Implementation and validation of a novel beat detection algorithm in wrist PPG recordings according to Papini et al.

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Created in the "Biosignal Processing" course in the master's study program "Medical Engineering and e-Health" at University of Applied Sciences Technikum Vienna under the guidance of Marco Ross. Submitted on 22nd of November 2020.

I. Introduction

Detecting beats and the heart rate from a photoplethysmography (PPG) recording with the help of algorithms has been a challenging task since digital processing has been used for the analysis of vital signs. While previous algorithms have shown to barely reject non-sinusoidal pulses (like artefacts or arrhythmic beats) as they evaluate mainly morphological features (pulse amplitude, duration and slope), *Papini et al.* proposed a novel, presumably more robust algorithm for the detection and rejection of beats in PPG recordings, including an estimation on the fitness quality of accepted pulses [1]. This report describes an implementation and validation of this novel algorithm in MATLAB.

II. Materials & Methods

Materials MATLAB was used to implement the algorithm, based on its documentation in the *Papini et al.* manuscript [1]. 19 EDF files containing datasets of wrist PPG from the *Physionet "Wrist PPG during Exercise"* database [2] and their beat reference (hand-scored from the corresponding ECG) were used for the implementation and validation of the algorithm. A dynamic time warping barycenter averaging (DBA) implementation by *Petitjean et al.* [3] was taken from the author's GitHub repository.

Algorithm implementation During algorithm implementation, one of the PPG datasets was used. The algorithm pre-processes the raw PPG by creating two bandpass filtered sets of the raw data: One set with 0,4 Hz - 2,25 Hz (slim band) and another set with 0,4 Hz - 10,0 Hz (wide band), both with a 3rd order Butterworth bandpass. Then, these two signals are segmented into single sets of beat candidates by localizing the minima in the slim band dataset. The algorithm thereby provides the points of time of (potential) heart beats in the raw PPG. In the next step, the algorithm normalizes the wide band snippets in two ways: First, subtracting the offset ("shift") from the beat candidates creates snippets that are lateron used to identify signal corruptions and reduce the quality index for this beat. Second, these wide band snippets are additionally normalized in terms of amplitude and in the next step are used to create an "average" beat template out of them. Also, amplitude correction factors are stored to later on compare each amplitude normalized beat candidate to the beat template considering their actual amplitude. The beat template eventually is created by dynamic time warping barycenter averaging (DBA) and lowpass filtering (10 Hz, 3rd order Butterworth). Then, with the help of the amplitude correction factors, an adjusted beat template is calculated for each beat candidate.

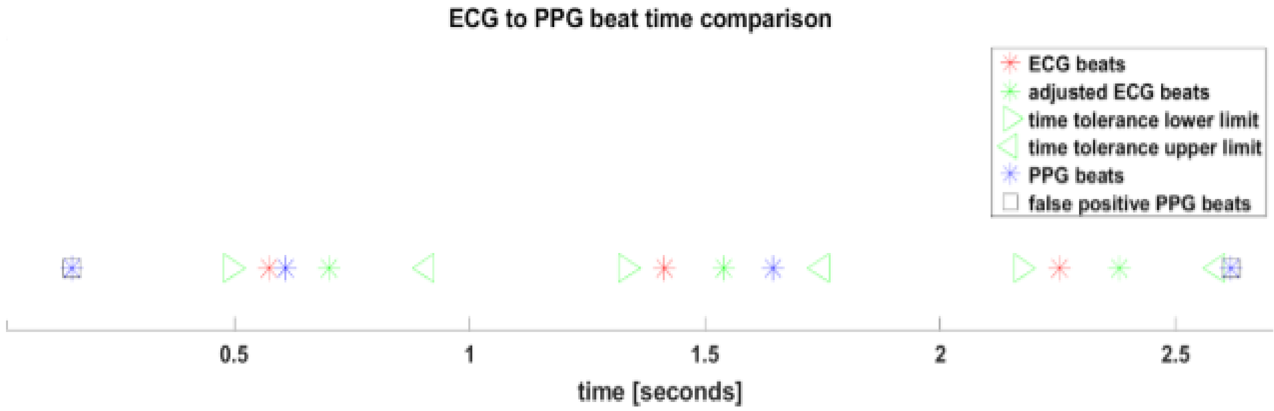

Figure 1: ECG to PPG beat time comparison.

Before each adjusted template can be compared to the according wide band beat candidate snippets, the offset normalized snippets need to be adapted to have the same length like the template (DTW warping). Finally, the Pulse Quality Index (PQI) is calculated by comparing the warped candidate to its adjusted template. Provided a definition of a PQI threshold, the PQI indicates whether to accept or reject the candidate snippet as a heart beat.

