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PHONOCARDIOGRAM SIGNAL ANALYSIS FOR MURMUR DIAGNOSING USING SHANNON ENERGY ENVELOP AND SEQUENCED DWT DECOMPOSITION

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Abstract

This paper presents a proposed procedure to analyze the PCG (Phono-Cardio-Gram) signal recorded by an electronic stethoscope. The procedure concludes heart sound cycle segmentation followed by a detecting step to categorize the normal cases from that which are characterized as an abnormal one (mainly Mitral Regurgitation MR and Mitral Stenosis MS). This is achieving using Shannon energy envelop. Furthermore, a diagnosing step is added to recognize the MR and MS cases from other abnormal cases using FFT (Fast Fourier Transform) applied to the segmented murmur period. The MR and MS cases were selected since it is the most popular abnormal heart cases recorded in the Middle East countries. The obtained results pleased and agreed many cardiac specialists. The MATLAB is the main software environment used in this work.

Keywords: heart sound, PCG, Shannon energy, DWT, FFT, and segmentation.

1. Introduction

Recently, modern technology has provided more powerful tools to evaluate the information related to heart sounds that traditional tools like stethoscope cannot achieve. One of the most common methods used for listening and tracking the heart sounds is to record them, the recorded heart sound is known as PCG (Phonocardiogram) signal. It is a particularly useful diagnostic tool because it contains different timings and relative intensities of heart sounds which are directly related to heart activity. With improvement of computer capabilities, the PCG signal has been digitally stored, managed, and manipulated for identifying its frequency and temporal contents [1].

Nomenclatures

A_2	Aortic valve
E	Shannon energy
M_1	Mitral valve
N	Number of samples
P_2	Pulmonary valve
S_1	First heart sound
S_2	Second heart sound
T_1	Tricuspid valve
X	The original PCG recorded signal

Abbreviations

DWT	Discrete Wavelet Transform
FFT	Fast Fourier Transform
MR	Mitral Regurgitation
MS	Mitral Stenosis
PCG	Phono-Cardio-Gram

Referring to Fig. 1, a PCG signal consists of two kinds of signals, the heart sounds and heart murmurs. The heart sounds are low-frequency transient signals produced by the heart valves and the vibrations of the cardiovascular system triggered by pressure gradients. The murmurs are high –frequency, noise-like sounds that arise when the velocity of blood becomes high as it flows through an irregularity [2]. Under normal conditions, the heart provides two major audible sounds (S1 and S2) for each cardiac cycle. Two other sounds (s3 and s4) with lower amplitude than S1 or S2 appear occasionally in the cardiac cycle by the effect of diseases or age [3].

The first heart sound S1, corresponding to the beginning of ventricular systole, is due to the closure of mitral (M_1) and tricuspid (T_1) valves. However, the second heart sound, marking the end of ventricular systole and signifying the beginning of the diastole, and corresponding to closure of aortic (A_2) and pulmonary (P_2) valves. On the other hand, systolic and diastolic murmurs of different shapes are added to the PCG signal within the cardiac cycle indicating different heart diseases [3].

Noninvasive study (diagnosis) methods such as phonocardiogram (PCG) offer useful information of functioning heart. In auscultation, the listener tries to analyze the heart sound components separately and then synthesize the heart features. Heart sound analysis by auscultation highly depends on the skills and experience of the listener [3]. Therefore, researches were focused on recording and analyzing the heart sounds by a computerized and objective ways. It is then a support of information by digital processing can be processed more easily in order to better appreciate the pathologies. Among researches, some concentrated on the time domain analysis methods, such methods allow us to appreciate the length of each heart sound, systolic and diastolic phases and the cardiac cycle [3-5]. Others focused on the frequency domain analysis [6, 7]. Moreover, the wavelet transform with Super-Paramagnetic Clustering (SPC) algorithm was proposed to detect and localize spikes from multiunit EEG recordings [8]. Furthermore, the Shannon energy envelop with DWT is used to detect and separate S1 and S2 sound from the PCG signals [9, 10].

