ISPUB.COM

The Internet Journal of Bioengineering
Volume 2 Number 2

Graphic representation and analysis of the PCG signal using the continuous wavelet transform

S Debbal, F Bereksi-Reguig

Citation

S Debbal, F Bereksi-Reguig. *Graphic representation and analysis of the PCG signal using the continuous wavelet transform.* The Internet Journal of Bioengineering. 2006 Volume 2 Number 2.

Abstract

Heart sounds can be utilized more efficiently by medical doctors when they are displayed visually, rather through a conventional stethoscope. Heart sounds provide clinician with valuable diagnostic and prognostic information. Although heart sound analysis by auscultation is convenient as clinical tool, heart sound signals (or PCG signal) are so complex and nonstationary that they have a great difficulty to analyze in time or frequency domain.

The performance of the Continuous wavelet transform (CWT) is discussed in this paper. This technique is a suitable technique to analyse such a signal. It was also shown that the coefficients of the continuous wavelet transform give a graphic representation to PCG signal that provides a quantitative analysis simultaneously in time and frequency. It is therefore very helpful in extracting clinically useful information.

INTRODUCTION

Most investigators agree that heart sounds originate from the vibrations of the whole cardiovascular system and not only by the movement of the valve leaflets. Analyzing heart sounds by phonocardiogram (PCG) enables one to obtain valuable information about the cardiovascular system and especially about the heart valves functioning

A normal cardiac cycle contains two major audible sounds: the first heart sound (S1) and the second heart sound (S2). As soon as the ventricular pressure exceeds the atrium pressure, the mitral and the tricuspid valves close and the vibrations of S1 begin. At the end of the ventricular systole and the beginning of ventricular relaxation, S2 occurs following the closure of the aortic and the pulmonary valves. The components for the sound S1 are M1 and T1, one due to closure of the closure of the mitral valve and the other due of the closure of the tricuspid valve. For the second Sound S2 also, one due to the closure of the aortic valve (A2) and the other due to the closure of the pulmonary valve (P2) . The ventricle pressure drops steeply, and when it falls below the atrial pressure, the mitral valve opens, and the rapid filling phase begins, with a possibility of another audible sound, S3, at its end. A forth heart sound, S4, may be heard sometimes due to atrial contractions displacing blood into the distended ventricles. Murmurs are sounds caused by certain cardiovascular diseases and defects.

Phonocardiography is a noninvasive, low-cost but accurate monitoring method for valves functioning; it is easily repeatable with no risk to the patient. However, heart diagnosis by auscultation requires high skills and experience of the listener.

Many disease of the heart cause changes in heart sounds and additional murmurs before other signs and symptoms appear. Hence, heart sound analysis by auscultation is the primary test conducted by physicians to assess the condition of the heart. Yet, heart sound analysis by auscultation as well as analysis of the phonocardiogram (PCG) signal have not gained widespread acceptance. This is due mainly to many controversies regarding the genesis of the sounds and the lack of quantitative techniques for reliable analysis of the signal features. The heart sound signal has much more information than can be assessed by the human ear or by visual inspection of the signal tracings on paper as currently practiced. Here, we review the nature of the heart sound signal and the various signal-processing techniques that have been applied to PCG analysis. The pathological conditions of the cardiovascular system generally cause abnormal murmurs and aberrations in heart sounds before they are reflected as other symptoms [1]. The auscultation technique in which a stethoscope is used to listen the sounds of a body is poorly suited to investigate the heart abnormalities. By analyzing the phonocardiogram (PCG) which is a recording of the acoustical waves produced by mechanical action of the heart by modern digital signal processing technique give more accurate and valuable information about the heart condition. The heart sounds are low-frequency transient signals produced by the heart valves. The heart murmurs are noise-like signals caused by the turbulence of blood flow. The murmurs generally heard in abnormal heart in addition to first and second heart sounds [2,3].

