THE FAST FOURIER TRANSFORM AND THE CONTINUOUS WAVELET TRANSFORM ANALYSIS OF THE NORMAL AND PATHOLOGICALS PHONOCARDIOGRAM SIGNALS

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Abstract

This paper present the applications of the fast Fourier transform (FFT) and the continuous wavelet transform (CWT) to analyse the normal and pathological cases of the phonocardiogram signals (PCG). The wavelet transform provides more features of the PCG signals that will help physicians to obtain qualitative and quantitative measurements of the time-frequency PCG signal characteristics. The frequency content of such a signal is shown to be determined by the FFT without difficulties.

***Key words**: Normal, pathological, phonocardiogram, first sound, second sound, FFT, CWT, time-frequency analysis.*

Résumé

Cet article présente les applications de la transformée de Fourier rapide (FFT) et de la transformée continue d'ondelette (cwt) pour analyser le cas normal et les cas pathologiques du signal phonocardiogramme (PCG). La transformée d'ondelette fournit plus de paramètres et de caractéristiques des signaux de PCG qui peuvent aider les médecins à obtenir des mesures qualitatives et quantitatives du contenu spectro-temporel du signal PCG. Le contenu fréquentiel du signal PCG peut être déterminé aisément par l'utilisation de la FFT seulement.

***Mots clés**: Normal, pathologique, phonocardiogramme, premier bruit, second bruit, FFT, CWT, Analyse spectro-temporelle.*

S.M. DEBBAL
F. BEREKSI-REGUIG
Laboratoire de Génie Biomédical (GBM)
Département d'Electronique
Faculté des Sciences de l'Ingénieur
Université Aboubekr Belkaid
Tlemcen, Algérie.

ملخص

هذا المقال يقدم تطبيقات المحوّل السريع لفوري و المحوّل المستمر للمويجة لتحليل الأعراض السليمة و المرضية لإشارة مخطط القلب الصوتي. المحوّل المستمر للمويجة يعطي أكثر وسطاء و مميزات لإشارات مخططات القلب الصوتي و بالتالي يسمح للأطباء المختصين للحصول على قياسات نوعية و كمية لمضمون الطيف و الزمن للإشارات.

المضمون الطيفي يمكن التحصّل عليه باستعمال المحوّل السريع لفوري فقط.

الكلمات المفتاحية: عادي، حالة مرضية، مخطط القلب الصوتي، النبض الأول، النبض الثاني، محول فوري، المحول المستمر للمويجة، تحليل طيفي-زمني.

Heartbeat sound analysis by auscultation is still insufficient to diagnose some heart disease. It does not enable the analyst to obtain heart disease. It does not enable the analyst to obtain both qualitative and quantitative characteristics of the phonocardiogram signals (PCG)[1, 2]. The PCG signal consists of two dominant events, known as the first (S1) and the second (S2) heart sound (see Figure 1a).

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, physician capabilities to diagnose heart sounds are limited.

The characteristics of the PCG signal and other feature such as heart sounds S1 and S2 location; the number of components for each sound; their frequency content; their time interval; all can be measured more accurately by digital signal processing techniques.

The FFT (Fast Fourier Transform) can provide a basic understanding of the frequency contents of the heart sounds. However, FFT analysis remains of limited values if the stationary assumption of the signal is violated. Since heart sounds exhibit marked changes with time and frequency, they are therefore classified as non-stationary signals. To understand the exact feature of such signals, it is thus important, to study their time – frequency characteristics.

In this paper the wavelet transform is used to analyse the normal heart sound in both time and frequency domains. 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 [4, 5].

THEORETICAL BACKGROUND

In this section we present a brief description of some properties of each of the FFT (Fast Fourier Transform) and the CWT (Continuous wavelet Transform).

Fast Fourier Transform (FFT)

The Fourier transform $S(\omega)$ of a signal $s(t)$ is definite as:

$$S(\omega) = \int s(t).\exp(-j\omega t)dt \quad (1)$$

where t and ω are the time and frequency parameters respectively. It defines the spectrum of $s(t)$ which consists of components at all frequencies over the range for which it is non zero.

Continuous wavelet transform (CWT)

Wavelet analysis represents a windowing technique with variable-sized regions. It allows the use of long time intervals where we want high frequency information.

