ACQUISITION AND TIME–FREQUENCY ANALYSIS OF THE PHONOCARDIOGRAM SIGNAL

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ABSTRACT: In this paper, we are presenting novel software allowing acquisition and analysis of the Phonocardiogram (PCG) signal. A microphone assembled with a stethoscope head and personal computer, which monitors the acquisition process, makes up the required equipment. The proposed software allows wide sampling frequencies range recording from 500 Hz to 22 kHz with 16 bits resolution, and time–frequency analysis using Reassigned–Spectrogram approach. The reassignment of the time–frequency plan overcomes the resolution limitation of such a classical method. The developed software seems to be a reliable tool for the evaluation of the severity of pathological cases with both temporal and spectral information.

Keywords: Phonocardiogram, Short–Time Fourier Transform, Reassigned–STFT Spectrogram, Aortic Stenosis, Temporal resolution, Frequency resolution.

1. BACKGROUND

Tavel *et al.* developed a hand–held visualization system of the Phonocardiogram signal [1]. Durand and Pibarot [2], [3] have quoted in their recent work an electronic stethoscope to be used with a computer through an interface monitored by special software allowing recording and visualization of heart sounds in real time.

Unfortunately, Acquisition of the Physiological signals such as Phonocardiogram signal without any external interface is still missing. The solution is however very simple and more practical, indeed the use of just a standard and low cost Personal Computer with an ordinary commercial microphone and a stethoscope head can achieve this aim.

2. DATA ACQUISITION

A novel MATLAB GUI (Graphical User Interface) *PCG Recorder,* which acquires the Phonocardiogram (PCG) Signal, has been developed. This interface allows recording of heart sounds with 16 bits resolution at different sampling frequencies.
A microphone connected to the Sound Card of a Personal Computer captures the Phonocardiogram signal. It also provides the physicians with time–frequency analysis of the acquired signal in order of aid in diagnosis. The system is tested in the CHU (Hospital of Tlemcen–Algeria) on patients with age varying from 17 to 84 years old.

2.1. Hardware

The acquisition system consists of a microphone, a stethoscope, an audio cable and a Personal Computer with an Integrated Hardware SoundBlaster as illustrated in Figure 1.

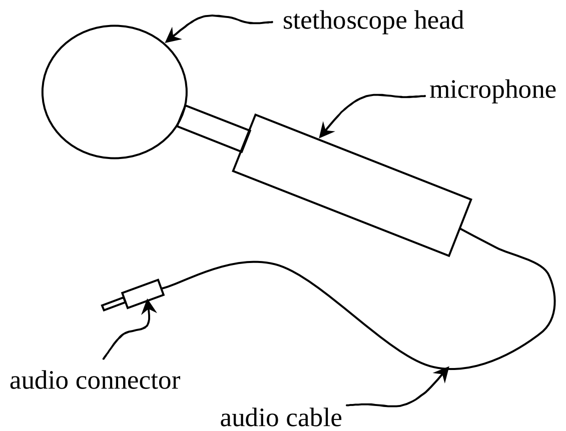


Fig. 1 – Descriptive diagram of the recording microphone.

The heart sounds are captured with an ordinary stethoscope head. Vibrations are then carried through a microphone connected to the analog input of the sound card of the PC. The acquisition is achieved using software, which we developed.

2.2. Software

The core of the acquisition is the script that we propose written in MATLAB Version 6.5 (R13), which allows acquisition of the analog input of the soundcard. The program uses functionalities of the "Data Acquisition Toolbox Version 2.2 (R13)" for monitoring the acquisition task, which are assembled in a Graphical User Interface (GUI). This GUI is made very interactive and easy to manipulate by medical staff (Figure 2).

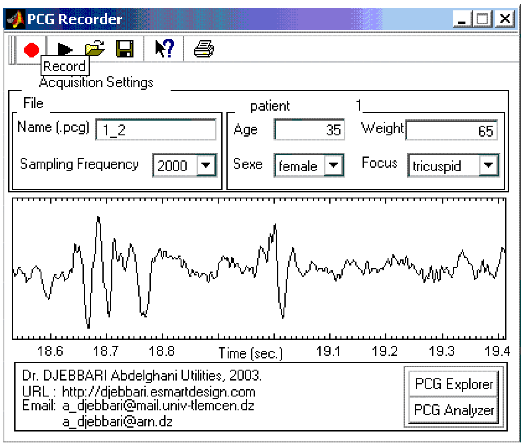


Fig. 2 – PCG Recorder Graphical User Interface.

