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The application study of wavelet packet transformation in the de-noising of dynamic EEG data

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Abstract. This paper briefly describes the basic principle of wavelet packet analysis, and on this basis introduces the general principle of wavelet packet transformation for signal den-noising. The dynamic EEG data under +Gz acceleration is made a de-noising treatment by using wavelet packet transformation, and the de-noising effects with different thresholds are made a comparison. The study verifies the validity and application value of wavelet packet threshold method for the de-noising of dynamic EEG data under +Gz acceleration.

Keywords: Wavelet packet, EEG, threshold, de-noising

1. Introduction

In the aerospace field, in order to prevent pilot occurring air syncope in flight, the human physiology signals under +Gz acceleration are needed for monitoring and management. The study that EEG signal under +Gz acceleration produced by human centrifuge is made an acquisition, recognition, judgment, and feature extraction and so on, has become a research hotspot in recent years. The measure and recording of EEG data is mostly applied in static case, less applied under dynamic condition, mainly because that EEG data is susceptible to all kinds of interferences under dynamic condition. When under centrifuge +Gz acceleration, equipment makes a high-speed rotation, and EEG is more susceptible to, EMG, ECG, EOG, body movement, baseline drift, electrode interference, power supply, rotation and other various kinds of interferences, so the pretreatment of signal de-noising and so on is very important. Signal de-noising is an important part of signal analysis technology. The traditional technique of signal de-noising is the analysis method in frequency domain by using Fourier transformation (FFT), and as a new signal analysis method, wavelet analysis has been widely used in various fields, such as image treatment, computer recognition，physiological signal de-noising and so on [1-9]. Wavelet packet transformation is a generalization of wavelet transformation, and it can make a more sophistical analysis for signal, having more application

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valuable [10-16]. Moreover, some scholars make a study by comparing the both together [17]. The threshold method of wavelet packet has also gradually got a wide apply in the de-noising of signal [18-25].

Although wavelet packet transformation has been applied much in de-noising of signal and data , until now, the relevant report that it is applied in the de-noising of dynamic EEG data under +Gz acceleration by adjusting different thresholds has not been seen. This is the first EEG data under +Gz acceleration is obtained by using human centrifuge, and this is also the first interference signals in dynamic EEG data are removed and extracted out to make an analysis by using the threshold method of wavelet packet. Wavelet packet transformation is made for the dynamic EEG data, and the coefficient of wavelet packet is made a threshold manipulation, then it is made a reconstruction, so the signal after de-noising is better than the processing result by wavelet transformation. This study discusses the method application and effect of wavelet packet transformation on the de-noising of dynamic EEG data under +Gz acceleration.

2. The basic principle of wavelet packet analysis [26, 27]

2.1. Wavelet transformation

For the any given function $x(t) \in L^2(R)$, the continuous wavelet transformation is as:

$$WT_x(a,b) = [x(t), \Psi_{a,b}(t)] = \frac{1}{\sqrt{a}} \int_R x(t) \Psi^*(\frac{t-b}{a}) dt \tag{1}$$

Among them, $\Psi^*(\frac{t-b}{a})$ is the conjugate function of $\Psi(\frac{t-b}{a})$. The essence of wavelet analysis is to decompose signal into the sub signals of different frequency bands in the form of wavelet basis function $\Psi(\frac{t-b}{a})$. Signal can realize reconstruction by seeking the inverse transformation of wavelet, and the expression equation for the reconstruction is that:

$$x(t) = \frac{1}{C_\psi} \int_0^{+\infty} \frac{da}{a^2} \int_{-\infty}^{+\infty} WT_r(a,b) \frac{1}{\sqrt{a}} \Psi(\frac{t-b}{a}) db \tag{2}$$

2.2. Wavelet packet transformation

Wavelet packet analysis is the promotion of multi resolution analysis, and it can make a multi-level classification for low frequency and high frequency parts of signal at the same time, to realize a more precise analysis of signal. In the premise of satisfying Heisenberg uncertainty principle, according to the arbitrary time-frequency resolution it can decompose signal into different frequency bands and project correspondingly the time frequency component of signal to the orthogonal wavelet spaces which represent different frequency bands. The decomposition equation of wavelet packet is as:

$$u_{2m}^j(n) = \sum_k h(k-2n) u_m^{j-1}(k) \tag{3}$$

$$u_{2m+1}^{j}(n)=\sum_{k} g(k-2n)u_{m}^{j-1}(k) \tag{4}$$

The reconstruction equation of wavelet packet is that:

$$u_{m}^{j-1}(n)=\sum_{k}\bar{h}(n-2k)u_{2m}^{j}(k)+\sum\bar{g}(n-2k)u_{2m+1}^{j}(k) \tag{5}$$

