Predicting the End of an Atrial Fibrillation Episode: The PhysioNet Challenge

F Cantini[1], F Conforti[1], M Varanini[1], F Chiarugi[2], G Vrouchos[3]

[1]CNR, Institute of Clinical Physiology, Pisa, Italy
[2]CMI-HTA, Institute of Computer Science, Foundation for Research and Technology - Hellas, ICS-FORTH, Heraklion, Crete, Greece
[3]ICU-CCU Department, Venizeleio-Pananeio Hospital, Heraklion, Crete, Greece

Abstract

The PhysioNet Challenge 2004 addresses two different goals: to separate the persistent atrial fibrillation (AF) from the paroxysmal AF (event 1) and, in case of paroxysmal AF, to identify the one-minute ECG strip just before the termination of the AF episode (event 2).

Both events were approached through the separation of the atrial activity by the ventricular one in the ECG recordings (1-minute, two leads, 128 Hz). This separation was obtained through two different methods: a) QRST cancellation through cross-channel adaptive filtering; b) beat classification and class averaged beat subtraction.

For event 1, the averaged RR (index of ventricular activity) was put into relationship with the Dominant Atrial Frequency (DAF) (index of atrial activity). A linear classifier was evaluated separating the RR/DAF plane into the N-type and T-type regions. The best score was 95% on learning sets and 27/30 on testing set A.

For event 2, once the S-type and T-type signals were joined for each patient using a QRST correlation method, significative parameters were singled out in the DAFs during the penultimate and last two seconds of the S-type and T-type recordings. Criteria based on the DAF trend of each signal in its last seconds and criteria based on the DAF comparison between S-type and T-type signals were jointly used. The best score was 80% on learning sets and 18/20 on testing set B.

1. Introduction

Atrial fibrillation (AF) is the most common arrhythmia. Paroxysmal (spontaneously terminated) atrial fibrillation (PAF) is, by evidence, antecedent to sustained AF that requires a pharmacological or external electrical intervention (cardioversion) to allow its termination. The risks of sustained AF are, nevertheless, serious because it predisposes to thromboembolism as a result of stasis and thrombus formation within the atria that can cause stroke or other thromboembolic events. Thus, the discrimination between paroxysmal and sustained AF and the prediction of PAF termination can be invaluable in order to avoid useless therapeutic interventions, to minimize the risks for the patient and to save money when the health care costs are strictly monitored.

In normal conditions the atrial and the ventricular rhythms are coupled. Each heartbeat starts in the right atrium [1]. Here, the sinus node (SN), a natural pacemaker, sends an electrical signal. This signal spreads throughout the atria to the area between the atria and the ventricles called the atrioventricular (AV) node. The AV node connects to a group of special pathways that conduct the signal to the ventricles. Thus, first the atria contract pumping blood into the ventricles, and, a fraction of a second later, the ventricles contract sending blood throughout the body. In case of AF [2], multiple wavefronts of depolarisation, termed wavelets, circulate more or less randomly across the atrial myocardium. The wavelets circle around, constantly changing area of conduction block, re-initiating themselves. In this case the P wave is substituted by a series of fibrillation waves (f waves) completely uncoupled with the ventricular rhythm. Thus, the atrial rhythm is out of synchronization with the ventricular rhythm.

In the PhysioNet Challenge 2004 [3] two different goals are pursued: to separate the persistent AF from the paroxysmal AF (event 1) and, in case of paroxysmal AF, to identify the one-minute ECG strip just before the termination of the AF episode (event 2).

2. Methods

For these purposes, real data from 3 different learning sets were provided by PhysioNet for a total of 30 records. Each record is 1 minute length and was extracted by a two-channel Holter ECG with sampling rate 128 Hz. Learning set N is composed by 10 records of persistent AF, learning sets S and T are composed each one by 10 records of paroxysmal AF, but, in learning set S, AF terminates one minute after the end of the record while, in learning set T, AF terminates immediately after the end of the record.

Real data from two different testing sets were also provided for the evaluation of the implemented methods. In the event 1, testing set A is composed by 30 records, of which about one-half are from group N, and the remainder is from group T. In the event 2, testing set B is composed by 20 records, 10 from each of groups S and T.

A surface ECG signal contains both the atrial and the ventricular activities. What was necessary was the separation of the atrial signal from the ventricular signal, in order to accurately analyse the atrial signal.

In figure 1, a record of learning set N (n02) is shown. In real signals, extrasystoles, artefacts, baseline wandering and high frequency noise are usually present and can play a significant role in hampering the proper cancellation of the ventricular activity from the original signal.

