Spectral Analysis of the Heart Sounds for Medical Diagnosis

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Abstract: - Cardiovascular diseases are affecting a constantly growing number of people. Due to this reason we are continuously looking for new ways of investigations. The processing of the heart's audio signals also belong to this category. Heart sound is an acoustic wave generated by the mechanical movement of the heart and blood. The sounds can be divided into normal heart sounds and heart murmurs. Murmurs are abnormal signals that appear over wider ranges of frequency than normal heart sounds. The auscultation is a very effective method in detecting heart diseases. Along this paper the authors present the results of the combined time-frequency analysis for short-time periods applied to cardiac signals useful for diagnosis in medical practice.

Key-Words: - Heart sound, signal processing, Wigner-Ville distribution, spectral analyse, automated diagnosis.

1 Introduction
The possibility of automating monitoring and diagnosis in intensive-care unit patients is an important objective, since it will increase both safety and efficiency of treatments, especially in difficult, unexpected and time-critical situations.

Human heart sounds are very natural signals, which have been applied in the clinical auscultation for health monitoring and diagnosis [1].

The phono-spectrogram combines traditional phonocardiogram with the presentation of the time-frequency distribution of the signal. Recent advances in information technology systems, in acoustic signal processing and in pattern recognition methods have inspired the design of systems based on electronic stethoscopes and computers. In the last decade, many research activities were conducted concerning automated and semi-automated heart sound diagnosis, regarding it as a challenging and promising subject.

The time plot of the heart sound phonocardiogram displays the amplitude of the sound at each instant, but no information about the energy is displayed. An accepted principle in acoustics is that the energy of the single frequency acoustic signal at each instant is proportional to the squared amplitude of the signal and the squared frequency of the signal. The best method to compute heart sound energy is to utilize joint time-frequency distribution. A heart energy signature is essentially a high-resolution 2D spectrographic image of the heart sound signal that is based on the Wigner-Ville joint time frequency distribution of recorded heart sound signal. It reflects the distribution of the signal energy in the time-frequency plane.

2 Spectral analysis of the heart sounds
Many times, we are interested in details of the temporal process represented through \( x(t) \) in certain time intervals as well as details as the spectral density in certain frequency bands. In these cases, the analysis needs to be done very specifically, in time intervals or in the frequency bands that we are interested in. Such situations can occur, for example, in the analysis of the vocal signal, in recordings of electrocardiogram signals, seismic signals and so on. Obviously, for the extraction of a window from a \( x(t) \) signal we can use the windowing process with a function \( w(t) \). The windowed signal:

\[
x_w(t) = x(t)w(t)
\]  

(1)
is defined on a shorter time interval. In the case of analogical moving signals, the instantaneous frequency is variable in time. This is what happens, for example, in the case of frequency or phase modulated signals with a harmonic carrier. The concept of heart sound spectral display was first introduced by McKusick in 1955, [2].

Unfortunately, this method must use various forms of the Short Term Fast Fourier Transform (STFT) to obtain instantaneous frequency characteristics of signals and due to this reason, it is not very accurate. As a result of this situation, a new concept has taken shape, becoming known under the name of heart energy signature (HES). The energy of a signal \( x(t) \), including both acoustic and PCG signals, is proportional to the squared amplitude of the signal. The signal energy \( E \), contained at the time interval \([t, t+T]\) is computed as \([3]\):

\[
E = \int_{t}^{t+T} |x(t)|^2 \, dt
\]

The time plot of the heart sound (PCG) displays the amplitude of the sound at each instant, i.e. no information about the energy is displayed. An accepted principle in acoustics is that the energy of the single frequency acoustic signal at each instant is proportional to the squared amplitude of the signal and the squared frequency of the signal. The best method to compute heart sound energy is to utilize joint time-frequency distribution (JTFD). A heart energy signature is essentially a high-resolution 2D spectrographic image of the heart sound signal that is based on the Wigner-Ville joint time frequency distribution [4] of recorded heart sound signal. JTFD reflects the distribution of the signal energy in the time-frequency plane [5], [6].

