Non Contact Methods of Heart Rate Variability Measuring and Analysis

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***Abstract* – It is well known that the heart rate variability (HRV) reflects the activity of the autonomic nervous system. HRV is calculated from heart rate (HR). HR is a nonstationary signal; its frequency variation may contain indicators of current disease, or warnings about impending cardiac diseases. Irregular variance of HRV can be considered as a predictor for sudden cardiac death or for cardiac transplant patient, etc. Measurements of HRV can be acquired by analyzing the changes of heart rate with power spectral analysis or obtained from model by using the nonlinear dynamics e.g. chaos theory. This paper deals on different approach for HRV measuring and their properties. All described methods were tested and results are shown.**

Keywords – accelerometer; balistocardiography; ECG; heart rate variability; non contact electrodes; pressure wave

I. Introduction

HRV causes irregular RR intervals in electro cardiograph signal (ECG). HRV is most often derived from ECG [1, 2, 3]. HRV can be separated in 4 frequency bandwidth:

1. High frequency (HF) [0.15 – 0.4] Hz, t_M=1 min
2. Low frequency (LF) [0.04 – 0.15] Hz, t_M=5 min
3. Very low frequency (VLF) [0.0033 – 0.04] Hz, t_M=50 min
4. Ultra low frequency (ULF) [<0.0033] Hz, t_M=24 hour

where t_M is measuring time.

From previous HRV separation is seen that measuring time is long for LF, VLF and ULF. Consider contact ECG as the gold standard, but if the HRV is measured by means of contact ECG there are problems with electrodes. E.g. the wet electrodes method uses conductive gels that contain toxic materials that can cause patient skin irritation and are therefore they aren't suitable for long-term ECG imaging. Patients may also be allergy to nickel particles or acrylic adhesive present in frequently used hydrogel ECG electrodes. Methods using wet electrodes are therefore not suitable for long-term ECG sensing. But there are other possibilities for HRV measuring, because other physiologic signals can be used, see Fig.1. In this paper is described and tested on several methods for HRV measuring, which are based on: non-contact ECG measuring (NCECG) which is almost similar as contact ECG, accelerometer based method (ACC), pulse wave method (PW) and balistocardiograpfy (BCG) method. All these methods belong to non-invasive non contact methods and are suitable for different types of patients [4, 5, 6].

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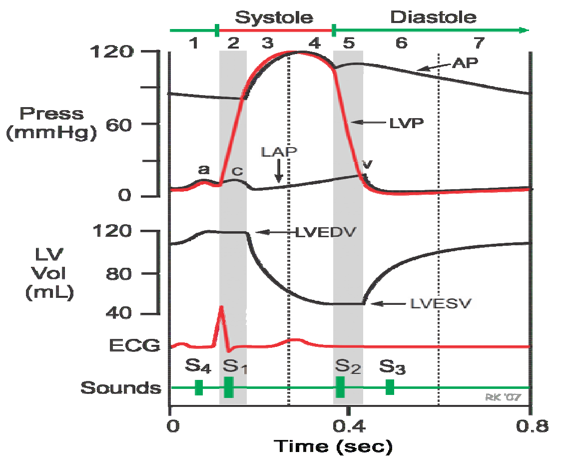

Figure 1. A single cycle of cardiac activity. Aortic pressure (AP), left ventricular pressure (LVP), left atrial pressure (LAP), left ventricular end-diastolic volume (LVEDV), left ventricular end systolic volume (LVESV), left ventricular volume (LV Vol), heart sounds (S_1-S_4). (Courtesy: Wikipedia)

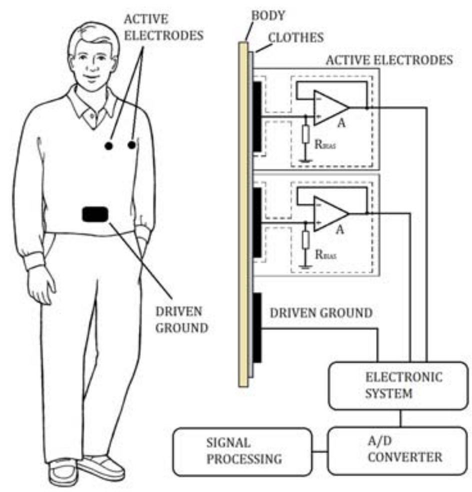

Figure 2. The block diagram of the system for NCECG method. The electrodes are placed on clothes