3. The method and step of wavelet packet de-noising

Wavelet packet subdivides low frequency part and high frequency part of signal at the same time, with more accurate partial analysis ability. Usually, it makes a subdivision according to the following steps [26-29]:

(1) The wavelet packet decomposition of signal: choosing a wavelet and determining the level number N of wavelet decomposition, then making a wavelet packet decomposition of N layers for the signal;
(2) Calculation of the optimal tree: computing the optimal tree for a given entropy standard;
(3) Threshold quantization of wavelet decomposition coefficients: selecting appropriate threshold, and making a quantization process for the high frequency coefficients of each layer of from 1 to N layer;
(4) Wavelet packet reconstruction: making a reconstruction according to the low frequency coefficients of the N layer after wavelet decomposition, and the high frequency coefficients of from 1 to N layer after quantization process.

In the 4 steps, the key is how to select the threshold and how to make a threshold quantization. In some ways, it is directly related to the quality of signal de-noising. Signal de-noising has 3 kinds of processing methods: 1. Compulsory de-noising, the high frequency coefficients after decomposition are forced to be 0, and this method is simple and easy to do, but it is easy to lose the useful component of signal; 2. The default threshold de-noising, the default threshold is selected and made a quantization process; 3. The given soft/hard threshold de-noising, the threshold is got according to the empirical formula, and the value has more credibility than the default threshold.

4. The de-noising results of wavelet packet threshold method on the dynamic EEG data under +Gz acceleration

4.1. Data acquisition

The experimental data is acquired from 5 healthy volunteers. The volunteers are all healthy, no human centrifuge contraindications. The main equipment is domestic, new type human centrifuge, and subjects are exposed under +Gz acceleration according to the set curve. The set curve starts from 1 G, reaches the maximum G value at a certain growth rate, lasting for 10-15 seconds, and then drops to 1 G at a certain growth rate. The maximum G value starts from 2.5 G, increasing at the rate of 0.5 G/r, until subject gets to the endurance end. The doctor real-time monitors ear pulse, ECG and other physiological signals, and comprehensively judges if the subject gets to the endurance end, according to the level state of ear pulse, combining with the subjective narration and the expression of the subject. EEG data when running, and before and after running is recorded by using a portable EEG recorder. Electrode signal of 16 leads is recorded in accordance with the electrodes positions of 10-20 system of international EEG standard electrodes installation method. All electrodes take the electrode at ipsilateral earlobe (A1 or A2) as the reference electrode [30].

4.2. The results of data processing

EEG data whose sampling frequency is 128 Hz is made a signal filtering. EEG signal measurement is mostly used in static case, and dynamic case is less applied, much less under +Gz acceleration. EEG measurement is difficulty and is vulnerable to all kinds of interferences, so the original signal contains a variety of artifacts. In this study, the interference signals mainly have EMG, EOG, body movements, baseline drift, rotation, power and others. When inside the cabin the subject is experiencing +Gz exposure, he will inevitably be nervous and do some confrontation movements, so the influence of EMG on EEG is larger, and EMG is mainly concentrated in the frequency band of 35.8-51 Hz; EOG signal is very difficult to remove, because it is mixed in multiple frequency bands of EEG, and it's elimination is likely to cause the loss of useful information, so according to experimental experience, the signal to be removed mainly focuses on the frequency band of 0.5-1 Hz; the interference of AC power whose common frequency is mainly concentrated about 50Hz; the interferences of low frequency signals coming from electrodes fixing and baseline drift and so on, whose frequency can be considered mainly to be below 1 Hz; and the interference produced by centrifuge rotation can not be ignored. The rotation angular velocity can be calculated according to the conversion formula of centripetal acceleration, the maximum G value which experiment can reach and the radius of centrifuge main arm, moreover, according to the calculation formula $T = (2\pi)/w$, it can be got that the interference of centrifuge rotation on EEG signal mainly focuses on the frequency below 0.5 Hz. In addition, magnetic field, body movement will also have different degrees of impacts.