Before any computerized analysis, the PCG signal needs to be segmented into components (sounds or murmurs) and then the components are analyzed separately. Once these are detected, features may be subsequently extracted for each type of sound.

Since most popular heart murmurs in the Middle East are detected as Mitral Regurgitation (MR) and Mitral Stenosis (MS), this work focused on detecting the heart sounds of normal cases from that ones that are categorized as MR or MS cases. The proposed approach to isolate the components of the PCG signal consists in isolating the heart sounds S1 and S2 of heart murmurs using a peak detection method. The normalized envelope of Shannon energy is calculated to detect the beginning and end of each of heart sounds using a fixed threshold from the maximum value of the Shannon envelope. After that, the murmurs period is isolating in order to analyse it using Fast Fourier Transform (FFT).

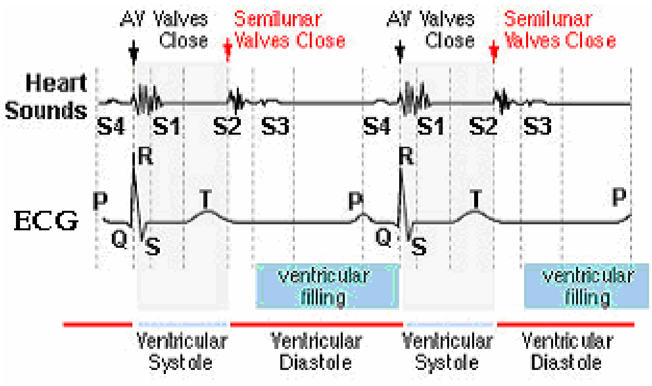


Fig. 1. Components of PCG signal and compared with ECG signal.

2. Proposed Procedure

In order to detect, isolate and analyze the PCG murmur, the main steps are:

i. Data acquisition and preprocessing of heart signal.
ii. Signal segmentation.
iii. Feature extraction.

2.1. Data acquisition and preprocessing of heart signal

Heart sounds have been recorded with an electronic stethoscope (model 3200_3m Littman) using the audio input, with sampling frequency defined as (44100Hz.). The recorded data are saved as WAV file. The filter of stethoscope was selected as (bell or diaphragm). The area of auscultation, as well as the recording of auscultation maneuvers, like sitting, standing, etc., and all the necessary information is recorded to be further processed [5]. In the preprocessing step, the heart sound signals were normalized as in

$$X_{normalized}(t) = \frac{X(t)}{|\max(X(t))|} \tag{1}$$

where $X(t)$ is the original signal.

2.2. Signal segmentation using Shannon energy

To extract the PCG signal, the proposed procedure based on the Shannon energy of the signal is adopted. Shannon energy is used to emphasize the medium intensity signal and to eliminate the effect of noise. It is the best solution to extract the envelope of the signal in comparison to, for example, Shannon Entropy or signal absolute value, or square of signal as indicated in the following equations [4].

Shannon Energy: $E = X^2 \log X^2$.

Shannon Entropy: $E = -|X| \log |X|$.

Absolute Value: $E = |X|$.

Energy (square): $E = X^2$.

In this work Shannon energy is applied on 300 samples of data, this is illustrated in Eq. (2):

$$E_{ave}(t) = \frac{-1}{N} \bullet \sum_{i=1}^{N} X^2{}_{normal}(i) \bullet \log X^2{}_{normal}(i) \tag{2}$$

where *ave* is average of the normalized signal, *N* is number of samples in window and *normal* is the normalized signal.

2.3. Feature extraction

In order to categorize the heart sound, signal as normal or abnormal and then diagnose the abnormal one as an MR or MS cases, the following steps are proposed:

i. Averaging energy envelop.
ii. Detecting averaged envelop peaks.
iii. Fixing threshold (S1 and S2 duration calculation).
iv. Murmurs detection and analysis.

2.3.1. Averaging energy envelop

The envelopes of instantaneous energy of PCG are computed as a moving average of this instantaneous energy. This is done because the envelopes are easier to process than PCG, while they retain enough information. The energy envelope provides useful information about the energy of the signal, remarking those sounds with high intensity (these sounds are often the first and second heart sounds). On the contrary, weak sounds with low amplitude (like the fourth heart sound, or noise) will probably be buried [5]. The energy envelop can be found using Eq. (2).

