

# Comparison between Electrocardiographic and Photoplethysmographic Peaks Intervals

Alexandru-Constantin Podaru<sup>1</sup>, Valeriu David<sup>1</sup>, Oana Neacsu<sup>1</sup>

<sup>1</sup>*Faculty of Electrical Engineering "Gheorghe Asachi"*

*Technical University of Iasi*

*Iasi, Romania*

[podarualex23@gmail.com](mailto:podarualex23@gmail.com), [valdavid@tuiasi.ro](mailto:valdavid@tuiasi.ro), [oneacsu@tuiasi.ro](mailto:oneacsu@tuiasi.ro)

**Abstract** – A low-cost wearable system has been developed, that was used to record simultaneously the electrocardiographic signal (ECG) and photoplethysmographic signal (PPG). The prototype permits an offline working mode, being capable of recording both signals, ECG and PPG, on a memory card, using Arduinonano board. The recorded signals consist from the first derivation of ECG and the PPG signal collected from the left-hand index finger. First, we collected signals from several subject, in the same manner for all, before detecting the interested peaks from those signals, we removed the noise, from ECG to avoid false or missed peaks that can appear during the recording process, and we determined the RR peaks and R-to-R time interval. Also from PPG signal, we determined the PP peaks and P-to-P time interval. Using these results we determined the differences ( $\varepsilon$ ) between the R-to-R and P-to-P time intervals, in order to observe which is the greatest difference between these parameters and if we can replace the RR intervals with PP interval. From the obtained results, we concluded that the majority of the differences are lower than 3%, about 92% from the total of the detected intervals. Also we detected that 5% of the differences are between 3% and 5%, and only 3% are above 5%.

**Keywords** – *electrocardiographic signal (ECG), photoplethysmography signal (PPG), portable system, RR intervals, PP intervals.*

## I. INTRODUCTION

The electrocardiogram (ECG) signals are used in diagnosis for heart disease. In our day's trends in medical diagnostic and patient monitoring include portable devices for "in situ" monitoring [1, 2].

Medical equipment has been more portable, due to the development of technology and the small design of components, which allows the usage of the equipment in different environments, while minimizing discomfort. In

addition, given the choice of various designs and software versions, new systems can be designed, the cost can be minimized, and specific parameters of interest can be chosen for monitoring.

Even if these systems are very popular among consumers, the signal noise will remain a major problem [3, 4]. Also, there are other biomedical signals that are used in diagnosis for heart disease, for example, photoplethysmographic signal (PPG). One important parameter that is used in diagnosis the heart diseases is the heart rate variability (HRV) [5, 6]. HRV represent the analysis of RR interval time series. The RR intervals are determined by detecting the R peaks of the ECG signal.

PPG represent the optical detection of pulsatile blood volume changes in the vascular bed under the PPG sensor. It can be used in clinical applications related mainly to the cardiovascular system [7], also it is known that the PPG signal can be useful for detection of cardiac arrhythmias [8]. Measurement of PPG signal is a non-invasive technique that can be used to investigate the functioning of the heart. Also, the PPG signal cannot be affected by electromagnetic interferences, due to the fact that the PPG sensor converts a mechanical signal to an electrical one, by measuring the changes of the light absorption, at the skin level.

In this work, we designed a portable system, which is capable of recording simultaneous the ECG and PPG signals. With these signals, we determined the R-to-R time interval, from ECG, and the P-to-P time interval from PPG and in the end, the differences between RR and PP time intervals are calculated.

## II. RELATED RESULTS IN THE LITERATURE

There is an increasing interest in the study of the HRV among the researchers from diverse fields [9]. Also, in previous years, many works have been done in order to study the compatibility of pulse rate variability (PRV) to HRV [10, 11, 12, 13, 14, 15], but the conclusions are divided. In their study [13], supports the theory that PRV

is not a surrogate for HRV, but following studies suggest that PRV can replace HRV in stationary condition [14,15].

The results obtained by [10], indicates that are some small differences in the time-varying spectral indices extracted from HRV and PRV, fact that suggested that PRV can be used as an alternative measurement of the HRV during non-stationary conditions. Similar results were obtained by [12], where they compared the results obtained from the healthy subject during normal breathing, but they also concluded that PRV does not reflect HRV for subjects with obstructive sleep apnea (OSA).

