THE BANDWIDTH VARIABILITY OF A TYPICAL ELECTROCARDIOGRAM

P. Augustyniak, R. Tadeusiewicz

AGH Technical University, Institute of Automatics, 30-059 Kraków, Mickiewicza 30, Poland

august@biocyb.ia.agh.edu.pl
rtad@biocyb.ia.agh.edu.pl

Abstract: The problem of local bandwidth of a typical electrocardiogram (ECG) is the first issue to consider when developing a structure-dependent algorithm for ECG signals compression. Our aim at this stage is to find out the bandwidth variability that means the bandwidth of every ECG structure taking into account the possible morphological changes, noise and so forth. The research done answered a very important question: "what signal bandwidth is expected at any time in an ECG?" It has been found that only about 19.4% of transmission channel throughput capabilities are really used for ECG signal. The presented results justify the hope for high compression ratio and low distortion of an algorithm based on the pre-recognised ECG structures (P, QRS and T waves localisation).

Introduction

For storing and transmitting of an electrocardiographic signal (ECG) full informative capacity (bandwidth) of transmitting channel is usually used. Our approach, proposed here, results from a motivated hope, that a typical pre-processing of ECG (i. e. automatic wave recognition) will allow to adapt the instantaneous bandwidth of the channel to the local density of information. The first issue is to determine the typical bandwidth or density of information and its variance for all ECG components. Different wave morphologies, for QRS-complex in particular, should be considered. This work determines the indispensable minimum of parameters, the pre-processor should deliver, for the optimum bandwidth adjustment for transmission or storage channels. The adjustment method is not taken under consideration hereby since we are still working on it.

Materials and methods

The well-known source of annotated ECG beats of different morphology is the CSE-Multilead Database [1] (sampling parameters: 500 Hz, 16 bit) that provides the exact start- and endpoints of P, QRS and T waves. Knowing these points for each signal made possible to retrieve their closest references in the time-frequency (t-f) representation of an ECG. The t-f decomposition we used was Mallat QMF-based wavelet [2] that provides sufficient frequency-band separation and time accuracy. To minimize the edge-effect distortion, all signals were prepared for the t-f transform by subtracting the constant value and slope, and then standardized in length to value 2^k. The lengths were 32 ms (16 samples) for baseline, 128 ms for P and QRS waves and 256 ms for T waves. These values determine the lowest frequency band for each wave: 32 Hz for baseline, 8 Hz for P and QRS waves and 4 Hz for T wave. As suggested in the CSE comments, the true values of waves for a particular signal were assumed to be equal in all leads. The t-f representation of each wave was related to the baseline content of the same signal in the same lead in order to assess the significance of the particular t-f items. The baseline (i. e. the P-end to QRS-start section) is commonly considered as a representation of no cardiac electrical activity period and thus widely used as a reference. Due to the very short baseline (1...4 t-f samples depending on frequency band) simple threshold method was used for the assessment, instead of statistical non-parametric significance test [3].

Signals preprocessing

Assuming the extracardiac signal (noise or other) to be stationary and no correlated to the ECG, the average energy $\boldsymbol{E}$ and its variance $\boldsymbol{\delta E}$ were measured at the baseline for each frequency band. The t-f representation of every wave was thresholded with the $\boldsymbol{th_f}$ values in all frequency bands in all leads: I, II, III, aVR, aVL, aVF, V1, V2, V3, V4, V5, V6, X, Y, Z.

$$th_f = E_f + \delta E_f$$

$$S_{t,f} = \begin{cases} S_{t,f} & \text{when } S_{t,f} > th_f \\ 0 & \text{otherwise} \end{cases}$$

The thresholded t-f representations were then averaged through all leads available and normalized in energy in order to eliminate the influence of amplitude to the result of intra-signal averaging. That result in three sets of wave specific normalized averaged thresholded t-f representations: NATTF-P, NATTF-

QRS and NATTF-T. All these representations were next averaged through all signals represented in the database excluding the pacemaker stimulated waves and some signals of extremely low quality.

The effective count of averaged t-f representations was: 99 for P wave, 123 for QRS-complex and 103 for T-wave. For QRS-complex representations the averaging was made separately for ventricular V (no P-wave) and supraventricular SV morphology in order to maintain the difference in their t-f content.

