VERIFICATION AND ADJUSTMENT OF HF-ECG PREPROCESSING IN EXPERIMENTAL CARDIOLOGY

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Abstract: The aim of this article is to propose an approach to High-Frequency ECG (HF-ECG) preprocessing with an intention to verify the settled methods of signal preprocessing in the perspective of the new requirements and possibilities in the area of signal processing. The method using Butterworth filters is often used. Nevertheless, for the presented type of analysis is not suitable. FIR filtering alongside with clustering and signal averaging were used for preprocessing of data from isolated rabbit hearts. Frequency bands for further analysis were chosen according to the estimated SNR (signal-to-noise ratio).

Keywords: ECG, high frequency, HF-ECG, signal processing, preprocessing, filtering, averaging, clustering, decomposition

1 INTRODUCTION

High-Frequency ECG (HF-ECG) is considered to be a valuable resource of information related to the physiology and pathophysiology of the heart. While the low-frequency ECG signal seems to include information about the classical ECG components such as P-wave, QRS-complex or T-wave, HF-ECG is thought to be related to local changes in conduction velocity. [1][2]

Preprocessing of data is a crucial aspect of any analysis. Even though there is no standard method for acquiring HF-ECG, often a band-pass filtering by Butterworth filter of the 4th order is used. The method was stated by Proakis and Monolakis (1996) [4]. Since then, the possibilities of recording high-quality and high-resolution signals in both time and amplitude were developed. Unfortunately, this method, often used by default for extraction of HF-ECG, was not compatible with analysis of animal data from isolated rabbit hearts. [3][5]

Therefore, a suitable approach towards HF-ECG preprocessing is presented along with the encouragement for confronting historically settled methods with new conditions and possibilities in signal processing.

2 ORIGIN OF THE DATA

Six adult New Zeland white rabbits (both sexes) were medicated by diazepam (2.5 mg), xylazine (4 mg/kg), ketamine (60 mg/kg) and heparin (1000 IU/kg). The heart was excised and fixed to a modified Working Heart System (Radnoti, USA) and perfused with Krebs-Henseleit solution (2.5 mM $CaCl_2$, 37 °C, pH 7.4) aerated by pneumoxyd (95% O_2; 5% CO_2).

For 15 minutes, heart was perfused in Langendorff mode at a constant pressure (80 mmHg). The system was then switched to working heart mode (preload 8 cmH_2O; afterload 60 cmH_2O) and the heart was left to stabilize for next 15 minutes.

Unipolar pseudo-ECGs were measured by 8 non-contact Ag-AGCl electrodes placed on an interior wall of buffer-filled chamber. Electrodes were uniformly spaced along the left ventriculus wall.

All animal experiments were carried out with respect to recommendations of the European Community Guide for the Care and Use of Laboratory Animals. The experimental protocol was approved by local Committee for Ensuring the Welfare of Laboratory Animals.

3 REQUIREMENTS OF HF-ECG ANALYSIS

The analysis designed for HF-ECG requires high resolution preprocessed data. According to the Nyquist theorem, the sampling frequency needs to be at least twice as high as is the highest analysed frequency. Working with higher sampling frequencies provides more details with the possibility to record even small changes in analysed parameters. [2][5]

The signal decomposition into respective HF bands is done by bandpass filtering. Method, which has been used for over 20 years, is based on non-linear filtering by Butterworth 4th order filter. Unfortunatelly, the method does not provide satisfactory results when applied to data from isolated rabbit heart. Therefore, the analysis requires a specified filtering approach towards data.

High resolution of processed signals is required for using the HF-ECG processing methods. Working with HF-ECG requires denoised HF signal. Applying classical filtering methods is problematic. Therefore, a signal averaging method is used to improve the signal-to-noise ratio (SNR). Signal Averaged ECG (SA-ECG) is based on signal averaging techniques. The useful component of the signal is always the same whether the noise components are variating through all the cumulated signals. [5][8]

4 METHODS

The paragraphs below describe the steps of the algorithm used to preprocess the HF-ECG signal for evaluating derived parameters. The algorithm needs to respect previously mentioned information about signal processing and also the physiological predisposition of the isolated rabbit heart. [1][2]

Experimental data enter the analysis in their raw form. The first step includes creating a piece of signal called averaged beat by using morphological clustering and signal averaging. The next step represents the choice of suitable bandpass filtering for analysed data. After that follows the decomposition of HF part of the signal's spectre into bands itself. The design of the algorithm can be seen in Figure 1.

