# ECG MEASURMENT AND ACQUISITION SYSTEM FOR HEART RATE VARIABILITY ANALYSIS

**Marcel STANCIU[1], Daniela FAUR[1], Anatolie BOEV[1], Adina STANCIU[2]**

*[1]University Politehnica Bucharest, Faculty of Electrical Engineering, 313 Splaiul Independentei, 060042, [2]Institute of Oncology "Prof. Dr. Alex. Trestioreanu" Bucharest, 252 Sos. Fundeni, smm93smm@yahoo.com, danielafaur@gmail.com, anatol_boev@yahoo.com, adinaelenastanciu@yahoo.com*

**Abstract – 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. 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. 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 analysis.**

***Keywords***: *EGG, measurement, acquisition, "Heart Rate Variability" (HRV).*

## 1. INTRODUCTION

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. "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. 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 clear 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 exercises. 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 HRV is a powerful, objective and noninvasive tool to explore the dynamic interactions between physiological, mental, emotional and behavioral processes.

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 digitized and stored on a personal computer which provides sufficient computational power for most analysis.

Following, a measurement and acquisition system designed for off line HRV analysis is described.

## 2. THE ECG MEASUREMENT AND ACQUISITION SYSTEM

The measurement system designed and used is a very modern one and contains the ECG amplifier module, a data acquisition module and a computer (Fig. 1).

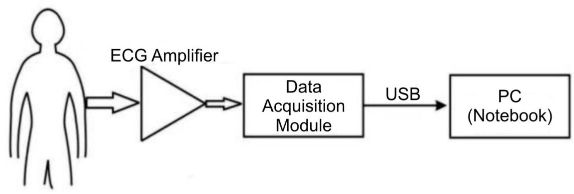


Figure 1: The ECG measurement and analysis system.

The schematic diagram of the ECG (Fig. 2) amplifier module - a dual channel version - contains:

$AI_1$, $AI_2$ - the instrumentation amplifiers;
GA - the active shiled circuit;
AOI - the inverting amplifier;
$FTS_1$, $FTS_2$ - the high-pass filters;

FTJ$_1$, FTJ$_2$ - the low-pass filters.

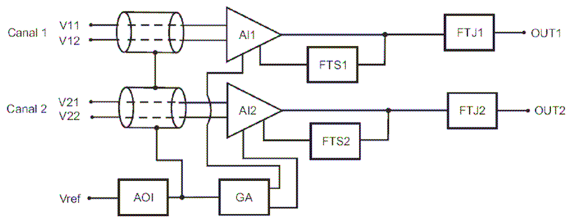


Figure 2: The schematic diagram of the ECG amplifier module (dual channel).

Gain by a factor of 100-1000 is desired for proper signal detection. The human body is not at ground potential but at a higher offset voltage common to both electrodes. This offset voltage is on the order of magnitude of a few volts making it difficult to distinguish the small differential voltages of the ECG signal. To combat this effect, a high common mode rejection ratio (CMRR) is essential. A high CMRR will allow the amplifiers to reject the large voltage variations and instead concentrate on the smaller differential voltages of the ECG signal. A minimum CMRR of 80 dB is necessary for this circuit design. The amplifiers used here have a CMRR of 120 dB and an input impedance of $10^{10}\Omega$. The electrodes are fed directly into the non-inverting inputs of amplifiers AI$_1$ and AI$_2$, as shown in the Figure 2. Amplifiers are designed with preset gains so that no external resistors are needed in this case. This allows the input impedance to remain high.
A detail of amplifier module systems is presented in Fig. 3.

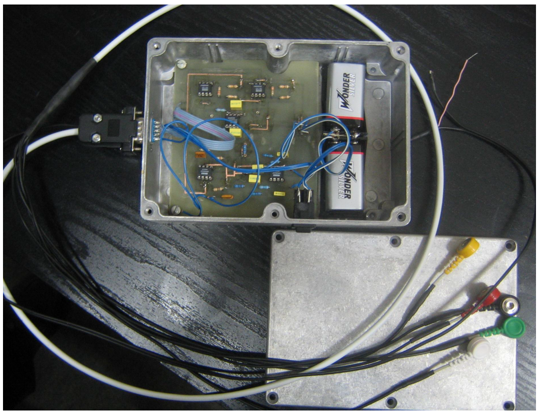

Figure 3: The ECG measurement system.

