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# Frequency Domain Methods For Measurement Of Heart Rate Variability

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## 1. Introduction

Nowadays, surface electrocardiography is the basic noninvasive technique in the clinical study of the electrical signal from the heart. Heart rate is usually defined as the number of heart beats per unit of time. Heart rate variability (HRV) is the measure of variation from one cardiac cycle on the next, utilizing normal morphology. HRV should not be confused with the time averaged heart rate changes as seen in minimum and maximum heart rate or other heart rate measurements on ambulatory ECG recording.

The analysis of very rapid fluctuations in heart rate (expressed as heart rate variability) is hampered by the fact that the cardiac events are not regularly spaced in time. However, if we are interested in rapid fluctuations theoretically the unit of time mentioned above should be as small as possible. The analysis of fluctuation in heart rate has become increasingly important boths in physiological studies and in modeling of the neurocardiovascular system.

Furthermore, a number of diagnostic applications of this analysis is emanating, such as in the field of acute myocardial infarction, congestive heart failure, sudden cardiac death and diabetic neuropathy, neonatalogy and fetal monitoring. Very often the fluctuations are studied in the frequency domain.

During the past 13 years, the provocative hypothesis by Akselrod et al. that quantitative analysis of fluctuations in hemodynamic parameters is a powerful quantitative means of probing mechanism of short-term cardiovascular control, a new field of impetuous research.

We will therefore discriminate three ranges of the rate of the fluctuations (in terms of average duration of one cycle):

1). Slow variations: few minutes to hours.

The heart rate can be defined as twice the number of beats in a 30 seconds time bin.

2). Rapid fluctuations: some tens seconds to a few minutes.

3). Very fast fluctuations: few seconds (or less) to tens seconds

Detection of a cardiac event series from the ECG is necessary and attention has to be paid to both reliability and accuracy of the QRS detection. The usage of some HRV signal is discouraged and event series (spectral) analysis should be applied. In practice, very often the series is still assumed to be equidistant and spectral analysis is carried out by applying the Fast Fourier Transform to this series.

Electrocardiographic assessment of heart rate is necessary. The QRS complexes have to be detected and converted to short pulses.

Consequently, a heart rate variability (HRV) signal is to be derived, which can be subjected to spectral analysis. This is schematically shown in figure 1, where F.T. refers to Fourrier Transform.

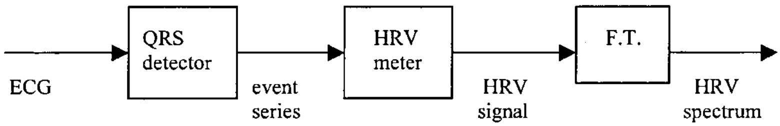


Figure 1. Spectral analysis of rapid fluctuations in heart rate

## 2. Method

To analyze cardiovascular variability signals, power spectrum analysis may be carried out either in nonparametric form (based upon the FFT algorithm) or in parametric form (based upon stochastic black-box modeling).

If heart rate were constant at 72 beats/minute it could easily be described at a frequency of 1.2 Hz. Since heart rate is not truly constant, multiple frequency components comprise its make-up.

The sinus node is highly innervated by the autonomic nervous system. Since the P wave is difficult to detect with precision, an assumption is made that the PR interval remains constant. Measurements are derived from the RR intervals. Successive heart beats are considered a series of events. Connecting the R to R intervals creates a rhythmatic pattern. Via spectral analysis, characteristic frequencies are extracted from the rhythm pattern, coupling them in order of range. In essence, spectral analysis measures the contribution of each of the many frequencies that exist in a given phenomenon (figure 2).

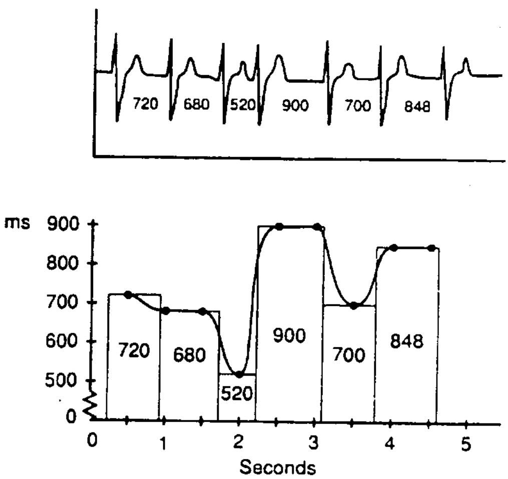


Figure 2. Measurements are derived from the R-R intervals.

Succesive heart beats are considered a series of events.

Connecting the R to R intervals creates a rhythmatic pattern.

Similar to the glass prism, spectral analysis uses a mathematical function called Fast Fourier Transform to separate the characteristic frequencies of the underlying rhythm (figure 3).

