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ORIGINAL ARTICLE

Non-invasive diagnosis methods of coronary disease based on wavelet denoising and sound analyzing

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Wavelet Transform

Abstract The heart sound is the characteristic signal of cardiovascular health status. The objective of this project is to explore the correlation between Wavelet Transform and noise performance of heart sound and the adaptability of classifying heart sound using bispectrum estimation. Since the wavelet has multi-scale and multi-resolution characteristics, in this paper, the heart sound signal with different frequency ranges is decomposed through wavelet and displayed on different scales of the resolving wavelet result. According to distribution features of frequency of heart sound signals, the interference components in heart sound signal can be eliminated by selecting reconstruction coefficients. Comparing de-noising effects of four wavelets which are haar, db6, sym8 and coif6, the db6 wavelet has achieved an optimal denoising effect to heart sound signals. The de-noising result of contrasting different layers in the db6 wavelet shows that decomposing with five layers in db6 provide the optimal performance. In practice, the db6 wavelet also shows commendable denoising effects when applying to 51 clinical heart signals. Furthermore, through the clinic analyses of 29 normal signals from healthy people and 22 abnormal heart signals from coronary heart disease patients, this method can fairly distinguish abnormal signals from normal signals by applying bispectrum estimation to denoised signals via ARMA coefficients model.
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1. Introduction

Over the past 20 years, the morbidity and mortality of cardiovascular disease have increased constantly, and heart disease has been claimed as a pathema which imperils humankind's health commonly and frequently (Wang et al., 2015; Zhou et al., 2015; An and Yu, 2016). The mechanical movements in the heart and the cardiovascular system can be reflected by heart sound, which contains the information about each part

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of the heart and interactions among all different sections in heart in both physiological and pathological fields. The presences of noise and distortion in the heart sound have been classified as a useful and reliable information diagnosing heart and cardiovascular diseases in an early stage (Cheng et al., 2016; Zhou et al., 2005). Since the heart sound diagnosis has to be executed in the noiseless environment in order to acquire accurate heart sound signals, the heart sound detection system publically adopts the analog method to eliminate noise utilizing the hardware, or the FIR digital filter (Wang et al., 2010; Joao et al., 2012; Gan et al., 2016; You et al., 2016). The weakness of heart sound signals, with the strength from 0.5 μV to 5 mV and the frequency from 1 to 1000 Hz, leads to vulnerability to external interferences, resulting in strong background noises in the signal detection process. Moreover, the traditional denoising method is not only undesirable in the elimination of noise, but also greatly impairs wanted signals in heart sound (Zhao et al., 2008; Zhu and Liu, 2006; Chen and Chen, 2005).

Comparing with the traditional method, the strategy presented in this paper has effectively denoised the heart sound signals through the Wavelet Transform. Besides, the wavelet filter used in this paper enables to control the cut-off frequency of the filter and reserve useful sections in signals whose frequency exceeds transmission bands according to the frequency distribution of heart sound: decomposing signals into detailed and approximate components on different ranges for the purpose of achieving effective separation between signals and noise (Zhang et al., 2013; Cheng and Li, 2015; Zhu, 2012; Yang et al., 2006; Liu, 2013).

The research of early diagnosis of coronary heart disease employs advanced digital signal processing technology to unveil the correlation between modern digital signal processing the heart sound and heart disease (Chen and Guo, 2006; Duan, 2016; Wang, 2014). In practice, heart sound diagnosis also has many advantages, such as, noninvasive operation, speediness, convenience, economy and so on.

2. Material and methods

The heart sound is an important biomedical signal of the human body, which contains a lot of information on heart health status. Analyzing the heart sound signal is quite essential to diagnose cardiovascular diseases, and its accuracy and reliability will directly affect the evaluation of patients' clinical diagnosis and prognosis. Traditional heart sound recognition is less accurate because of the subjectivity and instability of auscultation which completes by doctors. Therefore, the research in non-invasive diagnosis methods based on modern information technology in the prevention and diagnosis of cardiovascular system diseases, like coronary heart disease, has become one of the most important issues in medical profession.

2.1. The compositions of heart sound signal

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, formed in the cardiac cycle, 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.

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. The changes of heart sound and the emergence of the heart murmur are the early symptoms of the organic pathological changes of heart. The change of physical structure of the heart directly leads to alteration in the heart sound signals, so the heart sound 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 Fig. 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).

The first heart sound starts at 0.02–0.04 s after the beginning of the QRS wave on the electrocardiogram (ECG) , accounting for 0.08–0.15 s, caused by blood flowing into the great vessels during ventricular contraction, mitral valve and tricuspid valve closure.

The occurrence of second heart sound (S2), starting from the tail of T wave on the electrocardiogram, is aroused by the blood flowing from the atrium into the ventricle when the aortic and pulmonary valves are closing but the atrioventricular valve is opening. The second heart sound occurs at the beginning of the diastolic period of the heart, at a relatively high frequency, which is usually shorter than the first heart sound, and takes about 0.07–0.12 s.

The third heart sound has low frequency and small amplitude, lagging 0.12–0.20 s behind the T wave on the electrocardiogram, accounting for 0.05–0.06 s, caused by rapid ventricular filling and ventricular wall vibration.

The fourth heart sound, with small amplitude, starts at 0.15–0.18 s of the P wave on the ECG, caused by Ventricular wall vibration when Atrial contraction and the blood flowing into the ventricle.

The diagnoses of coronary heart disease is divided into Invasive diagnosis Methods and Non-invasive diagnosis Methods. The Non-invasive diagnosis Method is generally based on electrical activity and pump activity of the heart, including electrocardiogram, dynamic electrocardiogram and phonocardiogram, echocardiography and modern medical imaging techniques such as NMR, CT, PET and so on. However, not all patients with coronary heart disease can be diagnosed by ECG and other methods. Some patients, with mild coronary heart disease, have normal ECG. So, using ECG is difficult to achieve accurate diagnosis of coronary heart disease.

Invasive diagnostic methods mainly refer to coronary angiography, which is currently the most reliable method of

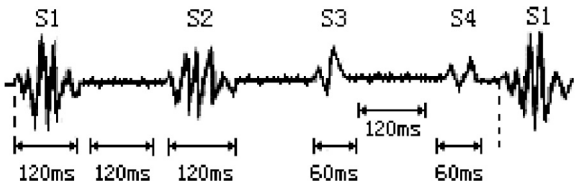

Fig. 1 Oscillogram of heart sound signals.

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