After introducing all details of patient, the heart sounds are then recorded with the selected sampling frequency.

3. CLINICAL TESTS

Using the developed software, pathological Phonocardiograms were collected in the Cardiology Service of The Hospital of Tlemcen (Algeria). Each patient recording includes the four basic PCGs signals recorded from respectively the mitral, tricuspid, aortic and pulmonary focuses. Additional information is saved with the .pcg file, namely the sampling frequency, the age, the sex, the weight and the focus of auscultation.

It is known that the phonocardiogram is mainly composed of four heart sounds noted S1, S2, S3 and S4. The two first heart sounds S1 and S2 (Figure 3) are respectively due to the systolic and the diastolic activities; the remaining ones are physiological rather than clinically indicators [2]. The first heart sound S1 is mainly due to the closure of the mitral, the tricuspid heart valves and the opening of the semilunar valves (aortic and pulmonary) marking the onset of the systolic phase. In the diastolic phase, all cardiac valves are altered generating the second heart sound S2, which is due to the closure of the aortic and the pulmonary heart valves and the opening of the mitral and tricuspid valves. The second heart sound contains higher frequencies and has short duration in comparison with the first heart sound S1 [2].

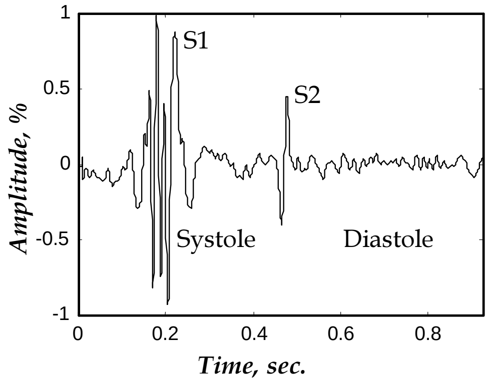
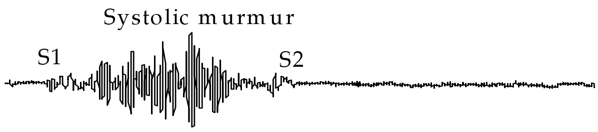


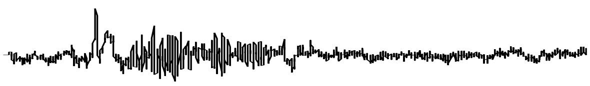
Fig. 3 – Normal subject PCG, 27 years old, male, mitral focus.

Various Pathological PCGs were recorded, such as: pericardial effusion, mitral and aortic stenosis, pericarditis, aortic insufficiency, etc.

The stenosis of the aortic valve leads to disturbances in the blood ejection from the left ventricle to the aorta during the systolic phase. Hence, the aortic blood flow decreases and generates a systolic diamond-shaped ejection murmur as shown in Figure 4.



(a) Aortic focus.



(b) Tricuspid focus.

(c) Pulmonary focus.

Fig. 4 - Aortic Stenosis PCG, 84 years old, female.

From the mitral focus, the acquired PCG contains no consistent information, since all heart sounds seems to be weaken because of the systolic murmur domination.

The stenosis of the ejection duct begets a hypertrophy of the left ventricle, the dilation is often weak because the ejection volume does not increase, and it is generally absent as long as the left ventricle is compensated.

4. METHODS

Reassigned Spectrogram

The bilinear time–frequency distributions are primarily characterized by the clearness of their representation, which means good concentration of the signal terms without overstated cross terms interference. Reassignment of the resulting time–frequency representation (TFR) can enhance its readability [4]. The purpose of this approach is to reassemble fragmented terms over the time-frequency plan by assigning to each determined area other more concentrated values around the most significant time–frequency region [4]. The main constraint is the inevitable trade–off between sharpness and apparition of additional cross terms upon the time–frequency representation.

The spectrogram expression can be viewed as a 2D–convolution (Equ. 1) between the Wigner-Ville Distribution (WVD) of the signal *s(t)* and that of the analyzing window *h*;

$$SPEC_s(t, f, h) = \int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} W_s(\tau,\gamma)\, W_h(t-\tau, f-\gamma)\, d\tau\, d\gamma \quad (1)$$

Where τ represents time and γ represents the frequency.