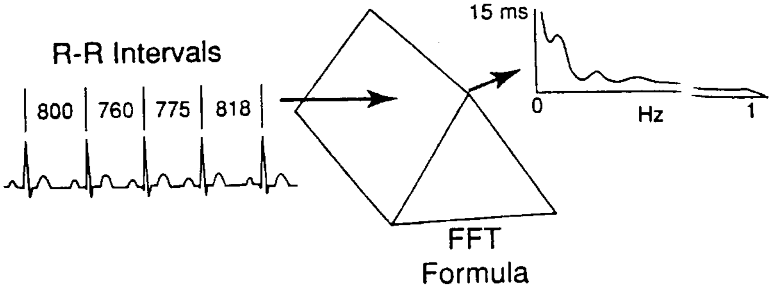


Figure 3. The Fast Fourier Transform (FFT) formula functions like a prism in analyzing heart rate variability.

Since respiration is a rhythmatic phenomenon, its measurement can be expressed in frequency.

Example:

10 breaths/minute = 1 breath/6 seconds;
breathing rate 1/6 seconds = 0.17 Hz.
OR
30 breaths/minute = 1 breath per 2 seconds;
breathing rate 1/2 seconds = 0.15 Hz.

Spectral analysis offers the clinician the proportional amount of variation at each component frequency. This may be illustrated by considering how a respiratory rate of 15 breaths/minute affects heart rate variability. The 15 breaths per minute translates to one breath every 4 seconds (1/4 of a respiratory cycle per second) equivalent to 0.25 Hz. (cycles/sec) on the frequency spectrum. A spectral peak would be seen at 0.25 Hz. The comparative height of this peak demonstrates its relative contribution to overall heart rate variability. This type of analysis becomes the basis for determining the pathophysiology of heart rate variability (figure 4).

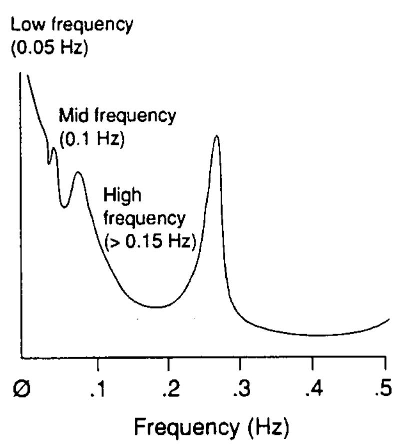


Figure 4. Power spectrum of instantaneous heart rate (HR) fluctuations featuring three main peaks: low-frequency peak (from 0.02 to 0.09 Hz), mid-frequency peak (from 0.09 to 0.15 Hz) and high-frequency peak (around respiratory frequency).

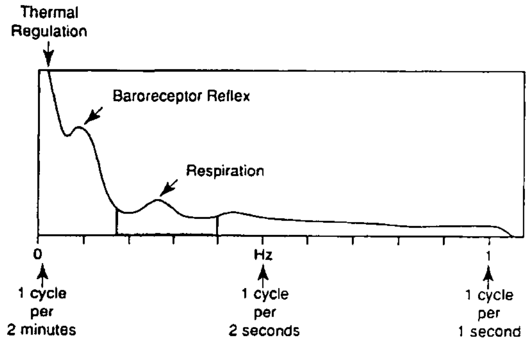


Figure 5. The cycling of various physiologic processes and their respective frequencies.

The spectral analysis of beat-by-beat RR interval shows two principal components:
1). Low frequency (LF), component generally centered around 0.05 to 0.15 Hz and whose change in power have been related to the sympathetic activity on the basis of pharmacological and clinical experiments;
2). High frequency (HF), component, in synchrony with the respiration rate (in the range between 0.15 and 0.5 Hz), which considered to be an expression of the respiration disturbances mediated by the vagal activity (parasympathetic) and are descreased by standing they are mediated solely by the parasympathetic system.

The power related to the LF and HF components is expressed in absolute values as well as in their ratio (LF/HF; so known autonomic index) and the related peak frequencies are useful parameters which help to quantify the sympatho-vagal balance activity.

The Fast Fourier Transform (FFT) accepts as input a time series of data samples (normal to normal coupling intervals) every half a second. The FFT returns a series of amplitudes for sine waves at many discrete frequencies.

The summation of those weighted sine waves would make a time signal that could be sampled to reproduce the original time series of samples, however the FFT output is not a continuos spectrum. The amplitude response from the FFT represents all the frequencies for each of the 128 output bins along the horizontal axis. These amplitudes are in milliseconds. To further explain this consider a time signal which is purely one frequency of variation within the entire sampling window. If the frequency was the center frequency of one of the bins in the FFT output spectrum, the output spectrum would contains zero values for every bin except one. That bin would contain zero-to-peak amplitude of the sinusoidal variation. The range is 0 to 15 ms.