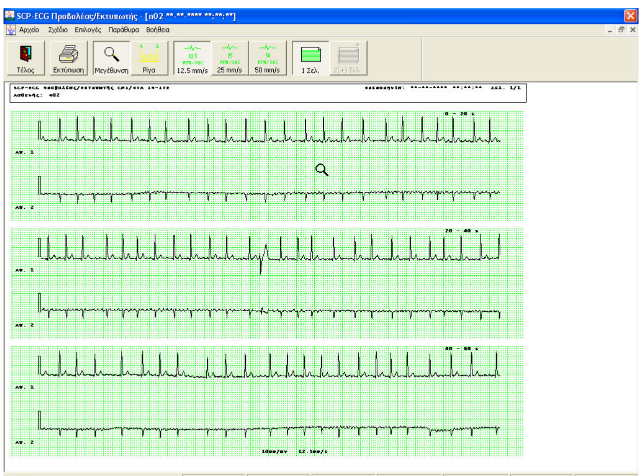

Figure 1: The record n02 from learning set N.

Different techniques can be applied to separate the atrial activity from the ventricular one [2, 4-8]. Two different methods were implemented: a) QRST cancellation through cross-channel adaptive filtering; b) beat classification and class averaged beat subtraction.

In the first approach, the lead with the highest atrial component power was identified by comparing the average of the maxima of a filtered derivative on 2 s and 200 ms windows. A second degree polynomial adaptive filter (19 coefficients, no cross-terms, not causal, delay half window length) using RLS algorithm (forgetting factor λ=0.996) was applied to cancel the ventricular component. The filter has at its reference input the signal with the lowest atrial activity and at the desired input the signal with the highest one. The high QRST power drives the adaptation of the filter coefficients providing at the error output a signal where the QRST is cancelled.

The adaptive filter was very effective in case of signals without extrasystoles and artefacts, but in case of extrasystoles or artefacts the QRST cancellation left some residual signal that might alter the subsequent signal processing.

Thus, the second approach was implemented.

The cancellation of the QRST complexes from both the two ECG channels was performed by the QRST complex detection, classification and subtraction of the relative class centroid. In details the process consists of the following steps: filtering (0.2-40 Hz) of both ECG signals and interpolation to 1024 Hz; QRS detection by a threshold on the signal obtained by absolute summing of filtered derivatives of each channel; QRST morphology clustering of both channels by L1 distance with wiggling and vertical shifting; subtraction of the relative class template from each QRST complex in the ECG signal.

This process produced two signals (one for each ECG channel) where the ventricular activity was cancelled. The residual power around the QRS detection points and the cross-correlation between the two signals were used to get a signal with enhanced atrial activity (AAS) by selecting the best signal among channel 1, channel 2, their sum and difference.

This method seems well suited for the treatment of signals with extrasystoles and artefacts, nevertheless the high variability of the ventricular rhythm and the RR interval produced sometimes a very early occurrence of the next ventricular depolarization that might cause an imperfect QRST cancellation and an imperfect identification of the DAF.

In both approaches, once isolated the atrial signal, this one was analysed in the frequency domain to extract the DAF. In fact, a main index of the atrial activity is the dominant atrial cycle length (DACL) or in terms of frequency the DAF [2, 4, 6, 8-10].

In method a) the residual signal and in method b) the signal AAS were analysed by Short Time Fourier Transform. A Gaussian window of 5 s was used, the power spectra were averaged over time discarding 10% percentiles and the peak of the resulting spectrum, in the band 3-10 Hz, was found.

Two different samples of resulting spectra are shown in figures 2 and 3 respectively for a case of learning set T and for a case of learning set N.

In both approaches an evaluation of the averaged RR (index of ventricular activity) was performed to correlate the ventricular activity with the atrial activity represented by the DAF (index of atrial activity).

For the event 1, the 20 cases of the 2 learning sets N and T were plotted in a plane with the averaged RR on the abscissas and the DAF on the ordinates. The N cases were well separated from the T cases. A linear classifier was applied and the two half-planes (T-type region and N-type region) were separated by a straight line.

Typically the cases with low DAF and low RR were T-type signals while the ones with high DAF and high RR were N-type signals. Using the adaptive filter 90% of cases were correctly classified in N and T learning sets, while using beat classification and class averaged beat subtraction 95% of records were correctly classified.

