Heart sounds and heart murmurs sepataion

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Abstract. The Heart sounds and murmurs provide crucial diagnosis information for several heart diseases such as natural or prosthetic valve dysfunction and heart failure. Many pathological conditions of the cardiovascular system cause murmurs and aberrations in heart sounds. Phonocardiography provides the clinician with a complementary tool to record the heart sounds heard during auscultation. The advancement of intracardiac phonocardiography, combined with modern digital processing techniques, has strongly renewed researcher's interest in studying heart sounds and murmurs. This paper presents an algorithm for the detection of heart sounds (the first and second sounds, S1 and S2) and heart murmurs. The segmentation algorithm is based on the detection of the envelope of the phonocardiogram signal by the homomorphic filtering, which used to extract a smooth envelogram which enable us to apply the tests necessary for temporal localization of heart sounds and heart murmurs

1 Introduction

Cardiac auscultation is widely used by physicians to evaluate cardiac functions in patients and detect the presence of abnormalities **[1].** Because phonocardiography (PCG) can provide valuable information concerning the function of heart valves and the hemodynamic of the heart, it has a high potential for detecting various heart diseases **[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 amplitudes than S1 or S2, appear occasionally in the cardiac cycle due to 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 atrioventricular valves. This sound is composed of two internal components: the mitral component (M1), associated with the closure of the mitral valve, and the tricuspid component (T1), associated with the closing of the tricuspid valve **[4]**. The second heart sound, marking the end of ventricular systole and signifying the beginning of the diastole, is made up of two components: the aortic component (A2), corresponding to the closure of the aortic valve, and the pulmonary component (P2), corresponding of the closure of the pulmonary valve **[4]**. Valvular pathologies induce significant changes in the morphology of the phonocardiogram signal (PCG) **[5]**. On the other hand, systolic and diastolic murmurs of different shapes can be added to the

PCG signal to build a track resulting from a given disease. The PCG signal is then a carrier of information to enable digital processing to be more easily performed. The energy of the PCG signal can prove, therefore, very important in the study of the cardiac cycle [6]. In the time domain, such representation allows us to appreciate the length of each heart sound, the systolic and diastolic phases and the cardiac cycle. Time-frequency analysis and classification of the PCG signals have been studied by several authors.[7] Before any analysis, the PCG signal needs to be segmented into components (sounds or murmurs), and then the components are analyzed separately. Some attempts to segment the PCG signal have been reported in the literature, but the majority of them depend on reference to the electrocardiogram (ECG) signal [8]. The aim of this study is to develop an algorithm for heart sound and heart murmur segmentation using the PCG signal as the only source. PCG signals have internal components with very close frequency bands. Fast Fourier transform (FFT) provides valuable frequency information, but the timing information is lost during the transformation process [9]. Discrete wavelets transform (DWT), using the band pass filter during PCG analysis, takes account only of the bandwidth of these filters.

In the context of analyzing other methods above, an approach of segmentation of heart sounds and heart murmurs, using Shannon Energy, was proposed by Mr. L. Hamza Cherif et al [6-10]. This approach consists in detecting of the side minima of each peak of the envelope by applying an empirically fixed threshold starting from the maximum value [6-10].

Based on this algorithm, we will try in this study to develop an approach for separation of heart sounds and heart murmurs using homomorphic filtering which is used to obtain a smooth envelogram of the phonocardiogram, which enables a robust detection of events of interest in the heart sound signal.

2   Envelope Detection of PCG signal

The advantage of such an *homomorphic envelogram* is its scalable smoothness, which handles the problems of splits and serrated peaks [11]. This is important when determining the locations of different components of the PCG signal. This technique converts a non-linear combination of signals (multiplied in the time domain) into a linear combination by applying a logarithmic transformation [12]. Thus, the resulting spectrum can be viewed as a combination of slowly varying and fast varying parts wherein the high frequency content would be removed using a low-pass filter.