The daubechies5 wavelet basis is selected to make a wavelet packet decomposition and reconstruction of 6 layers for the original signal. The following Figure 1 is the chart of the original signal, the signal after de-noising with the default threshold for Fp1 lead when 3 G for the same length EEG data, and the extracted interference signals from the eliminated signal. Figure 2 is the comparison chart of signal after de-noising with the default threshold and with different thresholds for Fp1 lead when 1 G. Figure 3 is the comparison chart of signal after de-noising with the default threshold and with different thresholds for Fp2 lead when 3 G. The following Figure 4 is the

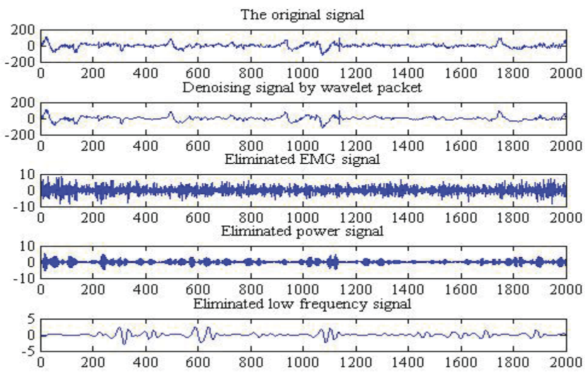

Fig. 1. Chart of the original signal, the signal after de-noising with the default threshold for Fp1 lead when 3G, and the extracted interference signals.

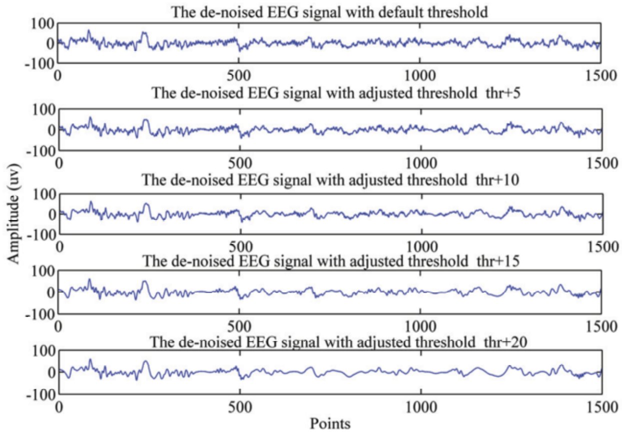

Fig. 2. Comparison chart of signal after de-noising with the default threshold and with different thresholds for Fp1 lead when 1 G.

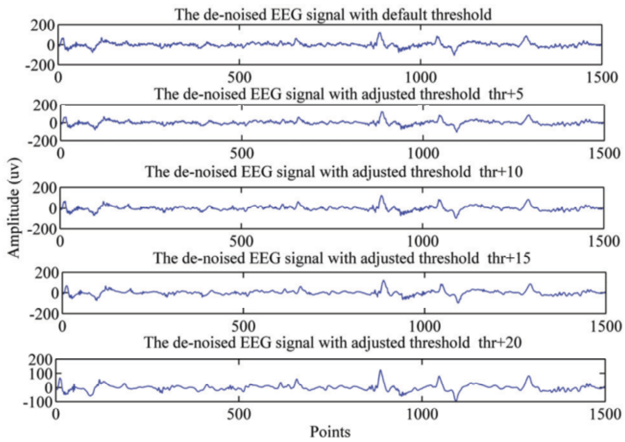

Fig. 3. Comparison chart of signal after de-noising with the default threshold and with different thresholds for Fp2 lead when 3 G.

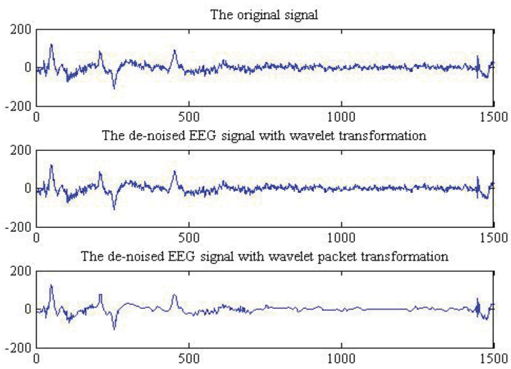

Fig. 4. Comparison chart of signal after wavelet de-noising and wavelet packet de-noising with the default threshold.

comparison chart of signal after wavelet de-noising with the default threshold and after wavelet packet de-noising with the default threshold. From the figure it can be seen that, wavelet decomposition and wavelet packet decomposition both can eliminate effectively interferences in EEG signal. Wavelet packet decomposition can not only retain well the high frequency components, but also the effect of de-noising is obviously more superior to the results of de-noising by wavelet method.

