Exploring the Stationary Wavelet Transform Detail Coefficients for Detection and Identification of the S1 and S2 Heart Sounds

N Marques[1] , Rute Almeida[2,3], Ana Paula Rocha[2], M Coimbra[4]

[1] CRACS Research Unit Faculdade de Ciências da Universidade do Porto, Porto, Portugal
[2] CMUP and Faculdade de Ciências, Universidade do Porto, Porto, Portugal
[3] CIBER-Bioingeniería, Biomateriales y Nanomedicina, Communications Technology Group (GTC), Aragón institute of Engineering Research (I3A), IIS Aragón, Univ. de Zaragoza, Zaragoza, Spain
[4] Instituto de Telecomunicações in Faculdade de Ciências da Universidade do Porto, Porto, Portugal

Abstract

Most work done in Heart Sound Segmentation approaches use a threshold-based approach to correctly identify S1 and S2 segments in a given signal. We propose a new method that uses the Stationary Wavelet Transform to segment the signal and hierarchical clustering to distinguish the S1 and S2 heart sound from noise. This approach was tested in the Classifying Heart Sounds PASCAL Challenge datasets and achieved better results than the winning approach of this contest, with a total error redcution of 21% and 43% for Digiscope and iStethoscope in test sets, respectively.

1. Introduction

Traditional cardiac auscultation is still taught and used in modern cardiology and clinical practise in spite of much more sophisticated and reliable methods, like the ultrasonic imaging and Doppler techniques, currently available in the today's digital era. Moreover the common stethoscope lacks some useful features like recording, and playing back sounds. It also does not integrate visual display or simultaneous transmition facilities. These limitations can be resolved by the use of electronic digital stethoscopes such as the Digiscope Prototype [1] and many others, which have proved to be of great use due to its non-invasiveness and to its low cost, whether it be for analysis or for teaching young cardiologists [2].

With this digital technology, the evolution of cardiac auscultation requires computer assisted cardiac evaluation systems, which auxiliate the detection of heart disease. Although there is a huge amount of work done already in this area, no reliable method is still available. In this work, we introduce an alternative heart sound segmentation method, aiming to improve with respect to the published approaches.

2. Materials

This work uses two public heart sound signal (HSS) datasets that were featured in the Classifying Heart Sounds Pascal Challenge competition [3]: the Digiscope (controlled protocol) and iStethoscope (uncontrolled protocol) datasets.

The Digiscope Project was a Portuguese funded project that aimed to develop a digitally enhanced stethoscope that extracted clinical features from the phonocardiogram PCG and provided clinical auxiliary dignostic tool regarding specific heart pathologies. The data used in this study was collected in the Real Hospital Português (Brazil), with the approval of the RHP Ethics Commitee, anonymized and shipped to Portugal. It consits in 200 auscultations were made from children using a Littmann Model 3100 electronic stethoscope with a sampling frequency of 4KHz. All of the auscultations did not have any abnormal heart sounds. An expert pointed out the correct positions of 120 auscultations, 90 of which had reference annotations available to the contestants (trainnig data) and 30 were used for the algorithm validation (test data).

The iStethoscope is an iPhone app that turns the iPhone into a digital stethoscope, using its microphone to record the HSS. The data is colected by ordinary app users that voluntarly recorded and upload the data extracted using iPhone versions 3G and 3GS, with a sampling frequency of 44100Hz. No information is available about the auscultated subjects regarding gender, age, condition,... An expert pointed out reference annotations of 30 auscultations: 40 of each were used as training set and 10 as test data.

The provided reference annotations in test data, correspond to any point within the S1 or S2 waves. A more informative reference was manually produces by marking the boundaries of each annotated wave. These marks were used to compute Sensitivity and PPV on the training set. After careful analysis, 10 instances were removed from each training dataset due to clear auscultation and annotation errors. The performance evaluation is obtained as a total error in an Microsoft Excel file provided by the organizers that can only be computed over test data.