Such a bilinear distributions reduces interference terms apparition, but at the cost of affecting the time and frequency resolutions, which are inversely proportional, and also by biasing marginals and moments of the resulting time–frequency representation.

The local energy $W_s(\tau,\gamma)\, W_h(t-\tau, f-\gamma)$ should be replaced by an accurate expression for every term for each instant and frequency. Indeed, the aim of the reassignment approach is to moves each value of the spectrogram to the center of gravity of the energy distribution of the signal at the vicinity of *(t, f)* (Equ. 2 and 3).

$$\hat{t}(s, t, f) = -\frac{d\Phi_s(t, f, h)}{df} \quad (2)$$

$$\hat{f} = f + \frac{d\Phi_s(t, f, h)}{dt} \quad (3)$$

Where $\Phi_s(t, f, h)$ represents the phase of the Short–Time Fourier Transform (STFT) of *s(t)*.

The structure of the reassigned spectrogram affects its bilinearity, but conserves a lot of interesting properties such the non–negativity property, time and frequency shifts covariance and the energy conservation.

5. RESULTS AND DISCUSSION

By analyzing the normal PCG signal of Figure 3, we lead to time–frequency representations of Figure 5, which illustrates the high-resolution capability of the reassignment approach by enhancing the spectrogram calculated by the Short–Time Fourier Transform (STFT) [3].

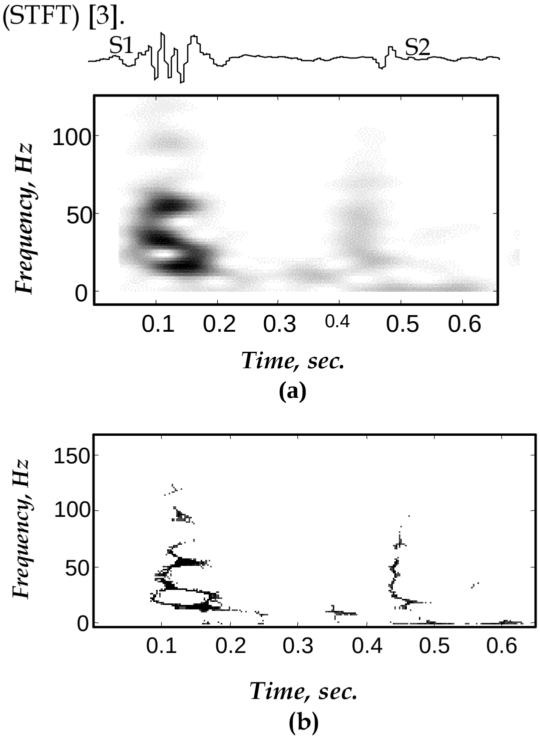


Fig. 5 – (a) STFT Spectrogram and (b) Reassigned–STFT Spectrogram of a normal PCG, 27 years old, male, mitral focus.

As shown in Figure 5, the first heart sound S1 contains more information than the second one. Indeed, this systolic sound occupies a relatively large bandwidth, from 20 Hz up to 100 Hz, when acquired from the mitral focus upon the chest. The diastolic heart sound S2 appears in a very short duration with approximately the same spectral range of S1, but with different content shape. The obtained result confirmed the rising frequencies hypothesis in correlation with ventricular systolic ejection pressure [3], [5]. Henceforth, we should use the reassignment method to forecast the spectral content of PCG signals. Results illustrated in Figure 6 highlights this finding.

