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# Recognition of congenital heart sound signals based on wavelet de-noising and bispectrum

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## ABSTRACT

Acquiring the heart sound signal without noise is the premise and foundation to realize noninvasive diagnosis of congenital heart disease. But the heart sound signal belongs to the weak biological signals of the human body on the strong noise background. Acquiring the signal is susceptible to noise interference, so how to eliminate the inside noise of heart sounds is the key to distinguish the children's normal and abnormal heart sounds. The heart sound signals acquisition system based on DSP is proposed in this paper, using db6 wavelet filter to smoothing the collected 21 cases of children's heart sound signals, which achieved the very good de-noising effect. Estimating these signals with bi-spectrum can accurately identify 3 cases of congenital heart disease in which the heart sound signals. Experiments show that this method can better identify the normal heart sounds and children congenital heart sound signals.


## KEYWORDS

Heart sound signals;
Congenital heart disease;
Biomedical signal processing;
Wavelet transform;
Bispectrum.

## INTRODUCTION

As a result of better standards of life in modern society, the increase in morbidity and mortality of cardiovascular disease has been getting higher and higher; heart disease has become a hazard to human health and the frequently-occurring diseases. Heart sound is the heart and cardiovascular system to reflect the state of mechanical movement and health, which contains the heart and between the various parts of the role of physiological and pathological information[1]. Heart sound murmurs and distortion occurs is a reliable early diagnosis of congenital heart disease information, diagnose of heart sounds is based on modern digital signal processing technology, research and reveals the heart sounds and the relationship between heart disease, including non-invasive diagnosis of heart sounds, rapid, convenient, economic and other characteristics.

## HEART SOUND SIGNAL AND DIAGNOSIS METHODS OF CONGENITAL HEART DISEASE

Heart sound signals is an important physiological signal of human, which contains a large amount of information concerning the pathological status of every part of the heart and the interaction among them. The analysis and processing of the heart sound signals plays a significant role in diagnosing the cardiovascular diseases, because its accuracy and reliability directly influences the clinical diagnosis of patients and the evaluation of curative effect[2]. The traditional heart sound recognition depends on the auscultation, while, the accuracy of such process was obviously undermined by the subjectivity and the instability. Therefore, the non-invasive diagnostic techniques of coronary heart disease based on the modern information technology are becoming one of the critical tasks faced by the medical profession.

## The compositions of heart sound signals

As other creatures in nature, the organs of human perform their physical activities in accordance with certain rules. The vibration caused by such physical activities will produce the sound signals, which contain the physiological and pathological characteristics. The heart sound signal is the weak signal, which is formed in the cardiac cycle and produced by the vibration of the myocardial contraction and relaxation, the opening and closing of the valve, and the impact of the blood stream on the heart wall and the aorta, which spread through the surrounding tissue to the chest wall.

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The heart sound signal is a kind of biological weak signals under the strong noise background. It is easily affected by a number of human factors, for the reason that the heart sound signals is a kind of instable natural signals, which is signaled by the complex life[3]. The changes of heart sound and the emergence of the heart murmur is the early symptoms of the organic pathological changes of heart. The change of physical structure of the heart directly leads to the alter of the heart sound signals, so the heart sounds analyzing is a vital means in learning the status of the heart and large blood vessels. Each component of the heart sounds is shown in Figure 1, including the first heart sound (s1), the second heart sound (s2), and under certain circumstances, there are the third heart sound (s3) and the forth heart sound (s4).

S1 starts 0.02~0.04 seconds lagging behind the beginning of QRS wave in the electrocardiogram, accounting for about 0.08~0.15 seconds, caused by blood flowing into aorta when both mitral valve and tricuspid valve close and ventricular systole happens.

