Research Journal of Applied Sciences, Engineering and Technology 5(5): 1568-1572, 2013
DOI:10.19026/rjaset.5.4905
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: July 12, 2012 Accepted: August 28, 2012 Published: February 11, 2013

Research Article

Method of Heart Sound Recognition Based on Wavelet Packet and BP Network

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Abstract: Based on the wavelet packet, a method for extracting the sub-band energy is developed to extract pathological features of heart sound signal. The db6 wavelet and sym7 wavelet are taken as the mother functions and the best wavelet packet basis of heart sound signal is picked out. Then, seven kinds of heart sound signals are decomposed into five levels and the wavelet packet coefficients of the best basis are obtained. According to the equal-value relation between wavelet packet coefficients and signal energy, the normalized sub-band energy of the best basis is extracted as the feature vector. Then, seven recognition models are trained separately based on BP network. These models are tested by using 70 heart sounds and the mean of recognition accuracy is 77.14%.

Keywords: Feature extraction, heart sound, recognition model, wavelet packet

INTRODUCTION

Early diagnosis of the heart disease has been a great challenge of human being, because the heart disease is one of the diseases that threaten human health severely (Zhiru *et al*., 2008). Heart sound contains much important diagnostic information, such as the heart function and mechanical condition of the aorta. Compared with the electro cardio signal, the pathology change caused by heart disease comes out earlier in heart sound (Zhidong *et al*., 2004). As one of important noninvasive detection methods, heart sound recognition is to classify the diseases according to the characteristics of the heart sound.

The heart sound usually is of non-stationary and time-varying characteristics due to the physiological, pathological or environmental effect (Yoganathan *et al*., 1976). So it is difficult to extract the feature of heart sound only by traditional time domain analysis and frequency domain analysis. The wavelet analysis has been widely used in the non-stationary signal analysis for its characteristic of time-frequency localization (Herold *et al*., 2005; Mizuno-Matsumoto *et al*., 2005). Although the wavelet analysis is a kind of effective time-frequency analysis method, its decomposition scale is proportional to the signal frequency. Therefore, its high-frequency resolution is poor and its effective decomposition is only suitable for the low-frequency part of the signal. However, wavelet packet analysis can carry out decomposition for both low-frequency and high-frequency parts simultaneously and determines the resolution in the different frequency band adaptively (Kim *et al*., 2005).

In order to extract and recognize pathological features of heart sound signal accurately, a method for extracting the sub-band energy feature is developed based on the wavelet packet analysis and the extracted feature vector is recognized by using BP network. Various heart sound samples of normal men and heart disease patients are recognized by using the method and the result indicates that the method is effective for heart sound recognition.

Wavelet packet: To a great extent, the mother function of wavelet packet influences analysis precision of signal. The time-frequency analysis of heart sound signal requires that the mother function has high energy concentration and good time localization. The db6 wavelet and the sym7 wavelet are picked out because they are suitable for extracting transient signal feature.

On the basis of the wavelet multi-resolution analysis theory, record the scaling function $\phi(t)$ as $u_0(t)$ and the wavelet function $\psi(t)$ as $u_1(t)$ and then the function set $\{u_n(t)\}_{n\epsilon Z}$ defined by Eq.(1):

$$\begin{cases} u_{2n}(t) = \sqrt{2}\sum_{k\in Z} h(k)u_n(2t-k) \\ u_{2n+1}(t) = \sqrt{2}\sum_{k\in Z} g(k)u_n(2t-k) \end{cases} \tag{1}$$

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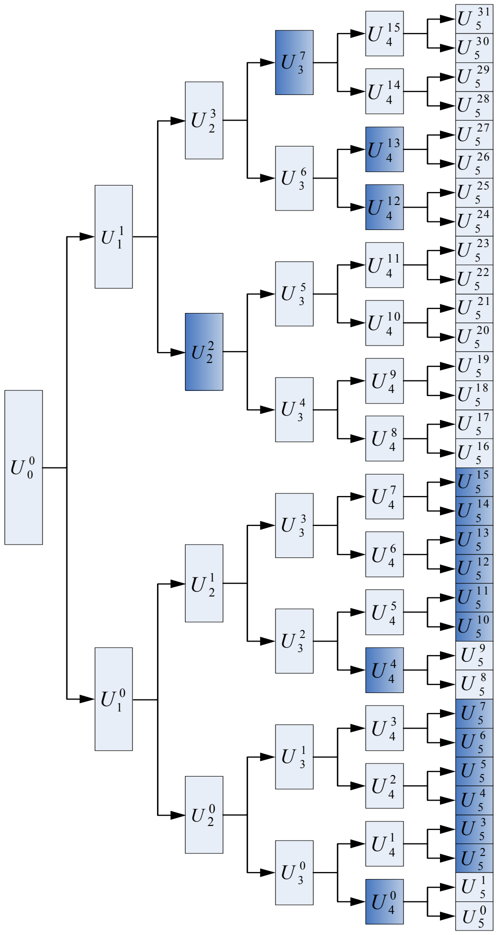

