Real-time pulse rate variability for remote autonomic assessment.

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Abstract

Remote medicine is an emerging and important field with the potential to improve patients' health at the distance of a teleconsultation. Here, we propose a novel remote photoplethysmography algorithm suited to extract pulse rate variability in real-time from the face of a patient that is being recorded by a consumer-grade webcam. Because the autonomic nervous system plays a big role in regulating the human heart rate, a remote, real-time pulse rate variability sensor might be of interest for telepsychology and telepsychiatry alike. We test the real-time algorithm with an experiment where both PPG and rPPG are recorded at the same time, from a bluetooth PPG finger sensor and a computer webcam pointed at the face, respectively and where we can see that both signals have similar periodicity, a part from a phase difference.

1 Introduction

For several years physicians have monitored heart rhythms through auscultation and have noted that beat-to-beat times shift depending on age, illness and psychological state [1]. Both electrocardiography and photoplethysmography are used to access cardiovascular signals (see Fig. 1).

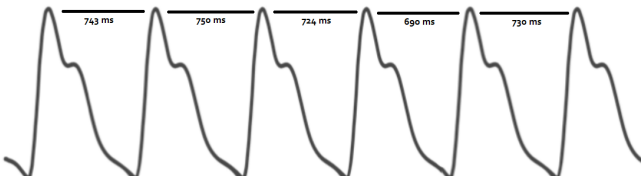

Figure 1: Five time differences (in milliseconds) between six pulses via photoplethysmography. This figure is not in scale.

But, while the electrocardiogram is a measure of electrical activity directly related to the contractions of muscular heart, the photopletysmographyic signal is an optical measure that captures the amount of blood coming and going from a given tissue, and thus only indirectly it captures the heart's beating. From electrocardiography, heart rate (HR) is defined as the number of heartbeats per minute and heart rate variability (HRV) concerns the fluctuation in the time intervals between adjacent heartbeats [5]. Similarly, we can define pulse rate (PR) and pulse rate variability (PRV) in the context of photoplethysmography.

In 2018, remote photoplethysmography (rPPG) was reportedly [6] the most popular name for a technique that can also be referred to as contactless PPG, camera-based PPG or imaging PPG. Aside from a source of light, the only component needed is a camera (e.g. low-cost webcam, mobile phone camera), which makes this technique really promising for the telemedicine context.

1.1 Heartbeat and autonomic regulation

Two types of cardiac muscle cells generate the heartbeat: (1) contractile cells produce strong contractions that cause the heart chamber to shrink and propel blood, and (2) specialized noncontractile muscle cells of the conducting system control modulate contractile cells. Contractile muscle cells, which comprise the majority of cardiac muscle cells, are activated by external action potentials, similarly to skeletal muscle. On the other side, noncontractile muscle cells are less in number and organized as a network made up of two types of cells: nodal cells and conducting cells. Nodal cells are autorhythmic, i.e. they contract on their own, without neural or hormonal stimulation, and generate the pacemaker potentials responsible for initiating the muscular heartbeat. They are located at the Sinoatrial (SA) and Atrioventricular (AV) nodes. However, nodal cells from the SA node naturally depolarize faster, 70–80 action potentials per minute, than those in the AV node, 40–60 action potentials per minute, being the effective pacemaker cells in the heart. [4]

Although the SA node spontaneously generates the normal heartbeat cardiac rhythm, autonomic motor neurons, circulating hormones and ions can influence the inter-beat interval and magnitude of the myocardial contraction [34]. More specifically, the cardiovascular center, located in the brain stem, integrates sensory information from various bodily receptors and responds through sympathetic and parasympathetic motor neurons (and endocrine systems), adjusting the HR continuously [3]. See Fig. 2.

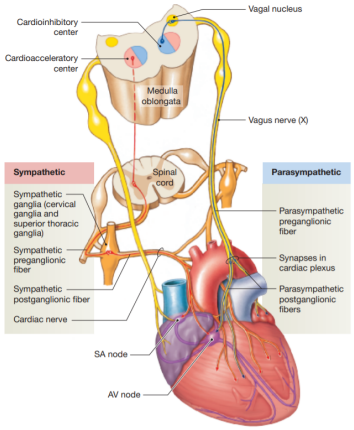

Figure 2: Autonomic innervation of the heart. Adapted from (Martini, 2018).

