A Novel Fourth Heart Sounds Segmentation Algorithm Based on Matching Pursuit and Gabor Dictionaries

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Abstract. In this paper we propose an efficient method for S4 heart sound segmentation based on the Matching Pursuit algorithm and Gabor Dicitonaries. An evaluation of this algorithm, through the use of different cardiac cycle events for S4 heart sound signals, showed a high performance, achieving a detection rate of 100% with the use of Gabor dictionary. The proposed method is practical, thus making it suitable for several applications such as signal compression and audio coding.
Keywords: Gabor, Matching Pursuit, Segmentation

1 Introduction

According to the World Health Organization (WHO) heart diseases represent the number one cause of death in the world: more people die every year from heart diseases than from any other cause [1]. Heart sound is a key signal to assess the mechanical functionality state of the heart. Auscultation is one of the simplest, quickest and, specifically, low cost effective techniques to analyze heart sounds. It is used to identify and diagnose a large number of heart pathologies simply by listening to cardiac sounds called "phonocardiograms" [2].

Thanks to recent advancements in data recording technology and digital signal processing it is now possible to record and analyze sound signals emitted by the heart. However, a computer analysis of the acoustic signals of the heart requires the different components of the heart cycle to be divided and timed separately. This is why we have developed a computerized method that allows such segmentation of both normal and abnormal heart sounds, first (S1) and second (S2), respectively. The analysis of systolc and diastolic murmurs is based on the frequency and location of the signal to determine the characteristics of the heart sounds in the time-frequency levels [3]. Methods based on Wavelet's theory have been used in the past to decompose, analyze and reconstruct heart sound signals [4]. Nevertheless, the robustness of reconstruction and compression

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in decomposition that Matching Pursuit (MP) offers has provided with a powerful tool to represent a phonocardiogram through a linear combination of well concentrated waveforms, also called atoms, while at the same time performing an extraction of components S1 and S2, called segmentation [5].

The purpose of the present study is to select the optimal atoms to be used in thereconstruction of a first heart sound (S1) and to propose a segmentation algorithm of extra sounds near S1 using the matching pursuit algorithm and Gabor atoms.

2 Matching Pursuit Algorithm

Matching Pursuit (MP) is an iterative greedy algorithm that decomposes a signal $x(t)$ into a sparse linear combination of waveforms that belong to a redundant dictionary of functions called time-frequency atoms and residual term $R_M(t)$ [6,7]. MP aims at to find sparse decompositions of signals, that is, to obtain a representation that accounts for most or all information of a signal with a linear combination of a small number of elementary waveforms (called atoms). The decomposition is performed by projecting the signal $x(t)$ over a redundant dictionary of functions $D = g_\gamma(t), \gamma \epsilon \Gamma$ where $g_\gamma(t), \gamma \epsilon \Gamma^2(R), \Gamma = R^+ \times R^2$ and by selecting the atoms which can best match the local structure of the signal. The signal $x(t)$ can be reconstructed from the sum of M atoms and a residual term $R_M(t)$ as

$$x(t) = \sum_{m=1}^{M} \alpha_m \cdot g_{\gamma_m}(t) + R_M(t) \qquad (1)$$

where $g_(\gamma_m)$ and α_m are the $m-th$ optimal and ponderation factor respectively. MP is an iterative descent algorithm which selects the optimal atom at each iteration [8]., see Algorithm 1.

Algorithm 1 Standard Matching Pursuit

```
input: $x(t)$; $\mathcal{D} = \{g_\gamma(t), \gamma \in \mathbf{\Gamma}\}$
output: $\alpha_m, g_{\gamma_m}(t)$

$R = x(t)$
$\alpha_m = 0$
for each m in M
    $g_{\gamma_m} = \arg\max_{\gamma \in \Gamma} |\langle R, g_\gamma \rangle|$
    $\alpha_m = \langle R, g_{\gamma_m} \rangle$
    $R = R - \alpha_m \cdot g_{\gamma_m}$
until target signal-to-noise ratio (SNR) or the $M$ iteration has been reached.
```

3 Dictionary Selection

Selecting an adequate dictionary plays a fundamental role in the performance of the MP algorithm. Several kinds of time-frequency dictionaries have been proposed in literature, for instance: The Wavelet Packet, The Cosine packet, MDCT (Modified Discrete Cosine Transform), and Gabor dictionaries [8]. After conducting preliminary tests using all of the above mentioned dictionaries we have found the Gabor's functions can model the non-stationary heart sound signal. In addition to this, the ability of its functions to model heart sounds has been previously reported [8]. Gabor atoms are obtained by dilating, translating and modulating a mother window $w(t)$ which is generally revalued, positive and of unit norm $\int w(t)^2 dt = 1$.

$$g_\gamma(t) = \frac{1}{\sqrt{s}} w(\frac{t-u}{s}) e^{i2\pi\xi(t-u)} \tag{2}$$

where w is the Gaussian window $w(t) = \sqrt[4]{2} e^{-\pi t^2}$, the scale s is used to control the width of the waveform envelope, the time displacement u is used to specify the temporal location of the atom and ξ is the modulating frequency. We define $\gamma_m = (s_m, u_m, \xi_m)$, where the index γ_m is an element of the set $\mathbf{\Gamma}$.