In digital phonocardiography, the identification and separation of the individual component of the first (S1) and second (S2) heart sounds is a complex and difficult problem that has not been solved yet. The first heart sound occurs during the isovolumic contraction period, when left ventricular pressure is rising rapidly. Four valvular events punctuate the first heart sound, mitral valve closure, tricuspid valve and aortic valve opening, generally in order. The second heart sound arises from the closure and vibration of the aortic valve followed by closure and vibration of the pulmonary valve. These mechanisms associated with the genesis of the heart sounds are more widely accepted [4].

The most recent studies aiming at better understanding of the structural content (signal components) of heart sounds performs the Time-Frequency Representation (TFR) of the transient signals. The studies showed that the new TFR techniques are powerful tools for the study of the basic mechanism implied in the production of the heart sound components. However, they also showed that their application to the analysis and synthesis of short transient signals like S1 and S2 is a complex and difficult task due to the inherent limitations of the TFR techniques for extracting the basic characteristic of each component contained in these multi component signals [5,6,7].

The research concentrated on Short Time Fourier Transform (STFT) analysis and transient chirp modelling of the heart sound as TFR. However, STFT is a useful tool in analysis of non stationary signal such as heart sounds, the problem with the STFT is a compromise in resolution. The smaller the window used, the better quickly changing components are picked up, but slowly changing details are not detected very well to investigate exact feature of the signal. If a larger window is used, lower vibrations may be detected, but the localization in time, which is important to determine the closure and opening of the heart valve becomes worse. In the analysis of the transient chirp modelling, it has been studied on analysis and synthesis of the short portion of the signal.

An alternative way to analyze non-stationary signals such as heart sound is to expand them onto basis function created by expanding, contracting, and shifting the considered signal. This is the wavelet transform (WT) designed to give good time resolution and poor frequency resolution at high frequencies and good frequency resolution at low frequencies. This approach makes sense especially when the signal at hand has frequency component for short durations and low frequency components for long durations, which is the case in most biomedical signals [8]. The continuous wavelet transform (CWT) provide more information of the time-frequency characteristics of the PCG signals and their interns components [8,9].

WAVELET TRANSFORM

Wavelet transforms have become well known as useful tools for various signal processing applications. The continuous wavelet transform is best suited to signal analysis [10].

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 [11] and various tasks in computer vision [12].

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 :

Figure 1

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

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 [10]. 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 [13]. Time t and the time-scale parameters vary continuously.

Figure 2

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

(the asterisk stands for complex conjugate).

RESULTS AND DISCUSSION

In fact three cases are considered, one normal and two abnormal or pathological: the coarctation of the aorta (CA) and the Drum rumble (DR). 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.

An algorithm under MATLAB environnement of the Continuous Wavelet Transform is developed then applied to analyse different PCG signals. The normal first sound (S1) and the normal second sound (S2) of the normal PCG is studied as illustrated in Figure1and Figure2. In these figures we can notice the wavelet transform analysis (b), the contour plot (c) and the view (0,0) of the obtained result (d). All of these representations can give more information of the signal PCG studied. Figure3 and figure 4 shows the result of continuous wavelet analysis of the two sounds (S1 and S2) of the pathological PCG type “CA”. The figure 5 concern the Continuous wavelet transform analysis of the second case of the pathological PCG : the Drum Rumble (DR) The continuous wavelet transforms analysis of the view(0,0) give more information of the level amplitude of these three PCG signals. These contours provide the importance and the difference of the frequency (or scale) between the components of the PCG signals used.

Figure 3

Figure 1: Wavelet analysis of the first sound (S1) for the normal PCG. a) Sound S1; b) continuous wavelet analysis of the sounds S1; c) countour plot of the figure 1b; d) view (0,0) of the figure 1b.

