Frequency analysis of the heartbeat sounds

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Frequency analysis of the heartbeat sounds

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Abstract: *This paper is concerned with a synthesis study of the fast Fourier transform (FFT) in analysing the heartbeat sounds or the phonocardiogram signal (PCG). This analysis concerns four sounds (S1, S2, S3 and S4) and PCG signal with click or murmur. It is shown that the spectral analysis can provides enough features of PCG signals that will help clinics to obtain qualitative and quantitative measurements of PCG signal's characteristics and consequently aid to diagnosis.*

Keywords Heartbeat, Phonocardiogram, Four sound, click, murmur, spectral analysis, FFT.

1. Introduction

The relationship between blood volumes, pressures and flows within the heart determines the opening and closing of the heart valves. Normal heart sounds occured during the closure of valves, but the wayhow they are actually generated is still under debate. The valvular theory states that heart sounds emanate from a point source located near the valves, but this assumption is probably an oversimplification [1]. In the cardiohemic theory heart and blood represent an interdependent system that vibrates as a whole [1]. Both theories originate from the time when physiological picture was based on one-dimensional conception of flow. Recent research provides means to visualize the actual three-dimensional flow patterns in the heart [2], and this new knowledge will probably clarify our view on underlying mechanisms of heart sounds. The blood's pathway through the heart is far from fully understood, but the induced vortices seem optimized to facilitate flow and thereby increase the efficiency of the heart as a pump. The impact of this new knowledge on understanding the heart sounds and their origin is yet to be investigated. Will awaiting this new insight, the cardiohemic theory is assumed valid. Normally, there are two heart sounds. The first sound (S1) is heard in relation to the closing of atrioventricular valves, and is believed including two major components [3]. 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. The second sound (S2) signals the end of systole and beginning ofdiastole which can be heard at the time of closing of the aortic and pulmonary valves [4]. S2 is probably resulted from the oscillations in cardiohemic system that caused by deceleration and reversal of flow into the aorta and pulmonary artery [1]. For the second sound S2 it is composed from the closure of aortic valve (A2) and pulmonary valve (P2) [5-6]. The importance of S2 in diagnosis has been recognised long, and cardiologist consider it as a significant "key" in auscultation of heart [7]. Specifically during expiration, A2 and P2 are separated by a relatively short interval typically less than 30ms [8_10].

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2. The Fourier Transform (FT)

In 1882, Joseph Fourier discovered that the any periodic function could be represented as an infinite sum of periodic complex exponential functions .The wavelet tutorial. periodic functions was later extended to any discrete time function. The Fourier transform (FT) 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 Figure2 . The FT is widely used and usually implemented in the form of the fast FT algorithm (FFT). The mathematical definition of the FT is given below.

$$X(f) = \int x(t)\, e^{-j2\Pi ft}\, dt \tag{1}$$

Where t and f are the time and frequency parameters respectively. The time domain signal $x(t)$ is multiplied by a complex exponential at a frequency f and integrate over all time. In other