The wavelet does not use a time-frequency region analysis, but rather a time-scale region analysis. One major advantage provided by wavelets is the ability to perform local analysis. That is to analyze a localised area of a larger signal.

The CWT of a signal $s(t)$ can be presented as an inner product of the analyzed signal with a function that depends on two parameters t and a (time and scale respectively):

$$C(a,b) = 1/\sqrt{a}.\int s(t).g^*\left(\frac{t-b}{a}\right)dt \quad (2)$$

or:

$$C(a,b) = \sqrt{a}.\int S(\omega).G^*(a\omega)\exp(j\omega t)dt \quad (3)$$

where:
- the parameter a is called scale factor; it is inversely related to the frequency.
- * denotes a complex conjugate.
- $g(t)$ is the analysing wavelet.
- $S(\omega)$ and $G(\omega)$ are, respectively, the Fourier transforms of $s(t)$ and $g(t)$.

The analyzing wavelet function $g(t)$ should satisfy a number of properties. The most important ones are continuity, integrability, square integrability, progressivity and it has no d.c. component.

Moreover, the wavelet $g(t)$ has to be concentrated in both time and frequency as much as possible. It is well known that the smallest time-bandwidth product is achieved by the gaussian function [4,6]. Hence the most suitable analyzing wavelet is the modulated gaussien function of the form:

$$g(t) = \exp\left(-\frac{t^2}{2} + j\omega_0 t\right) \quad (4)$$

Where $\omega_0 = 5.33$.

In a continuous wavelet transform, the wavelet corresponding to the scale a and the time location b is given by:

$$g_{a,b}(t) = 1/\sqrt{|a|}.g\left(\frac{t-b}{a}\right) \quad (5)$$

where $g(t)$ is the wavelet "prototype" or mother which can be thought of as a band pass function. The factor $|a|^{-1/2}$ is used to ensure energy preservation [7, 8]. There are various ways of discretizing time-scale parameter (b,a), each one yields a different type of wavelet transform.

In practice, for a given signal $s(t)$ with time-varying, the CWT consist of computing coefficients $C(a,b)$ that are inner products of the signal and a family of "wavelet".

$$C(a,b) = \int s(t)\,g(\text{scale, position})dt \quad (6)$$

where $a \in \mathrm{R}^+ - \{0\}$, $b \in \mathrm{R}$ and g, the wavelet "mother".

It is the wavelet applied in the analysis of the PCG signal.

RESULTS AND DISCUSSION

The Fast Fourier Transform (FFT) and the Continuous Wavelet Transform (CWT) techniques are applied to analyse different PCG signals.

In fact four cases are considered, one normal and three abnormals (or pathologicals). The sampling rate used is 8000 samples/s. The scale of both time and frequency axis is a linear scale. The frequency scan is from 1Hz to 500Hz.

A. Frequency analysis of the PCG (FFT)

An FFT algorithm is first applied on the PCG signal given in Figure1a. This figure shows a normal cardiac (heartbeat sound) cycle where the two major sounds S1 and S2 are clearly depicted. The frequency spectrum illustrated in Figure 1a shows that the normal PCG signal has a frequency content varying from around 40Hz up to 200Hz. At this stage the sound S1 or S2 cannot be separated. In fact; the application of the FFT on heart sounds S1 and S2 after their separation or identification [12, 13] show that the basic frequency components are obviously detected by the Fourier transform but not the time delay between these component. The two components A2 (due to the closure of the aortic valve) and P2 (due to the closure of the pulmonary valve) of the second sound S2 are obvious in Figure 1c. However, the FFT analysis of S2 cannot tell which of A2 and P2 precedes the other or the value of the time delay between them. For a normal heart activity usually A2 precedes P2 and the value of time delay between them is lower than 40ms [9, 10]. This parameters (position and time delay) of A2 and P2 is very important to detect some pathologicals cases.

The sound S2 seem to have higher frequency content than that of S1 as shown in Figure 1b and Figure 1c.

The spectrum of S1 has reasonable values in the range 10-200Hz. The spectrum is distinctly resolved in time into four majors components. Most of energy of the sound S1 seems, however, to be concentrated in the three components for the frequencies lower than 70Hz as shown in Figure1b.

