

Study of the split for the second cardiac sound using the wavelet Transform

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Abstract.

This paper is concerned with the identification of splitting patterns in the second heart sound (S2) of the phonocardiogram signal (PCGs). The second heart sound S2 consists of two acoustic components A2 and P2, the former is due to the closure of the aortic valve and the latter is due to the closure of the pulmonary valve. The aortic valve usually closes before the pulmonary valve, introducing a time delay known as "split". A technique based on the discrete wavelet transform (DWT) and the continuous wavelet transform (CWT) is developed in this paper to measure the split. To quantify the splitting, the two components in S2 (i.e. A2 and P2) are identified and, the delay between the two components can be estimated.

keywords : Second heart sound, phonocardiogram signal ,split S2, wavelet transform.

I. INTRODUCTION.

Cardiac sound analysis by auscultation only, is still insufficient to diagnose some heart disease. It does not enable the analyst to obtain both qualitative and quantitative characteristics of the sounds S1 and S2 of the phonocardiogram [1-2]. Moreover, in studying the physical characteristics of heart sounds and human hearing, it is seen that the human ear is poorly suited for cardiac auscultation [3]. Therefore, clinic capabilities to diagnose heart sounds are limited.

This paper will concentrate on analysing the second heart sound S2 and its two major components A2 and P2. The aortic valves normally close before the pulmonary valves leading to a time delay between these two components respectively A2 and P2. This delay is known as the "split" in the medical community [4-5-6].

This diagnosis importance of S2 has been recognised for a long time, and its significance is considered by cardiologist as the "key" to auscultation of the heart [7].

Specifically during expiration, in normal phonocardiogram, A2 and P2 are separated by a relatively short interval (split) typically less than 30ms [8]. A2 has higher frequency contents than that of P2 and generally A2 precedes P2. Moreover the order of occurrence of this two components of the sound S2 may reverse due to diseases [1].

In this paper the wavelet transform is used to analyse the split for the normal and pathological sound S2. This technique has been shown to have a very good time resolution for high-frequency components. In fact the time resolution increases as the frequency increases and the frequency resolution increases as the frequency decreases [9],[10].

Furthermore, the wavelet transform has demonstrated the ability to analyse the heart sound more accurately than other techniques STFT or Wigner distribution [11] in some pathological cases.

Because of their compatibility with non stationary random process, wavelet transforms are a powerful tool for analysing biomedical signals.

Wavelet analysis is a refinement of Fourier analysis. The Fourier Transform is a method of describing an input signal (or function) in terms of its "frequency components".

While usual Fourier methods do a very good job at picking out frequencies from a signal consisting of many frequencies, they are utterly incapable of dealing properly with a signal that is changing over time. The good time-frequency localization is the most important advantage that wavelets have over other methods.

Wavelets are intrinsically connected to the notion of "multiresolution analysis". That is objects (signals, functions, data) can be examined using widely varying levels of focus.

In this work, we limit our study to recognizing, measure and identify the split s2 of the normal and pathological heartbeats. Our approach has been developed of in that :

- a) The use of the discrete wavelet transform (DWT) as a filtering technique in order to locate and identify the best split S2.
- b) The result of stage a) is then used by the continuous wavelet transform (CWT) in order to measure the split S2.

II. Wavelet transforms.

Wavelet transforms have become well known as useful tools for various signal processing applications. The continuous wavelet transform is best suited to signal analysis [12].

Its semi-discrete version (wavelet series WS) and its fully discrete one (the discrete wavelet transform DWT) have been used for signal coding applications,

including image compression [13] and various tasks in computer vision [14].

Given a time-varying signal $s(t)$, wavelet transforms consist of computing coefficients that are inner products of the signal and a family of “wavelets”. In a continuous wavelet transforms, the wavelet corresponding to scale “ a ” and time location “ b ” is :

$$\Psi(a,b) = \frac{1}{\sqrt{|a|}} \Psi\left(\frac{t-b}{a}\right) \quad (1)$$

Where $\Psi(t)$ is the “mother wavelet” which can be thought of as a band-pass function. The factor $\sqrt{|a|}$ is used to ensure energy preservation [12]. There are various ways of discretizing time-scale parameters (b,a), each one yields a different type of wavelet transform.

The continuous wavelet transform (CWT) was originally introduced by G.Grossmann and J.Morlet [15]. Time t and the time-scale parameters vary continuously.

$$CWT\{s(t);a,b\} = \int s(t) \Psi(a,b)^*(t)dt \quad (2)$$

(the asterisk stands for complex conjugate).

