

ECG MONITORING SYSTEM FOR HEART RATE VARIABILITY ANALYSIS

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Abstract-A method to analyse HRV (heart rate variability) using an ECG monitoring system is presented. Variations in heart rate may be evaluated by a number of methods. The current methodologies used to analyse HRV are based largely on linear techniques to analyse 'past' and 'present' electrocardiogram (ECG) data in time and frequency domains. For conventional time domain analysis, the variability in the R-R interval time series derived from an ECG recording is statistically summarised using conveniently calculated measures such as SDNN (*standard deviation* of time interval between consecutive R peaks) and RMSSD (*root-mean square* of the difference between two adjacent R-R intervals). Depending on the length of the analysed ECG recording, which may vary from a few minutes to 24 hours, and the choice of the time domain measure, both short-term and long-term HRV can be quantified and characterised.

I. Introduction

The autonomic nervous system (ANS) is the portion of the nervous system that controls the body's visceral functions, including action of the heart, movement of the gastrointestinal tract and secretion by different glands, among many other vital activities. It is well known that mental and emotional states directly affect the ANS. Nowadays, research studies have examined the influence of emotions on the ANS utilizing the analysis of heart rate variability, which serves as a dynamic window into autonomic function and balance. This measure, derived from electrocardiogram (ECG), is a measurement of the naturally occurring beat to beat changes in the heart rate.

Over the last 25 years, 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. This paper describes a measurement system for off line HRV analysis and introduces aspects regarding the design of an on line measurement system.

II. Heart rate variability – Problem definition

The last two decades have witnessed the recognition of a significant relationship between the autonomic nervous system and cardiovascular mortality, including sudden cardiac death. Experimental evidence for an association between a propensity for lethal arrhythmias and signs of either increased sympathetic or reduced vagal activity has encouraged the development of quantitative markers of autonomic activity [1].

'Heart Rate Variability' has become the conventionally accepted term to describe variations of both instantaneous heart rate and RR intervals. In order to describe oscillation in consecutive cardiac cycles, other terms have been used in the literature, for example cycle length variability, heart period variability, RR variability and RR interval tachogram, and they more appropriately emphasize the fact that it is the interval between consecutive beats that is being analyzed rather than the heart rate per se.

Stress, certain cardiac diseases, and other pathologic states affect on HRV. A good review of physiological origins and mechanisms of HRV can be found in [2].

The normal variability in heart rate is due to the synergistic action of the two branches of the ANS, which act in balance through neural, mechanical, humoral and other physiological mechanisms to maintain cardiovascular parameters in their optimal ranges and to permit appropriate reactions to changing external or internal conditions. In a healthy individual, thus, the heart rate estimated at any

given time represents the net effect of the parasympathetic (vagus) nerves, which slow heart rate, and the sympathetic nerves, which accelerate it. These changes are influenced by emotions, thoughts and physical exercise. Our changing heart rhythms affect not only the heart but also the brain's ability to process information, including decision-making, problem-solving and creativity. They also directly affect how we feel. Thus, the study of heart rate variability is a powerful, objective and noninvasive tool to explore the dynamic interactions between physiological, mental, emotional and behavioral processes.

The current methodologies [1] used to analyse HRV are based largely on linear techniques to analyse 'past' and 'present' electrocardiogram (ECG) data in time and frequency domains. For conventional time domain analysis, the variability in the R-R interval time series derived from an ECG recording is statistically summarised using conveniently calculated measures such as SDNN (*standard deviation* of time interval between consecutive R peaks) and RMSSD (*root-mean square* of the difference between two adjacent R-R intervals).

Depending on the length of the analysed ECG recording, which may vary from a few minutes to 24 hours, and the choice of the time domain measure, both short-term and long-term HRV can be quantified and characterised. While time domain measures help in assessing the magnitude of the temporal variations in the autonomically modulated cardiac rhythm, the frequency domain analysis provides the spectral composition of these variations. The underlying assumption behind the traditional frequency domain HRV analysis is the 'time invariance' or 'stationarity' of the signal, i.e., the individual spectral components do not change over the duration of signal acquisition.

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. These spectral components are then grouped into three distinct bands: very-low frequency (VLF), low frequency (LF) and high frequency (HF).

In studies researching HRV, the duration of recording is dictated by the nature of each investigation. Standardization is needed, particularly in studies investigating the physiological and clinical potential of HRV. Frequency-domain methods should be preferred to the time-domain methods when investigating short term recordings. The recording should last for at least 10 times the wavelength of the lower frequency bound of the investigated component, and, in order to ensure the stability of the signal, should not be substantially extended. Thus, recording of approximately 1 min is needed to assess the HF components of HRV while approximately 2 min are needed to address the LF component. In order to standardize different studies investigating short-term HRV, 5 min recordings of a stationary system are preferred unless the nature of the study dictates another design.