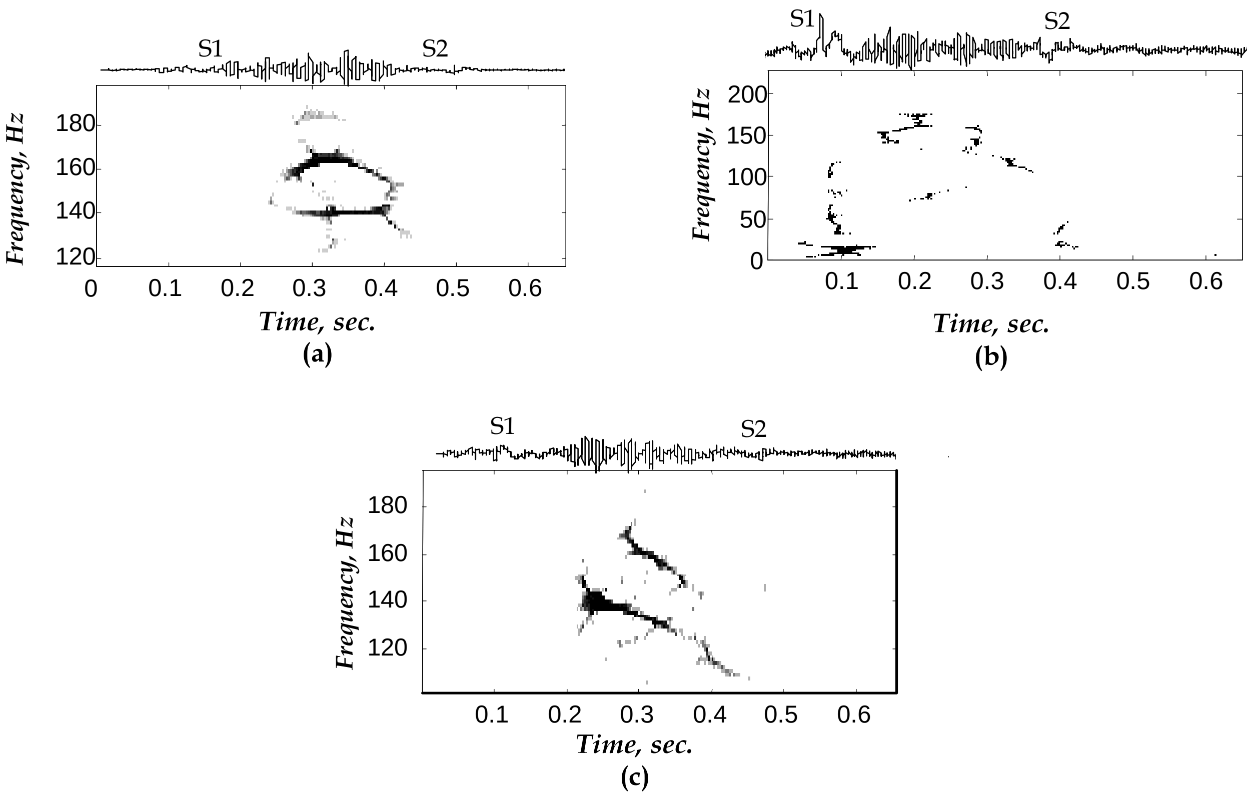


Fig. 6 – Reassigned–STFT Spectrograms of the Aortic Stenosis PCG; (a) Aortic, (b) Tricuspid and (c) Pulmonary focuses.

Before doing any analysis, we should mention that the aortic stenosis PCG signal acquired from the mitral focus gives no consistent information since the recording can just perceive fainter murmurs. The first and the second heart sounds are relatively weak in comparison with the systolic murmur when acquired from the other auscultation focuses. This murmur is continuously dominating the phonocardiogram signal with approximately the same intensity. From the TFR (a) of Figure 6, we can ascertain this finding since the first and the second heart sounds are blurred by the systolic murmur, which is well delimited when acquired from the aortic focus. The resulting TFR (c) of Figure 6 (pulmonary focus) is similar to that of the aortic one (Figure 6 (a)), but illustrating just decreasing frequencies of the systolic murmur. Rising frequencies are moreover recorded from the aortic focus concerned by the closer focus to the pathology source, *i.e.* the aortic valve. The adequate focus seems to be the tricuspid focus, since the resulting TFR (Figure 6 (b)) allows us to visualize S1, S2 heart sounds and the systolic murmur

6. CONCLUSION

The acquisition of the PCG signal by a personal computer is a tool to be valorized since the recorded heart sounds are well delimited. A playback of the heart sounds allows to physicians to evaluate easily the cardiac status of patients. In order to overcome the subjective diagnosis, a time–frequency analysis is implemented. Indeed, the Reassigned–STFT Spectrogram gives good results allowing adequate interpretation of the heart activity. The developed software with its interactive Graphical User Interface allows a flexible manipulation of the acquisition and analysis of PCG signals.

7. REFERENCES

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