3. Methods

The first goal of HSS analysis is to correctly locate and identify the S1 wave, systole interval, S2 wave and diastole interval. This analysis can consists in 4 tasks [4]: noise reduction, representation, detection and identification of heart sounds. This work uses as HSS representation a Shannon envelope (Shannon Energy of Shannon entropy) followed by Stationary Wavelet Transform implementation with a Daubechies wavelet system. According to [4] teh use of Shannon Energy is preferble, as it emphasizes medium intensity components, as S1 and S2 waves, and attenuates low intensity components lihe sustole and diastole. The detection stage takes the HSS representation and delimitates the signal into segments corresponding to S1, S2, Systolic and Diastolic phenomena, that are afterwards labelled in the identification stage, using an hierarchical clustering approach.

3.1. Stationary wavelet transform

The Stationary Wavelet Transform (STW), also know as *à trous* algorithm, is an alternative implementation of the discrete wavelet transform, in which the downsampling stage at each scale is replaced by an upsample of the filter before the convolution [5], as illustred in Fig. 1. While the traditional filter bank implementation loss coeficients at each scale, SWT has the advantage of mantaining the same number of coefficients throughout all scales, thus having a convenient one to one correspondence with the original signal. SWT having $2NK$ coefficients, where N is the length of the signal and K is the number of scales, is highly redundant, which is particularly suitable for event detection, the main goal of this work.

3.2. Detection stage

The segmentation of the HSS was performed based in the inflection points of wavelet approximation or detail coefficients at high scales. As one can see in Fig.2 for the case of a Digiscope signal and scale 10 of Daubechies wavelet system of order 38 , the inflection points of detail coefficients ($Db30c_d$) correspond to the boundaries of many of the S1 and S2 waves. However, due to the noise, this correspondence is not true for all waves. Nevertheless, these inflection points are able to separate segments in which exist one S1, one S2 or none of those (systole or diastole intervals). Several combinations of Daubechies wavelet system of orders ($\epsilon[1, 2, \ldots, 40]$) and

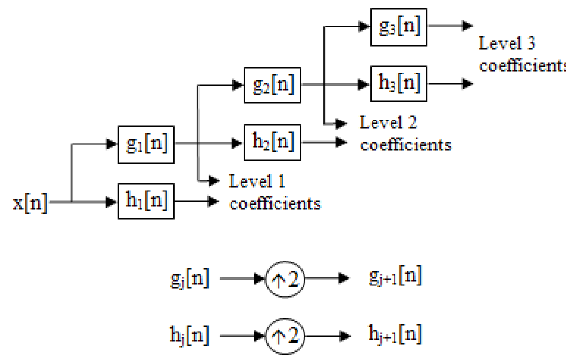

Figure 1. The Stationary Wavelet Transform

scales ($\epsilon[1, 2, \ldots, 12]$) were compared in their ability for correct signals segmentation.

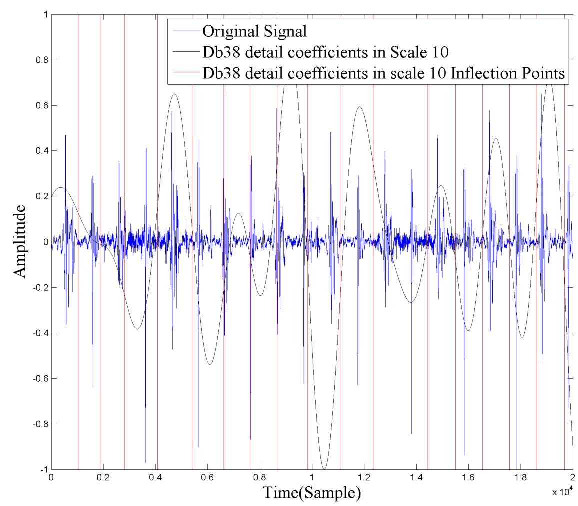

Figure 2. SWT Detail Coefficients in scale 10 superimposed with to a Digiscope Signal

