QRS Complex Detection

Assignment 1.a

Biomedical Signal and Image Processing 2020/21, Faculty of Computer and Information Science, University of Ljubljana

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I. Abstract

This is a report of the first assignment for the course Biomedical Signal and Image Processing. It follows the methods proposed in [1], with some minor improvements. The algorithm is evaluated on data from [2] on which it reaches sensitivity of 98.71% and positive predictability of 99.39%.

II. Introduction

QRS detection is the first step in many cardiac analysis algorithms. Its goal is to separate QRS complex from other waves in ECG signals. For good detection we need to filter out the noise and emphasize the biggest changes in the measured voltage, to be able to then find the main spike on the ECG, that is the QRS complex. The algorithm doing that is described in the next section.

III. Methodology

This detection system is composed of three stages: *moving average based high-pass filtering, nonlinear low-pass filtering* and a *decision-making stage.*

A. High-pass filtering stage

This stage is composed of an *m-point moving average filtering* and *delayed system* with delay of $\frac{m+1}{2}$. If x are the values in the ECG record, we can characterize MAF as y_1 and the delayed system as y_2

$$y_1[n] = \frac{1}{m}\sum_{i=1}^{m} x[n+1-i], y_2[n] = x[n-\frac{m+1}{2}],$$

and then we combine them as

$$y_{HP}[n] = y_2[n] - y_1[n].$$

We can see the graphical result on Figure 1.

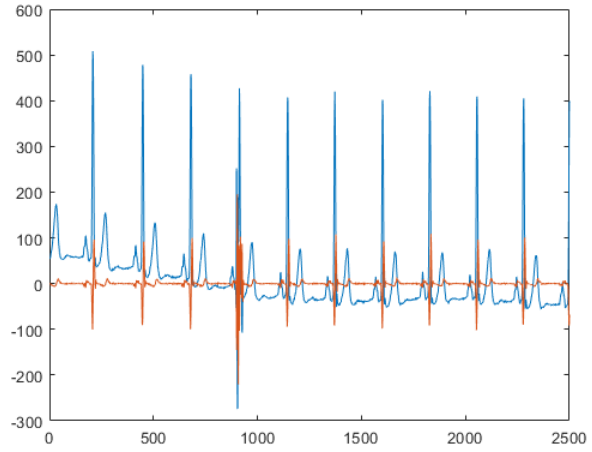

Figure 1. Original signal *s20011* and output of high-pass filtering stage.

B. Non-linear low-pass filtering stage

In this stage the output of HPF is squared point-by-point, then we go over it with moving window summation. We can see the output of LPF on Figure 2. Because of the scale of the output, the original signal can't be seen anymore.

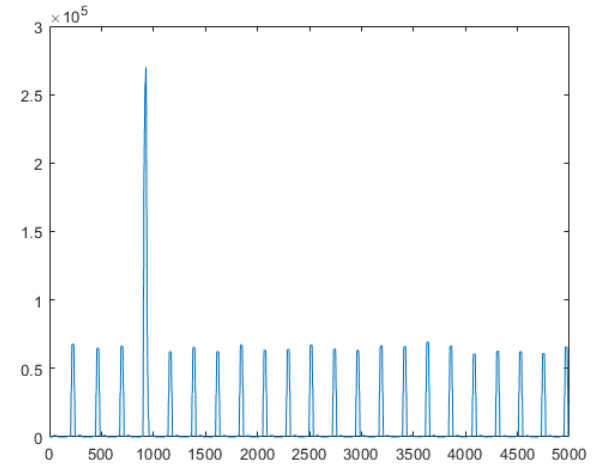

Figure 2. Output of non-linear low-pass filtering stage of sample *s20011*.

C. Decision-making stage

In [1] there is an adaptive threshold, that updates itself at every newly detected QRS complex by the rule:

$$threshold = \alpha \times \gamma \times PEAK + (1-\alpha) \times threshold.$$

We can interpret γ as a weighting factor between importance of a new peak and previous threshold, and α as the forgetting factor.

We adapted the method of decision-making a bit from the one proposed in [1]. In the beginning we set peak to the maximum value of first 100 samples, and threshold equal to this peak. That could mean we missed one of first two heartbeats, but that proved less valuable than setting the first threshold too low and potentially detecting many peaks that weren't actual heartbeats. Then we checked every value of LPF output and if it was bigger then threshold, we searched for local maximum in the next 100 samples, set the peak to that value, added index of that value to the list of detected QRS complexes and adapted threshold according to the rule above. Article [3] says that the theoretical limit for maximum heart rate is about 300 beats per minute, that limits one beat per 50 samples in our case. That is why when we detect a heartbeat, we skip the next 50 samples.