The spectrum of the sound S2 has reasonable values in the range 50-300Hz. The spectrum for this sound is distinctly resolved in time into two majors components (A2 and P2) as shown in Figure 1c. The same FFT is applied to analyse three different PCG pathological cases (the aortic-insufficiency, the aortic-stenosis and the mitral-stenosis). These are illustrated in Figure 2 along with the normal PCG signal. The basic frequency content is obviously different from that of the normal PCG signal. It is clearly shown that there is great loss of frequency component in each of the pathological case with respect to normal case.

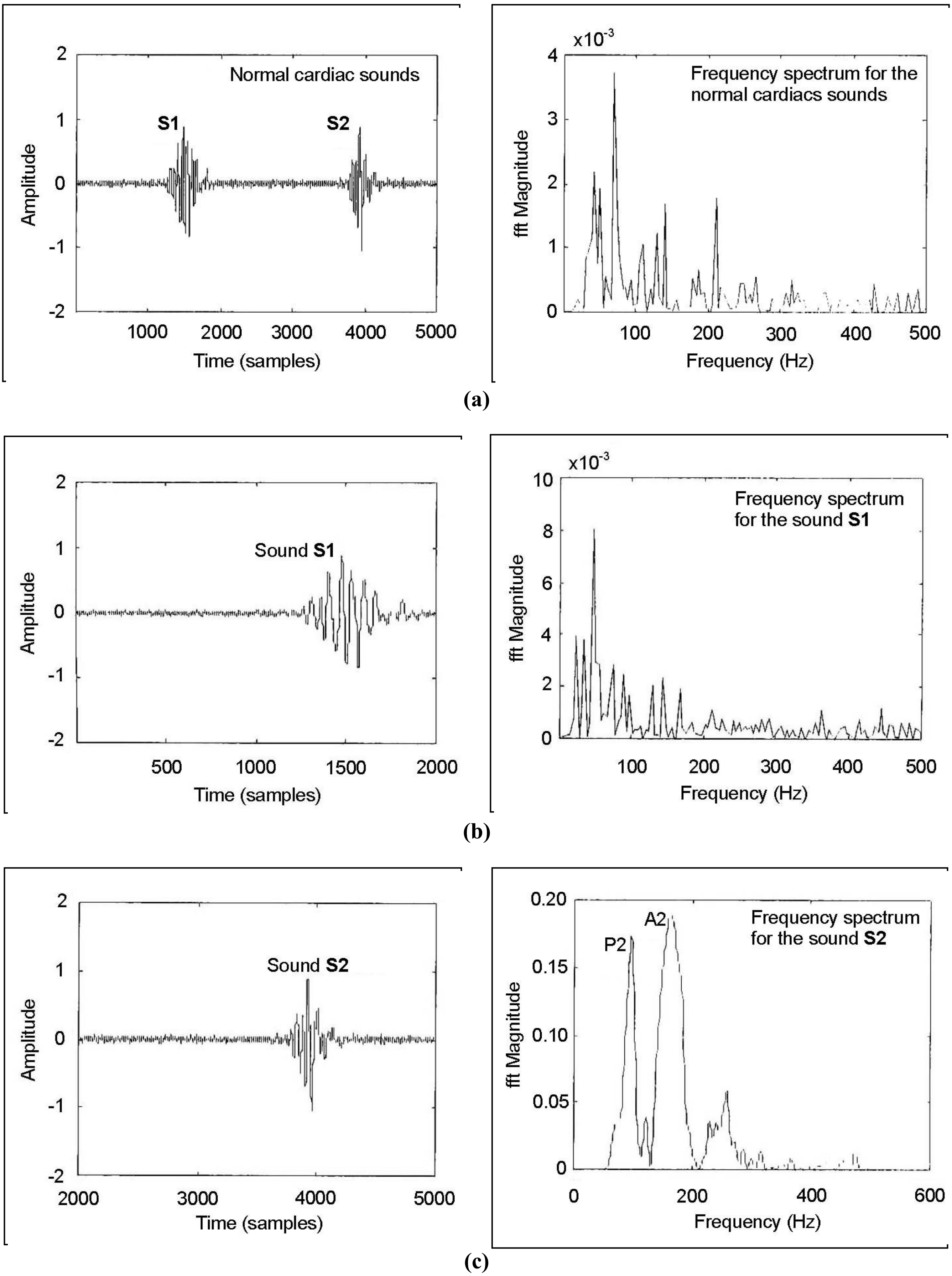

Figure 1: Frequency spectrum for the normal cardiacs sounds and the sounds S1 and S2.