Fig. 4 and 5 present recorded ECG signals before and after filtering stage (FTJ). The cut-off frequency is setted according to application and to signal processing possibilities.

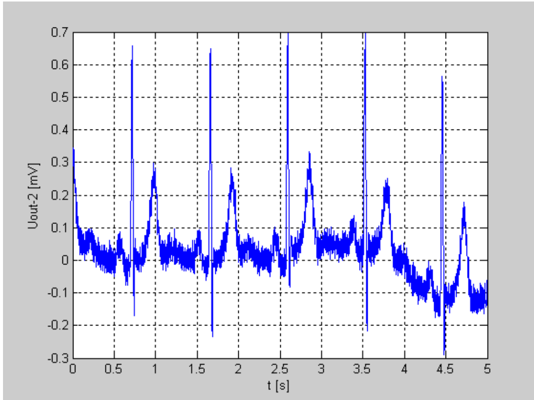


Figure 4 : The ECG signal – before filter stage.

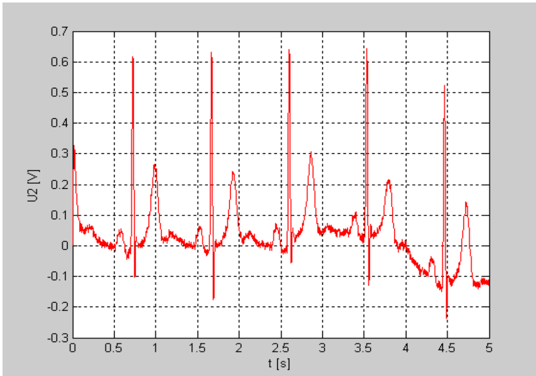


Figure 5 : The ECG signal – after filter stage.

The data acquisition (DAQ) module is a portable one that communicates with the computer through USB port. For this application there are many options and in this study had used two types: DATAQ DI-158U and NI USB-6218 (Fig. 6).


Figure 6: Data recording module: DATAQ DI-158U and NI USB-6218.

DATAQ DI-158 has 4 differential analog inputs, and can record at rates up to 14,4 kS/s, while the NI USB-6218 has 16 differential analog inputs and can record at rates up to 250 kS/s. The last one is favourable for

ECG 12-lead analysis or for fast recording and analysis.

## 3. THE HRV ANALYSIS

The variation in the time period separating consecutive heartbeats has come to be conventionally described as heart rate variability. These inter-beat intervals can be measured conveniently as the time separation between the R peaks of adjacent QRS complexes in a continuous electrocardiogram recording (RR). The sympathetic and parasympathetic branches of the autonomic nervous system (ANS) regulate the activity of the sinoatrial node, the cardiac pacemaker. The beat-to-beat variation in heart rate therefore reflects the time varying influence of the ANS and its components, on cardiac function. 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.

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 RRNN (***average*** of the R-R intervals), 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 characterized. 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 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 signals 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.

The cumulative spectral powers in the LF and HF bands and the ratio of these spectral powers (LF/HF) have demonstrable physiological relevance in healthy and disease states. Changes in the LF band spectral power (0.04–0.15Hz frequency range) reflect a combination of sympathetic and parasympathetic ANS outflow variations, while changes in the HF band spectral power (0.15–0.40Hz range) reflect vagal modulation of cardiac activity. The LF/HF power ratio is used as an index for assessing sympatho-vagal balance.