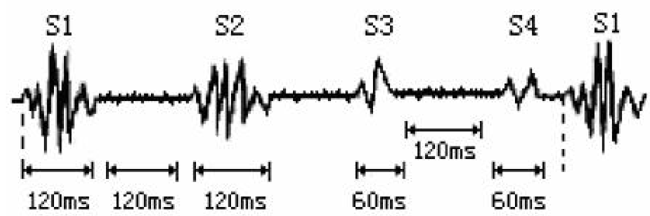


**Figure 1 : The oscillogram of heart sound signals**

S2 starts from the tail of T wave in the electrocardiogram, caused by

1) The vibration of ventricular wall when ventricular diastole happened;
2) The blood flowing from atrium into ventricle when both valve aorta and pulmonary valve close, and atria-ventricular valve opens. S2 happens at the beginning of diastole. Its frequency is comparatively high and duration is shorter than S1, taking about 0.07~0.12 sec.

## Diagnosis methods of coronary heart disease

Diagnosis of coronary heart disease is divided into two broad categories, which are non-invasive diagnostic methods and the invasive one. Generally, the non-invasive diagnostic method works are based on cords electrical activity and pump activity, including dynamic electrocardiogram, ultrasonic cardiogram and other modern medical imaging techniques like NMR, CT, PET etc. But it doesn’t mean that all patients can be diagnosed by electrocardiogram ways, because another great part of patients who have mild congenital heart disease do not show much problem in electrocardiogram. Therefore, all mentioned methods above which are represented by electrocardiogram hardly can guarantee their diagnosis accuracy.

Stethoscope is extensively adopted in heart sound analysis and diagnosis since Laennec invented it. Heart auscultation is one of the most old-aged methods used for diagnosing vascular disease and cardiac function, namely, medical staffs make a subjective analytical judgment to what they hear by their own knowledge and experience. So far heart auscultation still is a most basic measure to diagnose angiocardiopathy. Although it also has comparatively large limitations, heart sound analysis can go further in improving diagnosis accuracy. Heart sound is of great value in diagnosing angiocardiopathy and it proves to be a significant non-invasive detecting method, with possessing irreplaceable advantages compared with electrocardiogram and ultrasonic cardiogram.

As to the study of heart sound, the representative one is belong to M. Akay et al. Their research results show that when the blocking rate of coronary stenosis ranges from 25% to 95%, a kind of after-blockage overflow comes into being, which forms a weak heart sound signal that contains coronary artery blockage information and distributes in the high end.

## DIGITAL FILTERING OF HEART SOUND SIGNAL

### Heart sound acquisition system

The analysis and processing of the heart sound signals plays a significant role in diagnosing the cardiovascular diseases, In order to achieve correct classification of heart sound signals, High-performance heart sound signal acquisition system DSP-based is designed in this paper, the structure of the DSP collecting system is showed in Figure 2. Heart sound sensors is also known as the transducer, and is a widely used medical sensors, it can convert the mechanical vibration sound signal formed in the impact of the blood stream on the heart wall and the aorta to electrical signals. Amplifiers zoom in the slight heart sound signal. Transform analog signals to digital signals through 12 bit A/D converter, which were then send the signal to the computer via serial communication port, and processed by the computer with digital methods, including the digital filtering and other analysis and processing methods, according to the requirements. Then, pre-processing circuit amplifier and filter the heart sound signal, and transform analog signals to digital signals through 12 bit A/D converter, Finally, the digital signal transmitted to the DSP, which heart sound signals is filtered, then send the signals to the computer via serial communication port, and processed by the computer with digital methods, including the digital filtering and other analysis and processing methods, according to the requirements.