The effective bandwidth of the ECG was initially set to 16 Hz (the lowest frequency represented in the baseline). It may be lower in some circumstances, but the use of baseline as a reference is questionable in that case. For sections where P, QRS and T waves were detected, the effective bandwidth was expanded to the value corresponding to the 95 % of energy throughput. That value change with time inside the wave and that is what we called “instantaneous bandwidth”. At the application stage, depending on the adjustment method’s properties, the compromise between time and frequency precision should be made. The instantaneous bandwidth is expressed in information density units and compared to the full bandwidth.

The comparison of NATTF-QRS-V subset (11 elements) with the NATTF-QRS-SV subset (111 elements) was done with use of the non-parametric Kolmogorow-Smirnoff significance test ($p < 0.05$) [3]. This comparison is expected to confirm or deny the use of morphology detector in pre-processing phase.

Results

The average lengths of each ECG component are summarized in table 1.

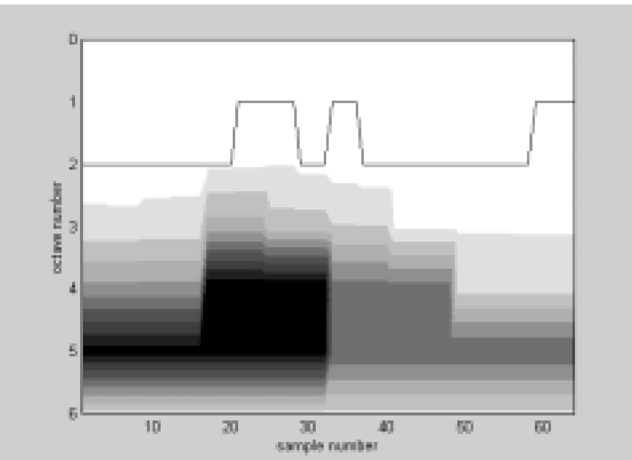

Figure 1. Averaged normalized time-frequency plane of a QRS complex; black line separates coefficients representing less than 5% of instantaneous energy.

Figure 1 presents the averaged NATTF-QRS plane. Horizontal axis is time in sample numbers (sampling frequency equals 500 Hz), and vertical axis is octave number, octave 1 corresponds to frequency band 125...250 Hz, octave 2: 62.5...125 Hz and so forth.

Table 1. Average lengths of ECG components (in samples, each representing 2 ms)

	RR	P	QRS	T
average	443.62	55.61	54.75	146.27
st. dev.	106.35	6.49	11.56	18.17
% of RR		12.5	12.3	24.0

Black line separates coefficients representing less than 5% of instantaneous energy and thus determines an instantaneous bandwidth of the signal. All samples on and above this line could be cancelled (set to zero or not transmitted) without disturbing the signal more than 5%. The averaged t-f plane allows calculate the count of samples that are essential to maintain the signal’s properties. Similar t-f planes were computed for P and T wave, and for QRS-SV and QSR-V morphologies separately, but due to the lack of space cannot be presented here. Table 2 summarizes the number of essential samples for each wave

Table 2. Number of essential samples for P, QRS and T wave.

samples	P	QRS	T	izoline	entire RR
original normalized	64	64	128	187	443
essential	29	20	26	11	86
% of orig.	45.3	31.3	20.3	5.8	19.4

Discussion

Compression factor of 5 can be easily achieved when using the instantaneous bandwidth coding of an electrocardiogram. The length normalization of waves verifies in average their real lengths (P and QRS are overestimated and T is underestimated). The use of non-parametric test showed no significant difference between corresponding samples of NATTF-QRS-V and NATTF-QRS-SV planes outside of the intersection of their bandwidths. That means, the use of morphology recognition algorithm does not improve the compression parameters. The wavelengths processing algorithm does not need to be very precise, the sample length at 2 octave equals to 8 ms. Others t-f decomposition methods (i. e. wavelet packets) should be applied to gain the maximum compression ratio with minimum distortion.

References

[1] J. L. Willems "Common Standards for Quantitative Electrocardiography" 10th CSE Progress Report, 1990. Leuven: ACCO publ., 1990, 384p.

[2] S. G. Mallat, „A Theory for Multiresolution Signal Decomposition: The Wavelet Representation”, IEEE Trans on PAMI, Vol. 11 No. 7, July 1989

[3] R. Tadeusiewicz, A. Izworski, J. Majewski, “Biometry”, AGH, Kraków, 1993 (in Polish)