The Wigner-Ville Distribution (WVD) has the mathematical expression:

\[
WVD(t, f) = \frac{1}{2\pi} \int_{-\infty}^{+\infty} x_w(t + \tau)x_w^*(t - \tau)e^{-j2\pi\tau} \, d\tau
\]

The WVD satisfies a large number of desirable mathematical properties. In particular, the WVD is always real-valued; it preserves time and frequency shifts and satisfies the marginal properties. Moreover, the WVD conserves the energy of the signal. For a time-series \( x(n) \), the expression of the discrete-time Wigner-Ville Distribution, \( WD(n, f) \) is:

\[
WD(n, f) = 2 \sum_{k=-\infty}^{\infty} h_n^2(k) x(n + k) \cdot x^*(n - k) \cdot e^{-j4\pi f k}
\]

where \( h_n(k) \) is a data-window, which performs a frequency smoothing. While Fourier spectra are periodic with period equal to the sampling rate, \( WD(n, f) \) is periodic in frequency with period equal to half the sampling rate. This may cause aliasing, which can be removed either by oversampling, or by using the corresponding analytic signal. The distribution is negatively affected by important cross-terms, which limit its practical use. Cross-terms may be adequately reduced smoothing the distribution over time. The resulting smoothed Wigner-Ville, \( SWD(n,f) \) is:

\[
SWD(n, f) = \sum_{m=-\infty}^{\infty} w(m) \cdot \sum_{k=-\infty}^{\infty} h_n^2(k) x(n + k + m) \cdot x^*(n - k - m) \cdot e^{-j4\pi f k}
\]

### 3 Histogram of the heart sounds

In statistics, a histogram is a graphical display of a table that shows what proportion of cases fall into each of several or many specified categories. In a mathematical sense, a histogram is a mapping that counts the number of observations that fall into various disjoint categories (known as bins). There is no "best" number of bins, and different bin sizes can reveal different features of the data. In the present paper the authors propose the usage of histograms in order characterise the time-series coming from the continuous glucose monitoring system. Also, due the fact that we are dealing with measurements that can be corrupted by errors, we have calculated a Gaussian distribution for these data. The Gaussian distribution, also called the normal distribution, is an important family of continuous probability distributions, applicable in many fields. Each member of the family may be defined by two parameters:

- The mean (average, \( \mu \));
- The variance (standard deviation squared) \( \sigma^2 \), respectively.

Many physiological measurements can be approximated well by the normal distribution. In addition, the normal distribution maximizes information entropy among all distributions with known mean and variance, which makes it the
natural choice of underlying distribution for data summarized in terms of sample mean and variance.

4 Experimental study

The signals represent measurements taken from patients being either normal or suffering from different vascular diseases. The goal is to find a measure, which allows classifying the different signals according to the medical conditions. Fig. 1 represents a typical example of the murmur caused by an atrial septal defect. Because the pressure in the left atria initially exceeds that in the right, the blood flows in a left to right shunt. This high volume of blood next passes into the right ventricle, and the ejection of the excess blood through a normal pulmonary valve produce the prominent mid-systolic flow murmur.

In Fig. 2 is represented the spectral analysis using the short term fast Fourier transform and in Fig. 3 is represented the Wigner-Ville distribution for this signal. The Wigner-Ville distribution has the advantage to evidence the moment (in time) when the spectral components appear. So, is more useful for automated diagnose. Fig. 4 represents the murmur caused by a ventricular defect and in Fig. 5 we have the spectral analysis. In Fig. 6 is represented the Wigner-Ville distribution for this case.

Fig. 7 and 8 represent the histograms attached to the analysed heart sounds.

The proposed method is an analytical solution, which represent a new approach for the computer-assisted diagnosis.
Therefore, this is an efficient decision support systems and would be very useful for supporting clinicians to make better heart sound diagnosis, especially in primary healthcare.

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**References**


