Analysis of Congenital Heart Sound Based on Envelope Waveform in Time-domain

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Abstract: In this paper, a study on analysis of congenital heart sound (HS) based on time envelope waveform (EW) technique was proposed. First, wavelet decomposition and reconstruction were used in preprocessing stage. Next, the EW in time-domain was proposed based on the Viola integral method. Furthermore, in order to extract the efficient analysis parameters, the center of gravity concept was applied in this study, under a selected threshold value (Thv), the parameters including the time interval of the first and second HS (T1, T2), the time interval between max value and the center of gravity of the first HS (T1mg) and the heart rate (HR) were extracted. A case study on the normal HS and CHD signals was demonstrated to validate the usefulness and efficiency of the proposed method.

Key-Words: *Quantitative Analysis, Congenital Heart Sound, Envelope Waveform*

1. Introduction

Congenital heart defects (CHDs) are problems with the heart's structure or function those are present at birth. They affect 8 out of every 1,000 newborns [1]. But it is known that this kind of defects can be cured with a high probability if the diseases could be detected in an early stage. For this reason, the research about early detection of CHD is one of the most important medical research areas [2]. The common CHD types are atrial septal defect (ASD), ventricular septal defect (VSD) and tetralogy of fallot (TOF), and TOF is a combination of four defects. In this study, ASD, VSD and TOF HS signals were selected as the abnormal heart sound (AHS) materials.

With the development of computer science, the HS signal should be segmented into some specific parameters for analysis. The basic HS signals are named as the first heart sound (S1) and the second heart sound (S2). As for heart defects, the murmurs as a systolic ejection murmur (e.g.,ASD) and a pansystolic murmur (e.g.,VSD) mostly appear between the S1 and S2 with different noise patterns like the diamond and rectangular shapes, and occur in the frequency range of 200–700 Hz [3].

From the literature, HS analysis methods can be divided into the time and frequency domain analyses. Most of these approaches can be viewed as the energy-based methods. Actually, the literature pays little attentions to the approximate cyclical characteristics of heart sounds, which are proved to be very useful information. Based on this, we provide an effective method to obtain the envelope waveform based on the Viola integral method [4-5,7], to quantitatively analyze the clinical congenital HS. The detail steps are introduced as following.

2. Envelope Waveform (EW) in Time Domain

Envelop waveform (EW) in time domain was presented based on integral waveform which is proposed by Paul Viola and Michael Jones in 2001[5], the idea comes from image

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processing and detection; however, it was first time to apply this concept to HS analysis [4]. Moreover, HS signals are two-dimensional signals; therefore, the complexity will be reduced much more than the image of face. We set a signal as $s(t)$, the random noise signal as $n(t)$, and the output signal as $x(t)=s(t)+n(t)$. It is easy to express their variances by $\sigma^2(x)=\sigma^2(s)+\sigma^2(n)$, Where $\sigma(\bullet)$ denotes as the variance of a signal. The output signal $\sigma^2(s)$ is defined as envelope waveform of HSs, here we assume $\sigma^2(n)$ is only an unknown constant, and the mean is 0, and variance is 1. Therefore, output signal can be viewed as $\sigma^2(x)$. The *EW* of the signal was denoted as $EW(t,\sigma)$, which is defined as the variance signal of actual output signal $x(t)$ and expressed as $EW(t,\sigma)=\sigma^2(x)$, Where δ is neighborhood of time t, called the width δ time scale, and then

$$EW(t,\delta)=\int_{t-\delta}^{t+\delta}(x(\tau)-\bar{x}(t))^2d\tau \tag{1}$$

Where $$\bar{x}(t)=\frac{1}{2\delta}\int_{t-\delta}^{t+\delta}x(\tau)d\tau \tag{2}$$

Therefore, $EW(t,\sigma)$ can be computed by

$$EW(t,\delta)=\int_{t-\delta}^{t+\delta}(x(\tau))^2d\tau-2\delta\bar{x}(t)^2 \tag{3}$$

In general, the interval of S1 and S2 is greater than 0.06s [6], in this study δ=0.03s was selected.

