ECG MEASUREMENT AND ACQUISITION SYSTEM FOR DYNAMIC ANALYSIS OF HEART RATE VARIABILITY PARAMETERS

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Analiza Variabilitatea Ritmului Cardiac (VRC) este o metodă neinvazivă de investigare indirectă a sistemului cardiovascular şi a sistemului nervos autonom, pentru persoanele aparent sănătoase cât şi pentru cele cu diverse afecţiuni. Acest articol prezintă un sistem de măsurare şi achiziţie a semnalului ECG pentru analiza parametrilor VRC şi un program pentru analiza în dinamică a parametrilor VRC, bazat pe ferestre de dimensiuni şi "alunecări" variabile (alese de utilizator), program care oferă un grad înalt de versatilitate.

Heart Rate Variability (HRV) analysis has established itself as a non-invasive research and clinical tool for indirectly investigating both cardiac and autonomic system function in both health and disease. The present paper describes an EGG measurement and acquisition system for off line HRV parameters analysis and a software application for performing a dynamic HRV parameters analysis using time framing (data windows) and appropriate sliding steps as chosen by investigator. The application provides a high degree of versatility and the paper presents the algorithms.

Keywords: Heart rate variability, dynamic analysis, ECG tachogram, time and frequency domain analysis

1. Introduction

Heart rate variability (HRV) has come to be defined as the variation in the time period separating consecutive heartbeats. The time separation between the R peaks of adjacent QRS complexes in a continuous electrocardiogram (ECG) recording can be measured as inter-beat intervals in ms. The sympathetic and parasympathetic branches of the autonomic nervous system (ANS) regulate the activity of the cardiac pacemaker - sinoatrial node. The beat-to-beat variation in heart rate therefore reflects the time varying influence of the ANS and its components, on cardiac function. A short acquisition for ECG is presented in Fig.1.

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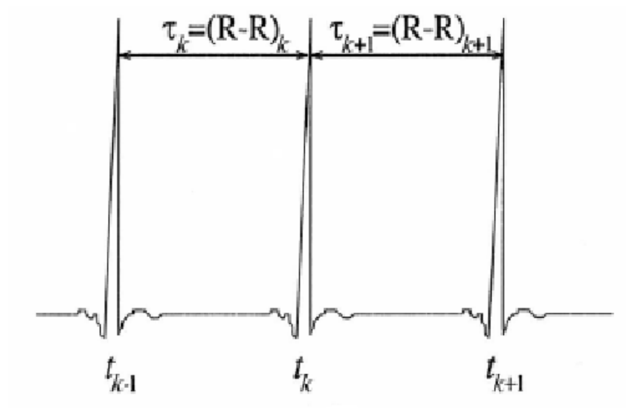


Fig. 1. ECG pattern (R-R peaks intervals)

The methodologies used to analyses HRV are based on analysis electrocardiogram data in time and frequency domains. From an ECG recording, each QRS complex is detected, determined as the time intervals between the „R” peaks from sinus node origin. Further, the ECG signal processing tools involve ECG recording, noise rejection, extracting RR series and concludes with the computation of the HRV parameters.

The ECG artifacts rejection are realized by cardiologist and implies manual rejection of abnormal (pathologic) RR intervals (HRV analysis uses only „normal” RR: „NN”). A schematic diagram of a system dedicated to the acquisition, recording and processing of the ECG signals is presented in Fig. 2.