Until now, it is still unclear, if the HRV parameters can be obtained from the PPG signal. Due to different opinions on this subject, works are needed to be done with the purpose of establishing a conclusive result.

### III. DESCRIPTION OF THE METHOD

We designed a wearable system, which can monitor cardiac activity and the blood flow at the surface of the skin, and we used it to conduct monitoring of ECG and PPG signals. The system was designed to record the first derivation of ECG and PPG signal from the left-hand index finger.

It consists of an ECG signal amplification stage, an infrared PPG sensor and the acquisition and processing part of the system. The block diagram of this system is presented in Fig. 1.

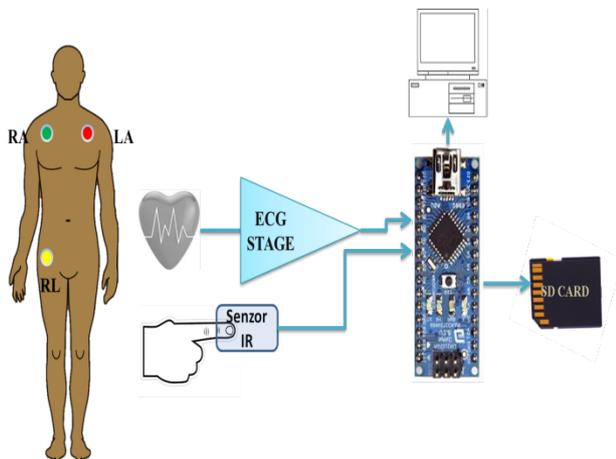


Fig.1. The block diagram of the wearable system

The ECG stage, consist of an instrumentation amplifier, a high-pass filter, with the cutoff frequency  $f_c=0.05\text{Hz}$ , a notch filter,  $f_n=50\text{Hz}$  and a low-pass filter with the cutoff frequency  $f_c=800\text{Hz}$ .

The instrumentation amplifier used for this system is INA 128. This is a precision amplifier, which can be used in biomedical instrumentation; the amplification can be set using an external resistor [16].

For the acquisition part, we used ATMEGA328 microcontroller, integrated into the development board Arduino Nano 3.0. It consists of 14 digital I/O, of which 6 are PWM outputs, 8 inputs for analogue to digital conversion, the converter resolution is 10 bits [17]. In our case, the system used the same sampling frequency for both recorder signals, ECG and PPG, which is  $F_s=770$  samples/second. We used the same sampling frequency for both signals, in order to avoid time decalation, caused by the analog-numerical conversion. The resulting data, is then stored on a memory card, into a text file. The format of the data is in decimal, and the ECG signal information is separated from the PPG signal information, by a comma.

We collected signals from several subjects, with age between 23 and 40. The signals were collected in the same way from all subjects. They were set on a chair, without having an activity. We recorded the first derivation of ECG and the PPG signal was collected from the left-hand index finger.

In order to extract the necessary information from the signal, we used MatLab software. We used it to determine ECG cycles, most important the R-wave peak. Before finding the R wave peaks from the ECG, first, we must remove the noise from the recorded signal. In this mode, we can avoid false or missed peaks that can appear during the recording process due the noise or artefacts. Fig.2 represents the ECG signal, before and after removing noise.

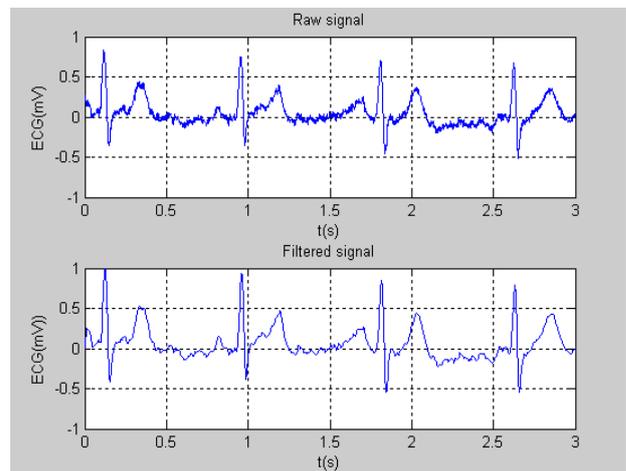


Fig.2. ECG signal before and after filtering

For the detection of R peaks, we used an algorithm based on Pan-Tompkins algorithm, until now one of the best ways to automatically detect peaks, as is seen in Fig. 3. After that, we detected the P peaks from PPG signal and calculated the R-to-R and P-to-P time intervals.

