

Evaluation of Heart Rate Variability by means of Laser Doppler Vibrometry measurements

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Abstract. Heart Rate Variability (HRV) analysis aims to study the physiological variability of the Heart Rate (HR), which is related to the health conditions of the subject. HRV is assessed measuring heart periods (HP) on a time window of >5 minutes (1)-(2). HPs are determined from signals of different nature: electrocardiogram (ECG), photoplethysmogram (PPG), phonocardiogram (PCG) or vibrocardiogram (VCG) (3)-(4)-(5). The fundamental aspect is the identification of a feature in each heartbeat that allows to accurately compute cardiac periods (such as R peaks in ECG), in order to make possible the measurement of all the typical HRV evaluations on those intervals. VCG is a non-contact technique (4), very favourable in medicine, which detects the vibrations on the skin surface (e.g. on the carotid artery) resulting from vascular blood motion consequent to electrical signal (ECG).

In this paper, we propose the use of VCG for the measurement of a signal related to HRV and the use of a novel algorithm based on signal geometry (7) to detect signal peaks, in order to accurately determine cardiac periods and the Poincaré plot (9)-(10). The results reported are comparable to the ones reached with the gold standard (ECG) and in literature (3)-(5). We report mean values of HP of 832 ± 54 ms and 832 ± 55 ms by means of ECG and VCG, respectively. Moreover, this algorithm allow us to identify particular features of ECG and VCG signals, so that in the future we will be able to evaluate specific correlations between the two.

1. Introduction

Heart Rate Variability (HRV) is the physiological variability of the heart rate. It is computed in terms of variation among Heart Periods (HP), which are the time intervals between two consecutive features of the signal. For this purpose, it is possible to consider signals of different nature: electrocardiogram (ECG), photoplethysmogram (PPG), phonocardiogram (PCG), vibrocardiogram (VCG), etc. In fact, the fundamental aspect is to identify a periodic characteristic related to the heartbeat, such as the R peak in the ECG signal or the first sound (S1) in the PCG one.

HRV is a fundamental parameter for the evaluation of the cardiovascular risk, for instance in the field of mortality prediction after myocardial infarction.

According to the international guidelines (1-2), it is necessary that the acquisition duration is at least of 5 minutes, in order to record all the relevant aspects of the cardiac activity.

This work aims to measure HRV by means of a non-contact method, namely the Laser Doppler Vibrometry (LDV), whose efficiency has already been demonstrated (3)-(4)-(5). This device is particularly convenient for the monitoring of burnt patients or preterm infants (with fragile skin) (6). LDV detects the vibrations (i.e. VCG is a mechanical signal) on the skin surface (e.g. on the carotid artery) resulting from vascular blood motion consequent to the electrical signal (ECG).

Results have been compared with those obtained by the gold standard method (e.g. ECG). Moreover, we have evaluated the performance of the algorithm adopted (7), not only in terms of precision in detecting main peaks in the signals acquired, but also in its capability of characterizing the waveforms according to their morphology, so allowing to extract possibly clinically relevant features.



2. Materials and methods

2.1. Measurement setup

To evaluate cardiac activity, we have investigated a subject by means of two different instruments, whose signals (Electrocardiogram (ECG) and Vibrocardiogram (VCG)) have been acquired simultaneously for a time duration of about 5 minutes. We have connected the two devices, electrocardiograph (ADInstruments MLA2540 5 Lead Shielded Bio Amp Cable) and LDV (PDV 100, Polytec), to an ADInstruments Acquisition Board (model PowerLab 4/25, 4 digital inputs). As shown in Figure 1, the subject was supine and asked to relax. Signals have been acquired with a sampling frequency equal to 1000 Hz and no filters were applied on the raw signals.