The homomorphic filtering procedures that we used are as given below:
- The PCG signal can be expressed by:

$$x(n) = a(n) \cdot f(n) \quad (1)$$

where a(n) is the slow varying part and f(n) is the fast varying part.
- To convert the multiplication operation to addition, the logarithmic transformation is employed:

$$z(n) = \log x(n) \quad (2)$$

- Thus

$$z(n) = \log a(n) + \log f(n) \quad (3)$$

The logarithms of the two signals are now combined in an additive manner. The high frequency component is now characterized by rapid variations in time. We apply the low-pass filter, L, to filter the unwanted components:

$$z_1(n) = L[z(n)] \ (4)$$

Assuming the logarithmic transformation does not affect the separability of the Fourier components of $a(n)$, $f(n)$ and also since L is linear, we have:

$$z_1(n) = L[log\ a(n)] + L[log\ f(n)] \approx log\ a(n) \ (5)$$

By exponentiation, we arrive at:

$$exp[z_1(n)] = exp[log\ a(n)] \approx a(n) \ (6)$$

After some preliminary experimentation (for suitable choice of the kind and the cut-off frequency of the filter), the low pass Chebychev filter (L) was used with a transition bandwidth from 10 to 20 Hz. The low-pass filter used is a finite impulse response (FIR) filter. This operation enabled us to obtain a smooth envelope of the PCG signal as shown in **Fig. 1**, which allowed easy peak detection.
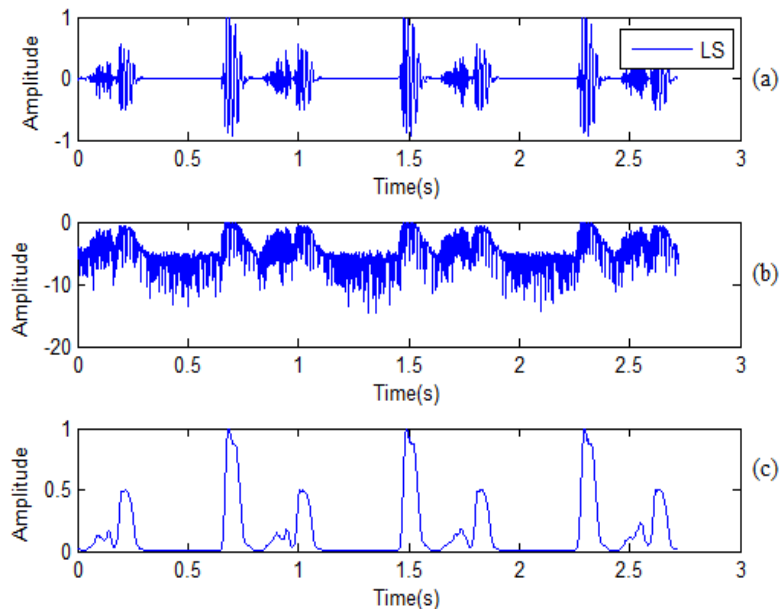

Fig. 1. Envelope detection of PCG signal LS. a) PCG signal (LS). b) the logarithmic transformation of PCG signal. c) Envelope detection.

3   Algorithm of the Segmentation

The organigram given by **Fig. 2** describes the different steps of the algorithm for segmentation of heart sounds.

Based on the envelogram extracted by the homomorphic filtering, a threshold is set starting from a maximum value according to the operator choice to eliminate the effect of noise and very low intensity signal, it have to be adjusted for each PCG 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 the heart sounds.

The identification of sounds is accomplished by comparing two consecutive sounds. The first sound S1 lies between two sounds whereby the gap from the next sound is smaller than the gap from the previous sound **[Fig. 3].** Conversely the second sound S2 is between two sounds in which the gap from the next sound is larger than the gap from the previous sound **[10]**.