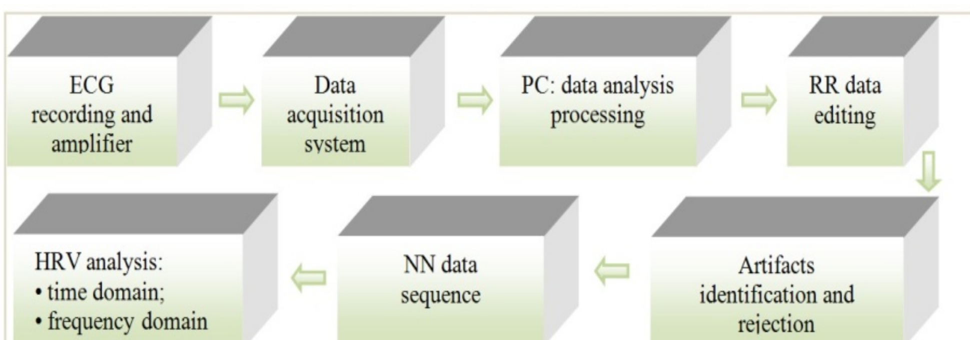


Fig. 2. ECG data acquisition, recording and processing system

For conventional time domain analysis, the variability in the R-R interval time series derived from an ECG recording is statistically summarized using conveniently calculated measures such as NN_{mean} [ms] (mean of all normal RR intervals), SDNN [ms] (standard deviation of all NN intervals) and RMSSD [ms] (the square root of the mean of the sum of the squares of differences between adjacent NN intervals) . The frequency domain analysis provides the spectral composition of these variations. The frequency spectrum of the HRV is calculated from the RR interval tachogram (RR durations vs. number of progressive beats). Through the use of computationally efficient algorithms such as Fast-Fourier Transform, the HRV signal is decomposed into its individual spectral components and their intensities, using Power Spectral Density (PSD) analysis - TP [ms^2] (total power for the analyzed NN intervals (0.003÷0.4 Hz)). These spectral components are then grouped into three distinct bands: very-low frequency (VLF [ms^2] - signal power in the very low frequency range (0.003÷0.04Hz)) and VLF_n [%] (power in normalized units: $VLF_n = (VLF / TP) \cdot 100 \quad [\%]$), low frequency (LF [$ms^2$] - signal power in the low frequency range (0.04÷0.15 Hz)) and LF_n [%] (power in normalized units: $LF_n = (LF / TP) \cdot 100 \quad [\%]$), high frequency (HF [$ms^2$] - signal power in the high frequency range (0.15÷0.4 Hz)) and HF_n[%] – (power in normalized units: $HF_n = (HF / TP) \cdot 100 \quad [\%]$), The cumulative spectral power in the LF and HF bands and the ratio of these spectral powers (LF/HF) [1].

2. The ECG measurement and acquisition system

The measurement system designed and used is a very modern one and contain the ECG amplifier module, a data acquisition module and a computer (Fig. 3).

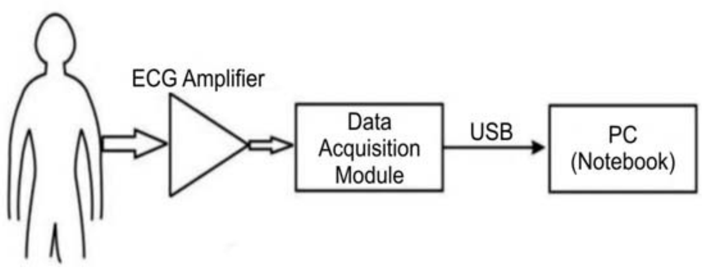


Fig. 3. The ECG measurement and analysis system

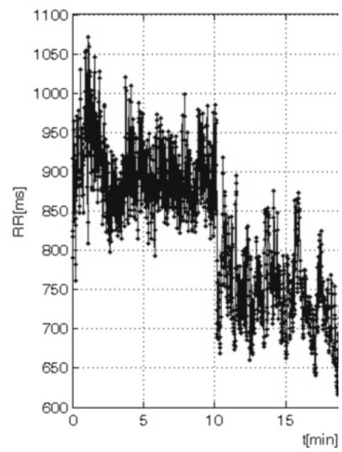
The schematic diagram of the ECG (Fig. 4) amplifier module - a dual channel version - contains:

AI_1, AI_2 - the instrumentation amplifiers;
GA - the active shield circuit;
AOI - the inverting amplifier;
FTS_1, FTS_2 - the high-pass filters;
FTJ_1, FTJ_2 - the low-pass filters [2].