Wavelet series (WS) coefficients are sampled CWT coefficients. Time remains continuous but time-scale parameters (b,a) are sampled on a so-called “dyadic” grid in the time-scale plane (b,a) [16]. A common definition is :

$$C_{jk} = CWT\{s(t); a = 2^j, b = k 2^j\} \quad (3)$$

with $j,k \in \mathbb{Z}$

The wavelets are in this case :

$$\Psi_{jk}(t) = 2^{-j/2} \Psi(2^{-j} t - k) \quad (4)$$

The discrete wavelet transform (DWT) has been recognized as a natural wavelet transform for discrete-time signals. Both the time and time-scale parameters are discrete.

The discretization process partially depends upon the algorithm chosen to perform the transformation.

The $C_{j,k}$ could be well approximated by digital filter banks. By using Mallat’s [17] remarkable fast pyramid algorithms which involve use of low-pass and high-pass filters.

The Mallat algorithm is in fact a classical scheme known in the signal processing community as two-channel subband coder.

The original signal S , passes through two complementary filters and emerges as two signals : signal approximation “ A ” and signal detail “ D ”.

The approximation are the high scale, low-frequency components of the signal. The details are the low scale, high-frequency components. The filtering process, at its most basic levels, look like this.

III. Identification of the split S2.

Our study is concerned with for PCG signals, one normal and three pathological. TableI specifies these various signals.

The signals PCG were normalized in energy to take into account the disparity in magnitude due to the different amplification used during acquisition as well as the variation induced by the lead sites. The decomposition (multiresolution analysis) of the PCG

signals by the DWT depicts different energy partitions for resolution levels of the beats under study. The high frequency information are localized on the coarser levels whereas the split S2 generally appear on the finest scales. This result is illustrated in Figures 1-2.

Consequently, based on different tests and our experience, the number of decomposition levels and the order of the wavelet used is given by tableI. The wavelet “db”(Daubechies) is used since it has oscillations very similar to those of signals PCG analyzed.

TableI provides also the levels of the details allowing a suitable measurement of the split S2 for the various signals.

The multiresolution analysis based on the discrete wavelet transform (DWT) is a powerful tool in and filtering, separating and identification of the internal components and murmurs of the various analyzed signals.

The split is best depicted on level d7 for the normal phonocardiogram (Figure1a), on level d6 for the pulmonary stenosis (Figure1b), on level d6 for the mitral stenosis (Figure2a) and finally on level d3 for the atrial septal defect (Figure2b).

IV. Measurement of the split S2.

The same signals given by TableII are also considered for the analysis by the continuous wavelet transform (CWT) in order to measure the split S2.

In the representation of the coefficients C (of the wavelet transform) the x-axis represents position along the signal (time), the y-axis represents scale (related at the frequency), and the color at each x-y point represents the magnitude of the wavelet coefficients.

The sampling rate used is 8012 samples/s. The scale of both time and scale (frequency) axis is a linear scale. The frequency scan is from 14Hz to 500Hz.

Figure3 shows the result of this analysis. Figure3c shows the two internal components A2 and P2 of the sound S2 of the normal phonocardiogram. Figure3d shows the wavelet transform of the PCG signal related to a mitral stenosis.

Figure3 make it possible to appreciate normal Split (< 30ms) for cases N and MS and have and pathological Split (> 30ms) for the cases ASD and PS.

From the different measurements which we carried and resumed in TableII and illustrated in Figure3 we can conclude that :

*PCG Signals (N,MS) have normal Split (< 30ms) while the signals (ASD and PS) have abnormal Split (> 30ms) thus pathological.

*The signals (normal and pathological) which have Split (< 30ms) have a sound S2 made up generally of two principal components (A2 and P2)

*On the other hand the signals having pathological Split (> 30ms) have a sound S2 different. It seems that each component (A2 or P2) under the effect of the dilation of the split, breaks up in turn into 2 or 3 under-components (Figure3c and Figure3d).