The choice of threshold is very important to achieve reliable results; in fact, the duration of the sound or heart murmur may change depending on the chosen threshold. Indeed, peak whose levels exceed the threshold are considered and assumed to be the first or second heart sound, heart murmur or click.
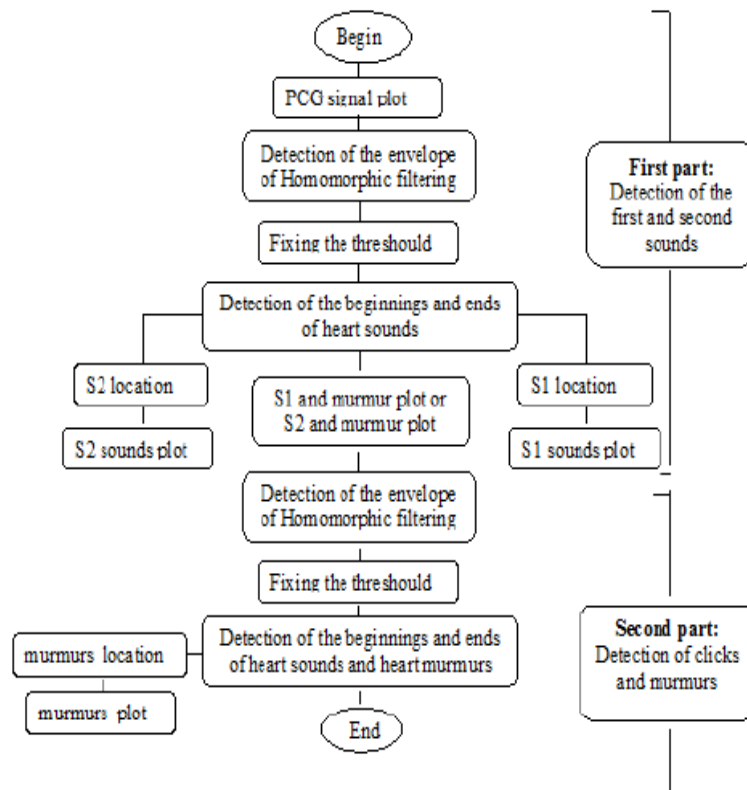
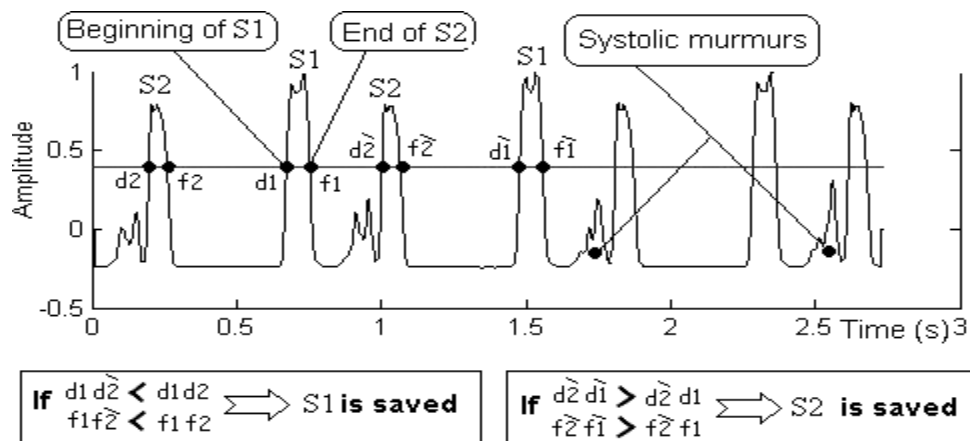**Fig. 2.** Algorithm of segmentation using the homomorphic filtering envelope

Fig. 3. Principle of separation of the heart sounds using an envelope of homomorphic filteing with a threshold of 60% for the maximum value.

4 Results and Discussion

The aim of this paper is to separate heart sounds and heart murmurs in order to as-sess their duration and that of the cardiac cycle. The algorithm of separation elaborat-ed was applied to several PCG signals (normal and pathological).

4.1 Separation of the heart sounds S1 and S2

The algorithm of segmentation was applied here for the separation of the heart sounds S1 and S2 of various PCG signals (using the first part of the proposed algorithm). **Fig. 4** gives the results of this segmentation of a normal PCG signal (N).

4.2 Separation of the heart murmurs

The heart sounds are the acoustic expression of cardiac phases. The first sound oc-curs during the systolic period and the second during the diastolic period. To these sounds can be added pathological sounds that occur when the valves are too narrow or when they cause leaks (stenosis or insufficiency). The pathological sounds can be murmurs or clicks, the third heart sound S3 (early diastolic sound) or S4 (presystolic sound).