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Figure 3. The capacitance electrodes placed on the T-shirt (under rubber belt)

II. NCECG Method

For NCECG the high input impedance, capacitive coupled electrodes were used. The ultra-high input resistance active electrodes with amplifier, type PS25251 was used for NCECG system construction [7]. PS25251 is ultra high impedance ECG sensor, with typically 20 GΩ input resistance and capacitive coupling. Input capacitance is only 15pF but high-pas -3dB cutoff is typically 0.2 Hz. Low-pass -3dB cutoff is typically 10 kHz The simplified block diagram of measuring system is shown in Fig. 2. It is important to note that signal was wirelessly transmitted. In Fig. 3 the photo of non-contact capacitive electrodes placed on T-shirt is displayed.

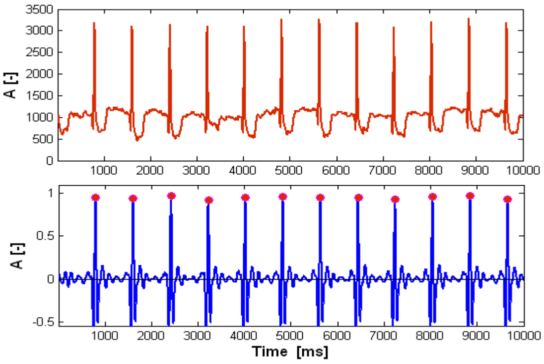

Figure 4. The example of NCECG - raw signal (top) and detected R waves (bottom)

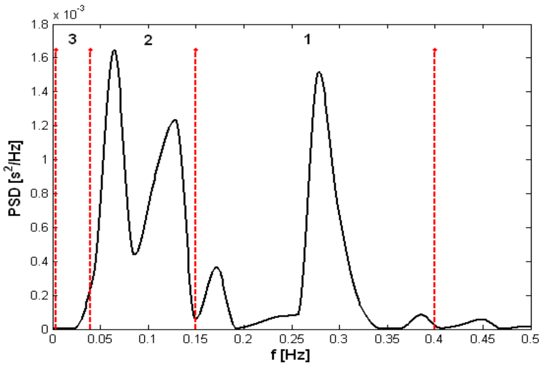

Figure 5. The example of PSD measured by means of NCECG separated in 3 bands, 1-HF, 2-LF, 3-VLF

The example of short NCECG signal measured by NCECG method and detected R waves are displayed in Fig. 4 In Fig. 5 the power spectral density (PSD) of NCECG signal is presented

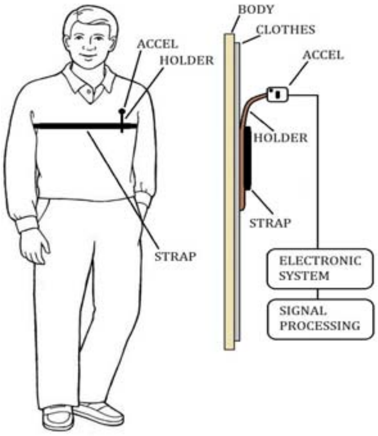

Figure 6. Acceleration method block diagram

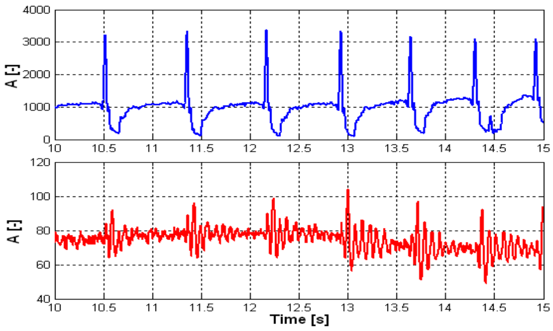

Figure 7. ACC method. ECG raw signal (top) and raw signal form accelerometer (bottom)