III. The ECG Measurement and analysis system

The increased research on cardiovascular variability has become possible and attractive thanks to the vast technological progress in measurement devices in computational power. Currently acquisition of rhythms in heart rate may be carried out non invasively safely and accurately using the standard electrocardiogram. Signals may be easily digitised and stored on a personal computer which provides sufficient computational power for most analysis.

Further, we describe a measurement system designed for off line HRV analysis. As the fig. 1 shows it contains the ECG amplifier module, a data recording module and a portable computer/notebook.

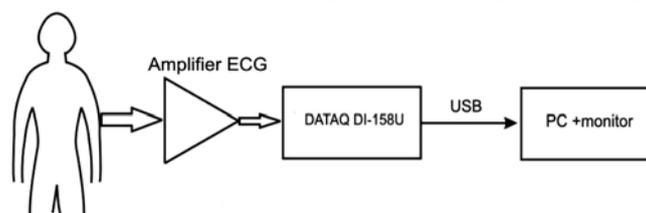


Figure 1. The ECG measurement and analysis system.

Equipment designed to analyze HRV in long-term recordings should implement time-domain methods including all four standard measures (SDNN, SDANN, RMSSD, and HRV triangular index)[5]. In addition to other options, the frequency analysis should be performed in 5 min segments (using the same precision as with the analysis of short-term ECGs). When performing the spectral analysis of the total nominal 24-h record in order to compute the whole range of HF, LF, VLF and ULF components, the analysis should be performed with a similar precision of periodogram sampling, as suggested for the short-term analysis, e.g. using 2^{18} points. The strategy of obtaining the data for the HRV analysis follows the design outlined in fig. 4.

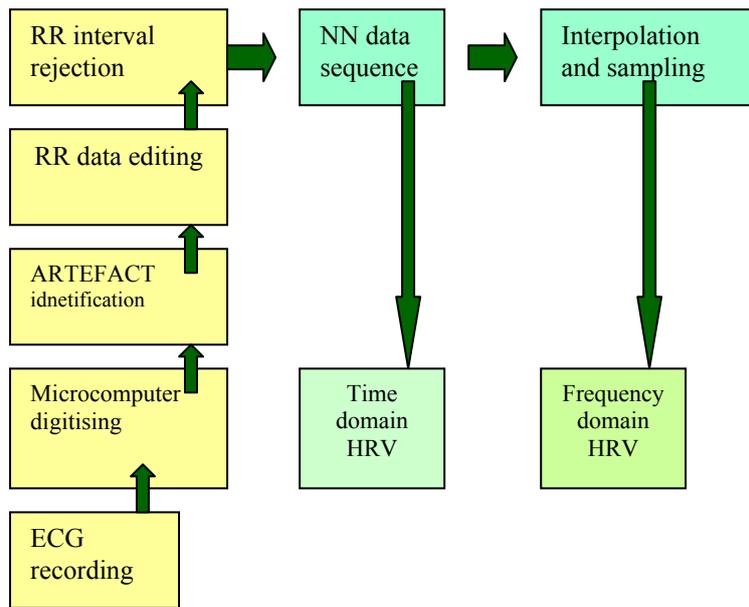


Figure 4. Flow chart summarizing individual steps used when recording and processing the ECG signal in order to obtain data for HRV analysis.

IV. Implementation and results

According to fig.1, the first section of the implemented software realises the identification , filetering and saving the ECG signal (fig. 5 a) and RR histogram (fig. 5 b).

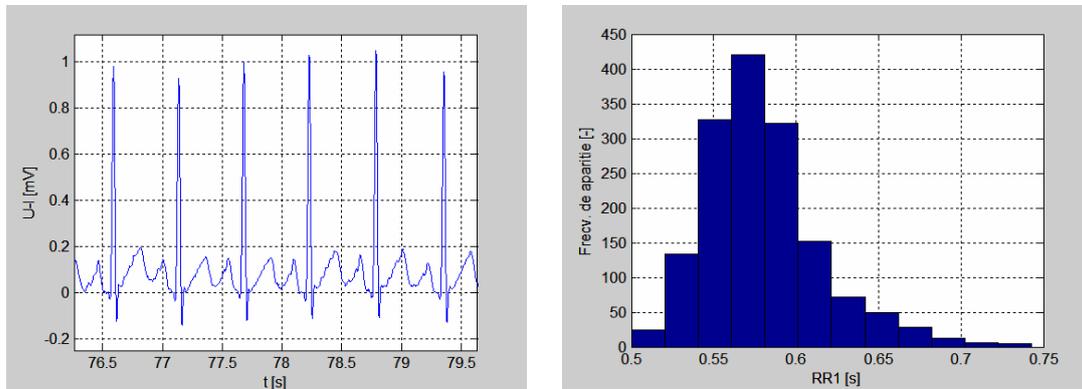
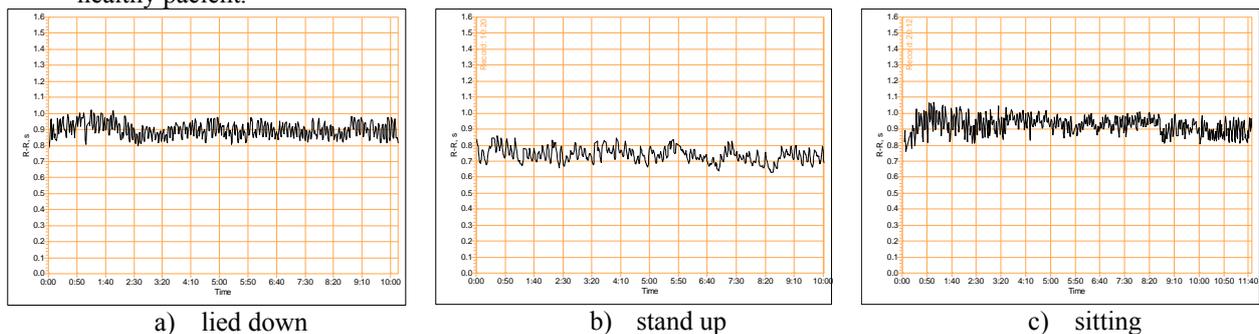