3.3. Hierarchical clustering

After computing the segments, we need to choose a representative feature that describes each segment. This feature should effectively allow a posterior classification system, to label them as S1/S2 or Noise(Systole,Diastole).The maximum absolute value of a segment was chosen as a descriptive feature of each segment. We use the UPGMA method [6], to build an hierarchical tree with the maximum of each segment. The UPGMA method is an iterative method that in each step builds one cluster from to sub-clusters which have the nearest distance according to eq. (1). This type of cluster aggregation allows us to obtain the S1's and S2's through the top cluster that had the highest median of maximums. This scenario, however, is not

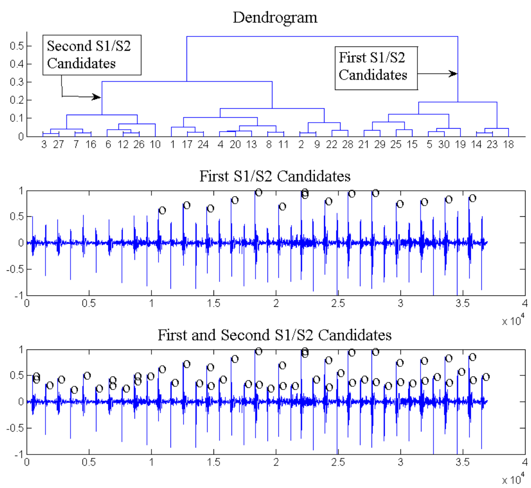

Figure 3. Dendrogram and the picked subclusters that represent the first and second sets of candidates (on the top). Candidates overlaped with HSS (two lower axis).

always true. The ideal scenario would happen if S1 and S2 heart sounds had the same intensity. This is not true as the intensities depend mostly on where was the auscultation point. So to obtain the next set of S1 and S2 candidates, we pick the sub-cluster of the low intensity cluster with the highest median of intensities which can be seen in Fig.3. Picking only two clusters can be explained by the fact that there are always two sets intensities regardless of where the auscultation point is.

$$\frac{1}{|A|\,|B|}\sum_{x\epsilon A}\sum_{y\epsilon B} d(x,y) \tag{1}$$

Ocasional errors in this segmentation can occur with two segmnents reporting the same S1 or S2 wave. This results in redundant detections, that correspond to outliers in the time intervals between detections. To overcome this problem, the median of the intervals between consecutive peaks is computed and peaks producing intervals below half of the this median are reject, by selecting the highest peak of the two.

4. Results

To assess the performance of the method, two different types of metrics were used: Sensitivity and Positive Predictivy (PPV), acording to standard definition, and total error computed using a Microsoft Excel spreadsheet, provided in the competition's website. For the training set, Sensitivity and PPV were considered using the manual annotation of each wave boundary constructed from the reference marks provided. The computation of total error cannot be performed, as no information on it is provided. For test set, Sensitivity and PPV cannot be obtained since the reference annotations were hidden, but total error was computed and presented.

All combinations of the following Daubechies orders, scales and coefficients were explored:

- Order $\epsilon[1, 2, \ldots, 40]$
- Scale $\epsilon[1, 2, \ldots, 12]$
- Coefficients $\epsilon[c_a, c_d]$

Tables 1 and 2, presents all the results from our approach's and the total error of the best 3 approaches presented in the Classifying Heart Sounds Pascal Challenge[3], for the Digiscope and Istethoscope datasets.

The Istethoscope validating dataset had some signals in which there were 2 error spikes, while the heart sound signals had intensities around $\frac{1}{20}$ of the intensities of those spikes. This was probably due to the fact that the iStethoscope user that performed that auscultation hit the microphone to begin and end the auscultation while placing the iPhone in a wrong position, making the heart sounds extremely hard to detect. To overcome this problem, the Shannon Entropy was used instead of the Shannon Energy, in order to accentuate some low-mid intensities while attenuating the highest ones. Focusing on the Positive Predictive value in Table.2, that lower scales result in a lower PPV given that the it will have higher variability, and consequently have more inflection points. Even with the best approach the method still had 0.63, a relatively low PPV. This is due to the Istethoscope's inherent noise given the lack of a controlled environment.