3.1 Segmentation Algorithm

We approximate the optimal attacks using the matching pursuit algorithm and Gabor dictionaries. Then, we look for all the x_j optimal attacks that satisfy the condition

$$\mathcal{O}(x_j) > \mu$$

where μ is the duration of S2 heart sounds i.e. = 0.12s. The optimal attacks were selected using the heart sound segmentation algorithm based on matching pursuit [5].

Once MP decomposition of heart sound signal has been performed, it produces a set of Gabor atoms. These Gabor atoms are optimal to represent the analyzed signal and are then stored in a so-called book. Te first step of the segmentation algorithm consists of selecting the position u_m for all optimal atoms.

The next step consists of identifying the minimum position for the analyzed signal. The Gabor atom with the minimum position is considered to be an onset and it is stored into θ_j. Fig. 1 shows the onset detected between S1 and S4 heart sounds.

The whole segmentation process is described in the form of pesudo code in Algorithm 2.

Algorithm 2 Segmentation

```
input: $book = \{g_{\gamma_m}, \gamma \in \mathbf{\Gamma}\}$
ouput: $o_i = 0, \theta_i = 0$
repeat j
    $x_j$
    repeat n=1:3
        $o_i = min(u_n)$
    end
    $\theta_j = o_i$
end
```

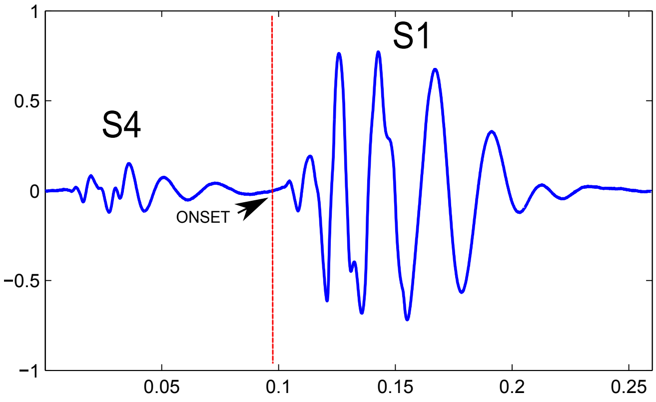

Fig. 1. Onset detection of S1 in a PCG waveform using the algorithm. It is shown also the waveform of S4 before this.

3.2 Test Corpus

The heart sound signals used in this study were all obtained from Littmann® website. Seven cardiac cycle events were analyzed, containing normal sounds (normal split S1, normal split S2) and s4 sounds. Five dictionaries were implemented for the S4 heart sounds segmentation. Table 1 shows a list of the dictionaries used.

A total of 240 simulations were carried out using Gabor dictionaries as well as four different iteration values. All onsets of the heart sounds were registered by hand separately by two different people, then results were averaged. The annotation process consisted of repetitively listening to the sound signal using headphones while visually inspecting the time waveform.

Table 1. Multi-block Gabor dictionaries implemented for segmentation of S4 heart sounds.

Dictionary	window size (%)	Size of atom	total of atoms
1	50	128,256,512	23639
2	50	64,128,256,512,1024	39038
3	50	32,64,128	24760
4	50	256,512,1024	22761
5	50	1024	7182

Table 2. Number of onsets detected using Gabor multi-block dictionaries.

onset identified	onset detected	Number of iteration	Gabor dictionary	Total of atoms
7	4	2	1	23639
7	5	2	2	39038
7	0	2	3	24760
7	5	2	4	22761
7	5	2	5	7182
7	7	3	1	23639
7	4	3	2	39038
7	0	3	3	24760
7	4	3	4	22761
7	3	3	5	7182
7	5	4	1	23639
7	4	4	2	39038
7	0	4	3	24760
7	4	4	4	22761
7	3	4	5	7182
7	3	5	1	23639
7	2	5	2	39038
7	0	5	3	24760
7	2	5	4	22761
7	3	5	5	7182

3.3 Evaluation

All the simulations carried out in the present work were performed under Matlab©. Heart sounds were decomposed using MPTK (Matching Pursuit ToolKit)[9]. MPTK is an open source package that provides a fast implementation of the Matching Pursuit algorithm.