More commonly seen in the literature than amplitude, power spectral density is drawn by squaring each component of the FFT output amplitude spectrum. The squaring function exaggerates the dynamic range, making the smaller amplitude components smaller and the bigger amplitude components bigger.

We have proposed to couple the analysis of HRV to the concept of sympatho-vagal balance. This assumes that the interplay between sympathetic and vagal modulations of sinus node pacemaker activity is organized in a reciprocal fashion, that increased activity in one system is accompanied by decreased activity by the other.

### 3. Results and disscussion

The study was performed in the Coronary Care Unit of the Cardiology Center Timisoara and data were analyzed in the Computer Department of the County Hospital Timisoara.

Acute myocardial infarction has been shown to result in autonomic imbalance that can be followed by power spectral analysis of the HRV. Power spectral analysis has the potential to quantify sympathetic and parasympathetic nervous system activity.

In our study, data were analyzed using first a ECG devices (PPG-HELLIGE EK 512 P CARDIOGNOST) with 12 leads, that use a “Arrhythmia” analyzer. Data were analyzed as heart rate (in digital form and also as a trend), trend of ventricular premature beats, trend of RR intervals (ms), and also as heart rate variability for short time intervals (10 –20 minutes) in time domain and frequency domain (figure 6).

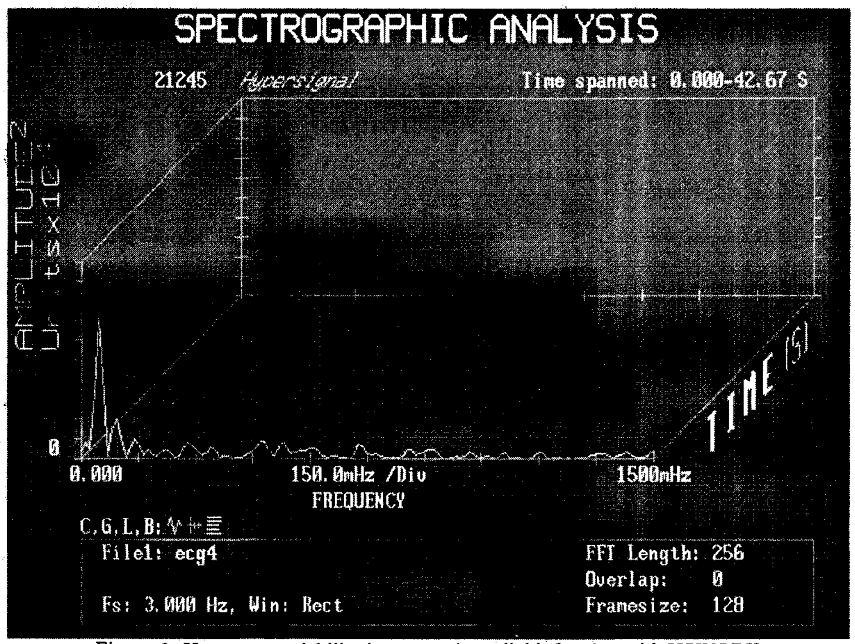


Figure 6. Heart rate variability in acute miocardial infarction with HSWORK program

Acute myocardial infarction is characterized by sympathetic activity and with loss of the high component of HRV, that means a higher risk for ventricular arrhythmias and arrhythmic death.

Data were analyzed off line. The software application was implemented a personal computer Pentium, 133 MHz. Since our software application is dealing with long-term recordings, one of the first problems encountered was the problem of "stationarity". The question was if spectral analysis performed in the entire 24-h period provide the same results as spectral results obtained from shorter segments (e.g. 5 min) averaged over the entire 24-h period.

Another problem is choosing the proper sampling rate. A low sampling rate may produce a jitter in the estimation of the R wave fiducial point which alters the spectrum considerably. The optimal range is 250 - 500 Mhz, while a lower sampling rate may behave satisfactorily only if an algorithm of interpolation is used.

We developed and implemented a software application for ECG processing. The application was written in Turbo Pascal and is running on MS-DOS operating system. The software application has a friendly interface and it is easy to use.

We implemented several signal processing techniques: fast Fourier transformation, different types of filters, autocorellation etc. The parameters required for running different processing techniques are established by the programme, but the user has the possibility to change them, function on type of the disease and type of the research performed.

We would like to develope a new version for our software application. This new version will work on Windows environment, which offers an easy to use man-machine interface and also supports network and multitasking functions. We will add new facilities for importing and exporting files using standard file formats (SCP, OEDIPE or CSE). Since acquired data occupies huge amount of disk space we will pay attention to compression techniques.