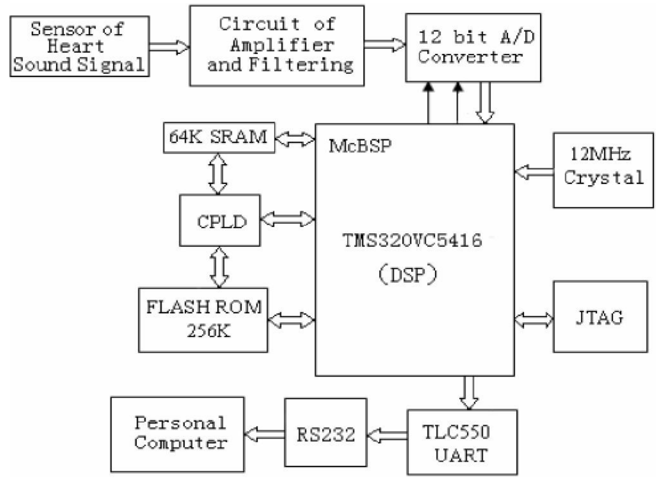


**Figure 2 : Heart sound detection system structure diagram**

### Wavelet de-noising experiment

Thanks to the advantages of wavelet transformation, wavelet analysis method is causing great academic concern both at home and abroad recent years. For wavelet analysis method not only inherits the excellent characteristics of Fourier transformation, but also makes up for its disadvantages, it can receives rapid development and wide application. Wavelet basis's translation and commanding function possesses wavelet flexible and variable time-frequency windows that narrow down at high frequencies and broaden at low frequencies, making it available to focalize on any detail of analytical object and perfectly suitable to analyze unstable heart sound signal, as a result, the multi-resolution analysis of wavelet has nice characters and advantages in space domain and frequency domain. Nowadays, wavelet analysis has successfully had application in biomedical engineering, intelligent signal processing, image processing, voice and image coding, speech recognition and synthesis, multi-scale edge detection and reconstruction, fractal and digital television and other fields. Wavelet transform is defined as follows:

Wavelet transform can be described as follows:

$$\begin{cases} \mathbf{WT_f(a,b)} = \dfrac{\mathbf{1}}{\sqrt{|\mathbf{a}|}}\int_{-\infty}^{\infty} \mathbf{f(x)}\psi^*(\mathbf{x})\mathbf{dx} = \{\mathbf{f}, \psi_{\mathbf{a,b}}\} \\ \psi_{\mathbf{a,b}}(\mathbf{x}) = \dfrac{\mathbf{1}}{\sqrt{|\mathbf{a}|}}\psi(\dfrac{\mathbf{x-b}}{\mathbf{a}}) \qquad \mathbf{a,b} \in \mathbf{R}, \mathbf{a} \neq \mathbf{0} \end{cases} \quad (1)$$

Where $\psi_{a,b}(x)$ represents Wavelet generating function, a represents scaling factor, b represents the time-shifting factor, when b take different values, the wavelet

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along the timeline move to a different location, $\psi$ *(t) represents Complex conjugation of $\psi$ (t). In the continuous wavelet transform, set variable a=2-j, b=k2-j, In which j, k "Z, so the discrete wavelet is:

$$\psi_{2^{-j},k2^{-j}} = 2^{\frac{j}{2}}\psi(2^j x - k) = 2^{\frac{j}{2}}\psi_{j,k}(x) \quad (2)$$

Thus the corresponding discrete wavelet transform as follows:

$$WT_f(j,k) = \langle f, \psi_{j,k} \rangle = 2^{\frac{j}{2}}\int_{-\infty}^{\infty} f(t)\psi^*(2^j x - k)dx \quad (3)$$

The decomposition structure of Mallart fast algorithm of this algorithm is illustrated in Figure 3.

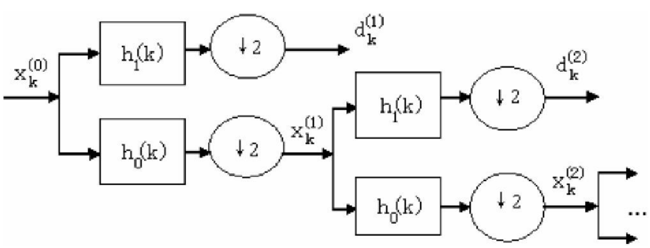



**Figure 3 : Signal decomposition structure of Mallat algorithm**

### Experiments of eliminating noise

As to the heart sound signal de-noising, different wavelet bases has different effect, similarly, for the same wavelet with different decomposition level, its de-noising effect is not exactly the same.