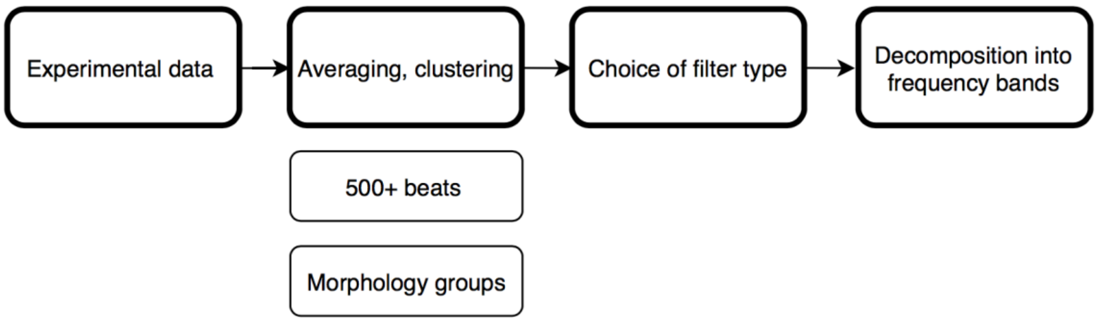

Figure 1: The design of the algorithm

4.1 SIGNAL CLUSTERING AND AVERAGING

Clustering following by averaging is a convenient method of how to denoise analysed signals without using low-pass filtering. Clustering is used to sort the HF ECG beats according to the respective morphological groups. [5]

Signal enters the sorting algorithm alongside with the global R-wave positions. The process of clustering is done with parts of the signal with the length of 1200 samples, which equals to 120 ms, 60 ms on each side from the selected R-wave position. The size of the windows was chosen according to the average width of the QRS complex in rabbit ECG signal and also the stimulation peak was not included. Cross-correlation threshold was set to 0.985, maximum lag to 20 ms around the R-wave. The morphological group for averaging should include at least 500 beats. The outcome of aligning beats can be seen in Figure 2. [1][7][9]

There is a possibility of the creation too many morphological groups. Therefore, it is useful to include also visual control of the outcome. If two groups with very similar morphology were found, the cross-correlation between them was computed again and if the coefficient was above 0.985, the two groups were merged. Every morphological group represents the part of the signal which is stable in its shape and amplitude.

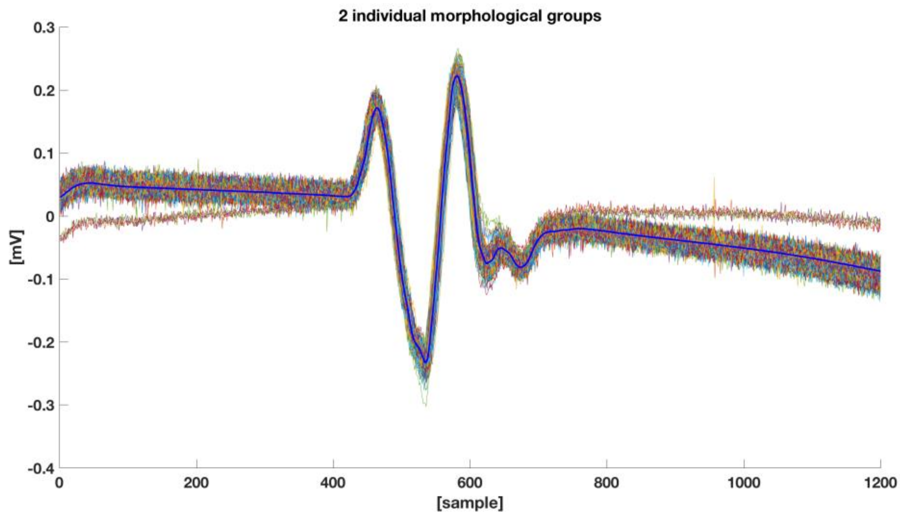

Figure 2: Aligned beats (circa 800) from one section of signal witch averaged beat highlighted.

4.2 FILTERING SETUP

Bandpass filtering is an already mentioned problematic part of the preprocessing. Mostly used method is based on Butterworth filter, often of 4th order. The method was estimated in 1996 and became almost a standard in HF-ECG preprocessing. Nevertheless, the verification of method's credibility should always be provided. In the described case, the application of said method provided outcomes, which differed from other approaches greatly.

In the Figure 3 can be seen, how much of an influence the filter choice is. The usage of Butterworth filter degraded the signal's morphology alongside with creating unwanted oscillations at the beginning of filtering window. Also, the amplitude of the signal was halved compared to the FIR filter outcome. Presented Figure3 outlines the results for the frequency band 300-500 Hz, but the signal degradation by Butterworth filter increased in higher frequency bands.

Finally, set of FIR filters was chosen for the purpose of decomposition, all stable with orders from 15 to 70 with the effective value at -3 dB being exactly the bands´ cut-off frequencies.

