ECG NOISE MODELLING IN TIME-FREQUENCY DOMAIN USING THE POLYNOMIAL EXTRAPOLATION

A. Izworski, P. Augustyniak

University of Mining and Metallurgy, Institute of Automatics, Kraków, Poland

Abstract: **The paper presents a new ECG-dedicated noise removal technique. The proposed algorithm makes use of the local bandwidth variability of cardiac electrical representation. Background activities of any origin (muscle, mains interference etc.) are measured in specified regions of the time-frequency plane. Outside of these regions, where normally the cardiac representation components are expected, we use the square polynomial extrapolation to estimate the noise level. The partially measured and partially calculated time-frequency representation of the noise is arithmetically subtracted from the noisy signal and the inverse time-frequency transform yields noise-free cardiac representation. The algorithm was tested with use of the CSE Database records with the addition of the MIT-BIH Database noise patterns.**
Keywords: **electrocardiography, noise removal techniques, time-frequency domain**

Introduction

The noise removal is a very important issue for the biomedical signals recording techniques. The primary reason is the unstable recording environment (unwanted signals, poor electrodes, electromagnetic pollution etc.). The second reason is the high importance of these signals for the final diagnosis and treatment of the patient including life-critical circumstances. And the systematically growing importance of the home care in the ageing population, results in technical aspect in moving the typical recording out of the hospital to the unknown and unstable environment. For that reason the traditional approach to the signal de-noising needs to be revised.

Usually two principal sources of ECG noise can be distinguished: the "technical" caused by the physical parameters of the recording equipment and the "physiological" representing the bioelectrical activity of the cells not belonging to the area of diagnostic interest (called also background activity) [1]. Both sources issue signals of random occurrence overlapping the ECG signal in the time domain and in the frequency domain. Both of them are difficult to eliminate when recorded with the signal, and thanks to the expected gaussian distribution of the noise, averaging technique is usually applied when appropriate [2]. This technique is perfect for the event-triggered potentials (like VEP) thanks to the assumed correlation of two adjacent responses but, unfortunately, it is not applicable when a reliable synchronisation point may not be determined. This is the case of noisy electrocardiogram.

Traditional de-noising techniques base on the assumption that any signal component may occur at any time [3]. Because of the unknown origin of the noise we have to consider it in this way. The electrical cardiac representation, however, is in some way predictable and the local bandwidth varies with the signal contents [4]. The discrete representation contains both of these components, and fortunately for some time periods (e.g. baseline) above a given frequency the cardiac components are not expected and thus the noise level can be reliably measured. For the remaining part of the signal it has to be extrapolated from the measured values.

Materials and Methods

The linearity of the time-frequency domain signals representation motivated us to design, implement and test the algorithm that not only estimates the ECG noise in a quasi-continuous way, but also removes it from the signal. The de-noising algorithm begins with the detection of the P, QRS and T waves with use of a subroutine designed for an interpretative ECG recorder. Next, the segmented signal is transformed to the time-frequency domain by the lifting wavelet transform (LWT) [5] that maps integer signal representation into integer t-f coefficients. The time-frequency plane is split into two parts by the standard function of the local bandwidth fitted to the current borders of the waves (fig. 1).

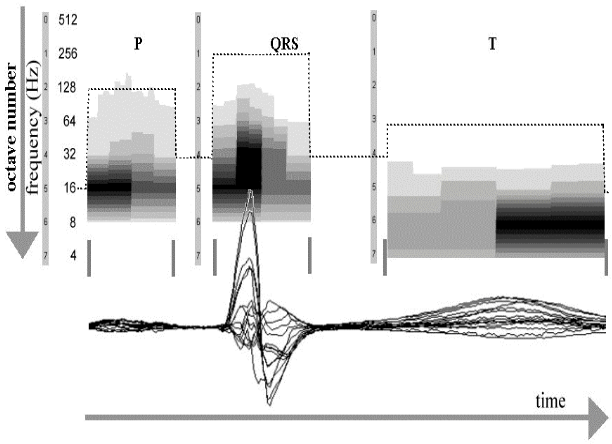

Fig. 1 Estimating the ECG local bandwidth with reference to the borders of P, QRS and T waves.

The measurement of the noise level is performed for all the t-f atoms belonging to the upper, "signal-free" part of the time-frequency plane. The polynomial extrapolation bases on the results of this measurement and reconstructs all remaining values, normally masked by the components of the cardiac representation. The extrapolation is performed in the time domain and in the frequency domain independently (fig. 2). The use of the local bandwidth of cardiac representation is the main novelty of our algorithm and results in its superiority over the traditional approach thanks to a reliable method of distinguishing the signal and the noise.