2.3.2. Detecting averaged envelop peaks

In order to apply and implement segmentation algorithm to different PCG signal, Shannon energy envelop peaks were illustrated to detect first sound S1, second sound S2 in cardiac cycle, and to extract different features like the systolic duration (the period between S1 and S2), diastolic duration (the period between S2 and S1) and the complete duration of the cardiac cycle. From these features it is clearly that the duration of cardiac cycle, S1, S2 in normal cases is less than of the duration of abnormal cases. Furthermore, murmur can be extracted from the original signal and applying Fast Fourier Transform on it to find the maximum peak and the frequency of the maximum peaks that help to recognize between abnormal cases. This envelope peaks can be illustrated in *MATLAB* using "***findpeak***" function:

[pks,locs] = findpeaks (data,'minpeakdistance', mpd).

where 'pks' is the number of peaks and 'locs' is the location of all peaks.

This function returns only peaks with indices separated by more than the positive integer ***mpd*** (*the* defaults of ***mpd*** is 1).

2.3.3. Fixing threshold (S1 and S2 duration calculation)

Based on the signal calculated by the average Shannon Energy, a threshold is set starting from maximum value according to the operator choice to eliminate the effect of noise and very low intensity signal. The application of this threshold will also enable us to detect the side minima of each peak of the envelope. The moments of these points will be determined later to be able to locate heart sounds [3]. The choice of threshold is very important in order to have good results. The duration of the heart sounds or heart murmurs may change if the choice of threshold is not taken into account [4]. In this paper we choose the threshold set to be 70% from the maximum value of the energy envelope in order to isolate heart sounds from murmurs in PCG signal.

2.3.4. Murmurs detection and analysis

Murmurs can be extracted using peak detection after isolating of heart sounds. The duration between first sound and second sound containing the murmur is extracted from the location of each heart sound in cardiac cycle. This location is separated from the original signal to isolate murmur from heart sounds. After that, the DWT is applied to decompose the isolated murmur signal into five levels using db7 as mother wavelet function. Double sided Fast Fourier Transform (FFT) is now applied on the detailed coefficients resultant from the fifth level. It is found that if the centre frequency of this spectral analysis is located between (200 and 250) Hz. one can conclude that this murmur is Mitral Regurgitation (MR) case. Consequently, if the centre frequency is located between (100 and 150) Hz, the conclusion is most probably Mitral Stenosis (MS) case. Steps (1-4) are illustrated in Fig. 2.

3.Experimental Results

The proposed procedure is illustrated by recording nine hart sound cases as follows:

i. Three abnormal MR cases (subjects 1-3).
ii. Three abnormal MS cases (subjects 4-6).
iii. Three normal cases (subjects 7-9).

However, details for one subject each case will be presented (i.e., subject 1, 4, and 7). Figures 3 to 5 illustrate the PCG details of Mitral Regurgitation case, Mitral Stenosis case, and Normal case, respectively.