In the following are presented the results of the ECG measurement, acquisition and HRV analysis for a healthy person:

- after measurement and acquisition process results a data file with recorded ECG signals (Fig.5);
- the first step of the signal processing (data analysis) is extraction process of RR intervals: the rhythmogram (Fig. 7);

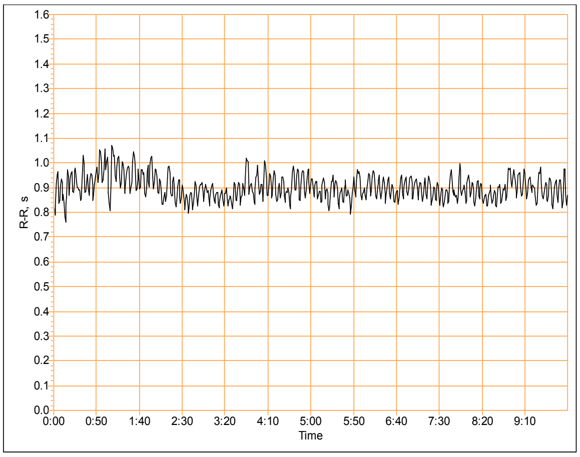


Figure 7 : The ECG rhythmogram (RR signal).

- the second step of the signal processing is the time-domain analysis (in Table 1 the most important parameters are presented);

| Parameter | Value |
|---|---|

| | |
|---|---|
| RRNN | 899 [ms] |
| SDNN | 50 [ms] |
| RMSSD | 40 [ms] |
| pNN50 | 20.2 [%] |

Table 1: Parameters' values for time-domain analysis.

- the last step of the signal processing is the frequency-domain analysis. In Table 2 are presented the most important frequency parameters and in Fig.8 and Fig. 9, the LF/HF power ratio (the sympatho-vagal balance) and the HRV spectrogram.

| Parameter | Value |
|---|---|
| TP | 2644 [$ms^2$] |
| VLF | 763 [$ms^2$] |
| LF | 676 [$ms^2$] |
| HF | 1205 [$ms^2$] |
| LF/HF | 0.561 [u.r.] |

Table 2: Parameters' values for the frequency–domain analysis.

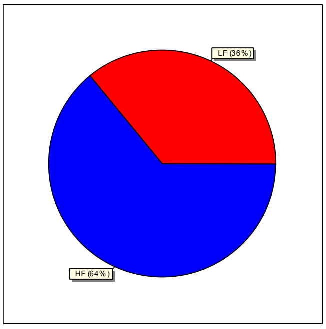


Figure 8 : The LF/HF power ratio.

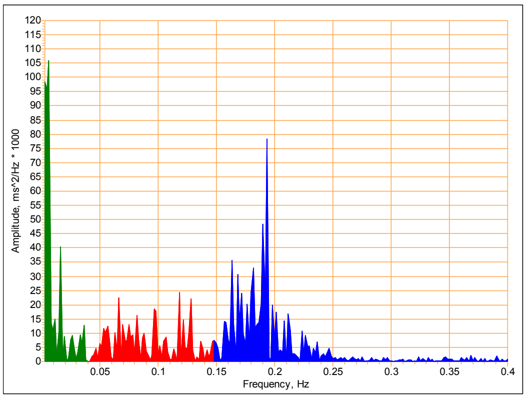


Figure 9 : The HRV spectrogram.

## 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 and on-line analysis, but our late interest is towards a HRV on-line analysis system which will bring many advantages.**

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.

## References

[1] Negoescu, R., *Inițiere în electronica medicală,* Editura Tehnică, Bucureşti, 1985.

[2] Negoescu, R, *Instrumentația electronică biomedicală*, Editura Tehnică, Bucureşti, 1985.

[3] Strungaru, Rodica, *Electronică medicală*, EDP, Bucureşti, 1982.

[4] Isar, Dorina, Isar, A., *Filtre*, Editura POLITEHNICA, Timişoara, 2003.

[5] Ciupa, R.V., *Introducere în Electronică Biomedicală*, Inst. Politehnic Cluj-Napoca, 1992.

[6] Costin, H., *Electronică Medicală*, Editura Cantes, Iaşi, 2000.

[7] Nagy, I., *Curs de electronică medicală,* Editura Eurobit, Timişoara, 1999.

[8] Policec, A., Gligor, T.D., Ciocloda, Gh., *Electronică medicală*, Editura Dacia, 1983.

*** INA-114, OPA2604, *Burr-Brown, Catalog Datasheet*, "pdf".