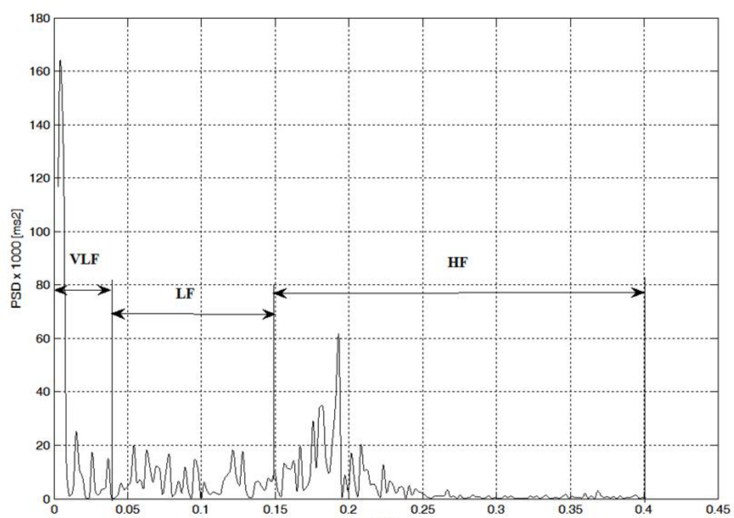
The data acquisition module (DAQ) used is a portable one that communicates with the computer through USB port (NI-6218) [3].

3. Software: dynamic analysis of HRV

The application designed and implemented in Matlab environment has several parts. As a result of the preprocessing phase, following the signal acquisition, the ECG tachogram is analyzed (Fig. 4. a). A second part performs the HRV analysis in frequency domain, by applying algorithms of spectral estimation to the ECG tachogram (Fig. 4. b).



a)



b)

Fig. 4. ECG tachogram (a) and frequency domain analysis of HRV parameters (b)

Dynamic analysis of HRV uses settable length of the NN vectors, with sliding windows chosen by the user. Performing such an analysis needs to consider following steps:

1. the NN intervals data are loaded and the algorithm resulting in the tachogram is performed ;
2. the user selects the analysis window size, NP from a set of predefined lengths (64÷1024 points);
3. the user selects the degree of superposition of the adjacent windows (the sliding windows rate), DF, from a set of predefined values, (10÷100% from NP);
4. the program displays the number of resulting windows (NF) and, for each window, the matrix having as elements the computed HRV parameters in time domain (NN_{mean}, SDNN and RMSSD) and in the frequency domain (TP, VLF_{norm}, LF_{norm}, HF_{norm} and LF/HF ratio) is presented (with option to export in Excel);
5. for an enhanced analysis the program displays also the HRV parameters evolution - ***dynamic analysis*** - (NN_{mean}, SDNN, RMSSD, TP, VLF_n, LF_n, HF_n and LF/HF): Fig. 5.

Next is presented the program running, with signs for 30 min ECG monitoring (Fig. 4. a):

- displays the number of points in data file (number of NN intervals observed after ECG recording editing/ artifact and noise rejection**): NRR =2235**;
- is selected number of points for analysis: **NP=256**;
- is selected moving/sliding windows rate (% from NP): **DF=25%**;
- displays the number of resulting windows, **NF=31** with sliding **A=64** points (“one point”=one NN interval);
- is estimated and displays the matrix of HRV parameters in time domain (NN_{mean}, SDNN and RMSSD) and frequency domain (TP, LF_{norm}, HF_{norm} and LF/HF ratio)., average times of the windows, in minutes [4].

Tables 1 and 2 contains in the first column the average time durations of the windows. In Fig. 5 is presenting evolution of HRV parameters: NP=256 (number of NN intervals); DF=25% (window rate moving/sliding analysis).