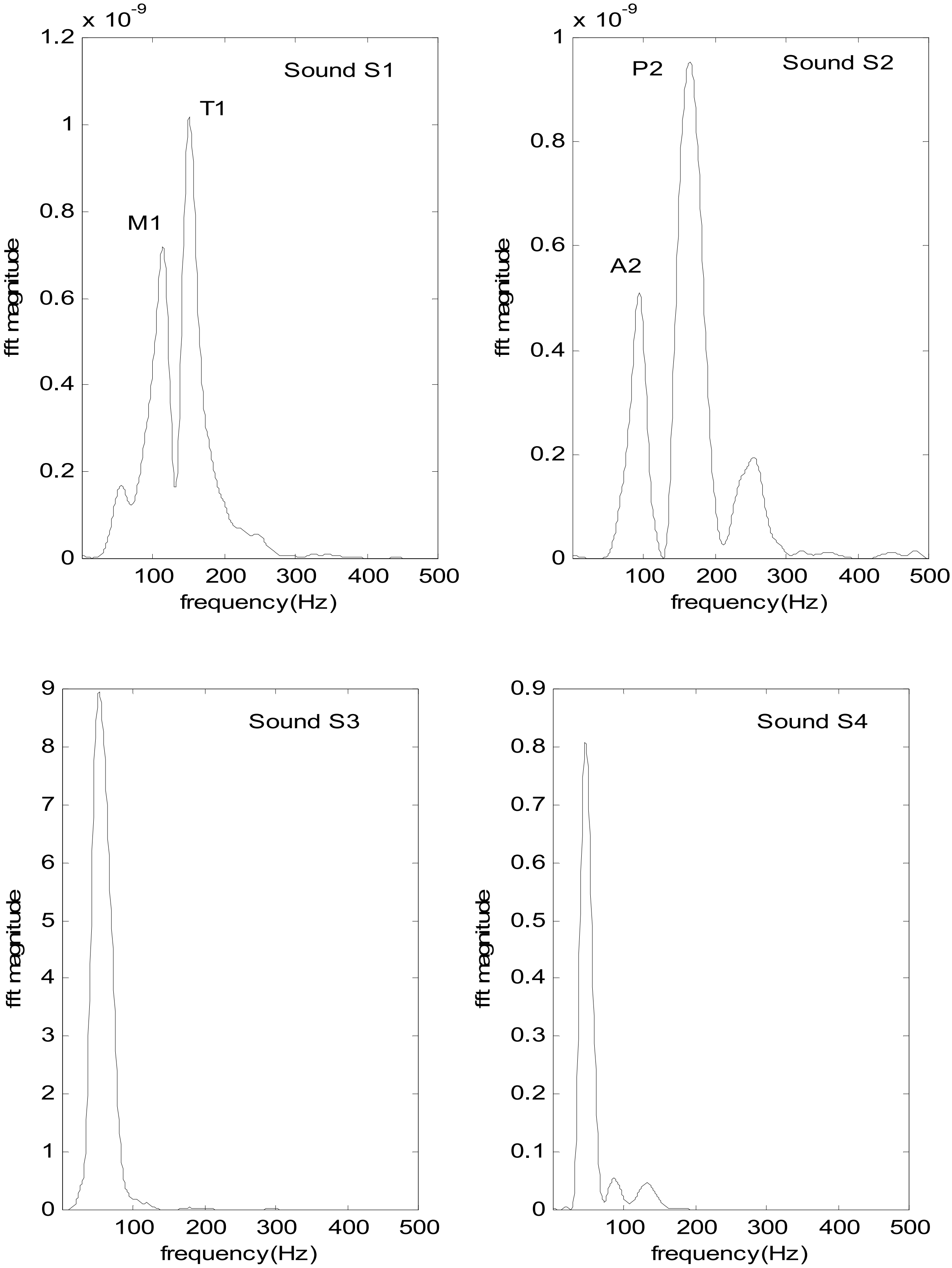

Fig.1. Fourier transform analysis of the sounds S1,S2,S3 and S4 with Hamming window (FFT 1024)

sinus and cosines, which are shifted and are multi words, any discrete time signal may be represented by a sum of plied 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.

3. Results and discussion.

The Fast Fourier Transform (FFT) techniques is applied to analyse differents PCG signals. 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. In this section we will present the experimental results and discuss the applications of the FFT to the analysis and diagnosis of the fours sounds (S1-S2-S3-S4-the PCG signal with click or murmur. The frequency scan is from 1 to 500 Hz.

3.1 Fourier transforms analysis of the sounds S1, S2, S3 and S4.

The fast Fourier transform can be applied to the fours heart sounds (S1-S2-S3-S4) to analyse the frequency content as shown in Figure1. A 1024 point FFT is applied to these sounds. The two components (M1 and T1) of the sound S1 and the two components (A2 and P2) of the sound S2 are also clearly depicted in this Figure1. According to results obtained by the FT analysis of these sounds we can say that the sound S2 have the high extent frequency and it is the sound S3 the most reduced

3.2 Fourier transforms analysis of the PCG signal with click.

In this section we consider three examples of the phonocardiogram signals : the Early-systolic (ES), the Opening Snap (OS) and the ejection Click (EC). Figure2 shows the Fourier transform analysis of these PCG signal. This click is a brief murmur. We can notice that the frequency extent of these type of these PCG signal is not very broad . that generally does not exceed the 100 Hz

3.3 Fourier transforms analysis of the PCG signal with murmur

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

4. Conclusions

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.