We present a number of simulation experiments to assess the performance of the proposed algorithm for heart sound segmentation. The tolerance criterion between the start of the attack and the detected onset was set to 0.01 s. Table 2 shows the results obtained from each cardiac cycle event as well as the number of atoms in each dictionary and detection of onsets. Although the dataset used to evaluate the algorithm is small, we consider the results highly encouraging since it exhibits high performance for onset detection. During our simulation we found that by using Gabor dictionaries with lengths of atoms [128,256, 512] and three optimal atoms 100% of the onsets can be detected. Three Gabor atoms were required to obtain 75% of the reconstruction of S1 heart sound. Using three Gabor atoms the residual energy of S1 heart sound is less than the energy of S4 heart sound. Then we can reconstruct only the S1 heart sounds. Fig 2. shows the S4 and S1 heart sounds segmentation using the dictionary parameters above mentioned. The time-frecuency representation of S1 heart sounds using three atoms is showed in Fig. 3.

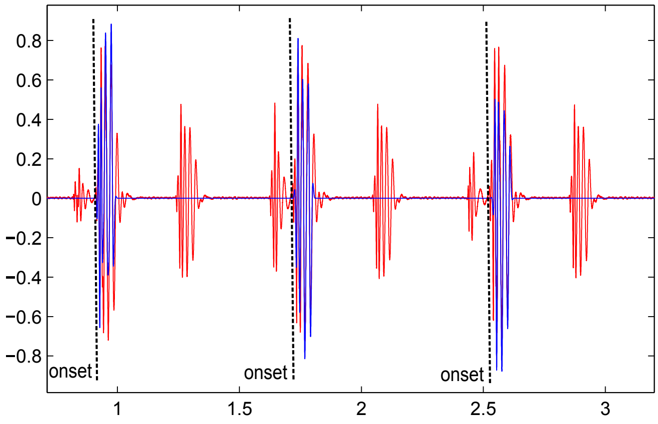

Fig. 2. Section of a S4l heart sound illustrating the main cardiac cycle events, namely the first heart sound (SI), the systolic period, the second heart sound (S2), the diastolic period.

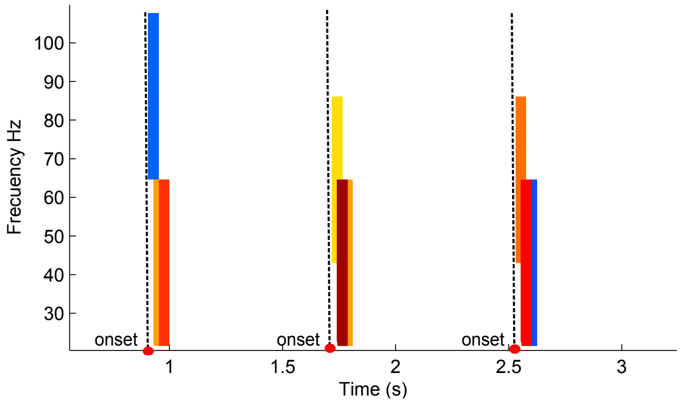

Fig. 3. Time-frequency representation of a normal heart sound obtained with the MP algorithm. Each of the rectangles (also called boxes) in this representation is a Gabor atom.

4 Conclusions

In this paper, we presented an efficient S4 heart sound segmentation method based on the Matching Pursuit and Gabor dictionaries. We have shown that Gabor dictionaries provide an efficient segmentation of S4 heart sound signals. The technique showed high performance achieving a detection rate of 100% for onsets between S1 and S4. The method presented can be directly used in the pre-processing step of PCG signal compression, and PCG based, audio coding, source separation and PCG signal enhancement.

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References

1. Organization, W.H.: Global status report on noncommunicable diseases 2010 (Geneva, Switzerland 2011)
2. Abbas, A., Bassam, R.: Phonocardiography Signal Processing. Synthesis Lectures on Biomedical Engineering Series. Morgan & Claypool (2009)
3. Boutana, D., Benidir, M., Barkat, B.: Segmentation and identification of some pathological phonocardiogram signals using time-frequency analysis. IET signal processing **5** (2011) 527–537
4. Martinez-Alajarin, J., Ruiz-Merino, R.: Efficient method for events detection in phonocardiographic signals. In: Microtechnologies for the New Millennium 2005, International Society for Optics and Photonics (2005) 398–409

5. Nieblas C.I., Alonso M.A., C.R.V.S.: High performance heart sound segmentation algorithm based on matching pursuit. IEEE Digital Signal Processing and Signal Processing Education Meeting (DSP/SPE). (2013) 96–100
6. Mallat S., Z.Z.: Matching pursuit with time-frequency dictionaries. IEEE Transactions on signal processing **41** (1993) 3397–3415
7. R., G., E., B.: Harmonic decomposition of audio signals with matching pursuit. IEEE Transactions on processing **51** (2003) 101–111
8. Ravelli E., R.G., L., D.: Union of mdct bases for audio coding. IEEE Transactions on audio, speech, and language processing **16** (2008) 1364–1372
9. Krstulovic, S., Gribonval, R.: Mptk: Matching pursuit made tractable. In: Acoustics, Speech and Signal Processing, 2006. ICASSP 2006 Proceedings. 2006 IEEE International Conference on. Volume 3. (2007) III–III