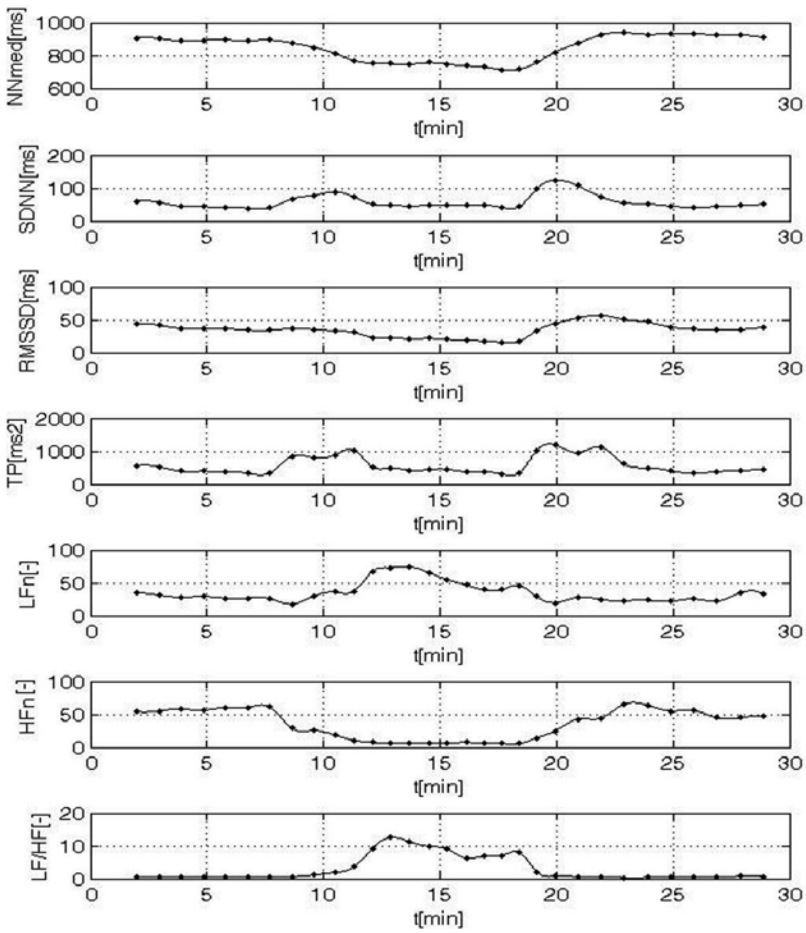


Fig. 5. Evolution of HRV parameters in time domain and frequency domain with NP=256; DF=25%.

Table 1

The evolution of HRV parameters in time domain (example)

T [min]	**NN_{mean} [ms]**	**SDNN [ms]**	**RMSSD [ms]**
2.0076 2.9429	906.37 904	60.302 56.969	44.138 42.025 .....
Avrage windows	**$(NN_{mean})_{avg}$[ms]**	**$(SDNN)_{avg}$ [ms]**	**$(RMSSD)_{avg}$[ms]**
—	841.96	57.881	33.69

Table 2

The evolution of HRV parameters in frequency domain (example)

T [min]	TP[ms2]	VLF_n [%]	LF_n [%]	HF_n [%]	LF/HF [-]
2.0076 2.9429 3.8818 …..	551.7 531.3 401.06 …..	11.374 13.437 14.047 …..	34.366 31.368 27.786 …..	54.254 55.193 58.166 …..	0.63342 0.56833 0.4777 …..
Average windows	$(TP)_{mean}$ [ms2]	$(VLF_n)_{avg}$ [%]	$(LF_n)_{avg}$ [%]	$(HF_n)_{avg}$ [%]	$(LF/H)_{avg}$ [-]
—	570.2	30.224	35.917	33.855	3.1821

4. Conclusions

The hardware system (the ECG amplifier, the data acquisition module and the computer) is a small and very flexible one, with good features. **This system was designed for HRV off-line analysis.**

For the best distinguish HRV parameters is necessary a smaller dimension of window and moving/sliding windows rate; under 128 points of window dimension are injured analysis in frequency domain, in the same time, a sliding that is too feebly can lead a very big number of windows and difficult program unreeling; our experience, the special situation is in fig. 5 **(N=256 /DF=25%)** ensures an optimal (a good compromise between the accurate and the quality of the physiological information from a frequency analysis of HRV).

An improper choice of these parameters can lead to false conclusions (from a medical interpretation); for example the selection of the setting is silently corrupting the results and therefore can contribute to wrong assessments regarding the patient.

The method of dynamic analysis performed to the ECG signals can be considered a handy instrument for the doctors during the patient monitoring phase. Moreover, it can be easily adapted for other clinic parameters for each time evolution and frequency domain features are of importance.

Unfortunately, most known software kits of the ECG recorder systems with HRV analysis used 10 minutes windows (NP≈512) and 100% sliding (succeeding window) and this facilities exist only in the newest generation device.

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