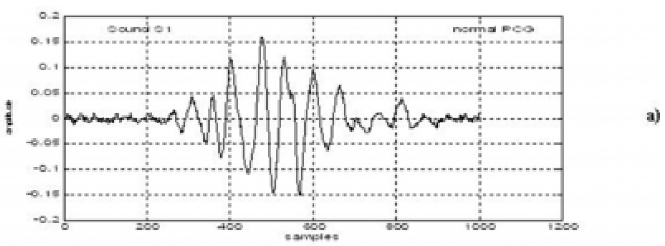


Figure 4

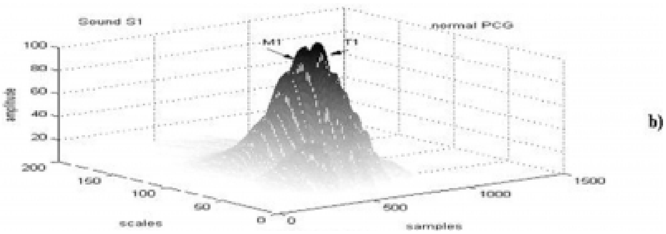


Figure 5

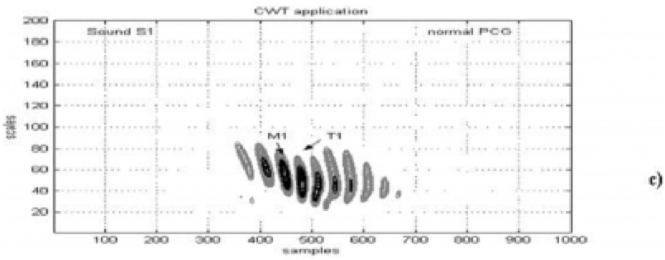


Figure 6

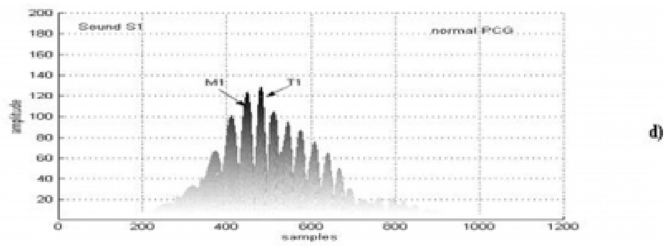


Figure 7

Figure 2: Wavelet analysis of the second sound (S2) for the normal PCG. a) Sound S2; b) continuous wavelet analysis of the sounds S2, c) contour plot of the figure 2b; d) view (0,0) for the figure 2b.

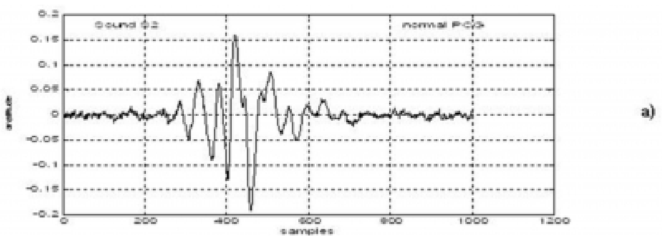
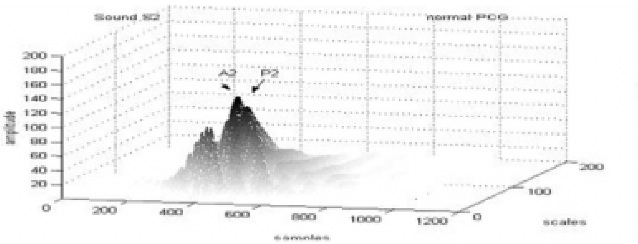
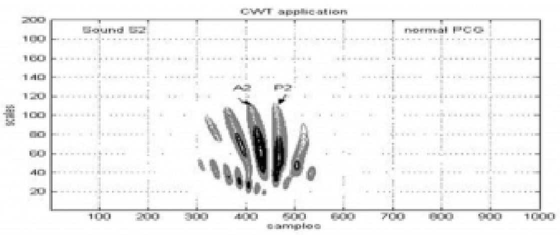


Figure 8



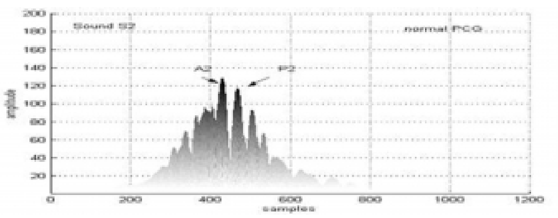
b)