3. Analysis of Clinical HS Based on EW

Clinical HSs contain lots of useful physiology and pathology information, therefore, the analysis of clinical HSs has important significance. The detail is described in next.

3.1 Pre-processing

The original HS signal recorded using a stethoscope with 16-bit accuracy and 44.1 kHz sampling frequency. At first, the recorded signal $x(i)$ is down-sampled by a factor of four from 44.1 kHz to 11.025 kHz. Next, the MATLAB program was used for the wavelet decomposition implementation. Daubechies type wavelet (DB10) was used as a mother wavelet. So the resulting signals $x_m(i)$ with band limit of 21.5−689.06 Hz [7] were reconstructed by the components of A4 and A8. At last, the normalization was applied by setting the variance of the signal within a value of 1.0. The normalization is applied and the resultant signals can be expressed by

$$x(i)=\frac{x_m(i)}{|\max(x_m(i))|} \tag{4}$$

3.2 EW Extraction

After the pre-processing procedure, the EW extraction procedure is performed; the original normal HS (NHS) and the EW based on filtered signals are showed in Fig.1. In this study, 22 healthy subjects and 65 patients (17 ASD, 29 VSD and 19 TOF) were acquired from healthy volunteers and patients who suffered from CHDs with no other coexistent valvular defects. And the EW of normal HS and CHDs were showed in Fig.2.

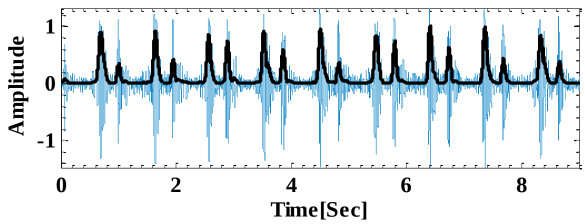

Fig.1 The original normal HS waveform (blue line) and the envelope waveform based on filtered signals (black line)

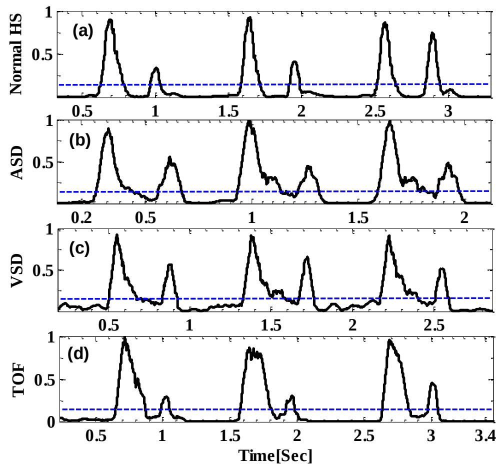

Fig.2 The envelope waveforms of the normal HS and common CHD HSs (a)Normal, (b) ASD, (c)VSD, (d) TOF

From Fig.2, we can see the EW patterns and cycle periods of normal HS and the congenital HSs are different.

And the different murmur patterns are existed and showed in Fig.3. ASD is associated with systolic murmur and a fixed split S2 [8]. The murmur pattern of VSD is usually holosystolic, and may be ejection type in character. While, TOF is a combination of four defects therefore, the murmur pattern is associated with diamond shaped holosystolic.

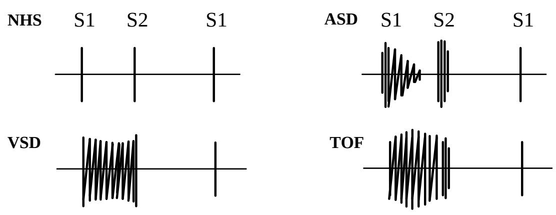

Fig.3 The heart sound and murmurs patterns of the normal HS and CHD HS

3.3 Parameters Extraction

Due to different types of CHD with different patterns in the heart murmur, it will be useful to parameters extraction. In this study, the concept of the center of gravity was introduced for parameters extraction to preliminary determine the heart murmur degree of HS in time domain.