Fig. 1: Space subdivision of wavelet packet and best basis of heart sound

Equation (1) is called wavelet packet which determined by $u_0(t) = \phi(t)$, where h(k) and g(k) are CQF coefficients:

$$U_j^n = clos_{L^2(R)}\{2^{-j/2}u_n(2^{-j}t-k), k \in Z\}$$

$$n = 0,1,2,\cdots; \quad j \in Z \tag{2}$$

For the non-negative integer n:

$$U_j^{2n} \perp U_j^{2n+1}, \; U_{j-1}^n = U_j^{2n} \oplus U_j^{2n+1} \quad j \in Z \tag{3}$$

Thus at random scale, the wavelet space can be decomposed as Eq. (4).

The space subdivision of wavelet packet is shown in Fig. 1. The first column represents the frequency:

$$\begin{aligned} W_j &= U_{j+1}^2 \oplus U_{j+1}^3 \\ &= U_{j+2}^4 \oplus U_{j+2}^5 \oplus U_{j+2}^6 \oplus U_{j+2}^7 \\ &\vdots \\ &= U_{j+k}^{2^k} \oplus \cdots \oplus U_{j+k}^{2^k+m} \oplus \cdots \oplus U_{j+k}^{2^{k+1}-1} \\ &\vdots \end{aligned}$$

$$m = 0,1,\cdots,2^k-1; \quad j,k = 1,2,\cdots \tag{4}$$

band of the original signal. The following columns represent the frequency bands at five decomposition scales and row numbers are the parameters of the frequency and location. At the first decomposition, divide the original signal frequency band into two and obtained the high frequency sub-band U_1^1 and low frequency sub-band U_1^0 on the second column. Then, divide each sub-band into two again, making sure that each column cover the whole frequency band of the signal. Therefore the wavelet packet analysis overcomes the limitation that the wavelet analysis only can carry out the decomposition in V_j. So the wavelet packet analysis is more suitable for the analysis and examination of the non-stationary signal.

Supposing $x(t)$ is the space function of $L^2(R)$, to its discrete sampling sequence $\{x(p)\}_{p=1,2,\ldots N}$, the algorithm of wavelet packet decomposition is expressed as Eq. (5):

$$\begin{cases} C_p^{j,2n} = \sum_k h(k-2p) C_k^{j+1,n} \\ C_p^{j,2n+1} = \sum_k g(k-2p) C_k^{j+1,n} \end{cases} \tag{5}$$

From the Eq. (5), the wavelet packet decomposition materially is to decompose the signal into the different frequency bands through a group of CQF made up of LPF h and HPF g (Yi *et al*., 2006).

Feature extraction: As shown in Eq. (6), wavelet transform coefficient $C_{j,k}$ is of the energy dimension, so it can be used in the energy analysis (Haiyan *et al*., 2006):

$$\int_{-\infty}^{+\infty} |x(t)|^2 dt = \sum_k |C_{j,k}|^2 \tag{6}$$

Heart sound signals of different heart diseases have the different energy distribution in each sub-band and thus the wavelet packet coefficients can be taken as the feature vectors of the heart sound signal.

Seven kinds of heart sound, which are easily confused in time domain analysis, were selected as research object. They are normal heart sound, splitting of first heart sound, splitting of second heart sound, soft first heart sound, loud second heart sound, early systolic murmur and complete left bundle branch block. For each kind of heart sound, ten samples were selected. The sampling frequency was set to 2000 Hz.