In this paper, some commonly-used orthogonal wavelets in heart sound processing such as Haar, db6, sym8 and coif5 etc get experimentally compared, which, as a results, db6 wavelet's de-noising effects is comparatively good. At the same time, the same wavelet with different decomposition level gets a contrast as well. Experiments show that when decomposition level is less than 5 layer, the effect is far from ideal; when the decomposition level equals 5, the de-noising effect is ideal; when the decomposition level is greater than 5, although the noise cancellation works well, but at the same time it filters a considerable part of heart sound signal. Therefore, using a 5-layer db6 wavelet decomposition get the best de-noising effect.

## THE HEART SOUND SIGNAL BASED ON BI-SPECTRUM ESTIMATION

Because AR model is easy to reflect the spectrum of the peak and MA model is easy to reflect the spectrum of the valley, ARMA model is adopted in calculating the heart sound signal's eigenvalue. ARMA model is a zero-pole model that reflects the peak and valley of the power spectrum.

### ARMA model and power spectrum estimation

Function armaqs and armarts in Matlab signal processing toolbox can be used to estimate the ARMA model parameters, and bi-spectrum estimates based on ARMA model can be achieved by using function bispect. armaqs function using the q-slice algorithm estimated ARMA model parameters, the format is as following:

[avec, bvec]=armaqs(y, p, q, norder, maxlag, samp_seg, overlap, flag)

armarts function using the residual time series estimated ARMA model parameters, bispect function armarts and format are as follows:

[avec, bvec]=armarts(y, p, q, norder, maxlag, samp_seg, overlap, flag)

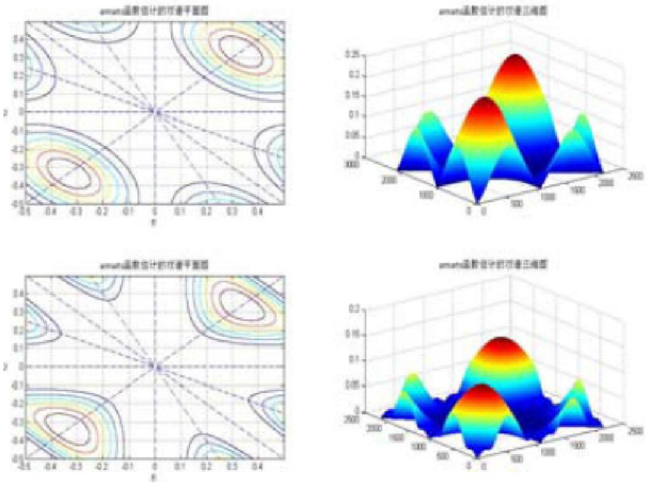
[Bspec, waxis]=bispect(ma, ar, nfft).

### The analysis of the heart sound identification results

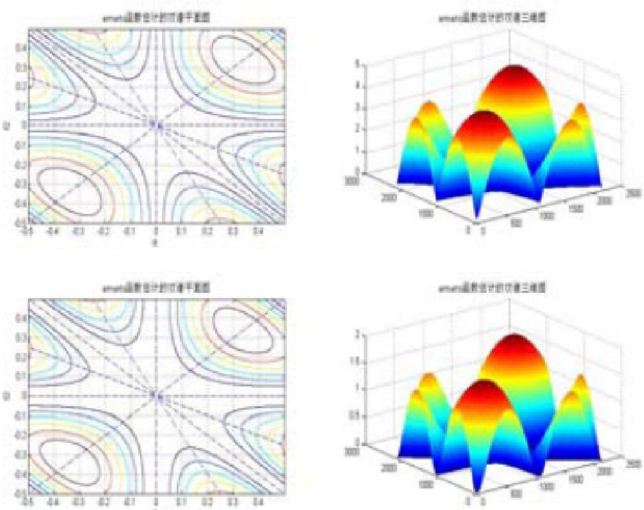
The collection of the sample signal was completed in the First Affiliated Hospital of Hunan University of Traditional Chinese Medicine and the Air Force General Hospital. The samples were divided into two groups, congenital heart disease and non-congenital heart disease.