In the Digiscope dataset the best results using our approach was obtained by using the approximation coefficients of Daubechies9 at scale 10, while for iSstethoscope the details coefficients of Daubechies6 at same scale performed better. For both datasets performance of the proposed method overperformed the best results presented in the Classifying Heart Sounds PASCAL Challenge, including the highly cited Liang approach [4] reproduced by the team ISEP.

This can be explained by the fact that the main lobe of the approximation coefficients of Daubechies9 in the 10th scale resembles the most in amplitude and width, to the Shannon Energy of the original signal.

5. Conclusion

The main contribution of this work is a peak detection procedure that leads to very good results that surpass all of the approaches used in the Classifying Heart Sounds PASCAL Challenge [3]. The success of this approach can be explained from the initial segmentation done by using the

Approach	Total Error	Sensitivity	PPV
$Daubechies_{9,Scale=10,c_a}$ (using Shannon Energy)	56732	0,91	0,95
ISEP	72242		
UCL	75569		
Stanford	76444		

Table 1. Digiscope Representation Results

Approach	Total Error	Sensitivity	PPV
$Daubechies_{6,Scale=10,c_d}$ (using Shannon Entropy)	706535	0,97	0,63
Stanford	1243640		
UCL	3394378		
ISEP	3905581		

Table 2. Istethoscope Representation Results

SWT Inflection Points. It is also due to the fact that on most of the signals the S1 and S2 peaks form 2 groups, which can be identified using hierarchical clustering. This method can be further improved either by verifying if the annotations produced correspond to physiological time intervals between the mechanical phenomena, as heart rythms don't change abruptly. That verification can be used not only to further eliminate FP detections but also to evaluate the need of a search back correcting FN.

6. Acknowledgements

CMUP research funded by the European Regional Development Fund through the programme COMPETE and by the Portuguese Government through the FCT - Fundação para a Ciência e a Tecnologia under the project PEstC/MAT/UI0144/2011. CIBER-BBN is an initiative funded by the VI National R&D&i Plan 2008-2011, Iniciativa Ingenio 2010, Consolider Program, CIBER Actions and financed by the Instituto de Salud Carlos III with assistance from the European Regional Development Fund. This study was partially supported by project TEC2010-21703-C03-02 from the Ministerio de Economia y Competitividad (MINECO) with European Regional Development Fund, Spain, and Grupo Consolidado GTC T30, from Gobierno de Aragón, Spain. Authors acknowledge the suport from Mortara Instr Inc. This work was supported by the European Regional Development Fund through the programme COMPETE and by FCT projects PTDC/EIA-CCO/100844/2008 , DECA-BIO IT/LA/01075/2011, PEst-C/MAT/UI0144/2011 and HEARTSAFE PTDC/EEI-PRO/2857/2012

References

[1] Coimbra M. The digiscope project. http://digiscope.up.pt/.

[2] Tavel ME. Cardiac auscultation: a glorious past–and it does have a future! Circulation 2006; 113(9):1255–9. ISSN 1524-4539.

[3] Bentley P, Nordehn G, Coimbra M, Mannor S. The PASCAL Classifying Heart Sounds Challenge 2011 (CHSC2011) Results. http://www.peterjbentley.com/heartchallenge/index.html.

[4] Liang H, Lukkarinen S, Hartimo I. Heart sound segmentation algorithm based on heart sound envelogram. In Computers in Cardiology 1997, volume 24. ISSN 0276-6547, 1997; 105–108.

[5] Cohen A, Kovačević J. Wavelets: The mathematical background. Proceedings of the IEEE April 1996;84(4):514–522.

[6] Murtagh F. Complexities of hierarchic clustering algorithms: State of the art. Computational Statistics Quarterly 1984; 1(2):101–113.

Address for correspondence:

Nuno Marques
Adress: Rua do Campo Alegre, 1021/1055 4169-007 Porto Portugal