Extracting heart rate data from PPG signals obtained by smartphone apps

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Background

Healthcare is rapidly changing because of technological innovations. On the rise are apps and devices that enable patients to monitor their own health states, called mHealth applications. These innovations are moving healthcare from the hospital to the patients' homes. In this thesis, monitoring the heart by smartphone applications is central. The possibility of at-home heart rhythm monitoring is promising in the context of early detection of heart arrhythmia and prevention of heart failure. Moreover, such an application offers low-cost, non-intrusive monitoring.

Several smartphone applications aim to record heart rythm by using the smartphone camera. They use *Photoplethysmography (PPG)*, an optical technique used for measuring cardiac-induced fluctuations in tissue blood volume [1, 2]. The beating heart leads to fluctuations in tissue blood volume. Blood absorbs more light than the surrounding tissue. Therefore, a smartphone camera in combination with the flash can detect changes in tissue blood volume through the skin, resulting in a PPG signal (Figure 1). The PPG signal is a waveform signal that can be seen as a time series, containing information about the heart. A shortcoming of PPG recordings is that they are corrupted with noise, especially when collected via smartphone apps: Besides measuring changes in tissue blood volume, PPG is sensitive to sources like movement, breathing, light intensity changes, and temperature [3]. Therefore, extracting heart rate from the signals is not straightforward.

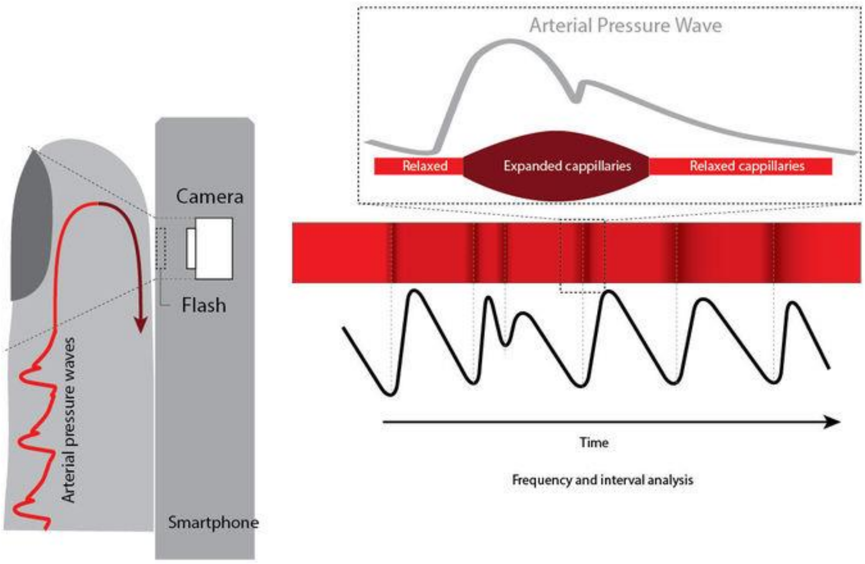

Figure 1. *Schematic explanation of obtaining PPG signals by smartphones. [4]*

Unfortunately, current solutions for extracting heart rate from PPG data are a black box. The underlying algorithms are not accessible as they have been developed by commercial institutions. Moreover, their accuracy and validity remain unclear [5-7]. When applied in healthcare settings, such solutions potentially lead to over- or underdiagnosis, which causes problems like unnecessary patient suffering and increased healthcare costs. Hence, accurate monitoring with open source algorithms is essential to the value of mHealth applications in healthcare settings.

The research question of this project is:

How can accurate heart rythms be extracted from noisy PPG signals?

Challenges to overcome are dealing with noise from sources like movement, and removing trend in the signal from sources like fluctuations in light intensity. Another problem to be dealt with is the fact that the time steps in the signal are unequally spaced, due to the smartphone camera not sampling at a constant rate. Dealing with this problem is of primary concern, because having equally spaced intervals is an attractive property for statistical analysis purposes. Therefore, interpolating the non-equal time steps of the PPG signals is the focus of the current project.

Approach

This thesis project involves developing a method for retrieving accurate pulses from noisy PPG signals. To remove unwanted features from the signal, a *smoothing algorithm* can be applied. Such an algorithm is proposed by Eilers [8]. This algorithm, called the Whittaker-Eilers smoother, can denoise, detrend, and interpolate noisy data. The unique advantage of this smoothing algorithm is that it can do this simultaneously. Moreover, it can be implemented in a few lines of code and is computationally fast. The smoother assumes uniform sampling, whereas the PPG signal is non-uniformly sampled. In order to retrieve accurate pulses from PPG signals, besides denoising and detrending, the method in this thesis has to interpolate the non-equal time steps of the PPG signal.

First, I will develop a PPG signal processing method that extends the Whittaker-Eilers smoother with the interpolation of non-equal time steps. The method will be applied to PPG data, in order to obtain accurate pulse waves from the noisy signals. From the pulse waves, baseline characteristics of heart rate will be extracted. Secondly, the method will be implemented in R, building an open source software package for analyzing noisy PPG data.

Finally, performance will be evaluated by comparing the method with other relevant smoothing algorithms. This will be an iterative process. Possible algorithms for comparison are the Butterworth [9] or the Savitzky-Golay filter [10], of which the specifics will be decided later on in the project.

This project is part of the BigData@Heart initiative and will be carried out within the Biostatistics department of the Julius Centre, UMC Utrecht. The data consists of 15,256 anonymized PPG recordings, crowdsourced through a smartphone application called HeartforHeart. By holding a fingertip against the camera and the LED flash, participants can 'donate' 90 seconds of their heart rhythm to heart research. Permission to analyze these data has been granted by Happitech, the initiator of HeartForHeart. A possible journal for publication of the project is PlosOne.

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