Figure 9



c)

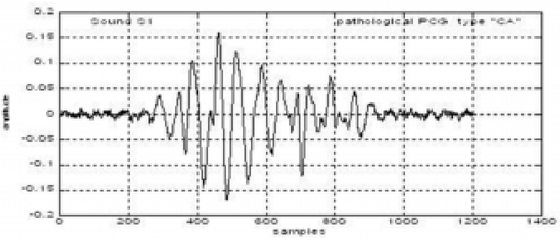
Figure 10



d)

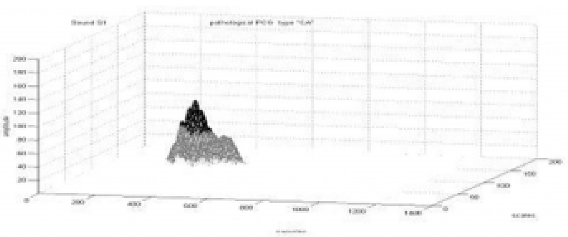
Figure 11

Figure 3: Wavelet analysis of the first sound (S1) for the pathological PCG type "CA". a) Sound S1; b) continuous wavelet analysis of the sounds S1; c) countour plot of the figure 3b; d) view (0,0) for the figure 3b.



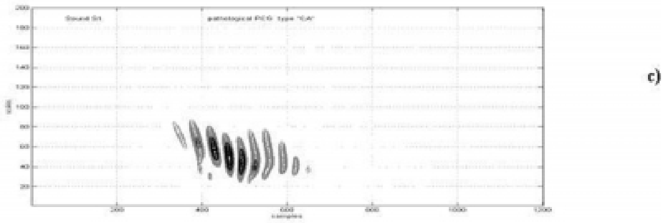
a)

Figure 12



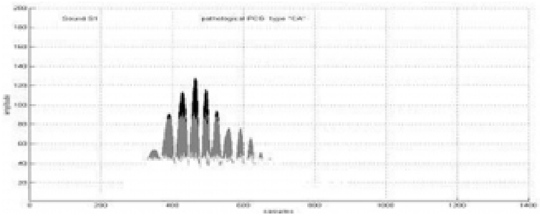
b)

Figure 13



c)

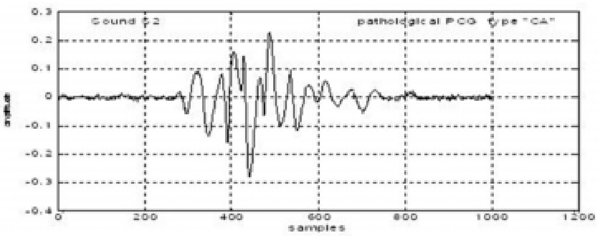
Figure 14



d)

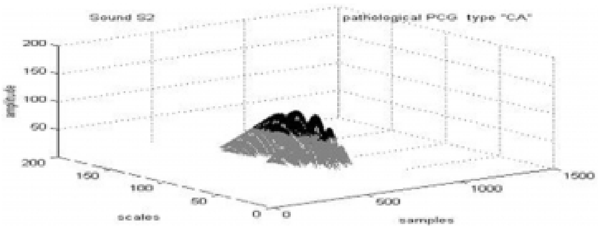
Figure 15

Figure 4: Wavelet analysis of the second sound (S2) for the pathological PCG type "CA". a) Sound S2; b) continuous wavelet analysis of the sounds S2; c) contour plot of the figure 4b; d) view (0,0) of the figure 4b.



