FILTRATION AND ACTION POTENTIALS RECOGNIZATION IN OPTICAL RECORDINGS

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ABSTRACT

The main objective of this paper is to find useful parts of signals in optical recordings of action potentials. The averaging technique combined with continuous wavelet transform (CWT) was employed to get better signal to noise ratio. CWT was used to decompose noisy signals in separate repetitions. Signal to noise ratio was improved from SNR=2.6 to SNR=11.6 in average. The signals were filtered and aligned in time, baseline and amplitude. Than the dynamic time warpping algorithm was used to recognize useful parts of signal.

1. INTRODUCTION

The optical mapping is widely used technique in animal cardiac electrophysiology experimental research. The optical mapping employes an application of voltage sensitive dye to measure action potentials on the examined heart tissue. During the experiment, the heart tissue is lit by a high intensity light source and fluorescence is simultaneously recorded. The recorded signal consists of transmembrane action potential signal, high frequency noise, motion artifact disturbation and other distortion. This paper describes methods which allow us to reduce high frequency noise, to improve signal to noise ratio and then to detect characteristic motion artifacts.

2. METHODS

2.1. DATA ACQUISITION

The optical signals measured from rabbit hearts experiment were used in the study. Each heart was mounted on Langendorff apparatus, filled with Krebs-Hensleit (K-H) solution (1.25 mM Ca^{2+}) and placed in a heated bath (37 ˚C). The hearts were perfused at the constant pressure of (85 mmHg). The hearts were stabilized for 30 minutes. After a control period, the hearts were perfused with 1mM solution of voltage sensitive dye di-4-ANEPPS diluted in K-H solution, duration of loading period was 20 to 25 minutes. Then dye was washed out for next 20 to 25 minutes[1].

ECG signals were recorded continuously during whole experiment. Optical signals were recorded since wash out period. An ECG recording system was assembled with touchless orthogonal lead system. The signals from electrodes were amplified and than digitized by a 12-bit AD converter at 2 kHz sampling rate using a LabView compatible data acquisition multifunction card PCI-611E (National Instruments,USA). The optical signals were obtained by a flexible bifurcated fiber cable (FCR-7IR200-2-ME Avantes, the Netherlands). The fibre cable was connected to a light source (150W tungsten-halogen lamp) on the one side and the emission light was sensed by photodiode sensor on the other side. The light source contains a band-pass filter (560nm +/- 30nm). The photodiode detector was combined with a high pass filter (>610nm). The signal was amplified and then digitized by the same way like ECG signals[2].

2.2. SIGNAL FILTRATION

For filtration of optical signals was used designed system which block diagram is depicted on figure 1. The input signals are time synchronized ECG signal and optical recorded signal. The output signal consists of filtered parts of input signal where action potential was detected and corresponding time marks.

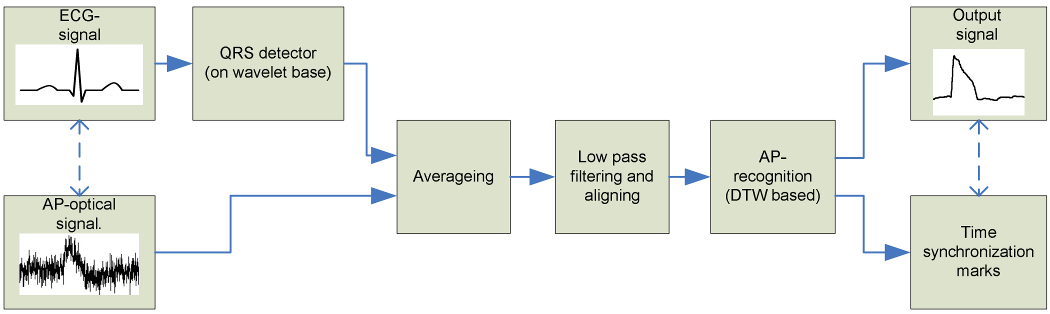

Figure 1: Signal reconstruction

The measured optical signals were reconstructed by using averaging technique with floating window (1)[3]. Various lengths of windows were tested. This technique was improved by our repetitions consideration algorithm which allowed us to consider only significant (similar lengths) repetitions.

$$y(kT) = \sum_{i=0}^{\max(j,M-1)} \left[\frac{1}{M} \cdot_{(j-i)} x(lT) \right], \; j = 0,1,2,...,$$

(1)

Each repetition consists of signal measured during a cardiac cycle. The optical signal was split to particular repetition by designed function. This function use measured data from one of the ECG channel. On this channel QRS complex was detected by designated continuous wavelet based algorithm (2). The detected points show us where the repetition starts and ends. Starts and ends of the each repetition were moved by desired offset to obtain alignment on entering edge. The length of each repetition was adjusted to the determined length. This length was calculated as median of the repetitions lengths for each window. The longer repetition was cut and shorter was appended by zeros.

$$X_w(a,b) = \frac{1}{\sqrt{|(b)|}} \int_{-\infty}^{\infty} x(t)\psi(\frac{t-a}{b})\, dt$$

(2)

The high frequency noise of AP was removed from reconstructed signal by a low pass filter (N=100, f_c=50Hz, Hamming window). This filter was designed to determine high frequency noise and preserve useful signal which frequencies are up to 40 Hz.