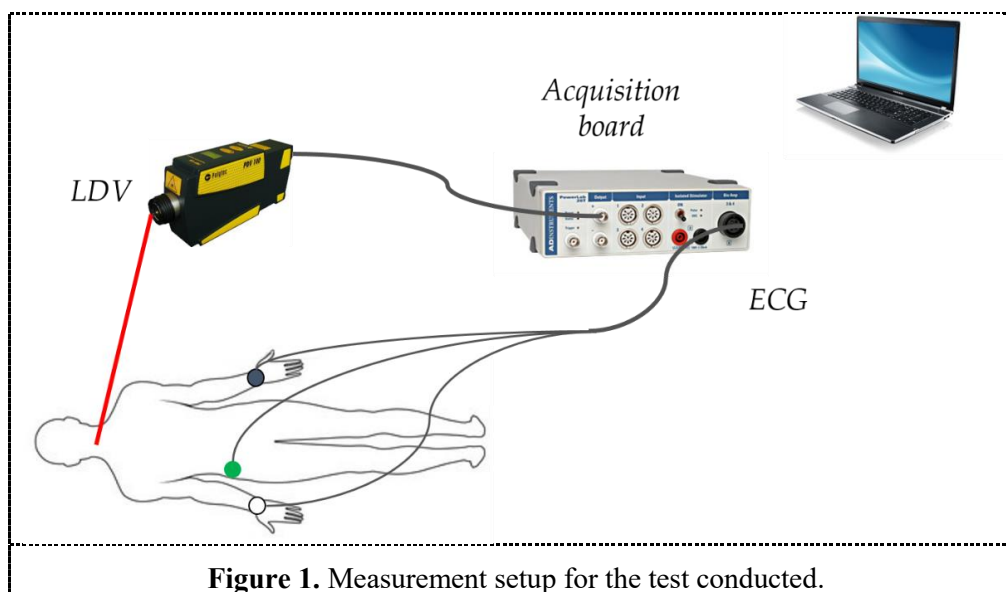


Figure 1. Measurement setup for the test conducted.

We have fixed the electrodes on the wrists and hip bone (reference signal) for the ECG signal acquisition. The VCG signal was acquired pointing the laser spot in correspondence of the carotid artery, placing the LDV on a tripod at a distance of 1 m from the subject, perpendicularly to the subject surface. An hydrating lotion (45% zinc oxide) was spread on the skin area of measurement, in order to maximize the reflectivity of the surface.

2.2. Data processing

At first, we have preconditioned the signals recorded, removing the mean value and filtering them by means of a Butterworth 3rd order band-pass filters, with the following cut-off frequencies: numbered as follows:

- 0.8÷20 Hz for ECG signal
- 5÷20 Hz for VCG signal

In order to identify the main peaks of the ECG and VCG signals, we have adopted an algorithm based on the theory described in the work of Xiao et al. [7]. It consists in calculating the slopes of the waveforms through a window of a proper width, which scans the signal in order to compute the angles trend, as shown in Figure 2 (for VCG signal).

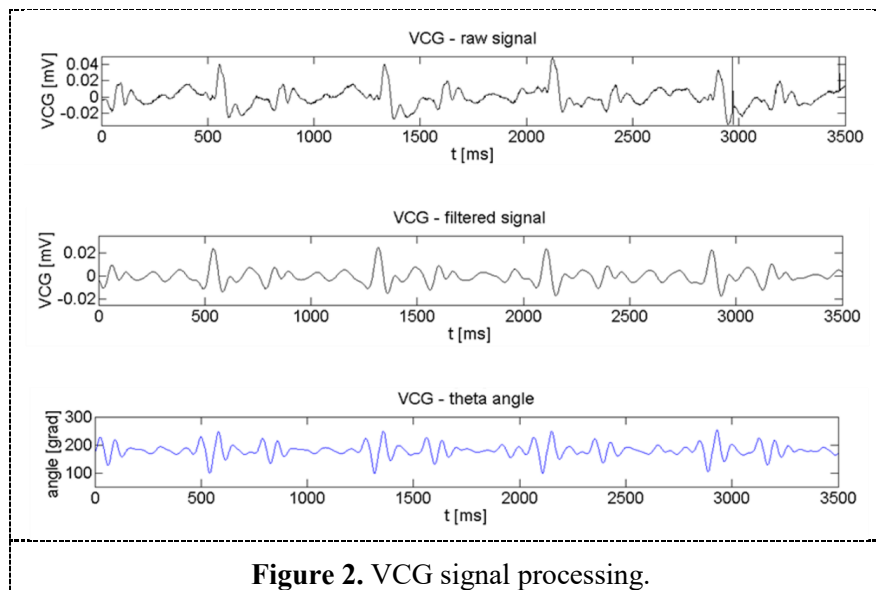


Figure 2. VCG signal processing.

Then we have analysed the angle evolution of both signals (i.e. ECG and VCG) by applying a 50% overlap of adjacent windows. Therefore, we have been able to detect the main features, R-peak in ECG signal and V-peak in VCG one, which corresponds to minima in the angle trend.

The reference method for R-peak detection in ECG signal is Pan&Tompkins algorithm (8), but it does not work well in waveforms different from the electrocardiographic one.