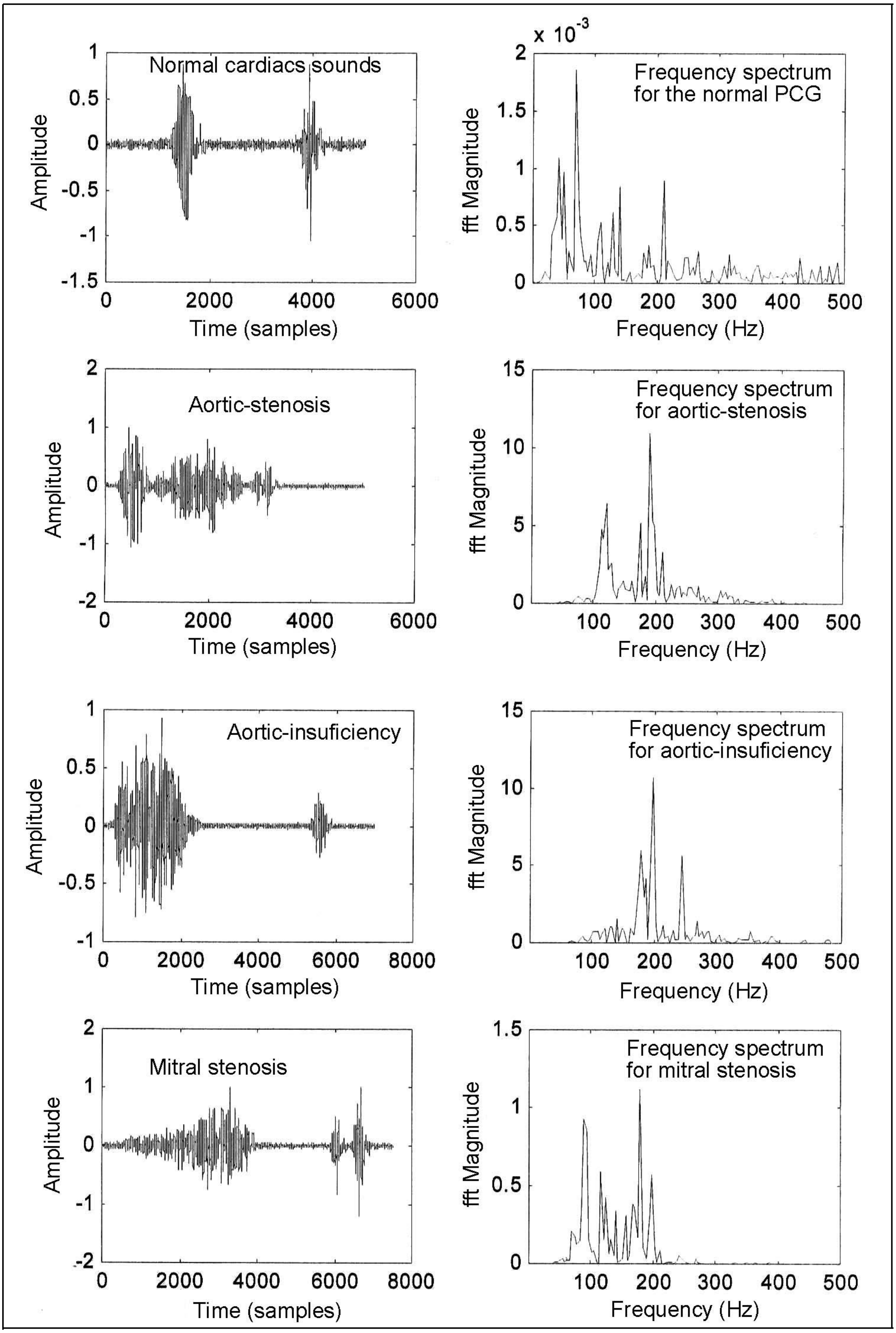

Figure 2: Normal and abnormal cardiac sounds and frequency spectrum respectively.