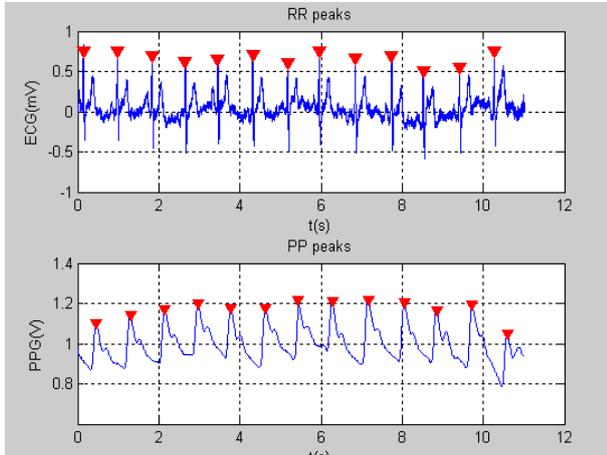


Fig 3. R and P peaks detections

To determine the differences between the R-to-R time intervals and the P-to-P time intervals we used formula (1):

$$\varepsilon = \frac{|RRi - PPi|}{RRi} \cdot 100 \quad (1)$$

where RRi represents the time between two R peaks and PPi the time between two P peaks.

The differences were calculated in the same manner for all subjects. The analyzed signals record duration is 5 minutes for each subject, unlike [10, 12, 14, 15], where they used 2 minutes from the recorded signals.

#### IV. RESULTS AND DISCUSSIONS

After calculating the time intervals and differences for each subject, we determined the maximum difference, the number of differences above 5% and the number of differences between 4%-5%, 3%-4%, 2%-3%, 1%-2% and below 1%. In Table I there are presented these values for each subject.

From the results that we obtained, we observe that the majority of differences, between the RRi and PPi, are below 3%. In Fig. 4, we can easily see that 92% of the detected intervals, the difference is under 3%. But if we set a higher limit, for example, the difference to be 5% as in other studies, the percentage rises to 97%, and only 3% have a difference above 5%.

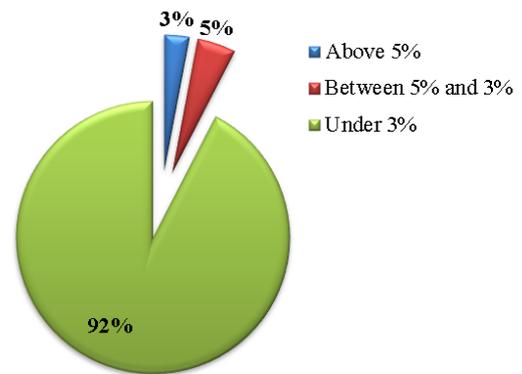


Fig.4 The diagram of the differences

Having these results, we can continue our study and record the ECG and PPG signals from subjects that are having an activity. We wish to see if the results are the same for no stationary conditions.

Table1: Detected differences between RRi and PPi, for each subject

Subject	Gender	Age	Max. $\varepsilon$ (%)	The number of differences between RRi and PPi						Total number of intervals
				>5%	4%-5%	3%-4%	2%-3%	1%-2%	<1%	
1	M	27	4.39%	0	1	6	30	92	202	331
2	M	28	5.20%	3	6	5	11	75	222	322
3	M	36	7.66%	6	4	6	18	74	251	359
4	M	36	8.70%	13	2	9	27	105	251	407
5	M	40	6.09%	7	25	46	74	96	138	386
6	M	23	9.56%	14	10	17	45	109	256	451
7	M	24	11%	19	9	12	38	113	277	468
8	M	23	13.4%	30	21	23	57	108	217	456
9	M	23	7.7%	13	7	10	22	121	242	415

10	M	24	12.5%	32	2	15	27	109	229	414
11	M	24	6.43%	7	5	8	9	62	255	356
12	M	24	11.68%	13	9	20	40	94	207	383
13	M	23	15.45%	6	1	6	26	112	250	401
14	M	33	6.45%	6	2	5	16	62	289	308
15	F	32	6.06%	5	4	10	20	108	277	424
16	F	26	13.36%	15	5	7	14	93	293	427
17	F	23	18%	10	2	3	16	77	303	411
18	F	30	17%	14	2	5	16	74	286	397

## V. CONCLUSIONS

We developed a portable system that can be used for simultaneous monitoring of ECG and PPG signals. Because the obtained data is stored on a memory card, the system can be used in any environment. Also, due to the fact that the Arduino boards have 8 inputs for analogue to digital conversion, we can improve our system by adding additional biomedical signals (eg. phonocardiogram, the respiratory signal, second ECG lead).