Afterwards, we have computed the HP vector through the identified peaks and we have compared the performance of vibrocardiography with the gold standard, after having synchronized the respective HP vectors. In this way, when the algorithm has not individuated a peak in one of the two signals, also the correspondent peak in the other one has been omitted. This has allowed us to compare features relative to the same physiological event.

We have evaluated HRV in time domain by means of HP. In particular, we have considered both tacogram and Poincaré plot. The former is the temporal sequence of HP, while the latter is obtained by plotting each HP against the previous one. Both the techniques can be quantified by specific descriptors; as regards tacogram, we can calculate:

- NN50 [n°]: number of consecutive HP with a time difference higher than 50 ms;
- pNN50 [%]: percentage of NN50 with respect to the total number of HP;
- RMSSD [ms]: standard deviation of HP.

The indexes deducible from Poincaré plot are the following ones:

- SD1 [ms]: standard deviation of the samples along the minor axis of the plot;
- SD2 [ms]: standard deviation of the samples along the major axis of the plot;
- SD12: ratio of SD1 against SD2;
- SDRR [ms]: standard deviation of HP;
- S [ms²]: area of the ellipse fitting the points.

3. Results

The algorithm adopted is able to correctly detect R peaks in ECG signal and V peaks in VCG one, as shown in Figure 3.

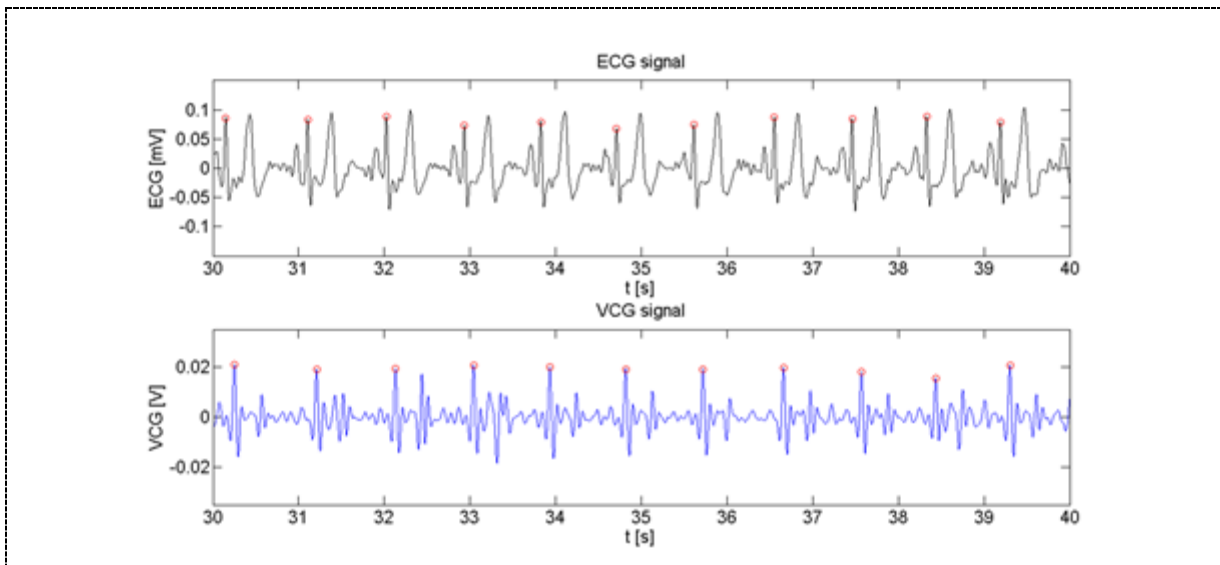


Figure 3. R and V peaks detection in ECG and VCG signals, respectively.

We have computed an almost constant time delay between each V peak and the correspondent R one, equal to 114 ± 4 ms for the subject under test. This value is related to the physiological delay between the electrical impulse (cardiac event) and the consequent mechanic vibration of the skin surface and depends on the physical characteristics of the subject.

The accuracy in measuring Heart Periods by means of LDV is very high. In fact, we have reported mean values of HP of 832 ± 54 ms and 832 ± 55 ms by means of ECG and VCG, respectively ($M \pm \sigma$, where M is the mean value and σ the standard deviation).

The tacograms related to ECG and VCG signals are reported in Figure 4 and their characteristic indexes are shown in Table 1, while the results from Poincaré plot are reported in Figure 5 and Table 2.