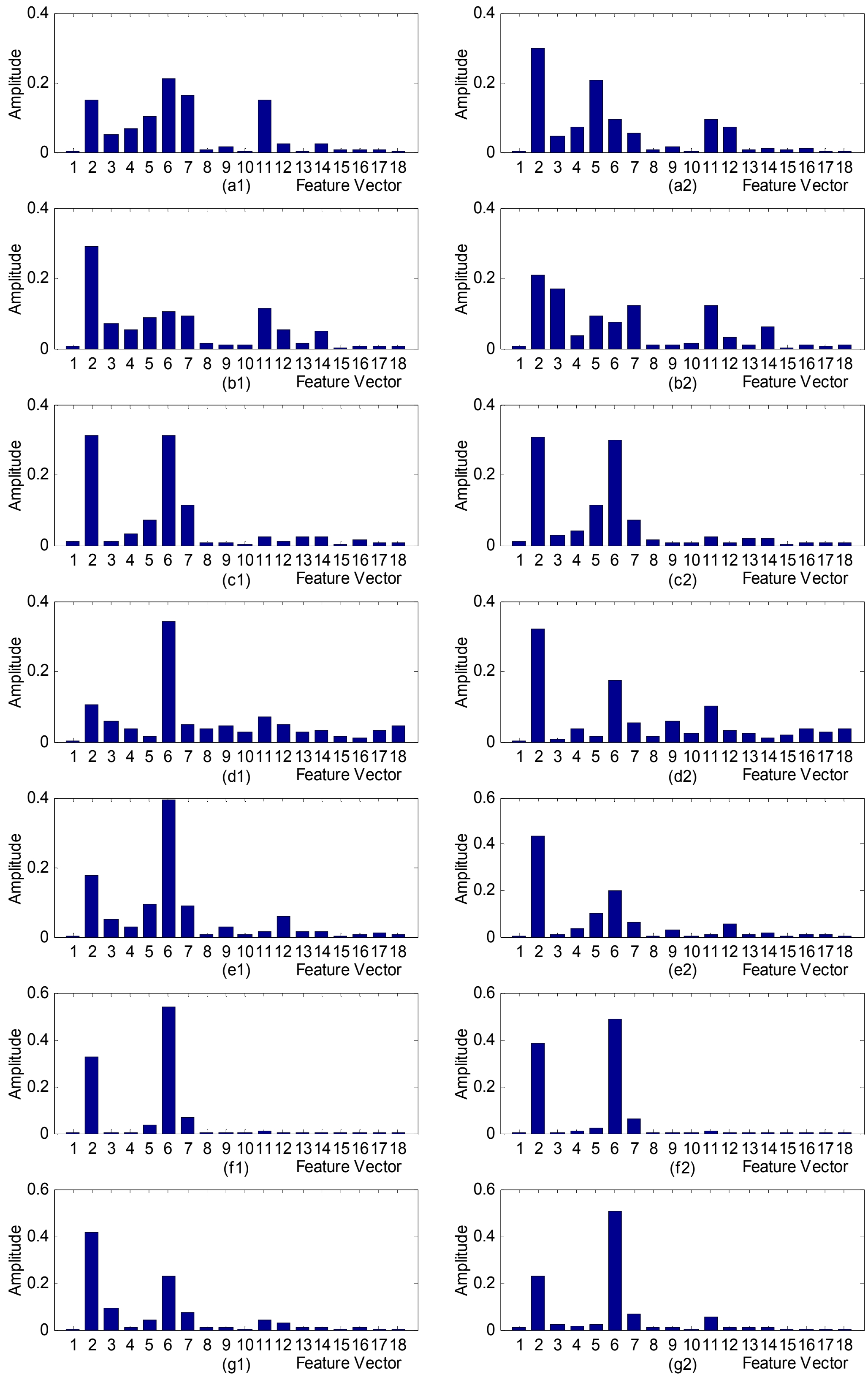

Fig. 2: Normalized feature vectors of seven kinds of heart sound signals (a) normal heart sound, (b) splitting of first heart sound, (c) splitting of second heart sound, (d) soft first heart sound, (e) loud second heart sound, (f) early systolic murmur, (g) complete left bundle branch block

According to the sampling theorem, the Nyquist frequency is 1000 Hz. Taking the db6 and sym7 wavelet as the mother function to carry out five levels wavelet packets decomposition, the space subdivision of wavelet packet is shown in Fig. 1. Through analysis of the samples, it can be discovered that the energy concentration of subspace U_4^0 is extremely low and the energy concentration of subspace U_4^4, U_2^2, U_4^{12}, U_4^{13} and U_3^7 are also low. To reduce the number of the wavelet packet basis, the further decomposition of U_4^0, U_4^4, U_2^2, U_4^{12}, U_4^{13} and U_3^7 subspace is not necessary. The best wavelet packet basis is shown in the gray area of Fig. 1.

