2 = 1 \tag{9}$$

Since $\phi(x) \in V_0 \subset V$ and $\psi(x) \in W_0 \subset V$, they can be represented as linear combinations of the basis of V [6-7]

$$\psi(x) = 2\sum_{k=-\infty}^{\infty} g_k \phi(2x - k) \tag{10}$$

$$\phi(x) = 2\sum_{k=-\infty}^{\infty} h_k \phi(2x - k) \tag{11}$$

In the frequency domain (10) and (11) become

$$\begin{aligned} \Phi(\omega) &= H(\frac{\omega}{2})\Phi(\frac{\omega}{2}) \\ \Psi(\omega) &= G(\frac{\omega}{2})\Phi(\frac{\omega}{2}) \end{aligned} \tag{12}$$

For orthonormal MRAs, the sequences h_k and g_k in (10) and (11) represent the impulse responses of quadrature mirror filters (QMF) .

PF theory is basing on the SIS[9]. The essence of SIS is estimating the true value at time K by samples at time K-1. The main steps are as following:

RESULTS

For the brain signals contains lots of information and some of them have nothing to do with our research, so we need to remove them first. And we should also remove the noise mixed in the signals we collected. The brain signals are non-stationary time series which can’t be done by traditional FFT theory. We can combine the wavelet transform theory and the threshold method to deal with the brain wave signals. Here are the computing steps:

1） Collecting brain signals. We choose 32 points on the head to collect information. After we get 32 channel’s information, we use space reconstruct method to choose which channel plays a more role for our research.
2) Choosing correct mother wave to do wavelet transform. We should also choose the levels. The more levels we choose, the more accurate results we will get, but it will also take more time for computer to deal with.
3)Setting right threshold. There are two main points in this step. We have already known that the frequency is between 8 Hz and 13 Hz, so we should keep the coefficients which are contained in the frequency band. Second, we should set right threshold to remove the noise.
4) Doing reconstruct to left coefficients. We can get the time field wave figure and judge when do the eyes movement happen.

After doing the above steps, we get the following results:

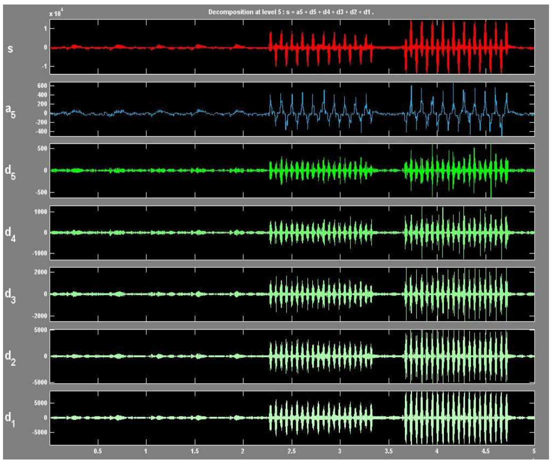

Figure 1. Wave for each level by wavelet transform

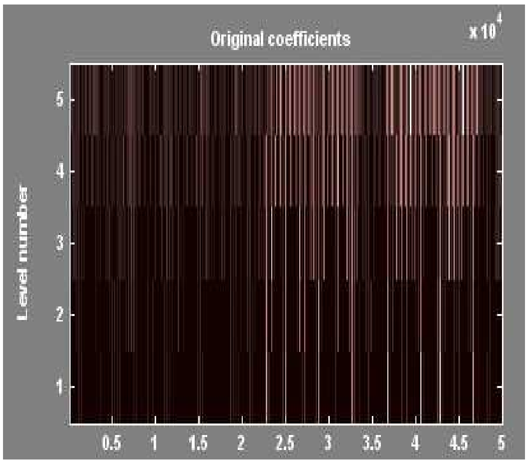

Figure 2. The original wavelet coefficient

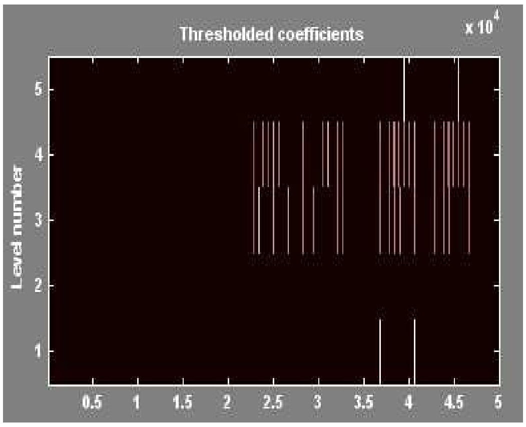

Figure 3. The Threshold wavelet coefficient

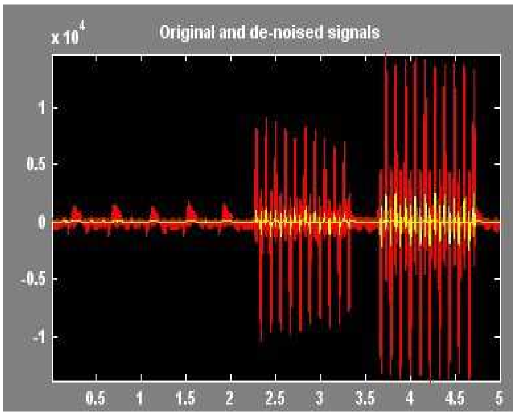

Figure 4. The Original and processed signals

Fig.1 shows the signals of original brain wave and the signals of each haar wavelet level. S shows the original signals, a_5 shows the lowest frequency part, $a_5 \oplus d_5$ reflect W_4, and d_4 reflect V_4. So use 5 level haar mother wavelet we can divide the brain signals to 6 parts, and each part reflect different frequency band. Fig.2 shows wavelet coefficients in all levels. Fig.3 shows the left coefficients by threshold theory. The sample frequency is 64Hz, so we kept the most coefficients in levels 4 and level 3, which means we kept most coefficients between the frequency 8 Hz and 16Hz. Fig.4 shows the reconstruct signals together with the original signals. From the reconstruct signals we can see the summit of the signals is the time when the eyes' status changes.

CONCLUSION

The article describes the method for brain wave analyzing by wavelet transform. Through wavelet transform, coefficient disposal and wavelet reconstruct, we get the signal that reflect when the eyes movement happening. This offer a good way for brain wave signals processing, but there is a premise that we should that the changing frequency first before signal processing, such as the eyes movement frequency is between 8Hz and 13 Hz. We can also do the same experiment for hand movement and even what people's thinking.

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