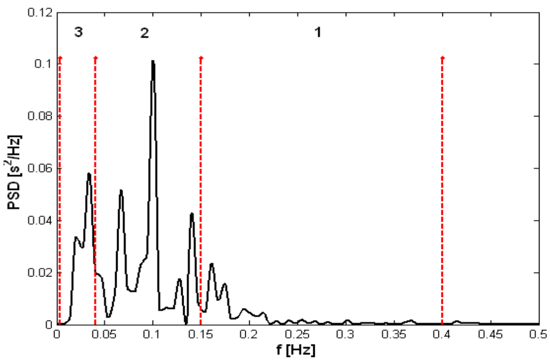

Figure 8. PSD measured by means of ACC method separated in 3 bands, 1-HF, 2-LF, 3-VLF

III. ACC Method

For this method the accelerometer was used. Block diagram of ACC method is shown in Fig. 6. Accelerometer is attached on rubber belt (ADXL345 3-Axis, ±2 g/±4 g/±8 g/±16 g was used) [8]. The short time evolution of NCECG and ACC signals are shown in Fig. 7. The PSD is presented in Fig. 8.

IV. PW Method

The third method is based on blood pressure waveforms measuring in finger [7, 8], see Fig. 9. The arterial pressure is measured non-invasively by means of small cuff placed around the finger with piezoelectric sensor inside. The principle is similar to photoelectric plethysmograph method, but it is much better concerning power consumption, because piezoelectric sensor is power source [9].

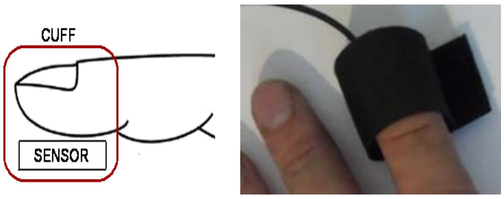

Figure 9. PW - piezoelectric senzor. Sensor principle (left), Photo of the sensor (right)

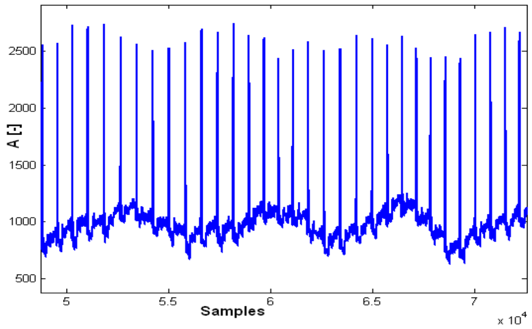

Figure 10. The example of raw signal. PW method

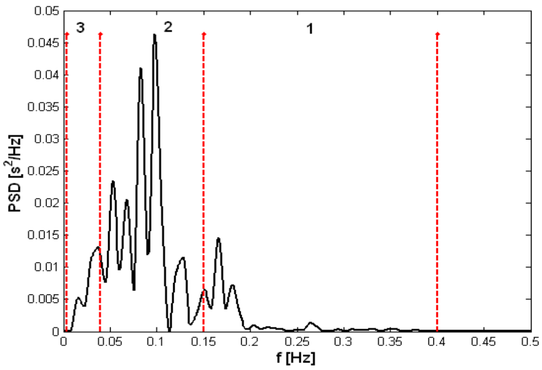

Figure 11. The example of PSD measured by means of PW separated in 3 bands, 1-HF, 2-LF, 3-VLF

Results of PW methods are displayed in Fig. 10, where time evolution of signal from piezoelectric sensor, the PSD is shown in Fig. 11.

V. BCG Method

The forth method is based on mechanical vibrations of body [10, 11, 12]. BCG is a newly revived inexpensive method where local vibrations due to cardiovascular function are detected non-invasively from the sternum. These vibrations provide information about the mechanical function of the cardiovascular system that can be used as an independent diagnostic method. Thus, BCG has been proposed to be a useful tool in ischemia detection. BCG is also proposed to function as a relatively simple method for assessing myocardial contractility. Measuring principle is shown in Fig. 12. The tested person only sits on rigid chair with force sensor. Balistocardiogram is a record of mechanical oscillations generated by a movement of heart and blood flow through great vessels in upper part of body. From BCG systolic forces, HR and HRV can be derived. Example of measured BCG signal with detected maximal values for derivation HR and HRV is presented in Fig. 13. PSD is displayed in Fig. 14.

Main advantage of BCG method is that sensor is not attached to tested person. Disadvantage of BCG is sensitivity on body movement. Time evolution of BCG signal is similar as signal from ACC method.