The order p and q of ARMA model in bi-spectrum estimation is of importance to the classification of heart sound. Pick order P, Q and different parameter to calculate in MATLAB. When p = 3, q = 2, the normal heart sound's bi-spectrum graph is shown as Figure 4. Figure 4(a) and (b) shows two cases of children with normal heart sound signals bispectrum graph. The Figure 5(a) and (b) shows two cases of children with congenital heart disease signals bispectrum graph.

The bispectrum graph of normal and abnormal heart sound signal is respectively shown as Figure 4 and 5. It can be concluded from the contrast of these four bispectrum graphs that healthy children and children with congenital heart sound bispectrum with significant differences, the fact that the abnormal heart sound signals has more high-frequency component than the normal ones, which gives rise to a clear difference between the

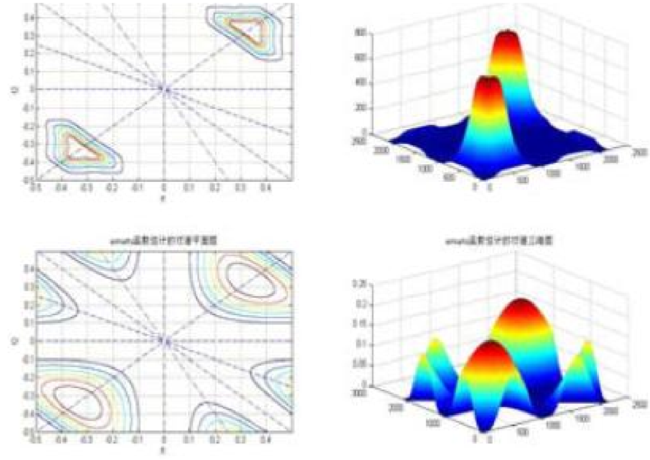


(a) Normal heart sounds of (10 years)

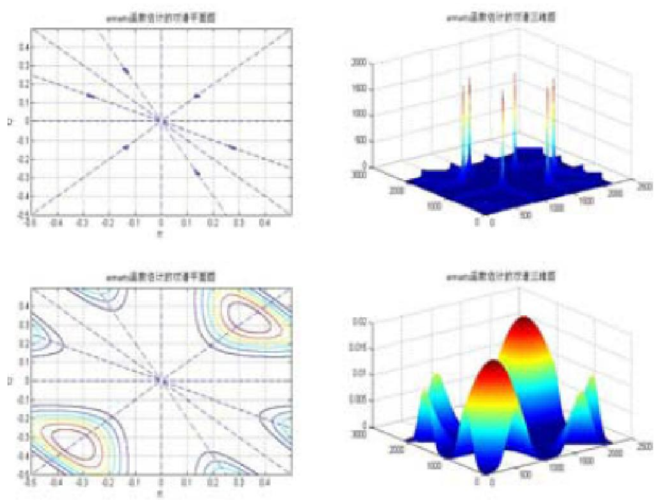


(b) Normal heart sounds (5 years)

**Figure 4 : Bispectrum of children Normal heart sounds**



(a) Congenital heart sounds (11 years)



(b) Congenital heart sounds (8 years)

**Figure 5 : Bispectrum of children abnormal heart sounds**

heart sounds of healthy children and congenital heart disease suffers, which help to achieve the non-invasive diagnosis of congenital heart disease.

## DISCUSSION AND CONCLUSION

Heart sound signal is an unstable, complex biological signals, especially children heart sounds. It is a kind of typical human biological weak signals, which is weak, strongly resistant to noise, of much randomness and vulnerable to the various factors of human body, therefore, various background noises are prone to appear in the detection of heart sound process. How to get the accurate children's heart sound signals is prerequisite and foundation for diagnosis of children with congenital heart disease. Experiments show that it is effective to eliminate the various random noises by adopting ab6 wavelet to do five-layer decomposition. After eliminating the signal noise and estimating the bi-spectrum by choosing appropriate parameters of ARMA model. the difference of bispectrum between normal and abnormal heart sound signals have obvious differences, it is very easy to identify.

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