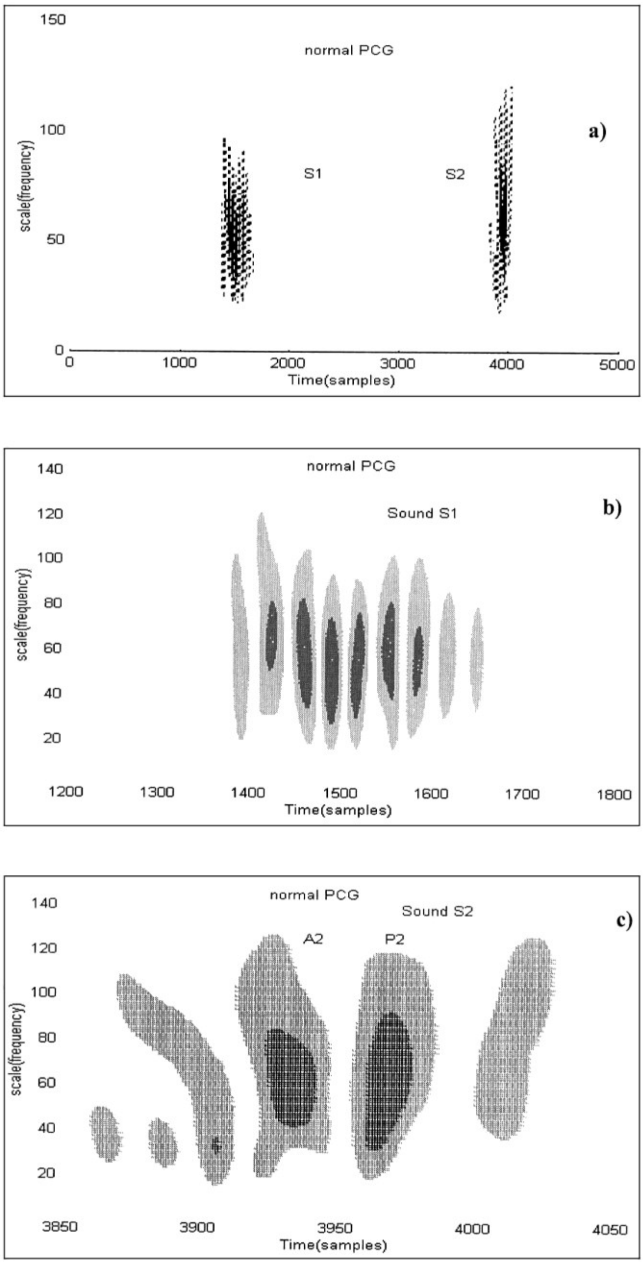

Figure 3: Coefficients of the continuous wavelet transform (CWT) for the normal PCG of:
a) one cycle **b)** sound S1 **c)** sound S2.