To conclude, we have applied the STFT techniques to the analysis of the first (S1), the second (S2), the third (S3) and the fourth (S4) heartbeat sounds of the phonocardiogram signal (PCG). The FFT can thus provide the frequency extent of these four sounds .

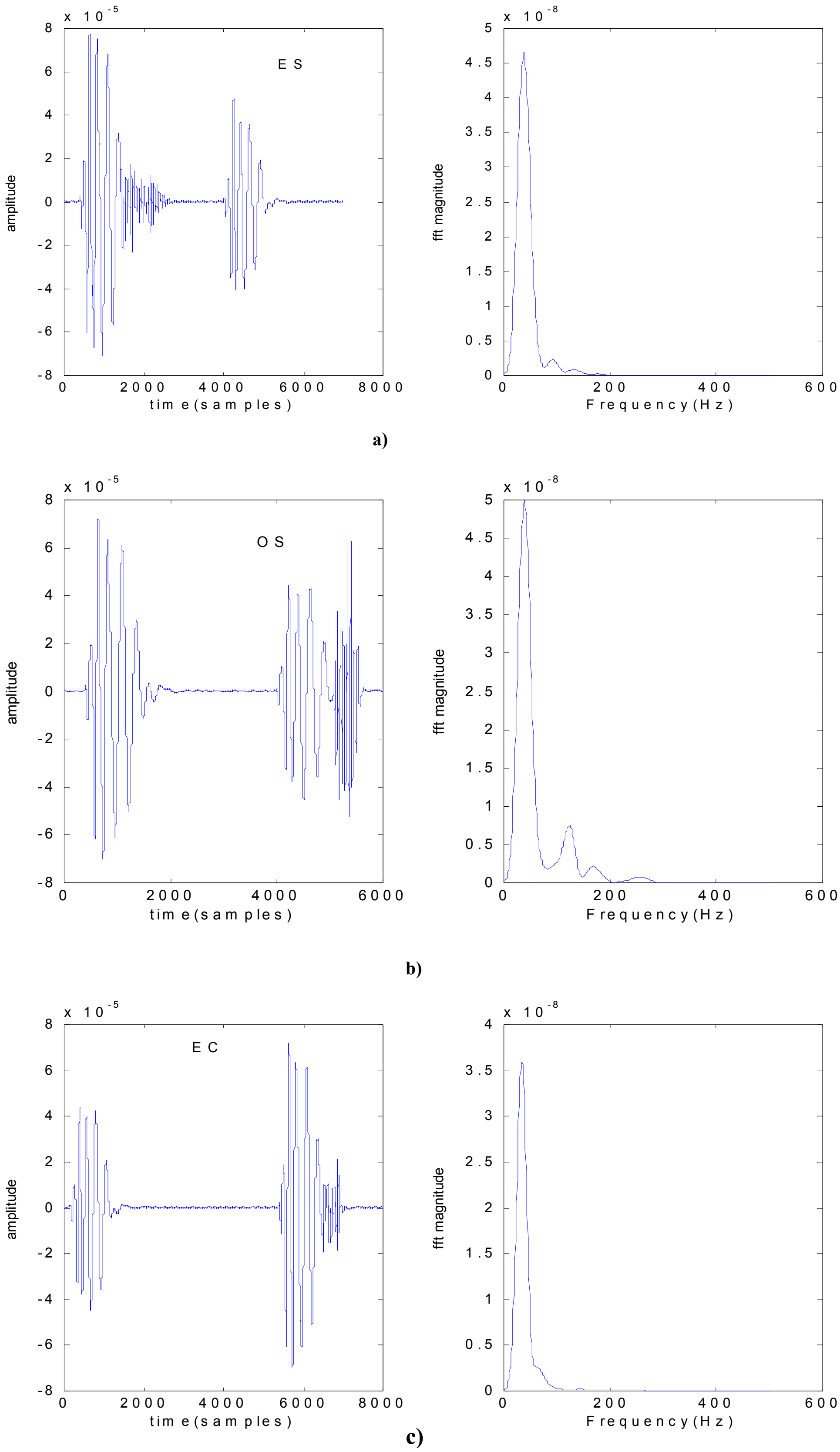

Fig.2. Fourier Transform analysis of the PCG signal with murmur:
a) Early-systolic, b) Opening-Snap c) Ejection-click