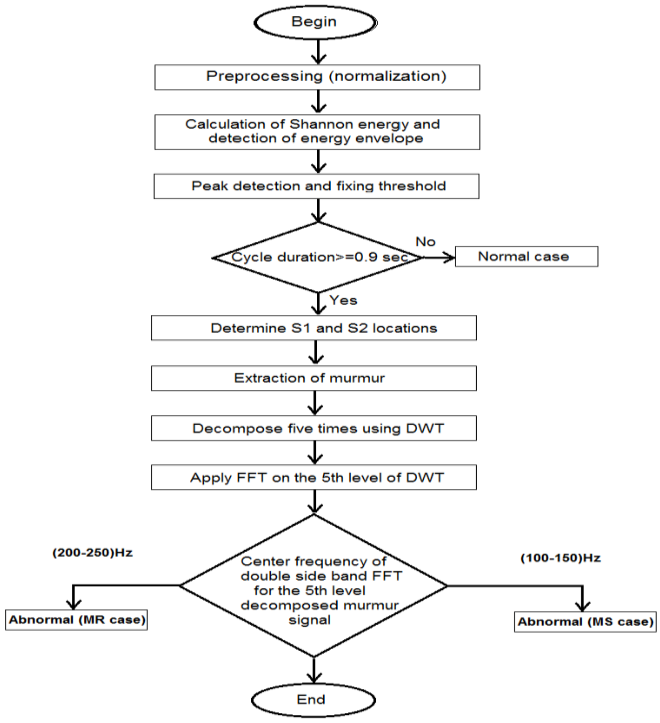


Fig. 2. Flow chart for PCG analysis and diagnosis.

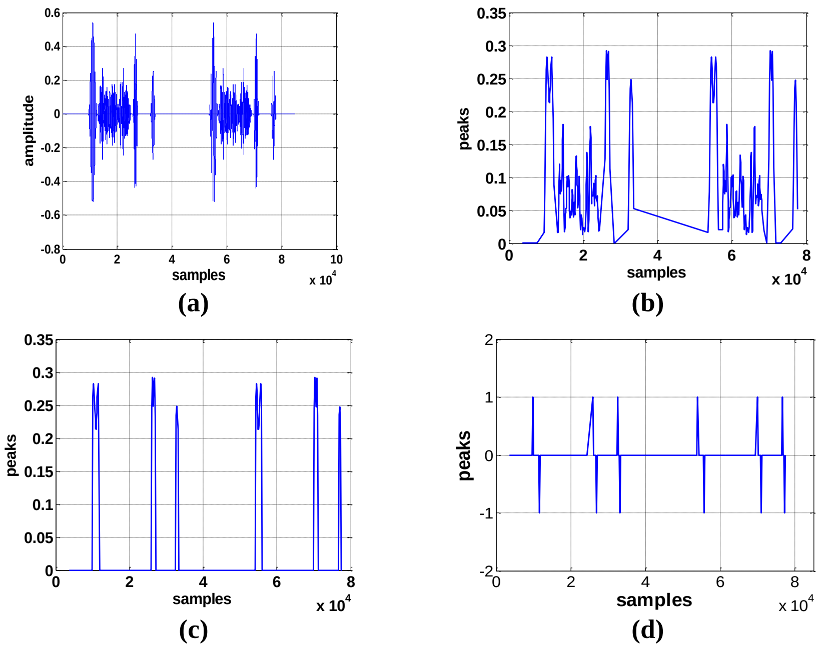


Fig. 3. The PCG signal for mitral regurgitation (Subject-1). (a) The stethoscope recorded signal, (b) The Shannon energy envelope, (c) isolated the systolic sound (S1) and the diastolic sound (S2) from murmur, (d) locating the beginning and ending of systolic and diastolic duration using differentiation.