Supposing $E_{a,b}$ is the b band energy of a level and then the feature vector is defined by Eq. (7):

$$T' = (E_{4,0}, E_{5,2}, E_{5,3}, E_{5,4}, E_{5,5}, E_{5,6}, E_{5,7}, E_{4,4}, E_{5,10}, E_{5,11}, E_{5,12}, E_{5,13}, E_{5,14}, E_{5,15}, E_{2,2}, E_{4,12}, E_{4,13}, E_{3,7}) \tag{7}$$

Supposing E_0 is the total energy of signal:

$$E_0 = E_{4,0} + E_{5,2} + E_{5,3} + E_{5,4} + E_{5,5} + E_{5,6} + E_{5,7} + E_{4,4} + E_{5,10} + E_{5,11} + E_{5,12} + E_{5,13} + E_{5,14} + E_{5,15} + E_{2,2} + E_{4,12} + E_{4,13} + E_{3,7} \tag{8}$$

Then, the normalized feature vector is defined by Eq. (9):

$$T = \frac{T'}{E_0} = \left(\frac{E_{4,0}}{E_0}, \frac{E_{5,2}}{E_0}, \frac{E_{5,3}}{E_0}, \frac{E_{5,4}}{E_0}, \frac{E_{5,5}}{E_0}, \frac{E_{5,6}}{E_0}, \frac{E_{5,7}}{E_0}, \frac{E_{4,4}}{E_0}, \frac{E_{5,10}}{E_0}, \frac{E_{5,11}}{E_0}, \frac{E_{5,12}}{E_0}, \frac{E_{5,13}}{E_0}, \frac{E_{5,14}}{E_0}, \frac{E_{5,15}}{E_0}, \frac{E_{2,2}}{E_0}, \frac{E_{4,12}}{E_0}, \frac{E_{4,13}}{E_0}, \frac{E_{3,7}}{E_0}\right) \tag{9}$$

Seven kinds of heart sound signals and their normalized feature vectors after the wavelet packet transform are shown in Fig. 2. The first column takes the db6 wavelet as the mother function. The second column takes the sym7 wavelet as the mother function. The results indicate that the energy distribution is different in each frequency band for different heart sound signals, so it can provide the basis for the following pathology analysis.

RECOGNITION MODEL

The Back Propagation Network consists of six layers: the input layer with eighteen feature vector nodes, the first hidden layer with six nodes, the second hidden layer with nine nodes, the third hidden layer with four nodes, the fourth hidden layer with twelve nodes, the fifth hidden layer with six nodes and the output layer with four nodes [8, 8, 8, 8]. The expected error is 0.0000001. Based on the principle to minimizing output errors, seven recognition models for seven kinds of heart sound are trained separately. Training errors of seven recognition models are shown in Table 1. These models are tested by using 70 heart sounds. As shown in Table 2, the mean of recognition accuracy is 77.14%.

Table 1: Training errors of recognition models

Model	Feature	Training error
A	T_d	9.6372×10^{-8}
B	T_d	8.9332×10^{-8}
C	T_d	9.2620×10^{-8}
D	T_s	9.4310×10^{-8}
E	T_d	9.3268×10^{-8}
F	T_s	5.9931×10^{-8}
G	T_d	9.5511×10^{-8}

A: Normal heart sound; B: Splitting of first heart sound; C: Splitting of second heart sound; D: Soft first heart sound; E: Loud second heart sound; F: Early systolic murmur; G: Complete left bundle branch block

Table 2: Test results of recognition models

Test sample		A	B	C	D	E	F	G
		10	10	10	10	10	10	10
Recognition results	A	9	0	1	1	1	1	0
	B	0	7	0	0	0	0	0
	C	0	0	8	0	1	0	1
	D	1	1	0	9	0	2	1
	E	0	0	1	0	7	0	0
	F	0	1	0	0	1	7	1
	G	0	1	0	0	0	0	7
Accuracy (%)		90	70	80	90	70	70	70
Mean (%)		77.14						

CONCLUSION

Heart sound is a typical non-stationary physiological signal (Yoganathan *et al*., 1976) and heart sound recognition based on the wavelet analysis has become the new research direction in the field of heart sound diagnosis. Compared with the wavelet analysis, the wavelet packet analysis can obtain richer time-frequency local information, so it is more suitable for non-stationary signal analysis. From Fig. 2, it can be seen that different kinds of heart sound samples were distinguished successfully by means of the scheme and as shown in Table 2, the mean of recognition accuracy is 77.14%, which indicates that the algorithm can recognize the seven kinds of heard sound effectively.

AKNOWLEDGMENT

This study was financially supported by the Natural Science Foundation of Shandong Province (ZR2010HL056).

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