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Automatic heart sounds segmentation based on the correlation coefficients matrix for similar cardiac cycles identification

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ABSTRACT

This paper proposes a novel automatic heart sounds segmentation method for deployment in heart valve defect diagnosis. The method is based on the correlation coefficients matrix, calculated between all the heart cycles for similarity identification. Firstly, fundamental heart sounds (S1 and S2) in the presence of extra gallop sounds such as S3 and/or S4 and murmurs are localized with more accuracy. Secondly, two similarity-based filtering approaches (using time and time-frequency domains, respectively) for correlated heart cycles identification are proposed and evaluated in the context of professional clinical auscultated heart sounds of adult patients. Results show the superiority of the novel time-frequency method proposed here particularly in the presence of extra gallop sounds.

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1. Introduction

Heart Sounds can be recorded and represented as Phonocardiogram signals for possible automatic auscultation, particularly in primary health care. Their segmentation is still a challenging phase before the interpretation and objective diagnosis. Phonocardiogram interpretation is mostly based on the envelogram calculated using the Shannon Energy [1–4], because it emphasizes the medium intensity signals and attenuates the high and low intensities signals. This tends to make medium and high intensity signals nearly similar in amplitude. This in turn makes the PhonoCardioGram (PCG) easier for visual localization of the Fundamental Heart Sounds (the first and the second heart sounds, S1/S2, or Fundamental Heart Sounds, FHS) and murmurs detection and classification. However, in some cases, the Shannon energy envelogram may display high amplitudes of extra sounds known as gallops, such as S3 and S4. These may lead to confusion with the peaks of the FHSs.

This paper addresses the problem of accurate automatic segmentation of the FHSs from a phonocardiogram signal for real-time applications, without the use of a reference signal such as an Electrocardiogram (ECG). The main contributions of this work are:

- Firstly, a novel automatic segmentation method of heart sounds is proposed. In this method the extra heart sounds, such as S3, S4 and murmurs are filtered prior to the envelogram calculation and an adaptive threshold is used for accurate boundaries localization of the FHSs.
- Secondly, a new method in time-frequency domain for the identification of similar cardiac cycles is proposed and compared to the standard time domain method. It computes the Short-Time Fourier Transform (STFT) for every heart period that got segmented in the first step, then compute the correlation coefficients matrix between all the heart periods. The identification of a highly correlated set of cardiac cycles (periods) which includes a reference period can be used for further analysis and diagnosis.

The paper is organized as follows: Section 2 describes the proposed segmentation process for accurate FHS boundaries localization from PCGs. In Section 3 two methods are proposed for similar heart cycle identification, in the time and time-frequency domains. Both methods use a-priori a synchronisation process of heart cycles before the calculation of the correlation coefficients matrix between them. The second method uses the Short Time Fourier Transform (STFT) to compute feature vectors which are used for the correlation coefficients matrix calculation. Results and discussion are given in Section 4 and Section 5 concludes the paper.

2. Segmentation of heart sounds

Segmentation aims to determine the boundaries of cardiac cycles from contiguous heart sound signals. This makes it the subject of many studies since it is considered as the most difficult step in heart sounds analysis due to interferences from murmurs,

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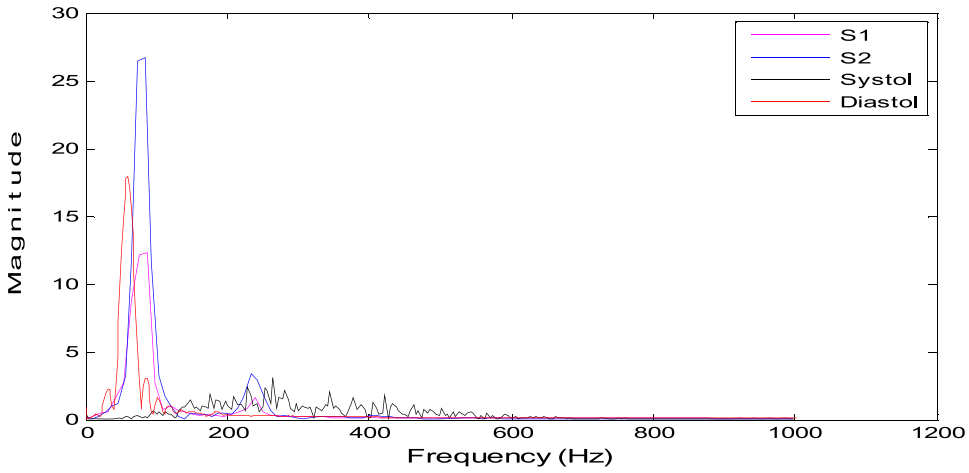

Fig. 1. Spectrum of a PCG period components S1, S2, diastole including S4 and systolic murmur.