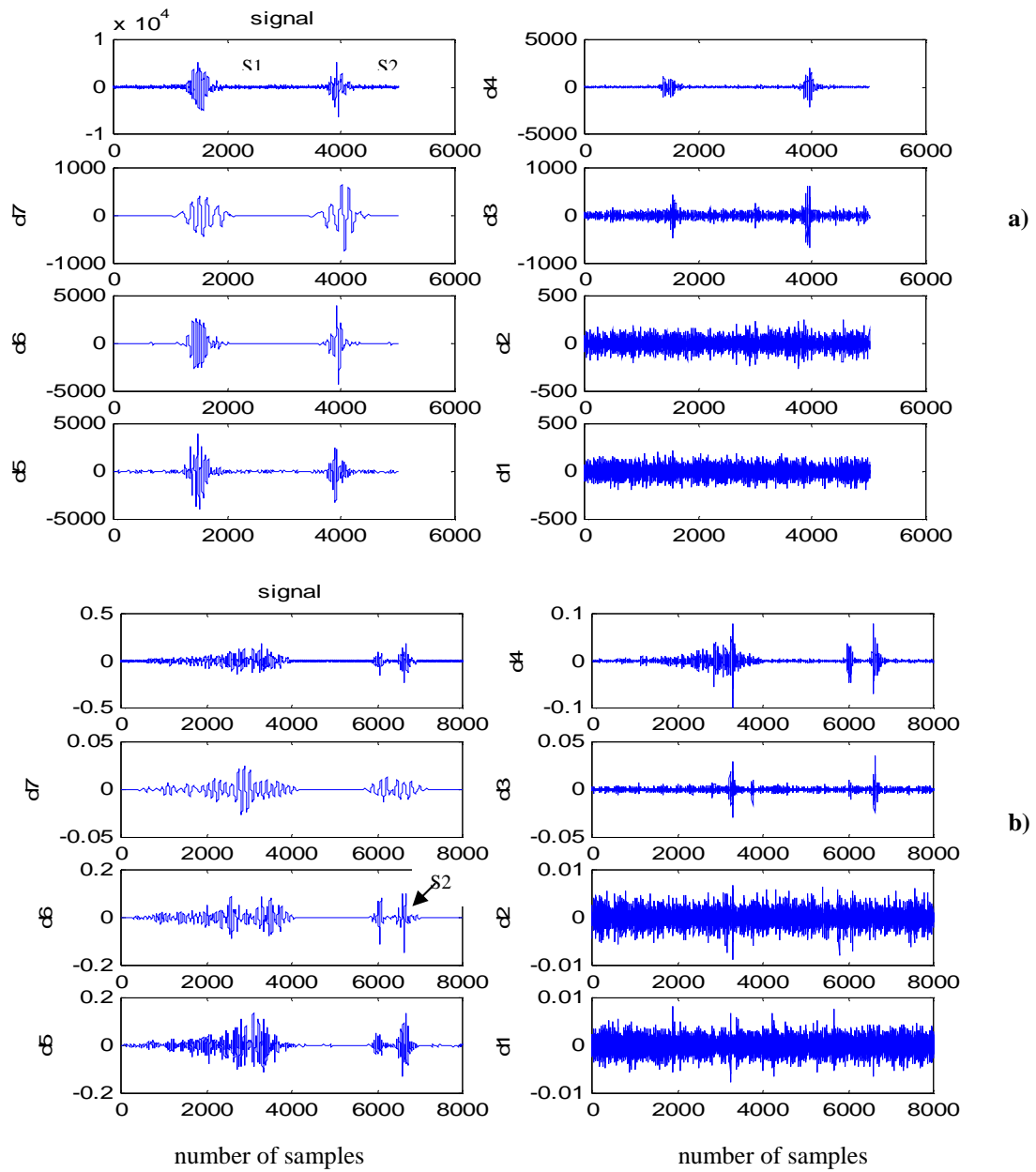


Figure1 : wavelet decomposition of :
a) The normal case (N)
b) The mitral stenosis (MS)

Type of signals	Abbreviation	Order of wavelet	Best level
Normal	N	db5	d7
Pulmonary stenosis	PS	db7	d6
Atrial septal defect	ASD	db10	d3
Mitral stenosis	MS	db7	d6

tableI : order of wavelet and best levels used for the analysed signals PCG.