D. Improvements

The first improvement was to do the above steps on both leads, add them together and apply the decision making on the sum.

Next was to fix the delay that appeared from HPF and LPF.

When looking at the results, there was one sample that had only 3.71% sensitivity. The reason was, that at the beginning there were really big changes and then the QRS complexes settled at lower rate. So the threshold was set to high, and the algorithm wasn't detecting other heartbeats. So the last improvement we tried was to set the threshold the same way as we do at the beginning if there is no detected heartbeat for 400 samples. That raised the mentioned sample's (s20231) sensitivity to more than 99%.

IV. Results

To get the best results there was still some parameters we needed to adjust. We were evaluating the results based on average *sensitivity* and average *positive predictivity* on data from [2]. Where we had two algorithms and one had better sensitivity and the other better positive predictivity, we calculated the *F1 score*, that is equal to the harmonic mean of the above metrics.

In the HPF stage in m-point moving average filtering we needed to choose value of m. The study in [1] suggests we use $m \in \{5, 7\}$, we tried both and got better results with $m = 5$.

In LPF we needed to set the window size for the summation. The study in [1] suggests using a window size 30 for sampling rate 200 Hz. We first tested the algorithm with window size 30, then we adjusted it to 38 for sampling rate 250 Hz. The new results were worse, so the final algorithm uses window size 30.

In decision making stage, we needed to set α and γ. Article [1] proposed γ to be 0.15 or 0.2, we tried both and got better results with value 0.2. We tried different values for forgetting factor: $\alpha \in \{0.05, 0.1, 0.2, 0.5\}$. The best results were obtained with $\alpha = 0.05$.

Bellow you can see the results of the original algorithm and ones after improvements.

Algorithm	Se	+P	F1
Original	97.14	97.48	97.31
Improvement 1	98.68	98.87	98.77
Improvement 2	98.53	99.41	98.96
Improvement 3	98.71	99.39	99.05

V. Discussion

There are some samples on which the algorithm with the last improvement works worse than the previous ones. For further improvements we should look at those, and see why that happens, than we could maybe fix it. For extreme cases of really fast heartbeats, our decision-making window would be too big, meaning we could leave out the lower of two sequential QRS complexes. If we would have such cases, we would need to adapt the window-size.

On the last figure, Figure 3 we can see graphical representation of the detection.

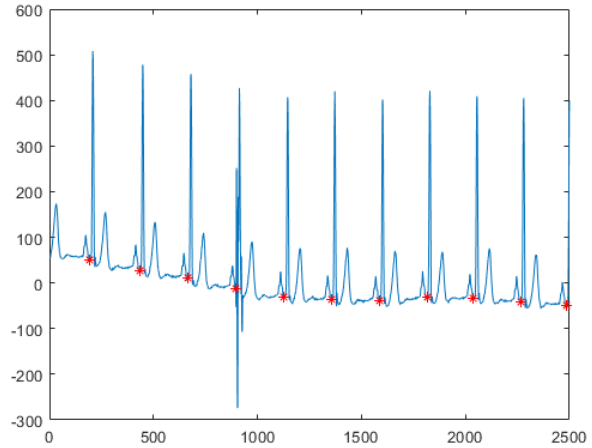

Figure 3. Detection of first 11 QRS complexes on sample *s20011*.

References

[1] H. Chen and S.-W. Chen, "A moving average based filtering system with its application to real-time qrs detection," in *Computers in Cardiology, 2003.* IEEE, 2003, pp. 585–588.

[2] F. Jager, A. Taddei, G. B. Moody, M. Emdin, G. Antolič, R. Dorn, A. Smrdel, C. Marchesi, and R. G. Mark, "Long-term st database: a reference for the development and evaluation of automated ischaemia detectors and for the study of the dynamics of myocardial ischaemia," *Medical and Biological Engineering and Computing*, vol. 41, no. 2, pp. 172–182, 2003.

[3] L. Chhabra, N. Goel, L. Prajapat, D. H. Spodick, and S. Goyal, "Mouse heart rate in a human: diagnostic mystery of an extreme tachyarrhythmia," *Indian pacing and electrophysiology journal*, vol. 12, no. 1, pp. 32–35, 2012.