Spectral analysis of the PCG signals

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Citation

Abstract

This paper is concerned with a synthesis study of the fast Fourier transform (FFT)I n analysing the phonocardiogram signal (PCG). It is shown that the spectral analysis can provides enough features of the PCG signals that will help clinics to obtain qualitative and quantitative measurements of PCG signal characteristics and consequently aid to diagnosis.

INTRODUCTION

Heartbeat sound analysis by auscultation is still insufficient to diagnose some heart diseases. It does not enable the analyst to obtain both qualitative and quantitative characteristics of the phonocardiogram signals [1,2]. Abnormal heartbeat sounds may contain,in addition to the first and second sounds, S1 and S2 , murmurs and aberrations caused by different pathological conditions of the cardiovascular system [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.

The caracteristics of the PCG signal and other features 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.

In this paper the Fast Fourier transform analysis is used to analyse both the normal and abnormal heart sound.

THEORITICAL BACKGROUND

In 1882, Joseph Fourier discovered that any periodic function could be represented as an infinite sum of periodic complex exponential functions [4]. The inclusive property of only periodic functions was later extended to any discrete time function. The Fourier transform (FT) [as regular Fourier Transform] converts a signal expressed in the time domain to a signal expressed in the frequency domain. The

FT representation of a signal may be seen in Figure2b. The FT is widely used and usually implemented in the form of FFT algorithm (fast Fourier transform). The mathematical definition of the FT is given below.

Figure 1

$$X(f) = \int x(t) e^{-j2\Pi ft} \, dt$$

Where t and fare respectively the time and frequency parameters. The time domain signal x(t) is multiplied by a complex exponential at a frequency fand integrate over all time. In other words, any discrete time signal may be represented by a sum of sines and cosines, which are shifted and are multiplied by a coefficient that changes their amplitude. X(f) are the Fourier coefficients which are large when a signal contains a frequency component around the frequency f.

The peaks in a plot of the FT of a signal correspond to dominant frequency components of the signal. Fourier analysis is simply not effective when used on non stationary signals because it does not provide frequency content information localized in time. Most real world signals exhibit non stationary characteristics (such as heart sound signals). Thus, Fourier analysis is not adequate.

RESULTS AND DISCUSSION.

The Fast Fourier Transform (FFT) techniques is applied to analyse differents PCG signals. In fact five cases are considered, one normal and four abnormals or pathologicals . Three "marked" (the aortic-insufficiency, the aortic-stenosis and the mitral stenosis) and one less marked (the

aortic-coarctation). The less marked pathological case is considered as the signal which is very similar to that of the normal PCG case. The marked pathological case are those where the PCG signal is completely different from the normal PCG. The sampling rate used is 8000 samples/s. This is was chwon so that the to obtain better reconstitution of the signal under study. The scale of both time and frequency is a linear scale. The frequency scan is from 1Hz to 500Hz.

NORMAL AND LESS MARKED CASE OF THE PHONOCARDIOGRAM.

An FFT algorithm is first applied to 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 Figure1a shows that the normal PCG signal has a frequency content varying from around 40Hz up to 200Hz. The FFT can be applied to the first part of this signal to analyse the frequency content of S1 as shown in Figure 1b and then to the second half to analyse the frequency content of S2 as shown in Figure 1c. A 512 points FFT is applied to S1 and S2. 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 [5,6] show that the basic frequency components are obviously detected by the fourier transform . 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 Figure1c. The spectrum of the sound S2 has reasonable values in the range 50-250Hz. The spectrum for this sound is distinctly resolved in time into two majors components (A2 and P2) as shown in Figure1c.

However the FFT analysis of S2 cannot tell neither which of A2 and P2 precedes the other, nor the value of the time delay known as the "split" which separate them. For a normal heart activity usually A2 precedes P2 [7] and the value of the split is lower than 30ms [8]. This time delay between 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 Figure1b and Figure1c.

The spectrum of S1 has reasonable values in the range 10-180Hz. The spectrum is distinctly resolved in time into four majors components. Most of the energy of the sound S1 appears, however, to be concentrated in the three components for the frequencies lower than 130Hz as shown in Figure1b.

A similar analysis is carried out on the pathological PCG signal. The PCG which considered is the case of the aortic-coarctation. At first glance, the temporal representation of this pathological case with respect to the normal case does not show appreciable differences from that of the normal PCG (Figure2a). However the spectral study by FFT show a difference in the frequential extent.

The sound S1 of the aortic-coarctation has reasonable values in the range 10-300 Hz as known in Figure2b. The spectrum is resolved in time with more components than the sound S1 of the normal PCG. Most energy of the sound S1 appears to be concentrated in four components located between the frequencies more than 100Hz and less 260 Hz as shown in Figure 2b. These four components are much more discernible than those of the normal case or we have a multitude of components minors added to the four important ones.