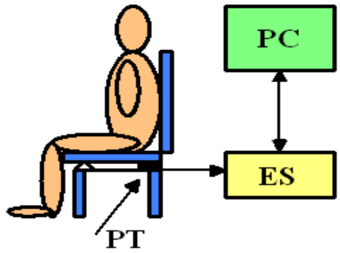

Figure 12. BCG PT - piezoelectric transducer (force sensor), ES - electronic system, PC - personal computer

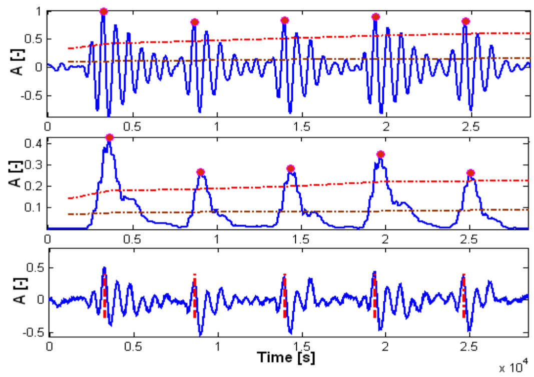

Figure 13. BCG method. Raw signal (top) and detected maximal values (middle), filtered signal with detected R (bottom)

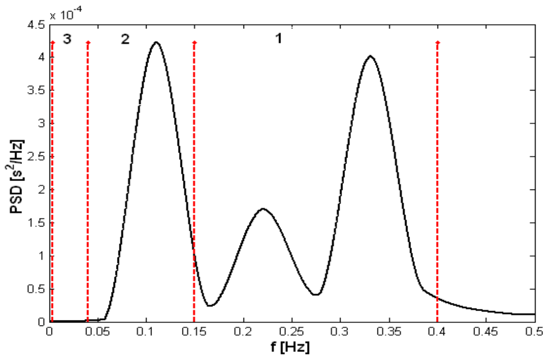

Figure 14. PSD measured by means of BCG method separated in 3 bands, 1-HF, 2-LF, 3-VLF

VI. Evaluation

The HRV is based on time domain and spectral methods [13 - 24]. The important parameters (calculated in Tab. I) are [25]: SDNN - the standard deviation of NN intervals. RMSSD - Root mean square of the successive differences – used for a good snapshot of the Autonomic Nervous System's Parasympathetic branch and is the basis of our "HRV Score", NN50 - The number of pairs of successive NN (R-R) intervals that differ by more than 50 ms. pNN50 - The proportion of NN50 divided by the total number of NN (R-R) intervals multiplied by 100 (result in %). HRM - mean HR during measuring, P_{LF}, P_{HF} - powers in LF and HF bands. Equations are following:

$$SDNN = \sqrt{\left(\frac{1}{N-1}\right)\sum_{j=1}^{N}\left(NN_j - \overline{NN}\right)^2} \qquad (1)$$

$$RMSSD = \sqrt{\left(\frac{1}{N-1}\right)\sum_{j=1}^{N-1}\left(NN_{j+1} - NN_j\right)^2} \quad (2)$$

$$SDSD = \sqrt{\left(\frac{1}{N-1}\right)\sum_{j=1}^{N-1}\left(\left|NN_{j+1} - NN_j\right| - \overline{\Delta NN}\right)^2} \quad (3)$$

TABLE I. RESULTS OF DIFFERENT METHODS

Method	NCECG	ACC	PW	BCG
SDNN [ms]	86.5	87.6	87	84
RMSSD [ms]	37.9	37.4	38.1	37.6
SDSD [ms]	38	37.5	37.9	38.1
pNN50 [%]	18.1	18.7	18.8	18.9
HRM [beat/min]	80.9	80.5	79.7	80.2
P_{LF} [ms^2]	2435	2427	2520	2470
P_{HP} [ms^2]	584	522	530	545

VII. CONCLUSION

In this work, several methods for HRV was described, constructed and tested. The data was transmitted wirelessly to a PC. It was proof (see Tab. I), that results are similar for one tested subject. The NCECG method is gold standard. The ACC and BCG signals are similar but booth methods are sensitive for patient movement. The one of most promising method is PW method, because of minimal power consumption what is important for long measuring. It would be best to test all methods simultaneously on one subject, but it has not been technically possible so fare. Also, the difference in values in the table for different methods is due to measurements at different times on different subjects.

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