With the help of our system, we successfully recorded both ECG and PPG from several subjects, with ages between 23 and 40. After processing the data we concluded that the P-to-P time intervals can be used in determining PRV metrics as an alternative for HRV metrics.

We can now use this system to perform monitoring of ECG and PPG signals, in stationary condition. We will continue the study to observe if we can obtain the same results in nonstationary conditions, and to enlarge our data base.

## REFERENCES

- [1] Mariel, A and Osborn, P, *FIR filters and their applications*, Journal of Engineering and Signal Processing, vol 6, no. 2, June 2005, pp. 118-126.
- [2] D. Andrițoi, V. David, R. Ciorap, "An Portable Device for ECG and Photoplethysmographic Signal Acquisition," *Faculty of Electrical Engineering "Gheorghe Asachi" Technical University of Iasi, Romania*
- [3] Jianqiang, Li, Genqiang Deng, Wei Wei, Huihui Wang, Zhong Ming, *Design of a Real-Time ECG Filter for Portable Mobile Medical Systems*, IEEE Access, vol 5, March 2017, pp 696-704
- [4] W. Wei and Y. Qi, "Information potential elds navigation in wireless Ad-Hoc sensor networks," *J. Sensors*, , vol. 11, no. 5, pp. 47944807, 2011.
- [5] H. Costin, C. Rotariu, A. Pasarica, "Identification of Psychological stress by analyzing Electrocardiographic signal," *Environmental Engineering and Management Journal*, VOL. 12, NO. 6, June 2013
- [6] H. Costin, C. Rotariu, A. Păsărică, "Mental Stress Detection using Heart Rate Variability and Morphologic Variability of ECG Signals", *Proc. of EPE 2012 Iasi*, Oct. 2012, pp. 591-596
- [7] J. Allen, "Photoplethysmography and its application in clinical physiological measurement", *Physiol Meas.*, 2007.
- [8] R. Yousefi, M. Nourani, S. Ostadabbass, I. Panahi, "A Motion-Tolerant Adaptive Algorithm for wearable Photoplethysmographic Biosensors" *IEEE Journal of Biomedical and Health Informatics*, VOL. 18, NO. 2, March 2014
- [9] J. F. Thayer, R. D. Lane, "Claude Bernard and the heart-brain connection: Further elaboration of a model of neurovisceral integration" *Neuroscience and Biobehavioral Reviews*, 2008.
- [10] E. Gil, M. Orini, R. Bailón, J.M. Vergara, L. Mainardi, P. Laguna, "Photoplethysmography pulse rate variability as a surrogate measurement of heart rate variability during non-stationary conditions" *Physiol Meas.* 31 (2010), 1271–1290.
- [11] M. Bolanos, H. Nazeran, E. Haltiwanger, "Comparison of heart rate variability signal features derived from electrocardiography and photoplethysmography in healthy individuals" *ConfProc IEEE Eng Med Biol Soc.*, 2006.
- [12] A. H. Khandoker, C. K. Karmakar, M. Palaniswami "Comparison of pulse rate variability with heart rate variability during obstructive sleep apnea", *Department of Electrical & Electronic Engineering, The University of Melbourne, Melbourne 3010, Australia*, 2010
- [13] I. Constant, D. Laude, I. Murat, J-L Elghozi, "Pulse rate variability is not a surrogate for heart rate variability", *Clinical Science*, 1999.
- [14] K. Charlot, J. Cornolo, J.V. Brugniaux, J.P. Richalet, A. Pichon, "Interchangeability between heart rate and photoplethysmography variabilities during

sympathetic stimulations”, *Physiol Meas.*, 2009.

- [15] N.D. Giardino, P.M. Lehrer, R. Edelberg, “Comparison of finger plethysmograph to ECG in the measurement of heart rate variability”, *Psychophysiology*, 2002.

[16]<http://www.ti.com/lit/ds/symlink/i-na129.pdf>

[17]<https://www.arduino.cc/en/Main/ArduinoBoardNano>