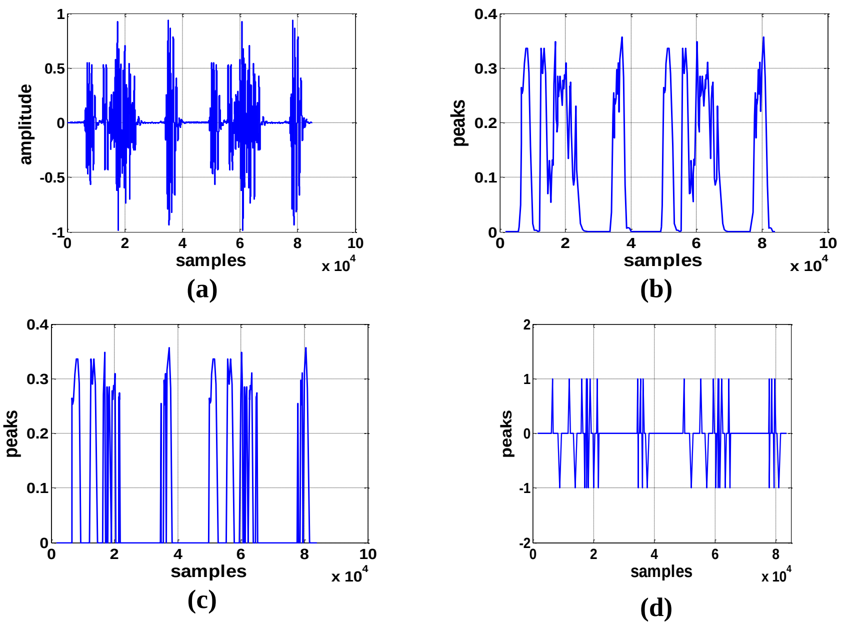


Fig. 4. The PCG Signal for mitral stenosis (MS) (Subject -4). (a) The stethoscope recorded signal, (b) The Shannon energy envelope, (c) isolated the systolic sound (S1) and the diastolic sound (S2) from murmur, (d) locating the beginning and ending of systolic and diastolic duration using differentiation.

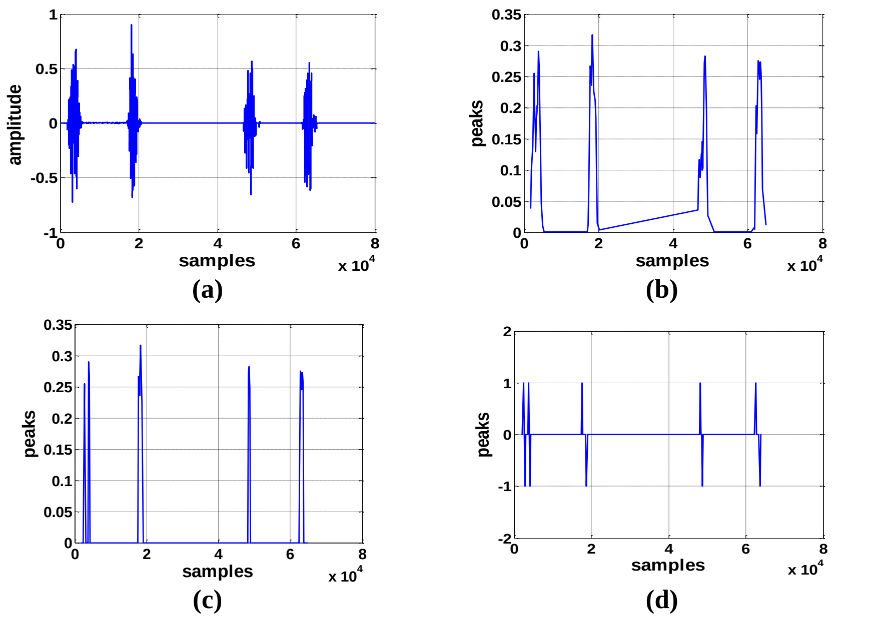


Fig. 5. The PCG signal for normal case (Subject -7). a) The stethoscope recorded signal, (b) The Shannon energy envelope, (c) isolated the systolic sound (S1) and the diastolic sound (S2) from murmur, (d) locating the beginning and ending of systolic and diastolic duration using differentiation.

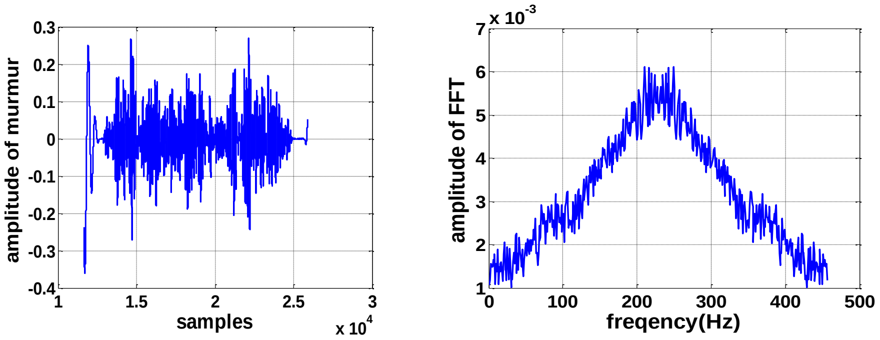
From Figs. 3(d), 4(d), and 5(d), the complete PCG cycle duration can be calculated as listed in Table 1.