Algorithm validation The PPG beat detection algorithm was validated with the use of the remaining 18 PPG signals from the EDF files and their corresponding hand-scored reference ECG files. For this, the data from the reference ECG files had to be adjusted to the PPG signal, by adding an average pulse transit time (avgPTT) to each ECG beat. This avgPTT was calculated by dividing the average distance from the heart to the finger with the average pulse wave velocity of healthy persons (6.84 m/s). The average distance from the heart to the finger (0.865 m) was calculated by averaging the body height of west European men and women and dividing this by 2, as the arm span of a human is about the same as the body height and the heart can presumed to be in the middle of the chest. This way, calculation of avgPTT resulted in 0.1265 seconds, which were added to the ECG beats [4], [5], [6].

In order to find the true positive (TP) and false positive (FP) PPG beat times from the beat detection algorithm, as well as the false negative (FN) beats from the adjusted reference ECG files, they were compared to each other. Comparison (see Figure 1) was done by adding a certain time tolerance window to each adjusted ECG beat and checking whether a PPG beat was found within this time tolerance window. The value of this time tolerance was determined by adding an empirical 15% tolerance to the avgPTT and additionally 0.125 seconds to account for the pulse transit time variations found in PPG signals [7].

Subsequently, the sensitivity of the beat detection algorithm for all 18 datasets was calculated by dividing the number of TP beats by the sum of TP and FN beats.

ECG and PPG beat intervals were calculated as the time difference from one beat to the next. Finally, an array with beat intervals was created containing each TP beat in the PPG signal, as well as a corresponding array containing the beat intervals from the ECG beats. With this combined beat interval data from all 18 datasets, regression and Bland-Altman plots were created.

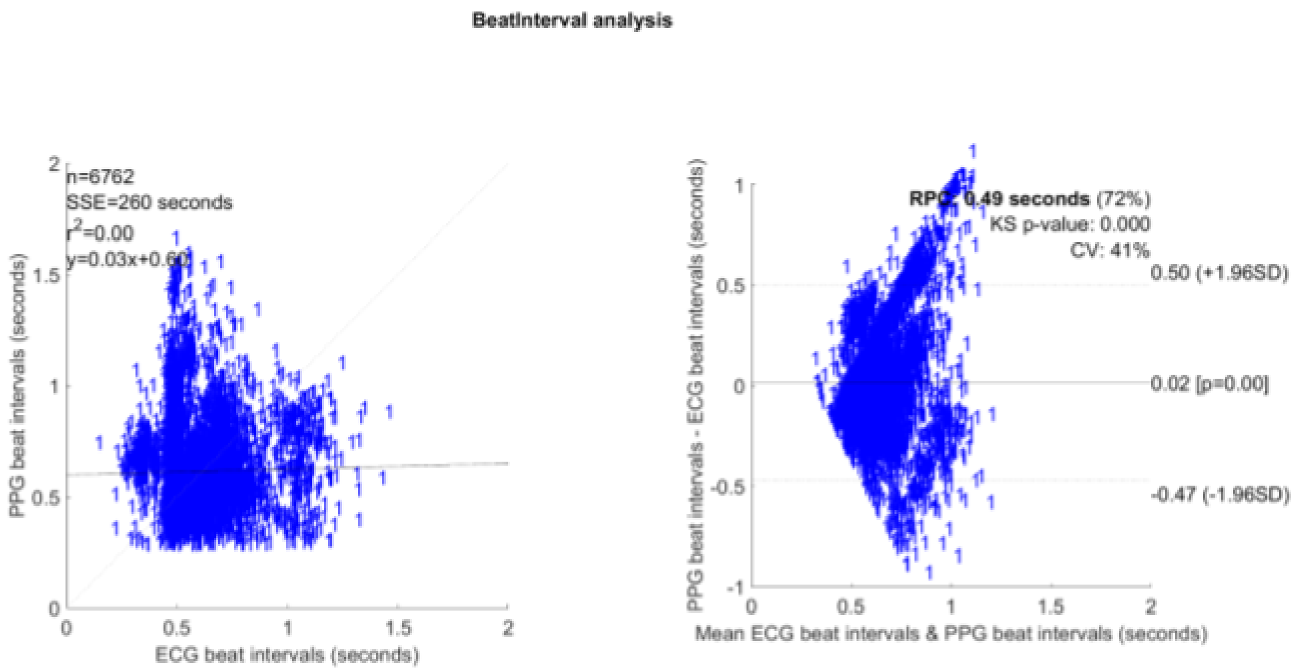

Figure 2: Results of the beat interval analysis in regression- and Bland-Altman plot.

III. RESULTS

Algorithm implementation Several of the intermediate steps were simplified in the implementation of the algorithm. Especially smoothing of the amplitude correction factors was skipped and provisionally replaced by the mean of the amplitudes in the wide band snippets. Therefore, the calculated PQIs must be considered to be not reliable and the validation of the algorithm focussed on the beat time detection only.

Algorithm validation The sensitivity of our beat detection algorithm via validation of 18 datasets was found to be 65.74%. The result of the beat interval analysis is shown in Figure 2.

IV. DISCUSSION

The sensitivity of the beat detection algorithm could be improved by excluding beats under a certain PQI value and by employing a different approach for beat detection rather than our approach of finding local maxima in the PPG signal. This also explains the poor results of our beat interval analysis.

REFERENCES

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