5. Discussions

From the chart，it can be seen that, the amplitude of EEG signal increases with the increasing of G value, and the method of wavelet packet de-noising can play an effective effect for both the static EEG signal when 1 G and the dynamic EEG signal when 3 G. Especially for the dynamic EEG signal, the signal curve becomes obviously smoother. On the whole, the threshold method of wavelet packet transformation can well remove EMG whose effect is biggest for the dynamic EEG under +Gz acceleration, power, and some other high frequency interference signals. It also has an obvious effect for the removal of low frequency interference signals such as baseline drift, electrode interference, EOG and others. Signal to noise ratio after de-noising can improve significantly. From the filtering results, it can be seen that, the method is effective for the removal of the EOG signal, but the effect is not very ideal, especially for the high frequency part of EOG signal. At present, many scholars in world all are studying the removal problem of EOG signal which is confused in EEG signal. It seems that the study of removal method on EOG artifact signal will still continue to be the hot point for quite a long period in future. In addition, the filtering effect is not very good for the interference produced by centrifuge rotation. So the effective removal of interference produced by centrifuge rotation is still needed to make a deeper research in follow up study.

In the process of wavelet packet de-noising, the selection of threshold is very important [31-35]. The signal de-noising by wavelet packet with the default threshold has a certain effect, but the effect is not obvious. From a large number of graphs drawn it can be seen that, with the increasing of increment of the default threshold, that is the threshold increases from th+5 to th+20, the amplitude of the curve after de-noising gradually reduces and the curve is smoother, indicates that the de-noise function is stronger and the de-noise effect is better, and the effect is more satisfying by the adjustment of threshold. Assuming that the increment of default threshold is expressed as △th, when 3 G, de-noising has some obvious effect when △th is at about 15, and when 4 G, de-noising has obvious effect when △th is at about 20; that is to say, the value of △th increases with the increasing of G value.

In general, selection of threshold value is different for different signal and different noise intensity, and selection of threshold is often related on levels for different decomposition levels, that is, for different scale or resolution. So the influence of noise can be reduced better and the reconstructed signal can retain the part of the original signal which is sharp and has steep change, namely better detecting the instantaneous mutation of signal [27-29, 36-38]. Wavelet packet decomposition is the complete decomposition of signal, not losing high frequency component, and finally retains the detail information at the same time in the process of signal de-noising. Wavelet decomposition and wavelet packet decomposition both can effectively eliminate the noise in signal, while wavelet packet decomposition can retain more high frequency component and in the approximation of signal, the de-noising effect is better than that of wavelet. This can be verified from the waveforms of comparison graph and the values of signal-noise ratio (SNR) and root-mean-square error (RMSE) which are got by calculation. Of course, the threshold method has some shortcomings as other methods of low pass filtering, such as high frequency part of the signal is easily confused with noise and so on, which leads to that the details of some signal will inevitably be removed in the course of threshold processing. But a large number of data shows that, this does not affect the perfect of threshold processing. In practical application, there are many kinds of methods to determine the threshold of signal, and the value should be selected according to different signal forms, different noise intensities, in the light of different rules or experience knowledge. This should be the concrete analysis of concrete problem.

6. Conclusions

The threshold method of wavelet packet transformation is applied to the de-noising of dynamic EEG signal under +Gz acceleration and achieves good results, explaining that the application of this method is feasible. The data analysis shows that, the threshold den-noising method of wavelet packet has simple algorithm and high reliability, can effectively remove the noise in signal, and gets to the purpose of retaining signal characteristic and suppressing noise. EEG data after de-noising can more truly reflect the change of EEG under +Gz acceleration, which lays a good foundation for the following related research such as EEG feature extraction and so on, and provides a more reliable data information and is helpful to improve the reliability of result of data analysis. In the process of de-noising, threshold selection is very important. Compared with the default threshold, the de-noise effect with the adjusted threshold is better. With the increasing of G load, the adjusted value, that is the increment based on the default threshold has also accordingly increasing of a certain extent, moreover, the amplitude of increasing should be decided according to the experience acknowledge and data analysis. So the key of influencing de-noising quality of signal is how to select the threshold and how to make the threshold quantization. So whether the selected threshold is appropriate is very important. The study that how to select threshold to make the de-noising effect better can be seen as the further and deeper research and discussion. By the de-noising of wavelet packet transformation, the original signal can be restored effectively, proving that this method is effective and has high practical value in processing of dynamic EEG data.

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