The spectrum of the sound S2 has reasonable values in the range 50-320 Hz. The spectrum for this sound is resolved in time into three major components, for the frequencies lower than 200Hz as shown in (Figure2c), instead of two components as in the case of the normal PCG (Figure1c).

Figure 2

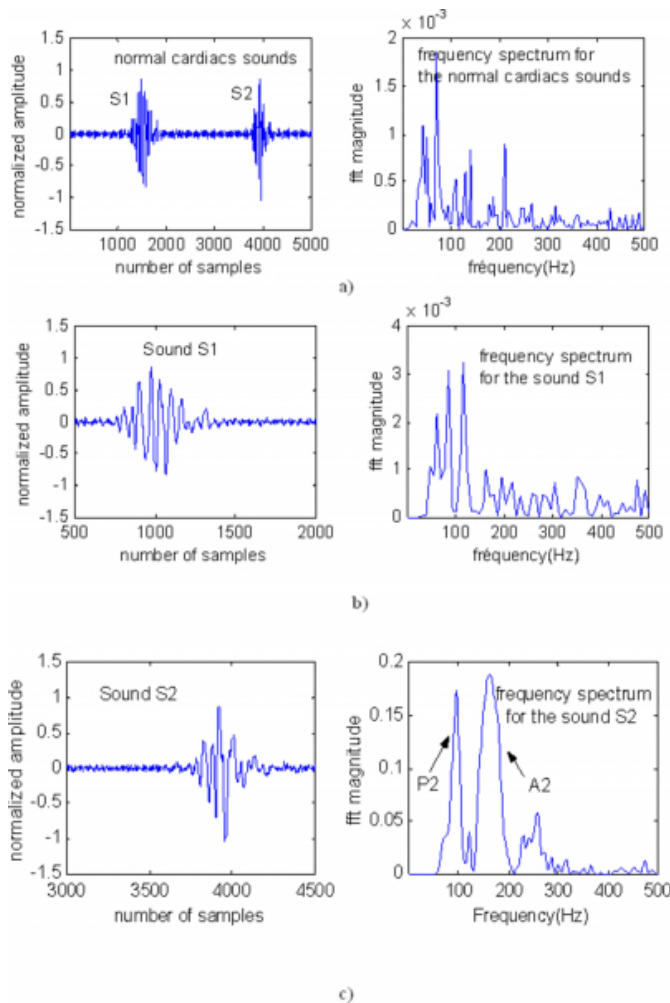Figure 1: Frequency spectrum for the normal cardiacs sounds and the sounds S1 and S2.

Figure 3

Figure 2: Frequency spectrum for the abnormal PCG (the aortic-coarctation) and the sound S1 and S2.
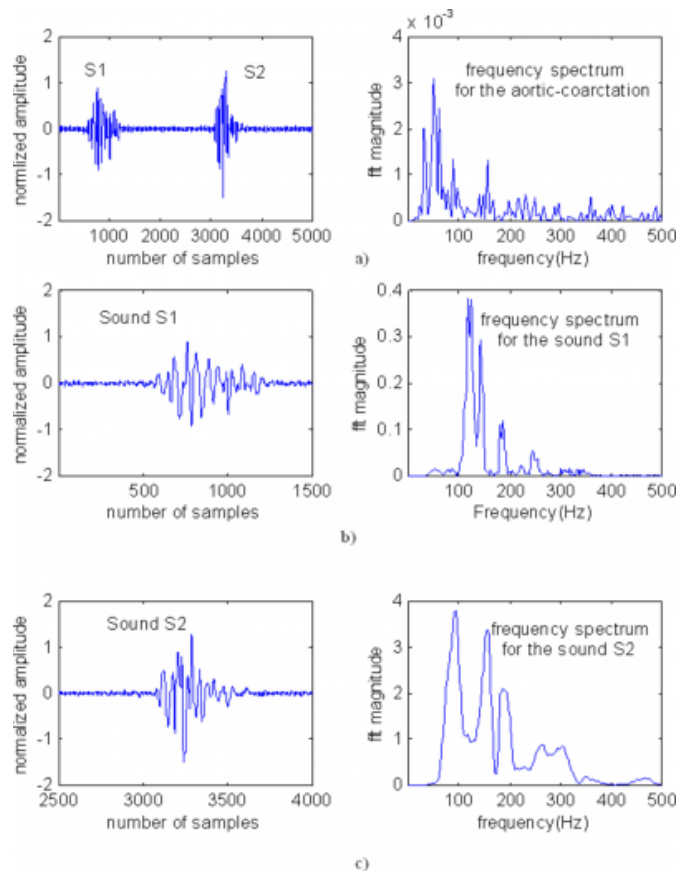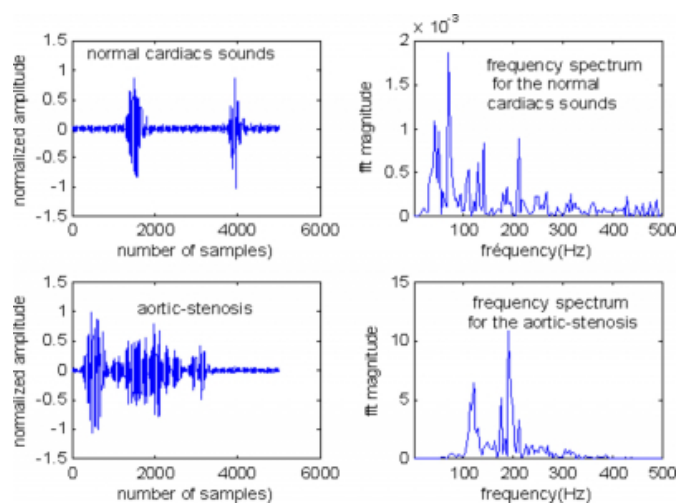