Figure 5.a) ECG signal ; b) RR histogram.

Six ICC patients and ten helthy people were the „subjects” for measurments and testing using a DATAQ module. Following figures present the cardiograms (6) and specrum samples (7) for a healthy patient.



a) lied down

b) stand up

c) sitting

Figure 6. Cardiogram samples for 3 study positons (A.RADU- healty subject)

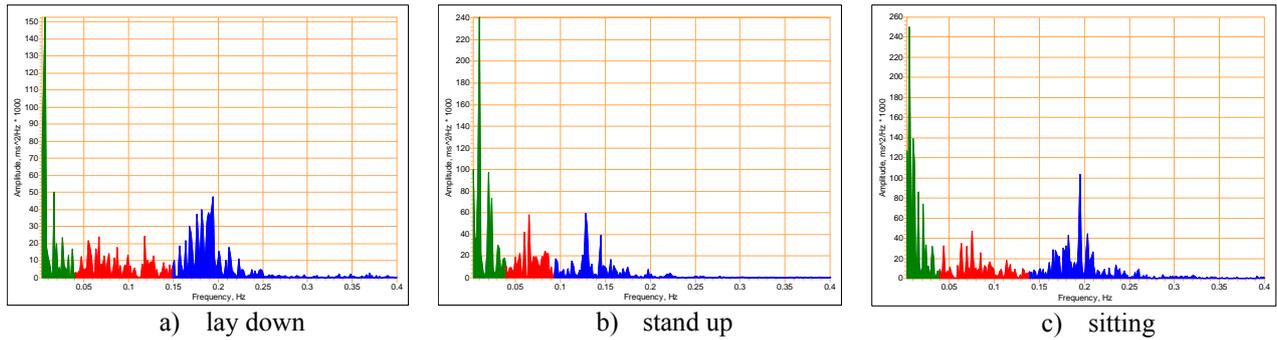


Figure 7. Spectrum samples for 3 study positons (A.RADU- healty subject)

Further, in the following tables for the date base are presented. Table 5 depicts VRC parameters in time domain and table 6 outlines VRC parameters in the frequency domain. Both of them present real data for two patients a normal one and a cardiac insufficiency one, before the implant.

Table 5. Time domain analysis.

Nr crt	Name	Test position	R-R min [ms]	R-R max [ms]	R-R med [ms]	SDNN [ms]	RMSSD [ms]	pNN50 [%]
1	Radu A.	1. LD	761	1072	898	51	40	20.3
		2. SU	617	918	739	51	21	2.95
		3. S	636	1070	916	64	46	23.1
2	Muntean F.	1. LD	622	946	772	52	29	9.72
		2. SU	508	1106	557	26	26	0.396
		3. S	342	1074	651	33	31	0.914

Tabel 6. Frequency domain analysis.

Nr.crt.	Test position	TP [ms ²]	VLF [ms ²]	LF [ms ²]	HF [ms ²]	LF norm [u.n.]	HF norm [u.n.]	%LF [%]	%HF [%]	LF/HF [-]
1	1. LD	2803	877	709	1217	36.8	63.2	25.3	43.4	0.583
	2. SU	3159	1480	749	930	44.6	55.4	23.7	29.4	0.805
	3. S	3777	1440	835	1502	35.7	64.3	22.1	39.8	0.556
2	1. LD	3338	1976	972	390	71.4	28.6	29.1	11.7	2.49
	2. SU	868	587	135	146	48.2	51.8	15.6	16.8	0.93
	3. S	1243	681	356	205	63.5	36.5	28.7	16.5	1.74

II. Conclusions

The trends in the further development of quantitative HRV indices that more closely represent the underlying physiological mechanisms are driven by new insights into these basic mechanisms together with the enhancements in computational methodology and speed of code execution. These should result in more specific diagnosis of the pathophysiology of the mechanisms regulating the beating of the heart. The presented ECG system is designed for HRV off-line analysis, but our late interest is towards a HRV on-line analysis system which will bring many advantages.

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