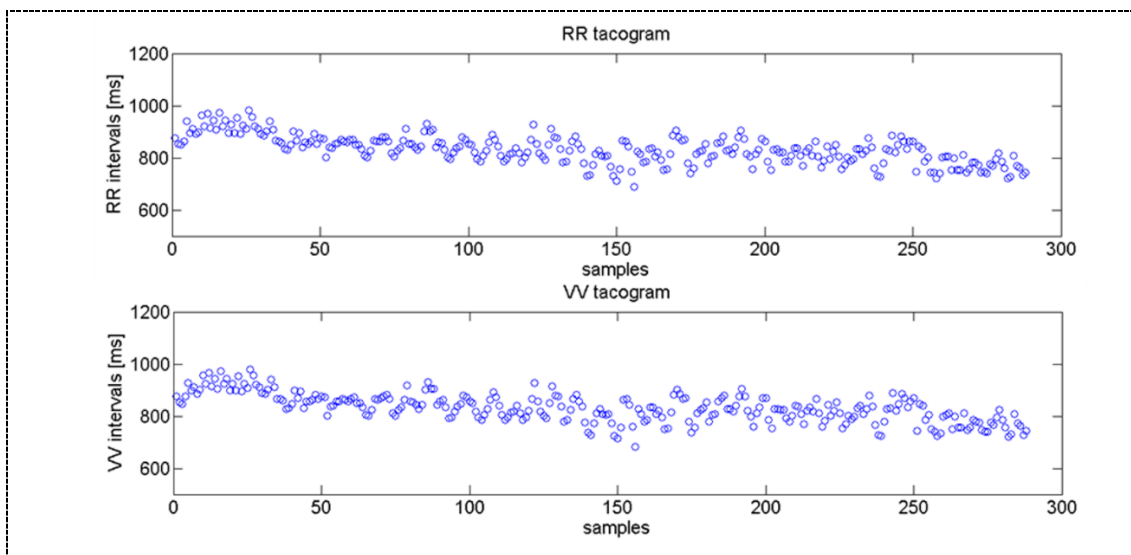
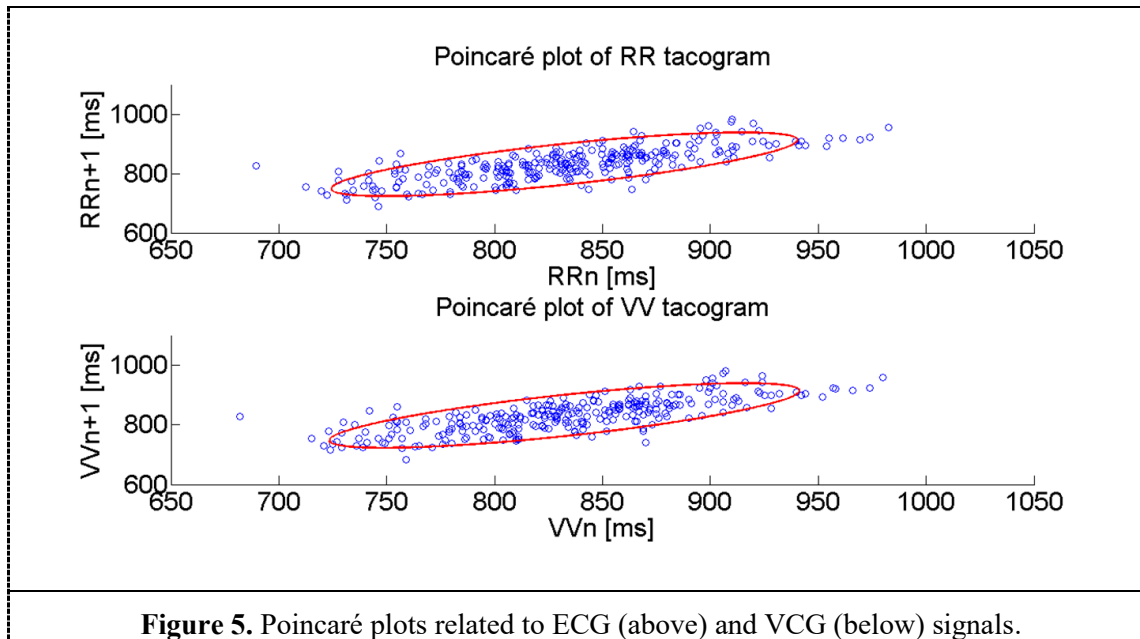


Figure 4. Tacograms related to ECG (above) and VCG (below) signals.

Table 1. Tacograms indexes related to ECG and VCG signals.

	ECG signal results	VCG signal results
NN50 [n°]	27	27
pNN50 [%]	9.38	9.38
RMSSD [ms]	54	55

**Figure 5.** Poincaré plots related to ECG (above) and VCG (below) signals.**Table 2.** Poincaré plots indexes related to ECG and VCG signals.