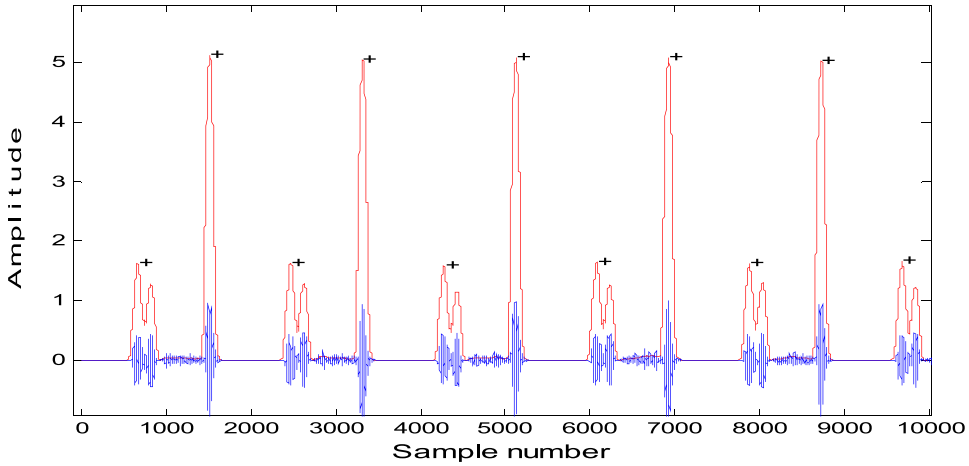

Fig. 2. Energy envelope (red) and PCG(blue) including S4 and systolic murmur before FHS filter. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

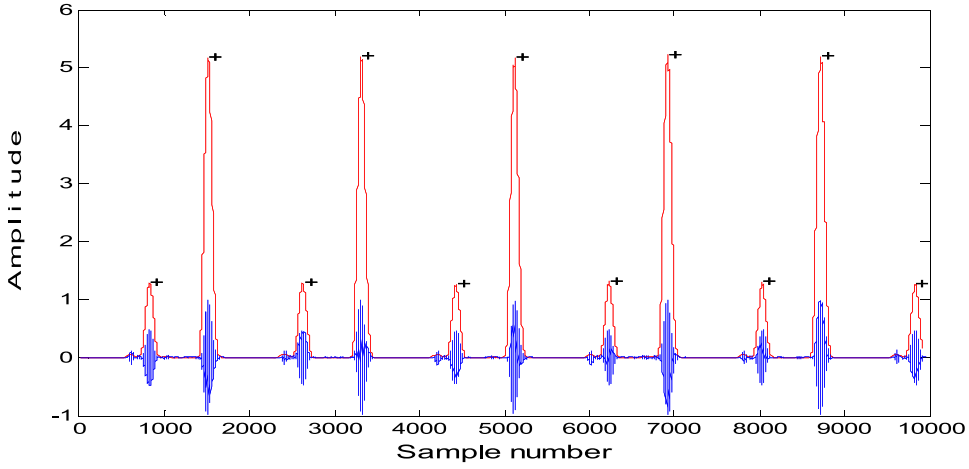

Fig. 3. Energy envelope (red) and PCG (blue) including S4 and systolic murmur after FHS filter. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

extra peaks and noises. Most approaches are based on the envelogram analysis for FHS, S1 and S2 sounds localization [5–7]. These approaches calculate the energy envelope of the original heart sound signal and use a threshold value (THV) to detect peaks of the envelope signal. Following this step, localization is done for which peaks correspond to S1 or S2. One cardiac cycle is composed of S1, S2, systole (the silence between S1 and S2) and diastole (the silence between the end of S2 and the start of the next S1).

The peaks are defined as segments of an envelope situated between two consecutive threshold crossings which localize the

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