Figure 4

MARKED CASE OF THE PHONOCARDIOGRAM

The FFT is applied also to analyse three different marked pathological cases of the PCG (the aortic-insufficiency, the aortic-stenosis and the mitral-stenosis). These are illustrated in Figure3 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. In addition except the aortic-insufficiency case where we note the apparition of frequency component higher than 200Hz , the other cases (mitral-stenosis and aortic-stenosis) present a frequency spectrum limited to 200Hz.

The aortic-insufficiency and the aortic-stenosis are two pathologicals cases resulting from a severe organic attack , which generally involves a disappearance of the aortic component A2 of the sound S2. This shown in their corresponding PCG frequency responses illustrated in Figure3, where we notice a lack in frequency contents in the range under 100Hz compared to the normal case, where there is much more frequency component in this range. It is therefore due to te disappearance of the aortic component A2 and the fact the pulmonary component P2 has less frequency component, as it is resumed in tableI.

On the other hand the mitral-stenosi is rather a severe attack of the mitral valves thus involving a presystolic reinforcement as well as a bursting of the sound S1.

As the frequency extent of the sound S1 is less important than that of the sound S2, the spectral response of the PCG signal related to this pathological case is not much affected comparad to that of the normal case as was the case in the aortic -insufficiency and aortic-stenosis

In conclusion, and by applying the spectral analysis to different PCG signals, we can affirm which of the sounds S1 or S2 is directly concerned by the pathology, and more precisely which component of these sounds is affected.

With regard to normal PCG the basic frequency components are obviously detected by the FFT but not the time delay between these components. In fact as it was shown for example in Figure1c, the components A2 and P2 of the second sound S2 are obvious. 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.

Figure 5

Figure 3: Normal and abnormals cardiacs sounds and their frequency spectrum respectively.
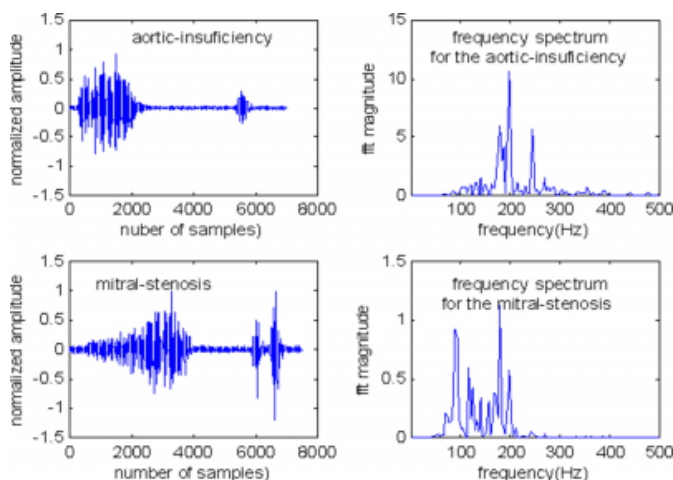
CONCLUSION

The cardiac (heartbeat sound) cycle of phonocardiogram (PCG) is characterized by transients and fast changes in frequency as time progresses. It was shown that basic frequency content of PCG signal can be easily provided using FFT technique.

This will help physicians to obtain qualitative and quantitative measurements of frequency characteristics of the PCG signals. Normal and pathologicals signals have been considered to give some idea of the generality of the evaluation.

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