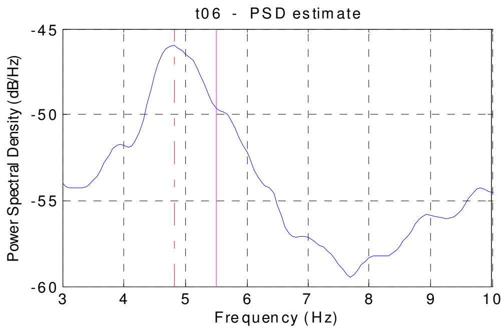

Figure 2: The atrial activity power spectrum of the record t06 from learning set T.

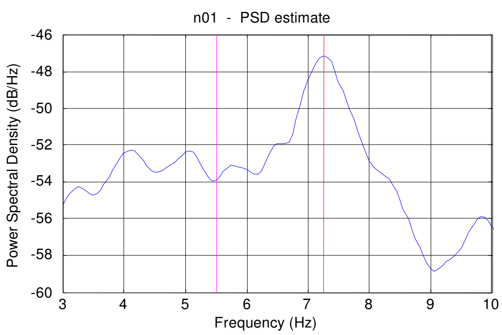

Figure 3: The atrial activity power spectrum of the record n01 from learning set N.

For the event 2, records from the same patient were used in order to discriminate between the signals terminating one-minute after the end of the recording (S-type signals) and the ones terminating one-second after the end of the recording (T-type signals). To join signals from the same patient, QRST complex classification was carried out. The most numerous class of each record was compared to the most numerous class of each other record by calculating L1 distance. Records with the smallest distance between their most numerous QRST classes were assumed to be from the same patient. All the records in the learning-set were correctly joined.

Once produced the couple of S and T signals for each patient, QRST cancellation was carried out in each ECG recording, like in method b) of the event 1, in order to enhance the atrial activity. The AAS signal was considered for the extraction of the atrial activity significant parameters.

The classification criteria were based on the analysis of the atrial activity. Criteria based on the DAF trend of each signal in its last seconds were used jointly with criteria based on the DAF comparison of the two S and T signals in their last seconds.

For each S and T couple of the same patient Fast Fourier Transform (FFT) was calculated using the intervals between 56 s and 58 s and between 58 s and 60 s (see an example in figure 4).

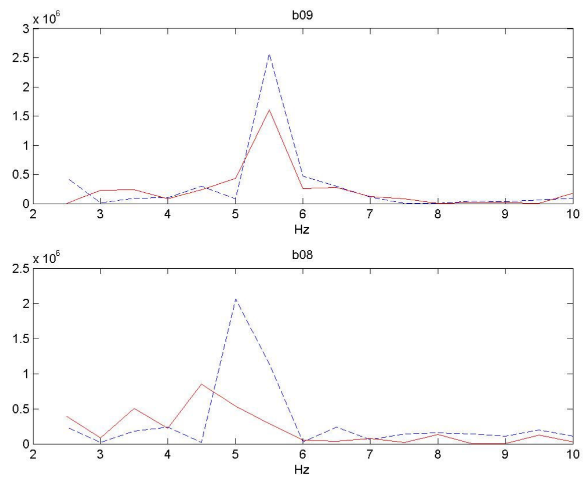

Figure 4: The FFT spectra of the penultimate (dashed) and last (continuous line) two seconds of the couple b08/b09.

For each couple of recordings of the same patient one was randomly assumed to be S-type and consequently the other one was assumed to be T-type. The DAFs calculated on the two intervals for the S-type and the T-type signals were compared according to the following same-weighted criteria:

1) ***criteria based on the DAF trend of each signal in its last seconds***: for the assumed T-type signal a check was made to verify if the DAF on the 58 s to 60 s interval was lower than DAF on the 56 s to 58 s interval and an opposite trend was checked in the assumed S-type signal;

2) ***criteria based on the DAF comparison between S-type and T-type signals***: checks were made to verify that the DAF decrement in the assumed T-type signal was bigger than an eventual DAF decrement in the assumed S-type signal, and the value of DAF in the last 2 seconds was lower for the T-type signal than for the S-type signal.

If these criteria were verified, according to their combined score, the initial assumptions were confirmed and the assumed S-type and T-type signals were finally classified respectively as S and T. Otherwise the classification was reversed and the assumed S-type and T-type signals were finally classified respectively as T and S. Using this algorithm, 80% (16/20) records of the learning sets S and T were correctly classified.

3. Results

In both methods used for the ventricular activity cancellation from the original signal, the same classification on the testing set A for event 1 was obtained. The resulting score was 27/30 (entry 20040416.045753, entrant 6). The classification of each case of the testing set was not changed; there only was a small improvement in the learning set that was not reflected on the testing set.