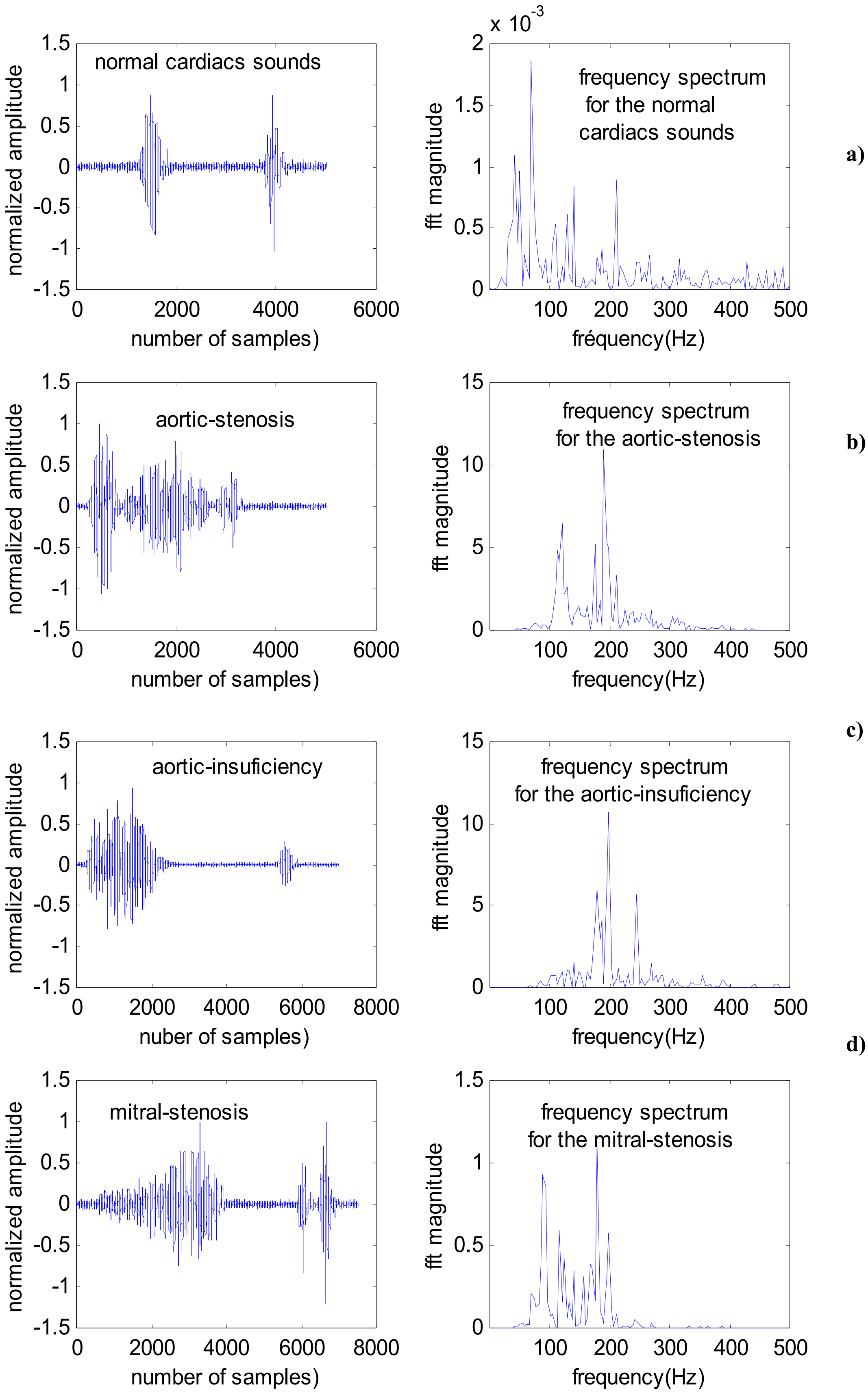

Fig.3. Fourier Transform analysis of the PCG signal with murmur :
a) normal PCG, b) aortic-stenosis; c) aortic insufficiency; d) mitral-stenosis

The second sound seems have high extent frequency than the three other sounds. This study is concerned also the PCG signal with click or murmur. The PCG signal with click have a less broad frequency extent than the PCG signal with murmur. We can finally say that the results are complementary to facilitate a good approach and to better understand the heartbeat sounds.

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