Cardiac sympathetic nerves target the SA node, AV node, and the bulk of the myocardium and trigger norepinephrine and epinephrine release and binding to beta-adrenergic (b1) receptors located on cardiac muscle fibers, speeding up spontaneous depolarization in the SA and AV nodes (increasing HR) [2]. The parasympathetic vagus (X) nerves also innervate the SA node, AV node, and atrial cardiac muscle and trigger acetylcholine release and binding to muscarinic receptors, decreasing the rate of spontaneous depolarization in the SA and AV nodes (slowing HR) [7].

2 Method

The proposed method takes as input a timestamped stream of video, *i.e.* a sequence of tuples of the form $(frame[i], timestamp[i])$, where i is the counter of video frames captured, $frame[i]$ is a $(width, height, 3)$ matrix storing each pixel's RGB intensities and $timestamp[i]$ is the time at which the corresponding $frame[i]$ was captured. It is assumed that all frames of the video contain a face.

First, for every video frame, $frame[i]$, an average of the RGB channels over a predicted facial skin region of interest, $avg\_rgb[i]$, is produced. This can be accomplished with face detection, facial landmarks prediction and ROI selection, as seen in fig. 3.

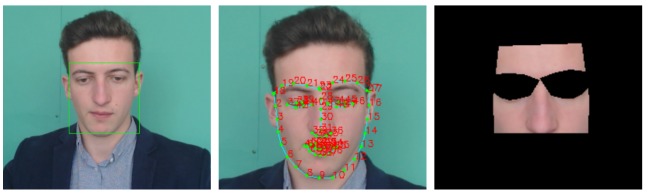

Figure 3: The first three steps of the algorithm.

Here, the regions comprising the cheeks, the nose and the forehead are considered, while the regions for beard and eyes are removed. Since

following algorithms assume that samples are evenly distributed in time, resampling the asynchronous RGB signal is needed.

After that, we must estimate a blood volume pulse (BVP) signal, $bvp[t]$, from the collected RGB signal, $avg\_rgb[i]$. For that we apply the POS method to transform the skin RGB signal into a BVP signal [9]. The POS method can be found in the chrominance category of rPPG algorithms, which means this algorithm integrates skin tone knowledge *a priori*, *i.e.* it requires less knowledge of the BVP signature and is more tolerant to distortion. A bandpass filter is further applied to clean the signal for peak detection. Cut off frequencies were set as [0.8, 2.5] Hz, since these frequencies correspond to a normal human heart rate range of 48 to 150 bpm. See fig. 4.

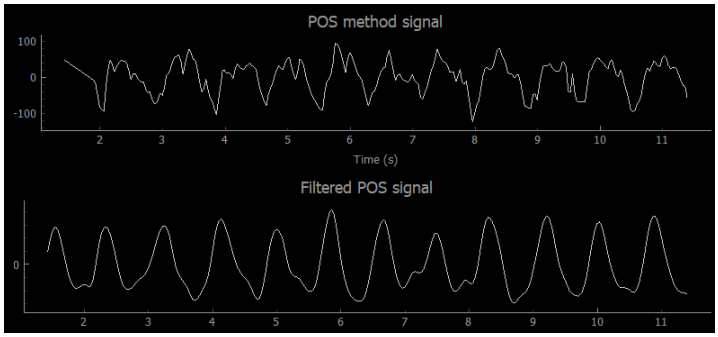

Figure 4: On the top, we can see the blood volume pulse obtained from the RGb signal via the POS method and, below, we see the filtered BVP.

Lastly, PR and its variability are estimated via the filtered BVP signal. Peak detection is firstly applied to the BVP signal in order to detect true heartbeats and, from the peaks, we can compute PP intervals. See fig. 5.