In figure 5 the two different regions with T-type signals and N-type signals are shown related to the classification of the testing set A.

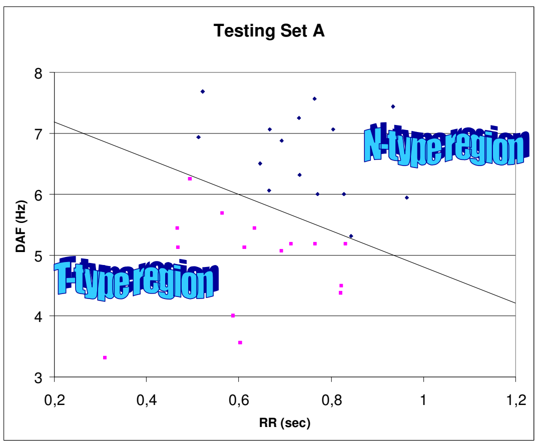

Figure 5: The linear classifier on testing set A with QRST classification and subtraction of the averaged QRST complex.

For the event 2 the described classifier was applied to the testing set B with a score of 18/20 (20040426.022624, entrant 6).

4. Discussion and conclusions

The ventricular activity cancellation seems to be the very crucial point of the overall processing chain.

The applied techniques offer satisfactory results; nevertheless methods could be further improved. In case of adaptive filtering, it should be useful to minimize the effects of signal artefacts and extrasystoles, while, in case of the QRST classification and QRST average beat subtraction, changes of QRST morphology due to significant variations of the instantaneous RR intervals should be taken into account in order to avoid imperfect QRST cancellation and spikes in the residual signals.

In this study other methods were investigated like an adaptive notch filter hooking and tracking the DAF, with no significant improvements respect to the results presented in this paper. Other more recent techniques like the convolutive Independent Component Analysis (c-ICA) and the Empirical Mode Decomposition (EMD) are under evaluation but, at the moment, no definitive results are available.

Acknowledgements

This work was partially supported by the Department of Internal Medicine, University of Pisa, Italy.

References

[1] Atrial Fibrillation Atrial Flutter Fibrillation - What are they? (http://www.hoslink.com/heart/af.htm).

[2] Meurling CJ, Sörnmo L, Stridh M and Olsson SB. Non-invasive assessment of atrial fibrillation (AF) cycle length in man: potential application for studying AF. Ann Ist Super Sanita 2001;37(3):341-9.

[3] The PhysioNet Challenge 2004. (http://www.physionet.org/challenge/2004/).

[4] Holm M, Pehrson S, Ingemansson M, Sörnmo L, Jahansson R, Sandhall L, Sunemark M, Smideberg B, Olsson C, Olsson SB. Non-invasive assessment of the atrial cycle length during atrial fibrillation in man: introducing, validating and illustrating a new ECG method. Cardiovasc Res. 1998 Apr;38(1):69-81.

[5] Stridh M, Sörnmo L. Spatiotemporal QRST cancellation techniques for improved characterization of atrial fibrillation in the surface ECG. Proc. EMBS, IEEE Eng. Med. Biol. Soc., 1997.

[6] Stridh M, Sörnmo L, Holm M, Olsson B, Sattar F. Spectral analysis and time-dependent properties of atrial fibrillation in the surface ECG. Proc. EMBS, IEEE Eng. Med. Biol. Soc., 1998.

[7] Xi Q, Sahakian AV, Swyrin S. The effect of QRS cancellation on atrial fibrillatory wave signal characteristics in the surface electrocardiogram. J Electrocardiol. 2003 jul;36(3):243-9.

[8] Langley P, Stridh M, Rieta JJ, Sornmo L, Millet-Roig G, Murray A. Comparison of atrial rhythm extraction techniques for the estimation of the main atrial frequency from the 12-lead electrocardiogram in atrial fibrillation. Computers in Cardiology 2002;29:29-32.

[9] Fujiki A, Sakabe M, Nishida K, Mizumaki K, Inoue H. Role of fibrillation cycle length in spontaneous and drug-induced termination of human atrial fibrillation. Circ J. 2003 May;67(5):391-5.

[10] Tai CT, Chen SA, Liu AS, Yu WC, Ding YA, Chang MS, Kao T. Spectral Analysis of Chronic Atrial Fibrillation and its Relation to Minimal Defibrillation Energy. Pacing Clin Electrophysiol. 2002 Dec:25(12):1747-51.

Address for correspondence

Federico Cantini
CNR, Institute of Clinical Physiology,
Via G. Moruzzi, 1
56124 Pisa
Italy
federico.cantini@ifc.cnr.it