Table 1. PCG cycle duration for normal, MR, and MS cases.

PCG case	PCG durations details (Sec.)		
	S_1 duration	S_2 duration	Cycle duration
MR-1 (subject-1)	0.0353	0.0228	0.991
MR-2 (subject-2)	0.036	0.019	0.99
MR-3 (subject-3)	0.0414	0.03994	0.9231
MS-1 (subject-4)	0.0327	0.0297	0.986
MS-2 (subject-5)	0.0304	0.0198	0.997
MS-3 (subject-6)	0.0394	0.0313	0.952
Normal-1 (subject-7)	0.0308	0.0249	0.7895
Normal-2(subject-8)	0.0236	0.0696	0.796
Normal-3 (subject-9)	0.031	0.0428	0.771

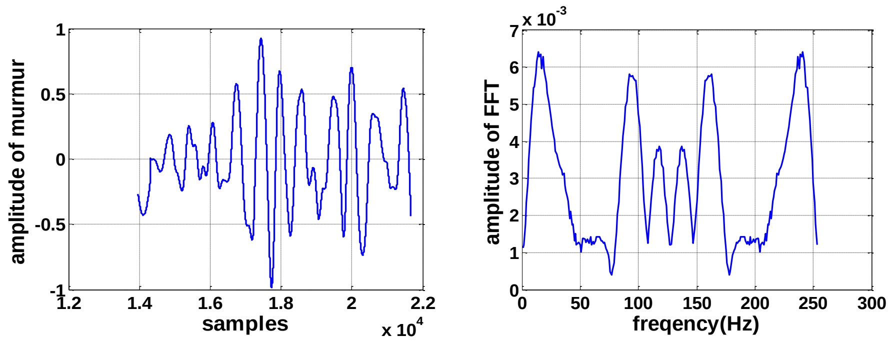
At this stage, the murmur part can be isolated from the whole PCG cycle. To deep analyze this important part for diagnosis, five sequenced level of DWT are performed. In more details, firstly the murmur part was analyzed into approximate coefficients and detailed coefficients using DWT with "db7" as a mother wavelet function. Then the detailed coefficients of this first level was analyzed again into approximate coefficients and detailed coefficients using DWT with "db7" as a second level. This procedure was accomplished five times. At the fifth level, the detailed coefficients were analyzed using double sided FFT in order to present the frequency spectrum of the richest information contained in the murmur part of the PCG signal under consideration.

The isolated murmur and the double sided FFT frequency spectrum of the Fifth level DWT are illustrated in Figs. 6 and 7 for MR and MS cases, respectively. It can be easily shown that the center frequency of the spectrum is located in the range (200- 250 Hz) for the MR case, while it is located in the range (100-150Hz) for the MS case. This can be a good feature that one can recognize the MR cases from that of MS cases.



(a) (b)

Fig. 6. The PCG signal for MR case (Subject -1). (a) The isolated murmur, (b) The double sided FFT frequency spectrum of the5th level DWT of isolated murmur.



(a) (b)

Fig. 7. The PCG Signal for MS case (Subject -4).
(a) The isolated murmur, (b) The double sided FFT frequency spectrum of the 5th level DWT of isolated murmur.

4. Conclusions

The algorithm that implemented in this work allows segmenting of the PCG signal and calculation of different temporal parameters: the durations of heart sounds S1 and S2, duration of heart murmurs, and the duration of cardiac cycle. Heart segmentation should be done, as it is essential for the diagnosis of heart sounds and heart murmur. With this segmentation, we can easily extract the features of each component of the PCG signal. Indeed, the extracted murmur part of the PCG is then deeply analyzed using five sequenced levels of DWT. In the fifth level the detailed coefficients calculated from DWT are analyzed using FFT. By this approach the rich information (the high frequencies) contained in the murmur part of the PCG are seen clearly in a way that one can easily distinguish between the most confusing and abnormal PCG signal records which are studied here (i.e., the Mitral Regurgitation (MR) case, and the Mitral Stenosis (MS) case).

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