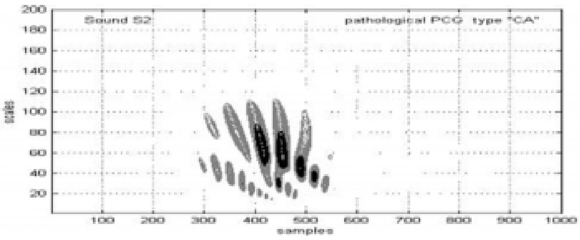
a)

Figure 16



b)

Figure 17



c)

Figure 18

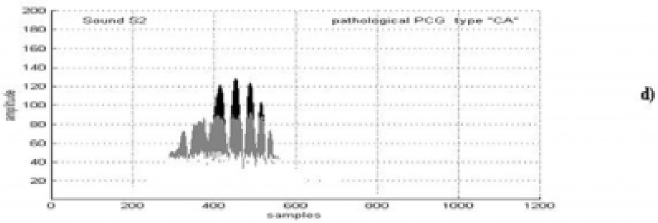


Figure 19

Figure 5: Wavelet analysis of the pathological PCG type “DR”. a) PCG type “DR” ; b) continuous wavelet analysis of the PCG type “DR”; c) contour plot of the figure 5b; d) view (0,0) of the figure 5b.

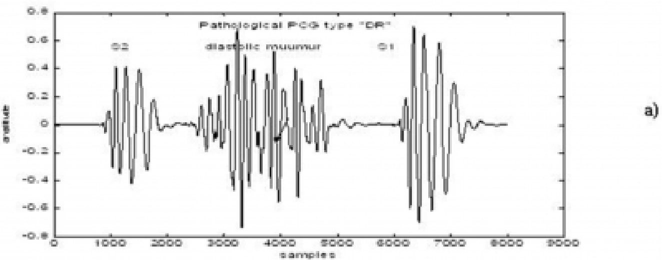


Figure 20

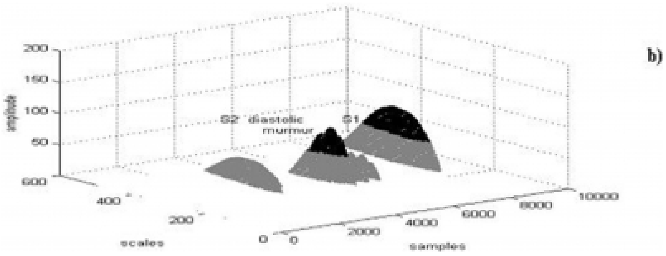


Figure 21

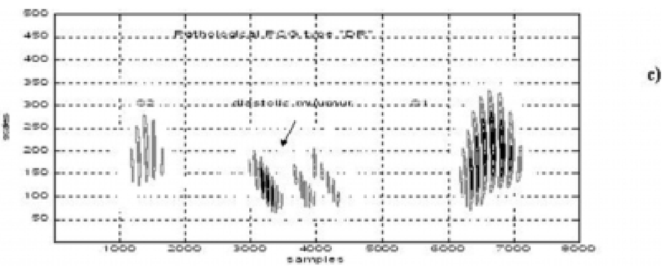
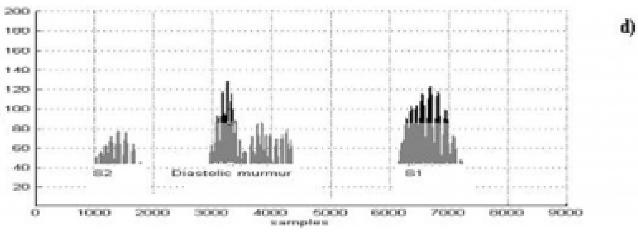


Figure 22



The time delay between A2 and P2 can be easily measured with the use of the wavelet coefficients (Figure2c). It is smaller than the 30ms in the normal conditions of the PCG signal. Pathological conditions could cause this time difference to narrow or widen [14]. 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 diagnosis process regarding this important parameter to be produced [9].

It can be concluded for the normal PCG that:

- The component A2 precedes in time the component P2.
- The components A2 have higher frequency content than P2.
- The amplitude of A2 is more important than that of P2.

These parameters, particularly the frequency, make it possible to see a difference between A2 and P2.