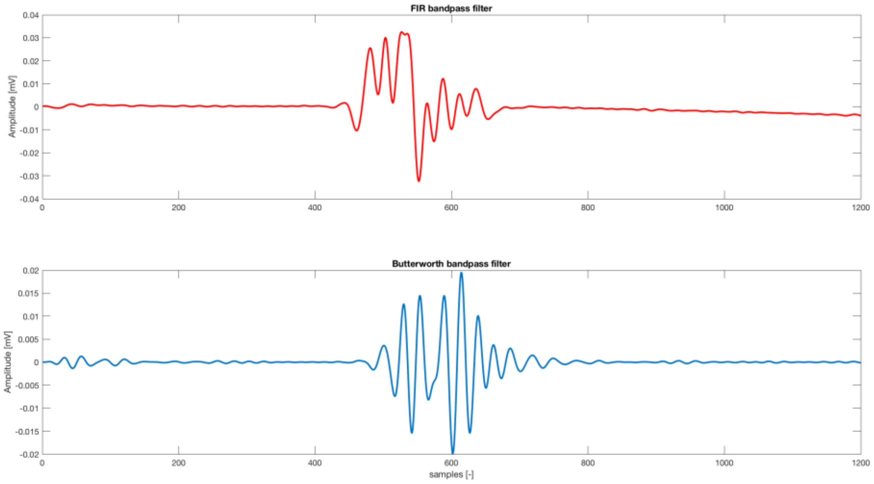

Figure 3: The comparison of FIR (upper) and Butterworth (lower) filtering outcomes in the frequency band 300-500 Hz.

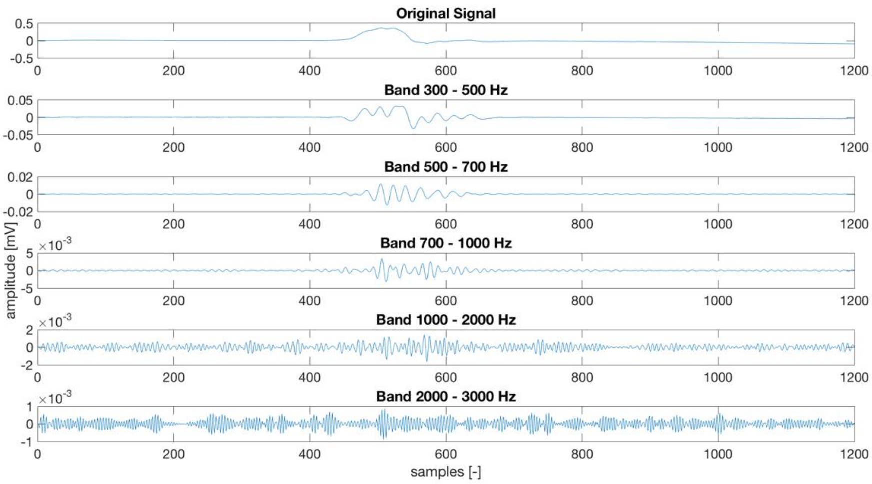

Figure 4: Averaged beat decomposed into 5 frequency bands.

4.3 SIGNAL DECOMPOSITION

The last step of HF-ECG data preprocessing for further analysis is a decomposition into respective frequency bands. Input into this step is the averaged signal computed by clustering and averaging. The number of bands needs to be settled according to the analysis aims and the physiological requirements of the analysed data. In this case, originally the number of bands was set to 5 with the range from 300 Hz to 3000 Hz. [3][6][7]

Not all frequency bands were used for further analysis. In Figure 5, the comparison of signal energy in respective frequency bands for the QRS area and area with no useful signal information (noise) can be observed. SNR in first 3 bands varies in range 53-185. In the last 2 band, it decreases to 1-8,3. Therefore, the last two bands were not used for further analysis.

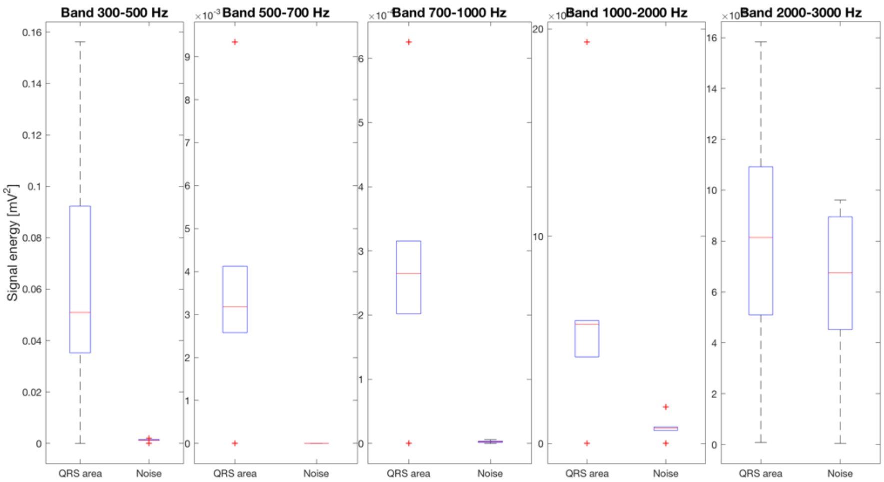

Figure 5: Comparison of signal energy in QRS complex area and non-QRS area (noise)

5 CONCLUSION

The aim of this article was to describe the process of preprocessing HF-ECG data from isolated rabbit heart for further analysis and to encourage for verifying the credibility of long-term settled methods. The follow-up presented in this article could be considered as general suggestion for such preprocessing, but the specific attributes of data and designed analysis must always be taken into account. Experiments with animal data and their following analysis are also crucial for further understanding the physiology of the human heart. The functionality of rabbit heart is very similar to the human one and because of that, we can design and develope studies and experiments to help cure and prevent cardiovascular diseases in human population.

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