Similar to the separation of the cardiac sounds S1 and S2, the separation of heart clicks or heart murmurs requires detection of the side minima of each peak of the Homomorphic filtering envelogram by applying a fixed threshold starting from the maximum value (T1 is the threshold used to detect the heart sounds and T2 is used to detect the clicks or murmurs), and then detection of the moments of these points and

consequently localization of the heart clicks or heart murmurs (using the second part of the proposed algorithm).
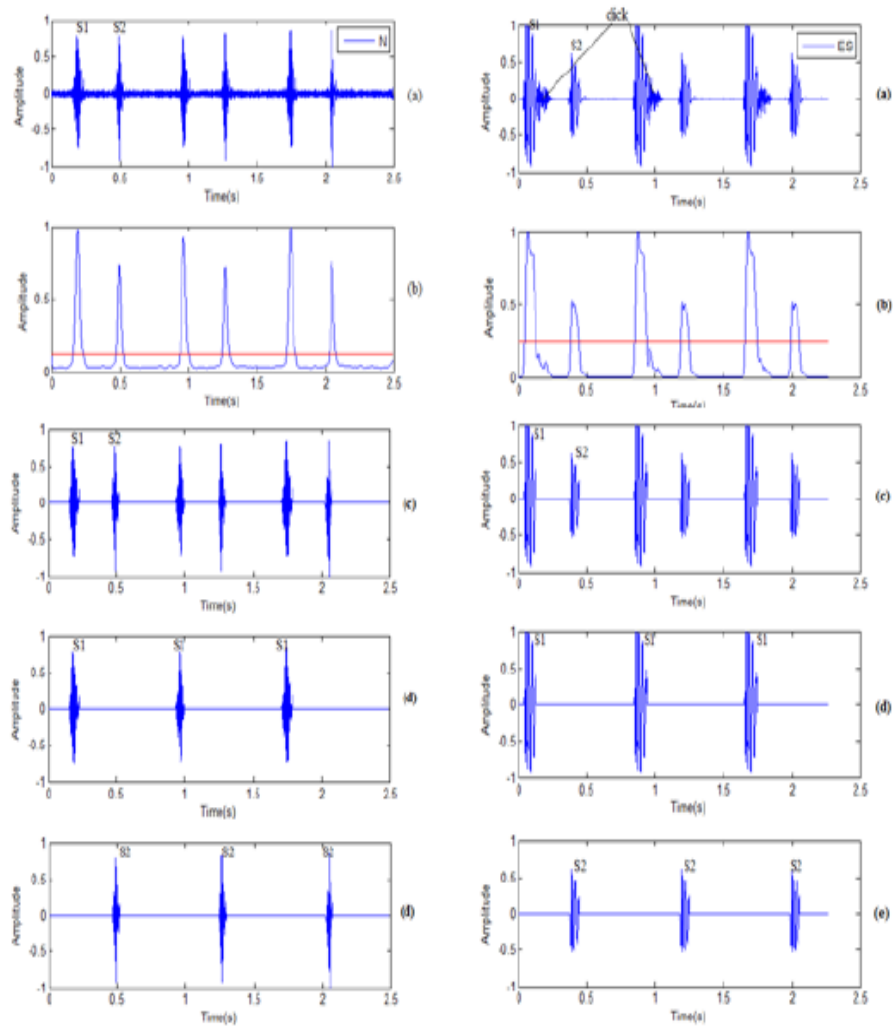