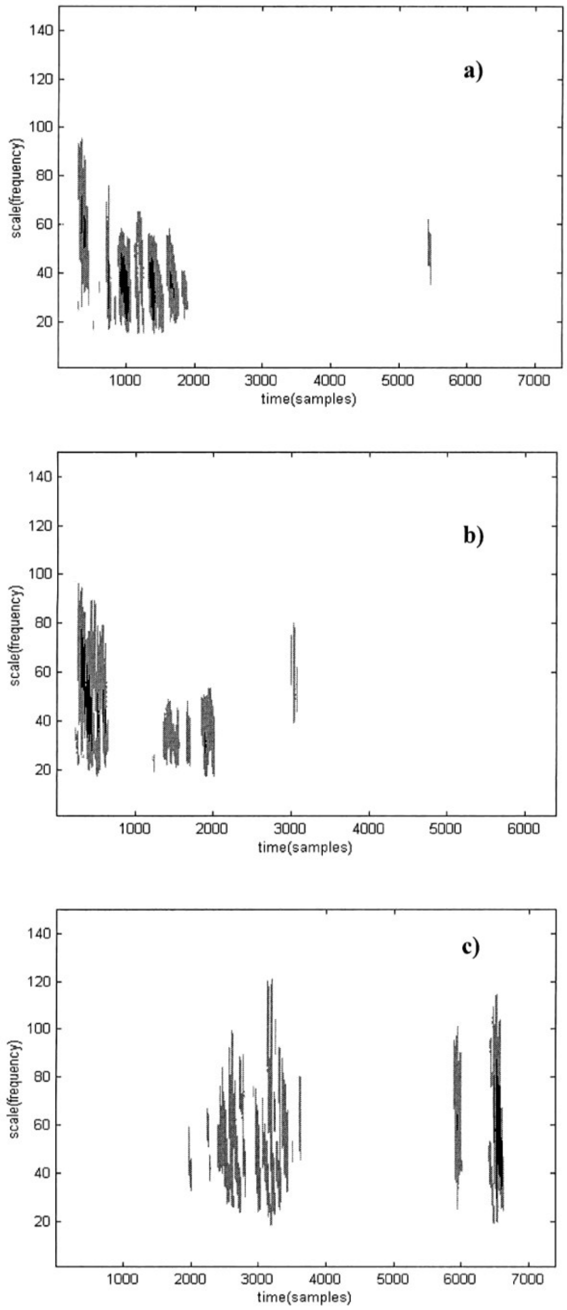

Figure 4: Coefficients of the continuous wavelet for the abnormals cardiac sounds:
a) aortic-coarctation **b)** aortic_stenosis **c)** mitral-stenosis

In addition except the aortic-insufficiency case where we note the apparition of frequency component higher than 200Hz the others cases (mitral-stenosis and aortic-stenosis) present a frequency spectrum limited by 200Hz.

The basic frequency components are obviously detected by the FFT but not the time delay between these components. For example, the two components A2 and P2 of the second sound S2 are obvious in Figure 1c. However, the FFT analysis of S2 cannot tell what is the value of the time delay between A2 and P2. It is thus essential to look for a transform which will describe a kind of "time-varying" spectrum. The CWT can give better results under the same conditions and same sampling rate.

B. Time-frequency analysis of the PCG signal using the Continuous Wavelet Transform (CWT)

An algorithm of the Continuous Wavelet Transform is applied to analyse the PCG signal of a normal cardiac cycle illustrated in Figure 1c. Figure 3a shows the result of this analysis. The two heart sounds are clearly shown in dark color. They are space with 2500 samples corresponding to 0.312 seconds.

The continuous wavelet transforms of S1 and S2 are also displayed separately in Figure 3b and Figure 3c respectively. As it is illustrated in Figure 3c the sound S2 is shown to have higher frequency content than that of the S1. This is expected since the amount of blood present in the cardiac chambers is smaller [2, 14].

Besides this the spectrum of S1 is clearly resolved in time into four major components [15]. The spectrum of the sound S2 is resolved in time into two majors components (A2 and P2). These results confirmed those found by spectral analysis (FFT technique) (Fig. 1b and Fig. 1c).

The time delay between A2 and P2 can be easily measured with the use of the wavelet coefficients (Fig. 3c). This delay is measured to be 13ms. It is smaller than the 30ms as foreseen in the normal pathological conditions of the PCG signal [16].

Pathological conditions could cause this time difference to narrow or widen. Moreover, the order of occurrence of A2 and P2 may be reversed. The wavelet transform allows measurement and determination of this time difference, and thus allows a diagnostic process regarding this important parameter to be produced.

Moreover, the ability of the wavelet transform in heart disease diagnosis can be studied by applying the CWT algorithm on different pathological cases.

The result of this application are illustrated in Figure 4a (aortic-insufficiency), Figure 4b (aortic-stenosis) Figure 4c (mitral-stenosis). The coefficients of the CWT allow us to clearly discern the frequency range of each signal. It also shows the major components according to the temporary variation; the maximal amplitude is characterized by a darker color than that of the small amplitudes.

CONCLUSION

The cardiac (heartbeat sound) cycle of phonocardiogram (PCG) is characterized by transients and fast changes in frequency as time progresses. It was shown that the CWT wavelet transform is a suitable technique applied to analyze this type of signal.

It was also shown that the coefficients of the continuous wavelet transform give a graphic representation that provides a quantitative analysis in time as resumed in the table below, and frequency It is therefore very helpful in extracting clinically useful information.

The measurement of the time difference between the A2 and P2 components in the sound S2, the number of major components of the sounds S1 and S2 and the frequency range for all this components and sounds can be accurately achieved as was clearly illustrated.

However, the basic frequency content of a PCG signals can only be detected using the FFT technique.

Type of PCG	Measure of length of 1 cycle (ms)
Normal	780
Aortic-insufficiency	977
Aortic-stenosis	770
Mitral stenosis	970

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