To the conception of the center of gravity, in two dimensions, assume a rectangular coordinate system O-*xy*, and the object of particles is *j*, the coordinate is (x_j, y_j), and the mass is m_j, given $M=m_1+m_2+...+m_j$, the definition of center of gravity $G(X, Y)$ is expressed as:

$$G(X,Y)=\begin{cases} X=(x_1m_1+x_2m_2+\cdots+x_jm_j)/M \\ Y=(y_1m_1+y_2m_2+\cdots+y_jm_j)/M \end{cases} \quad (5)$$

In order to define the parameters, the conceptual diagram for defining is described in Fig.4. The time interval of the S1 and S2 computed from the EW of HS signals were used as the parameters, which were defined by T1, T2, T1mg and T11 as summarized in Table1.

As for the analysis parameters T1 and T2, which could be used for judging HS splitting, such as in Fig.3, for ASD there is a fixed split, so to some extent T2 might be larger than other HS. From Fig.2, the EWs of the CHDs have different shapes due to the different pattern types; what's more, the center of gravity is varied with the different shapes. Therefore, the parameter T1mg may be indicator to express the CHDs murmurs. Furthermore, T11 is the time interval between two abutted S1, which indicates the cardiac cycle.

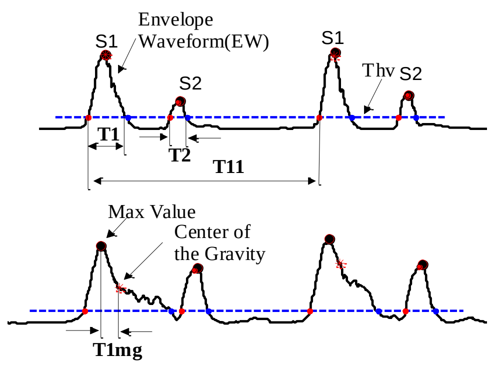

Fig.4 The definition figure of the analysis parameters

Table1 Definition of the analysis parameters

Analysis parameters	The definition and significance
T1	The time interval of the S1
T2	The time interval of the S2
T1mg	The time interval between center of gravity and the max value of S1
T11	Cardiac cycle

3.4 Parameters Analysis

It was showed such as in Fig.4 that a Thv would be a sensitive factor in the HS analysis with the EW method, because it was strongly related to the recording condition by stethoscope hardware, personal difference and so on, in this study, to the many experiment results, the Thv=0.15 was selected for parameters extraction, and heart rate of the signals can be calculated as HR = 60/T11. Table2 shows the mean and variance of the parameters in time domain.

Combined the EWs in Fig.2 and the values in Table2 to analyze, and take parameters [T1, T2, T1mg, HR] of NHS as the base. The T2 and HR of ASD are the largest, so there might be a splitting S2 and tachycardia of ASD. Moreover, as to VSD, [T1, T1mg] is larger than ASD, it implies the systolic murmurs might be existed. Furthermore, about TOF which is a combination of four defects, [T1, T1mg] is largest, which is associated with holosystolic murmurs. Therefore, the analysis parameters are useful to study on HS splitting, CHDs murmurs and the heartbeat rhythm of the normal HS and CHD signals.

Table2. The mean and variance of the parameters

Tave±Tstd	T1(s)	T2(s)	T1mg(s)	HR(b/m)
NHS	0.12±0.004	0.075±0.006	0.0064±0.002	76.4±2.9
ASD	0.13±0.005	**0.11±0.01**	0.0072±0.006	**116.3±5.6**
VSD	**0.20±0.02**	0.076±0.008	**0.028±0.007**	**97.0±5.3**
TOF	**0.28±0.02**	0.065±0.002	**0.067±0.02**	**100.6±3.3**

4. Conclusion

A study on analysis of congenital heart sound (HS) based on time envelope waveform (EW) technique was proposed. And under a selected threshold value (Thv), the analysis parameters including T1, T2, HR, and T1mg were extracted. Combined with the pathology of congenital heart disease, the time-domain analysis parameters were presented. A case study on HS splitting, CHDs murmurs and the heartbeat rhythm of the normal HS and CHD signals was demonstrated to validate the usefulness and efficiency of the proposed method.

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