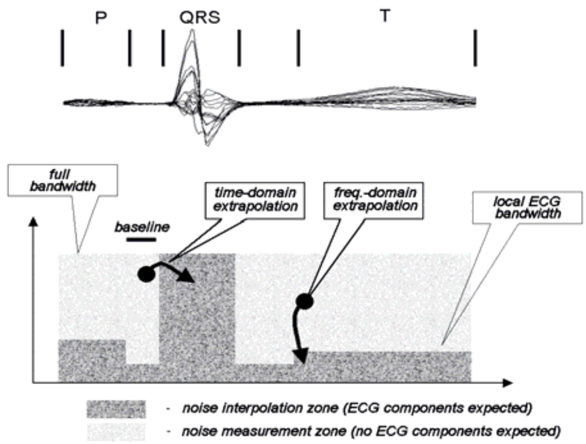

Fig. 2 Extrapolation of the noise representation in the time domain and in the frequency domain.

The practical advantage of having the noise model in the t-f domain is that the noise, expressed by values of the t-f atoms may be immediately subtracted from the signal. The use of a reversible time-frequency decomposition issues lossless reconstruction of all components considered as signal, while the noise is removed.

Results

Testing the noise removal algorithms is difficult and the results are often questionable because of the use of artificial test signals, that in the statistical aspect are far from the real signals or, when real signals are used, because of the presence of hardly controllable noise. Our algorithm was tested with use of the original ECG signals [6] and original noise strips [7] added in a controlled way at four levels of -3, -7, -10 and -13 dB. The noise was then removed and both signals were compared with use of the Percent Root-mean-square Difference (PRD). Numerical verification of the de-noising procedure was coded and carried out in Matlab 5, the segmentation points were provided by the database.

Table 1: The average difference of de-noised and original signals for most frequent noise patterns.

noise pattern	difference PRD [%] (SNR [dB])			
	50 (-3)	20 (-7)	10 (-10)	5 (-13)
poor electrode contact	47 (-3.1)	13 (-8.8)	4.7 (-13.2)	2.7 (-15.7)
electromagn. interference	17 (-7.7)	4.3 (-13.6)	1.3 (-18.9)	0.95 (-20.2)
muscle fibrillation	14 (-8.5)	2.3 (-16.3)	1.0 (-20.0)	0.85 (-20.7)

Discussion

The variability of the electrocardiogram bandwidth provides opportunity for the local measurements of the noise level and for computing of the quasi-continuous noise model with use of polynomial extrapolation. The de-noising performance depends on the noise pattern:

- the noise caused by poor electrode contact has high variability and thus the time-domain values are not accurately extrapolated
- the noise caused by the electromagnetic interference is stable in time, but concentrated around 60 Hz in frequency - in result frequency-domain values are not accurately extrapolated
- the muscle fibrillation noise best fulfils the assumptions about the stability in both domains - the de-noising yields best results for this type of noise.

In real ECG recordings the muscle noise being an artefact of physiological origin is the most problematic and difficult to avoid. The mains interference and the electrodes contact artefacts may be reduced by using the equipment of the highest quality.

Conclusions

The proposed algorithm has a high performance of ECG noise discrimination (up to 10 dB), however its performance for noisy records (SNR below 10 dB) is very poor. Thanks to the use of integer data representation at every processing stage, the algorithm may be implemented in any DSP-based recorder. The presented approach may be also useful for de-noising of other variable-bandwidth signals sampled at the constant rate.

Acknowledgment

This work is supported by the University of Mining and Metallurgy Krakow, Poland, grant no. 10.10.120.39

REFERENCES

[1] W. Zaręba, P. Maison-Blanche, E. H. Locati "Non-invasive electrocardiology in clinical practice" Futura Publishing Co. New York, 2001.

[2] W. J. Tompkins, "Biomedical Digital Signal Processing" Englewood Cliffs, NJ: Prentice-Hall, 1993.

[3] D. L. Donoho "Interpolating wavelet transforms" Preprint. Department of Statistics, Stanford University, 1992.

[4] P. Augustyniak, R. Tadeusiewicz "*The bandwidth variability of a typical electrocardiogram*" in proc. EMBEC ’99, Wien Austria, pp. 394-395, 1999.

[5] I. Daubechies, W. Sweldens "*Factoring wavelet transforms into lifting steps*" J. Fourier Anal. Appl., vol 4, no 3, pp. 245-267, 1998.

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

[7] G. B. Moody "The MIT-BIH Arrhythmia Database" Harvard-MIT Division of Health Sciences and Technology. Available: CD-ROM, 1992