Fig. 4 Separation of the heart sounds S1 and S2 of normal (N) and early systolic (ES) PCG signals. (a) PCG signals (N and LS). (b) Homomorphic filtering envelogram with a threshold of 90% for the PCG N signal and 70% for the PCG LS signal for the maximum value. (c) Heart sounds S1 and S2. (d) Heart sounds S1. (e) Heart sound S2.
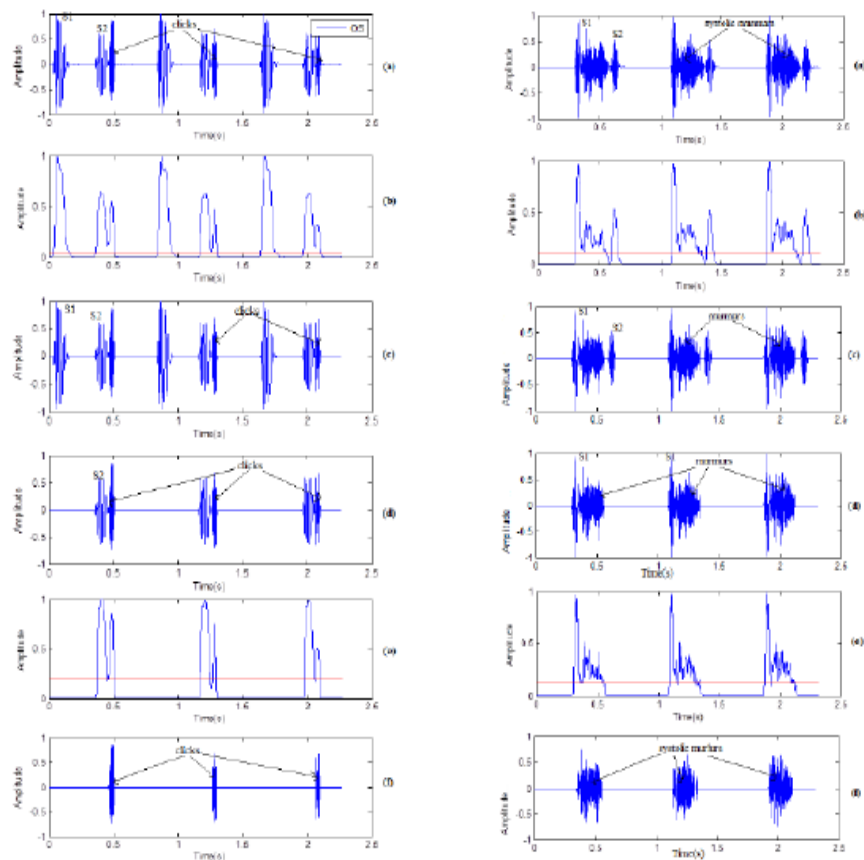
Fig. 5 Separation of heart murmurs and clicks. (a) PCG signals (with clicks OS, and with systolic murmurs AS). (b) Homomorphic filtering envelope with a threshold of 96% and 90%for the maximum value. (c) Heart sounds S1, S2 and heart murmurs. (d) Heart sounds S1 and heart murmurs. (e) Homomorphic filtering envelope with a threshold of 88% and 90% for the maximum value. (f) clicks or systolic murmurs.

Table 1. The Abreviations and the Number of Simples of differents PCG signals

PCG signal	Abreviation	Number of simple
Normal	N	25000
Later systolic	LS	32000
Early Systolic	ES	25000
Aortic Stenosis	AS	25000
Open Snap	OS	25000

Table 2. Summary of the average durations of heart sounds, heart murmurs and the cardiac cycle for various PCG signals (N, ES, OS, AS)

PCG signal	Duration of sound S1 (s)	Duration of sound S2 (s)	Duration of mur-mur(s)	Duration of cardiac cycle (s)	T1(%)	T2(%)
Normal	0.0675	0.0490		0.7779	80	
Early Systolic	0.0829	0.0674		0.8013	70	
Open Snap	0.1052	0.0955	0.0436	0.8013	96	88
Aortic Stenosis	0.0706	0.0576	0.1597	0.7978	90	90

T1 is the threshold used to detect the heart sounds and T2 is used to detect the clicks or murmur.

Table 2 gives the results of segmentation for Normal and pathologic PCG signals: (N), (ES), (OS), (AS). According to **Table 2**, the duration of the heart sound S1 is always higher than the duration of the heart sound S2 for all studied PCG signals. The activity of filling of blood in the myocard as well as the ejection of blood during the heart sound S1 lasts longer than the second sound S2.

The duration of each heart sound appears proportional to the quantity of ejected blood. Not also that the duration of the heart sounds (S1, S2) of the signal (AS) were slightly higher than the duration of the normal PCG. We can remark also that the click is brief, The duration of the heart sounds (S1, S2) of these signals (ES and OS) were significantly higher compared to normal the N and AS PCG signals; this may be due to the disease itself. The point that we can make here is that the cardiac cycle length varies with the presence of pathological heart sounds.

5   Conclusion

The algorithm for separating heart sounds that we have developed allows segment-ing of the PCG signal and calculation of the different temporal parameters: the dura-tions of heart sounds B1 and B2 and heart rate. Heart segmentation should be done, as it is essential for the diagnosis of heart sounds and heart murmurs. With this segmenta-tion, we can easily extract the features of each component of the PCG signal. The choice of threshold is important so as to have interesting results; the duration of heart sounds or heart murmurs may change if the choice of threshold is not taken into con-sideration.

Compared with the results of the algorithm for segmentation of PCG signals using Shannon Energy envelope, the proposed algorithm using the Homomorphic filtering envelogram provides good performance for its smoothness which solves the problems

of splits and serrated peaks especially in case of existence of heart murmurs that often includes many variations. As it is able not only to separate the fundamental heart sounds S1 and S2, but also separate heart clicks or murmurs.

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