2.3. ACTION POTENTIAL RECOGNITION

The reconstructed signals at this stage consist of small portion of high frequency noise, but motion artifact and other distortion is still present. Motion artifact and other distortion vary during the time of measurement. For finding and evaluating sections, where the signal contains minimum of the distortion or the motion artifact, we employ the algorithm which uses the dynamic time warpping method (DTW). The DTW is used for its time independence to ensure that similar signals with different lengths of AP will be properly classified. We chose a part of signal (one repetition) with minimal distortion or motion artifact, and set up this part like reference pattern R. Then we were looking for similarity between others repetitions (considered as test patterns). Pattern similarity is determined by aligning test pattern, T, with reference pattern, R, with distortion D(T,R)(3)[4]. The decision rule was determined (the number of D(T,R)) to consider which repetition responding to acceptable signal. This method is also used to find the characteristic motion artifact described like reference pattern.

$$D(T,R) = \frac{1}{M\phi} \sum_{k=1}^{K\phi} d(t_{\phi t(k)}, r_{\phi r(k)}) m_k \tag{3}$$

There are also other methods, especially for signal measurement, which improve SNR and reduce motion artifact but these do not deal with our task[5].

3. RESULTS

The reconstructed optical signal after application of cumulation techniques is shown on figure 2. The optimal length of M=25 was determined to preserve temporal resolution and also find the sufficient SNR. The SNR was SNR_m=2.6 before reconstruction and SNR_r=11.6 after reconstruction. The presented SNR is peak-to-peak SNR. The peak to peak amplitude of the noise was computed during the diastole phase of AP and the peak to peak amplitude of the signal was computed during the systolic phase of AP.

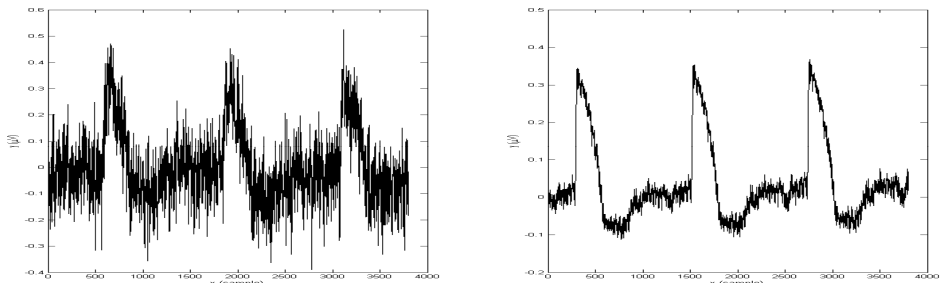

Figure 2: Signal reconstruction

The figure 3 shows one repetition of signal (transmembrane action potential) with characteristic motion artifact (The negative wave after repolarization). Signals are shown before and after filtration with low pass filter.

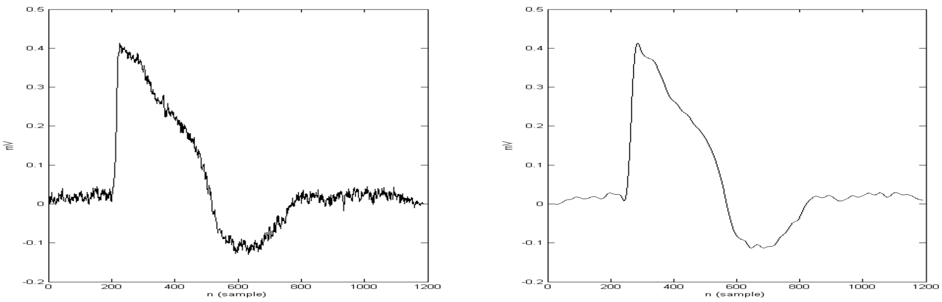

Figure 3: AP signal with motion artifact.

