Non Contact Methods of Heart Rate Variability Measuring and Analysis

Milan Stork
Department of Applied Electronics and
Telecommunications/RICE
University of West Bohemia
Plzen, Czech Republic
stork@kae.zcu.cz

Josef Houzar
Department of Applied Electronics and
Telecommunications/RICE
University of West Bohemia
Plzen, Czech Republic
jhouzar@gmail.cz

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 electrocardiograph 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, \( t_{HF} = 1 \) min
2. Low frequency (LF) [0.04 – 0.15] Hz, \( t_{LF} = 5 \) min
3. Very low frequency (VLF) [0.0033 – 0.04] Hz, \( t_{VLF} = 50 \) min
4. Ultra low frequency (ULF) [<0.0033] Hz, \( t_{ULF} = 24 \) hour where \( t_{n} \) 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 balistocardiography (BCG) method. All these methods belong to non-invasive non contact methods and are suitable for different types of patients [4, 5, 6].

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 (S1-S4). (Courtesy: Wikipedia)

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

This work was supported by Department of Applied Electronics and Telecommunications, University of West Bohemia, Pizen, Czech Republic and by the Ministry of Education, Youth and Sports of the Czech Republic under the project OPVV Electrical Engineering Technologies with High-Level of Embedded Intelligence, CZ.02.1.01/0.0/0.0/18_069/0009855 and by the Internal Grant Agency of University of West Bohemia in Pizen, the project SGS-2018-001.

ISBN 978-80-261-0892-4, © University of West Bohemia, 2020
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-pass -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 3. The capacitance electrodes placed on the T-shirt (under rubber belt)](image)

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.

![Figure 6. Acceleration method block diagram](image)

![Figure 7. ACC method. ECG raw signal (top) and raw signal form accelerometer (bottom)](image)

![Figure 8. PSD measured by means of ACC method separated in 3 bands, 1-HF, 2-LF, 3-VLF](image)

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].
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.

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:

\[
SDNN = \sqrt{\frac{1}{N-1} \sum_{j=1}^{N} (NN_j - \bar{NN})^2}
\]
I), that results are similar for one tested subject. The transmitted wirelessly to a PC. It was proof (see Tab. described, constructed and tested. The data was times on different subjects.

Also, the difference in values in the table for one subject, but it has not been technically possible so would be best to test all methods simultaneously on consumption what is important for long measuring. It is PW method, because of minimal power patient movement. The one of most promising method signals are similar but both methods are sensitive for NCECG method is gold standard. The ACC and BCG

TABLE I. RESULTS OF DIFFERENT METHODS

<table>
<thead>
<tr>
<th>Method</th>
<th>NCECG</th>
<th>ACC</th>
<th>PW</th>
<th>BCG</th>
</tr>
</thead>
<tbody>
<tr>
<td>SDNN [ms]</td>
<td>86.5</td>
<td>87.6</td>
<td>87</td>
<td>84</td>
</tr>
<tr>
<td>RMSSD [ms]</td>
<td>37.9</td>
<td>37.4</td>
<td>38.1</td>
<td>37.6</td>
</tr>
<tr>
<td>SDD [ms]</td>
<td>38</td>
<td>37.5</td>
<td>37.9</td>
<td>38.1</td>
</tr>
<tr>
<td>pNN50 [%]</td>
<td>18.1</td>
<td>18.7</td>
<td>18.8</td>
<td>18.9</td>
</tr>
<tr>
<td>HRM [beat/min]</td>
<td>80.9</td>
<td>80.5</td>
<td>79.7</td>
<td>80.2</td>
</tr>
<tr>
<td>Rv [ms²]</td>
<td>2435</td>
<td>2427</td>
<td>2520</td>
<td>2470</td>
</tr>
<tr>
<td>Psv [ms²]</td>
<td>584</td>
<td>522</td>
<td>530</td>
<td>545</td>
</tr>
</tbody>
</table>

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 both 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.

REFERENCES