We extract PP intervals as the difference between pairs of consecutive peaks.

$$PPinterval_i = IBI_i = PeakTime_i - PeakTime_{i-1} \quad (1)$$

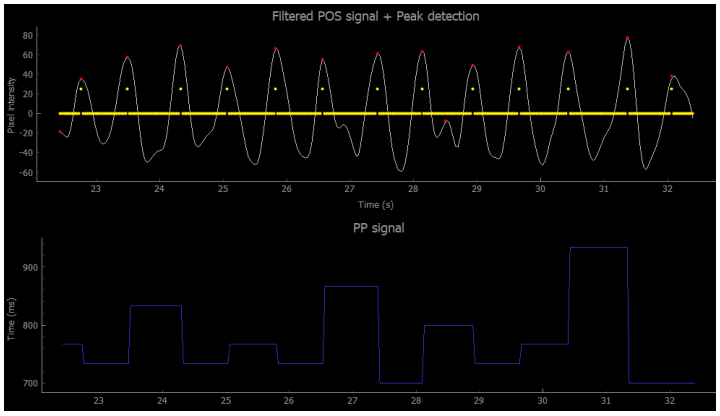

Figure 5: On the top, we can see the peak detection; below, we see the PP signal, or IBI signal.

From the PP intervals, we can provide estimations of PR and time-domain measures of PRV. For a full review on PRV metrics see [8].

3 Results and Discussion

To test the proposed algorithm, a standard grade laptop (MSI GF63 8RD) runs the whole rPPG pipeline in real-time using the embedded webcam as video input in one thread, and, on another thread, it acquires the traditional PPG signal from a pulse oximeter finger clip sensor, i.e. the ground truth signal. The PPG acquisition is mediated through a BITalino board, which stores the data at a constant rate and sends it via bluetooth to the laptop. In the end, we can display both signals at the same time and confirm that the rPPG signal follows the PPG signal closely (see Fig. 6), though we can see that the two signals are not perfectly aligned. This delay might be related with: 1) PPG thread starting acquisition first than the webcam thread, or vice versa and 2) the amount of time blood takes to travel from the heart to the face is different from the time it takes travelling from the heart to the finger, and their also target of regulation by the circulatory system control mechanisms. Anyway, we can see that for every PPG-sensor pulse we can count a corresponding delayed rPPG-sensor pulse, confirming the ability of the proposed real-time algorithm to capture pulse rate variability, just like traditional PPG can do.

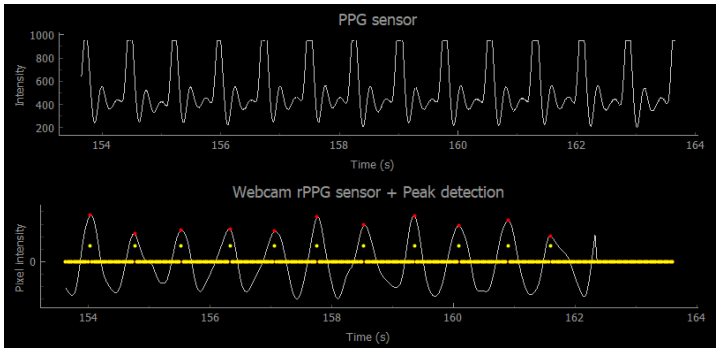

Figure 6: Real-time comparison of the photoplethysmography signal obtained through the finger clip sensor (upper panel) and the remote photoplethysmography signal obtained from the webcam video.

4 Conclusions

Virtually all published work on rPPG is based on offline computations. Accomplishing real-time pulse rate variability means that we can inspect the raw signal and PRV features during recording, which allows to identify artifacts, make sense of the values and overall have control over the precision of the process. Plus, a real-time rPPG algorithm ensures the doctor has some control over the quality of the measurement. The real-time display not only allows him to search for a sweet spot in terms of patient positioning and ambient lighting, but also to control overall quality of the record. This work is relevant because telemedicine is an emerging, cheaper form of providing health services and reliable tools must be developed to support doctors in making decisions within the remote context. In the future, it should be tested whether PRV features produced by the algorithm correlate with different groups of psychiatric patients.

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