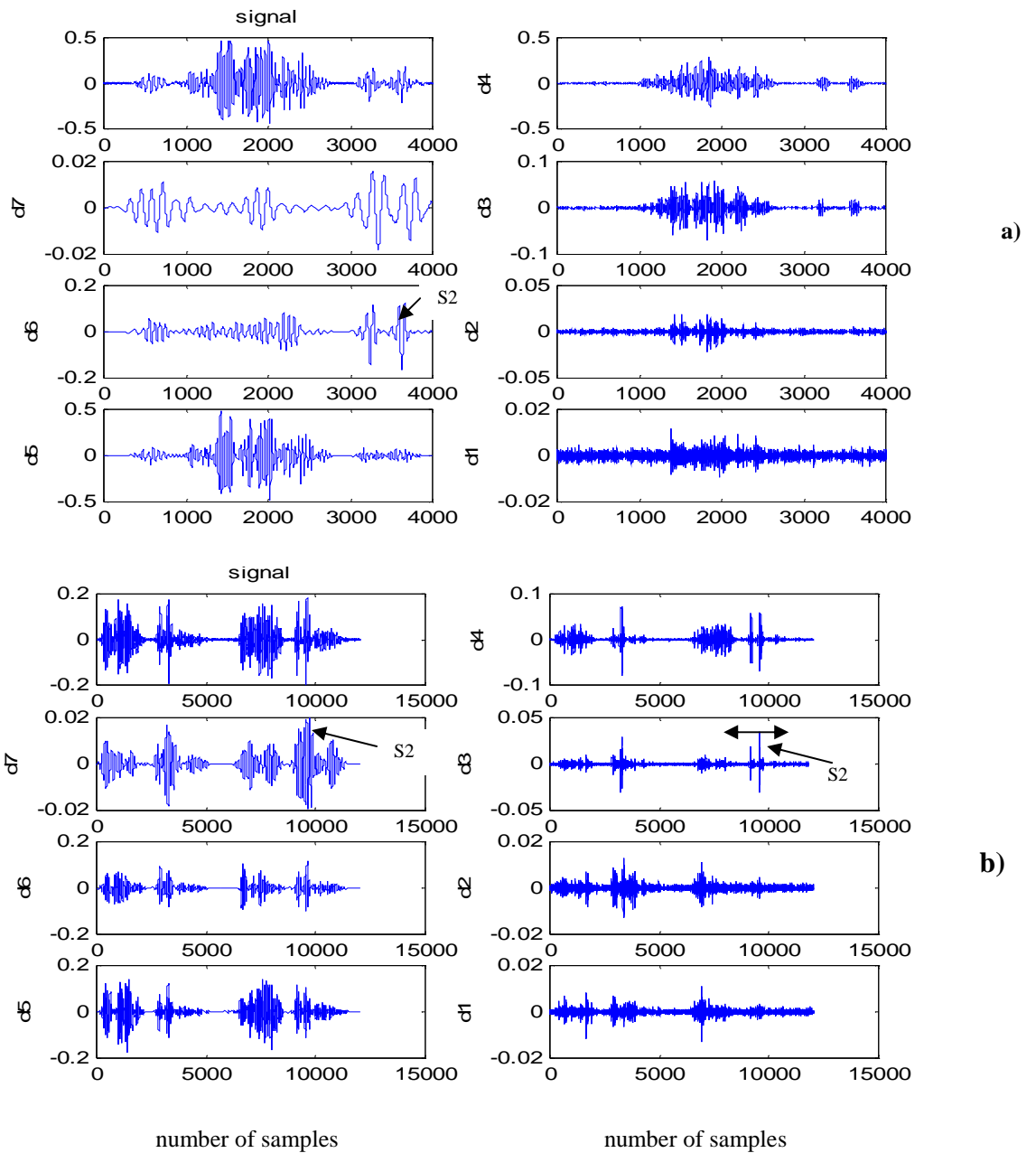


Figure2 : wavelet decomposition of
 a) The pulmonary stenosis (PS)
 b) The Atrial septal defect (ASD)

Type of signals	N	MS	PS	ASD
Split(ms)	6	4	38	43

TableII : measure of the split of the analyzed signals

VI Conclusion.

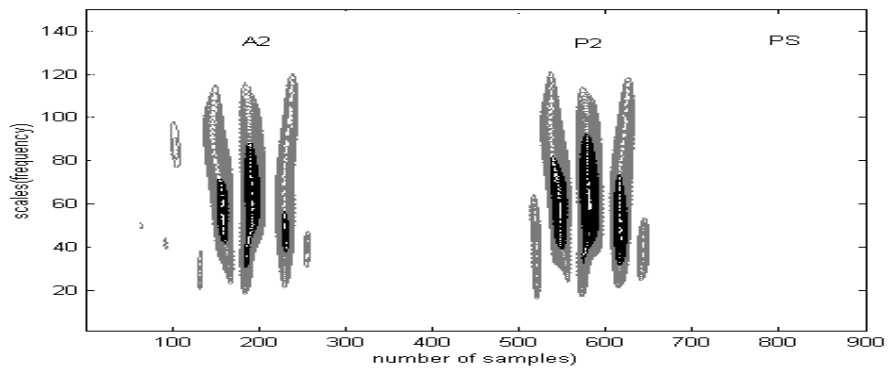
The cardiac (heartbeat sound) cycle of the phonocardiogram (PCG) is characterized by transients and Fast changes in frequency as time progresses . The wavelet Transform therefore is a suitable technique to analyze such a signal. The discrete wavelet transform (DWT) with the multiresolution analysis, is an easy tool used to decompose the signal into elementary building blocks and best localized the split S2 between the components A2 and P2. The continuous wavelet transform (CWT) after the localization of the split S2, give a graphic representation that provide a quantitative analysis simultaneously in time and in frequency. It is therefore very helpful in extracting clinically useful information.