CONCLUSION

The heart sound is characterized by transients and fast changes in frequency as time progresses. The wavelet Transform is a suitable technique and gives a graphic representation that provides a quantitative analysis simultaneously in time and frequency. The amplitude of such parameters is also indicated (by amount of colour).

The results we obtain show that the measurement of the time delay between A2 and P2 components in sound S2, the number of majors components for each sound and the frequency range and localisation of all these components and sounds can be easily and accurately achieved by the Continuous Wavelet Transform (CWT) analysis and make it possible to gather time-frequency information concerning the characteristics of the cardiac sounds.

It is shown that the CWT analysis provides enough time-frequency features and consequently can help to aid to medical diagnosis.

References

1. R.M. Rangayyan and R.J. Lehner, "Phonocardiogram Signal Analysis: A review", CRC Critical Reviews in Biomedical Engineering, vol.15, Issue 3, pp.211-236, 1988.
2. D.W. Sapire, "Understand and Diagnosing pediatric HeartDisease: Heart Sounds and Murmurs", Norwalk, Connecticut, Appleton & Lange, pp. 27-43, 1992.
3. Z. Xuan, L-G. Durand, L. Senhadji, H.C. Lee, J-L.Coatrieux, " Analysis - Synthesis of the Phonocardiogram Based on the Matching Pursuit Method ", IEEE Trans. Biomed. Eng. Vol.45. pp.962-971, 1998.
4. J.C. Wood and D.T. Barry, "Time-Frequency Analysis of the First Heart Sound", IEEE Engineering In Medicine and Biology Magazine, pp. 144-151, 1995.
5. J. Xu, L.-G. Durand and P.Pibarot, "Nonlinear Transient Chirp Signal Modeling of the Aortic and Pulmonary Components of the Second Heart Sound", IEEE Trans. Biomed. Eng., vol.47, pp.1328-1334, 2000.
6. J.Xu, L.-G. Durand and P.Pibarot, "Extraction of the Aortic and Pulmonary Components of the Second Heart Sound Using a Non-linear Transient Chirp Signal Model", IEEE Tran. On Biomed. Eng., vol.48, pp. 277-283, 2001.
7. M. Akay, "Wavelet applications in medicine", IEEE Spectrum Mag., pp.50-56, May. 1997
8. S M DEBBAL and F BEREKSI REGUIG: "Analysis of the second heart sound using the continuous wavelet transform" ; journal of Medical Engineering & Technology; ISSN: 0309-1902 ; Vol. 28, No. 4, July-August 2004, pp 151-156
9. S.M DEBBAL and F.BEREKSI-REGUIG: "Analysis and study of the variation of splitting In the second heartbeat sound of the wavelet transform"; journal of Medical Engineering & Technology; ISSN: 0309-1902 ; accepted June 2005.
10. J.M COUBES,A.GROSSMANN (1989).ph. Tchanmitchian. Wavelet, Time-frequency Methods and Phase Space. Berlin, Springer, IPTI.
11. S.MALLAT and S.ZHONG (1990). Signal Characterisation from multiscale edges. In Proce.10th Int.Conf.Pattern recogn., Syst.Applica., Los Alamitos, CA, pp 891-896.
12. S.MALLAT (1989). Multifrequency channel decompositions of images and wavelet models. IEEE Trans. Acous., Speech, Signal Processing, vol 37, pp 2091-2111.
13. P.GOUPILLAN, A.GROSSMANN and J.MORLET (1984/85). Cycle-octave and related transform in seismic signal analysis. Geoexploration, vol 23, pp 85-102.
14. S.M DEBBAL, F BEREKSI-REGUIG:" Automatic measure of the split in the second cardiac sound by using the wavelet Transform technique", Computers in Biology and Medicine (CMB), In Press.

Author Information

S. M. Debbal
Genie -Biomedical Laboratory (GBM), Department of electronics, Faculty of science engineering, University Aboubekr Belkaid

F. Bereksi-Reguig
Genie -Biomedical Laboratory (GBM), Department of electronics, Faculty of science engineering, University Aboubekr Belkaid