The DTW was used to find section of signal with minimal noise or other distortion and also to find signals (repetitions) with typical motion artifact (shown on figure 2). The figure 4 shows distortion D(T,R) for four different signal repetitions measured during one minute. The reference pattern R (gray line) was compared to test signals (black line) on the left. Relevant distortions are depicted on the right. The distance matrix on the right side, was computed like difference between tests and reference patterns. The test patterns were adjusted before computing of distance matrix. This means adjusting of DC offset and amplitude. DC offset was adjusted to get same baseline in compared signals. There is possibility to remove DC offset by high pass filter, but in this case it is not coming with acceptable results. The used algorithm computed average offset in first 1/15 of the signals, which is considered like baseline, and this offset subtract from the whole signal. The maximal amplitude of test patterns was adjusted to the same level like was in reference pattern. The adjusted, time and baseline alignment signals are shown in figure 4 on the left.

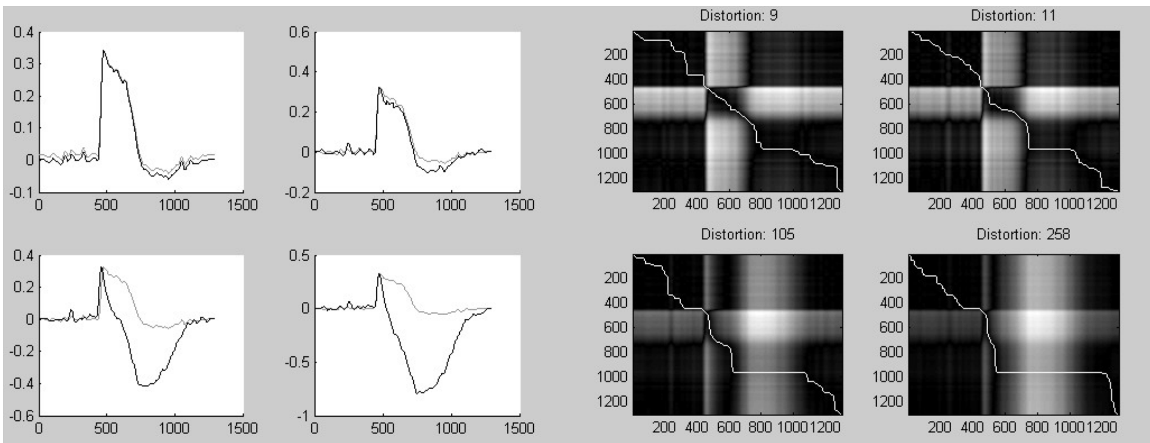

Figure 4: Using DTW for signal classification.

The decision rule was determined (the level of distortion D(T,R)) for marking the relevant signal sections. Figure 4 shows detection of repetition of AP in optical recorded signal. On the left are depicted all considered repetition and on the right side we can see selected repetitions of AP, where distortion D(T,R) was smaller than chosen threshold = 20 (D(T,R)<20). The chosen distortion threshold says how similar signal to the reference pattern we take into account. Threshold has been chosen experimentally during filtration process. Although, there are no databases of similar signals which allowed us to compare algorithm with, it is obvious that we can check predictivity of chosen signals by the figure 5 on the right. The sensitivity of the algorithm has to be computed manually.

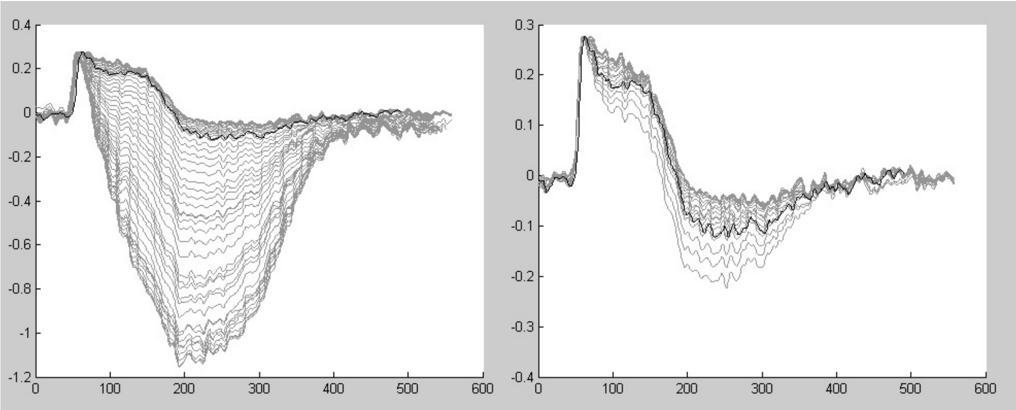

Figure 5: Classificated signals.

4. CONCLUSIONS AND DISCUSSION

The optical signal reconstruction employing averaging technique with floating window comes with significant improving of SNR. The improving of SNR helps us to make signal analysis and evaluation. The DTW methods allowed us to find sections of signals witch minimal distortion. Finding and filtering useful signal parts will help us to make future analysis of measurement data.

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