The main constitution of this paper is in the identification and the measurement of the split of the sound S2.

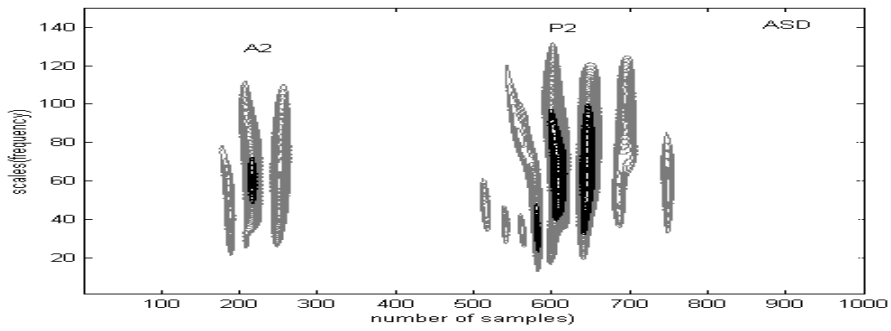
The ability to identify the splitting pattern will certainly help diagnosis. Finally the study suggested, the existence of a relationship between the values of Split and the morphological constitution of the sound S2 : being either mono - component or multi – components.

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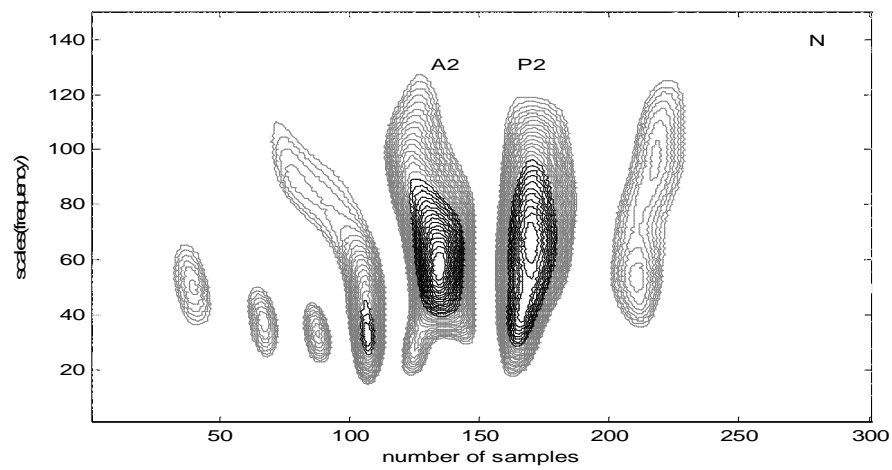
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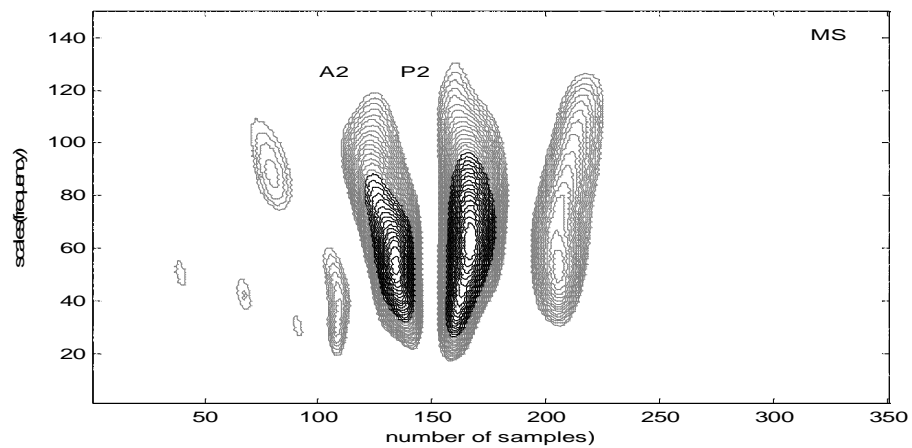
a)



b)



c)



d)

Figure3 : continuous wavelet transform for the sound S2 of :
 a) the pulmonary stenosis b) the atrial septal defect (ASD)
 c) the normal PCG (N) d) the mitral stenosis (MS)