	ECG signal results	VCG signal results
SD1 [ms]	26	26
SD2 [ms]	72	72
SD12	0.37	0.36
SDRR [ms]	54	55
S [ms ²]	5936	6008

As regards tacogram and Poincaré plot parameters, we have reported a deviation lower than 1% between ECG and VCG results, except for SD12 and S values, whose deviations are equal to 2.7% and 1.2%, respectively.

4. Conclusions

VCG is an important sensing method for the assessment of biological signals (e.g. cardiac, respiratory and muscular activities). LDV measurements have the great advantage of being a contactless method, particularly important when patient's skin conditions are critical (e.g. burnt patients or preterm infants). When we acquire a biological signal, it is fundamental to correctly identify its main features. HP can be evaluated from different techniques by detecting a periodic feature in the waveform acquired, such as V-peak in VCG signal.

The algorithm adopted allows to correctly identify R and V peaks in ECG and VCG signals respectively according to their morphology, differently from Pan&Tompkins algorithm, applicable only to ECG waveform. In this way, it is possible to accurately measure HRV also with a non-contact method like VCG, obtaining results comparable with the gold standard (deviations lower than 1%).

Moreover, the method used in this work allow to characterize an ECG signal according to its geometry, not only for what regards the main peak, but also for different ones, like P, Q, S and T waves. The same procedure can be applied to VCG waveform, even if the clinical meanings of its features are not acknowledged yet. An example of the features identification related to a heartbeat is shown in Figure 6, as regards both ECG and VCG signals.

The adopted processing method could allow to find some correlations between VCG signal and other waveforms of different nature, e.g. ECG, PCG and PPG. In this way, it would be possible to obtain relevant physiological information from a unique non-contact device (i.e. LDV), instead of applying several contact sensors to the patient monitored, also out of the clinical (e.g. elderly patients at home).

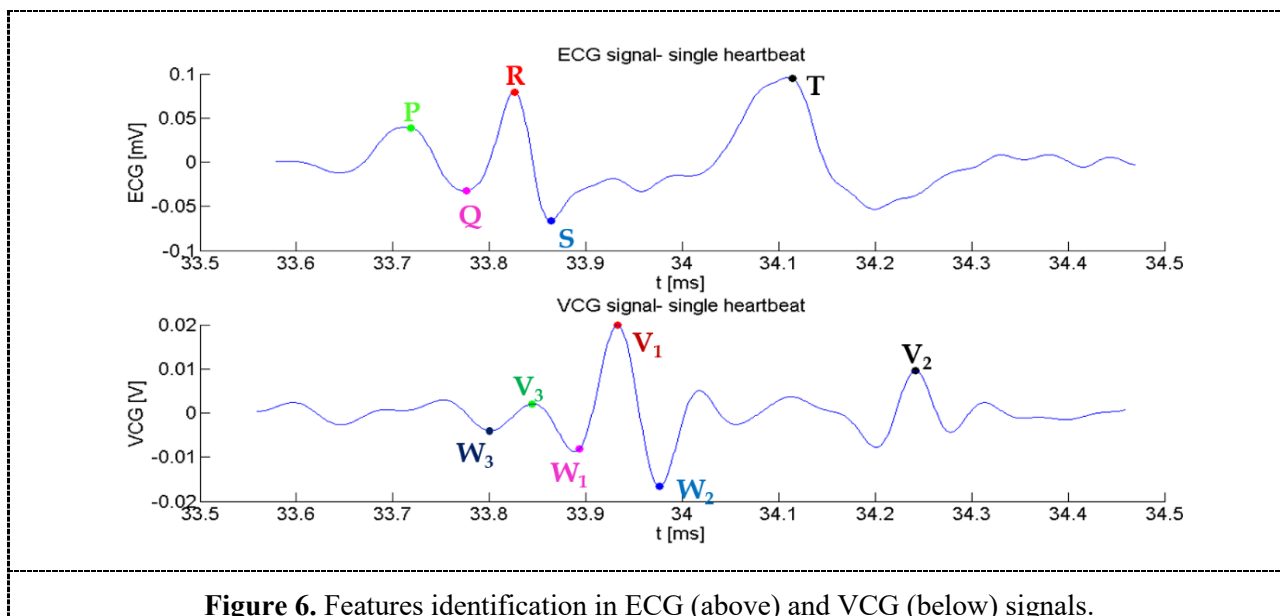


Figure 6. Features identification in ECG (above) and VCG (below) signals.

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