Comparison of Pulse Rate Variability Derived from Digital Photoplethysmography over the Temporal Artery with the Heart Rate Variability Derived from a Polar Heart Rate Monitor

Mara Greve\textsuperscript{1}, Edgars Kviesis-Kippe\textsuperscript{1}, Oskars Rubenis\textsuperscript{1}, Uldis Rubins\textsuperscript{1}, Viktorija Mecnika\textsuperscript{1}, Andris Grabovskis\textsuperscript{1} and Zbigneves Marcinkevics\textsuperscript{2}

\textsuperscript{1}Institute of Atomic Physics and Spectroscopy, University of Latvia, 4 Skunu street, Riga, LV-1586, Latvia
\textsuperscript{2}University of Latvia, Faculty of Biology, Riga, 4 Kronvalda blvd., LV-1586

Heart rate variability (HRV) is beat-to-beat changes in successive heart intervals, and since it is linked to autonomic nervous system, HRV analysis is a valuable method for investigation of different health states. The conventional method for estimation of heart intervals for the HRV analysis is electrocardiography (ECG), measurement of the electric activity of the heart. Photoplethysmography (PPG), optical detection of a pulsatile blood volume changes in the vascular bed under the PPG sensor, can be also used (Fig. 1).

Generally pulse rate variability (PRV) is not accepted as a surrogate measurement of HRV \cite{1}, however, during stationary conditions it has shown reliable results \cite{2}.

We have developed an easy-to-use and cost-effective wireless digital PPG prototype device for heart rate and PRV measurements with PPG sensors integrated in wearable garments, such as a headband. PPG sensor location over superficially located arteries can provide better signal quality in cases when the fingertip or earlobe PPG measurement is altered for patients with poor peripheral perfusion.

The aim of this study is to investigate the precision of the developed PPG device in heart rate estimation; and to compare obtained PRV variables with HRV variables. Polar heart rate monitor S810i (Polar HRM) was used as a reference device.

**Introduction**

**Measurement protocol**

- 12 healthy adult female subjects, aged 18 to 29 years (median = 20 years);
- separate room, comfortable high-back upright seat, attachment of the Polar HRM sensors and the PPG sensor over the superficial temporal artery;
- 5-min adaptation; 5 min data capturing in resting conditions with both devices;
- data exporting, time-matching in the Microsoft Excel;
- artifact elimination (difference between two successive intervals > 200 ms);
- comparison of HR, estimated from RR and PP intervals;
- 256 consecutive heart cycles from a stable period of the recording; HRV and PRV computing (Kubios HRV 2.0; autoregressive model for spectral variables) and comparison (two subjects excluded due to artifacts in either the PPG or Polar HRM signals.

**PPG signal processing**

- Signal was filtered by second-order reverse phase Butterworth filter in frequency range 0.2-8 Hz.

Heart intervals were calculated in a real time as a distance between two feet of consecutive PPG waveforms:

- 1st derivative was evaluated from the PPG signal (Fig. 5, blue line);
- first maximum of derivative was found and threshold function was calculated (Fig. 5, magenta line; Fig. 6 - equation);
- from the site where the threshold function crosses the 1st derivative signal, the nearest zero-crossing point was found; this corresponds to foot position. (Fig. 5, violet arrows).

\begin{equation}
g = \begin{cases} 
  f_{s-1}, & f_{s-1} < f_{s-1} \\
  f_{s}, & f_{s} > f_{s} 
\end{cases}
\end{equation}

**Fig. 1.** Two different ways how to estimate the length of the cardiac cycle and calculate heart rate variability.

**Fig. 2.** Wireless digital prototype device: (1) headband with integrated PPG signal measurement and transmission unit, and (2) laptop with software for signal capturing via Bluetooth and real-time heart interval detection, and PRV variable calculation.

**Fig. 5.** PPG signal (a); 1st derivative (b, blue line) and threshold function (b, magenta line) for the detection of foot positions (violet arrows).

**Fig. 6.** Equation for threshold function, where \(f_s\) is \(j\)th sample of derivative signal, \(f_{s-1}\) is previous sample, \(s\) is the sample rate, \(k\) is the threshold decay coefficient.
Technical parameters of wireless digital PPG device

Technical parameters: a sampling frequency – 1 kHz, a 875 nm light emitting diode (LED), and a photodiode with a daylight filter and peak spectral response wavelength at 880nm. The device has an integrated LED driver that provides stable power throughout the battery’s discharge range. LEDs were driven by 55 ± 15 mA (5 mA stepping), so that no perceptible warming of the upper tissue layer was produced. A digital analog converter was used to regulate the LED current. Block diagram of the wireless digital PPG prototype device is shown in figure 3.

The main idea of the digital PPG is that the LED emits constant amount of light, and due to changes in blood volume and flow characteristics in tissue under the sensor, different amount of light is absorbed and reflected. A photodiode (PD) is charged by central processing unit in 30-microseconds. The PD acts like a capacitor that exponentially discharges in time. Discharge is proportional to the amount of the reflected light detected by the PD. Discharge time is captured by a microcontroller and therefore does not require software resources. One measurement composes a single point on a time-axis of PPG waveform. The PPG signal is restored digitally without standard ADC-conversion.

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References