Surface-ECG Atrial Activity Extraction via Blind Source Separation: Spectral Validation

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Abstract

The isolation of atrial activity (AA) from the surface electrocardiogram (ECG) remains a challenging unsolved problem. Different methods based on the ventricular activity (VA) cancellation have been proposed, validated from the performance obtained over synthesized AF recordings where the AA is known. This performance is measured by comparison (e.g. correlation and quadratic error) of real and estimated AA lead by lead. Other methods estimate one AA as a global contribution of all leads, and so, performance can not be computed in the same way. In this case, the present work explores this problem from a spectral-domain perspective. Several AA extracted from real atrial fibrillation (AF) and atrial flutter (AFL) patients have been analyzed. A spectral analysis reveals the existence of characteristic patterns.

1. Introduction

Higher amplitude of ventricular activity (VA) masks atrial repolarization, as well as despolarization in noisy environments. The observation of Atrial activity (AA) is further hindered when the AA becomes arrhythmic, or even chaotic, as in atrial fibrillation (AF) episodes. For the study of AF and atrial flutter (AFL) from the surface ECG several techniques have been put forward and validated by means of synthetic signals where the simulated AA component was directly available. However, in real ECG recordings AA is by nature unknown, and so its correlation with the estimated AA signal cannot be computed. Some validation criteria have been proposed in the time domain, but lack thoroughness, reproducibility and simplicity. The present work explores this problem from a spectral-domain perspective.

Malign ventricular arrhythmias have extensively been characterized since the 1980's. In this sense, different algorithms have been implemented to automatically detect Ventricular Fibrilation (VF) and other common ventricular arrhythmias as Ventricular Tachycardia (VT). Research in the frequency domain is fundamentally based on the fact that the energy of the fibrillation signal is concentrated around a main peak, and is contained within a certain frequency band [1,2]. In fig 1 Sinusal Rhythm (SR), VT and VF episodes with their corresponding power spectrum density are illustrated.

Nygards and Hulting [3] performed this type of analysis to implement an automatic monitorization system capable of detecting the presence of VF. Forster and Weaver [4] in turn based the detection of VF on the calculation of the relation between the RMS levels of the signal in the VF and low-frequency bands. Barro et al. [5], based on the power spectrum density, defined four parameters: the normalized first spectral moment and three others representing the energy distribution by bands. Nolle et al. [6] employed a series of parameters characteristic of VF, such as total power in the 1.5 to 24.2 Hz band or the maximum power components within the detection band. Millet et al. [7] reproduced these parameters plus other ones in the frequency and time domain after applying a wavelet transform.

So, a variety of spectral features have been found to be common to most such as spectrum concentration around a main frequency, bounded interval containing the main frequency, harmonic presence/absence at the main frequency, etc.

This paper considers such indices in the characterization of the AA estimated via blind source separation (BSS) from surface ECG signals. Bearing in mind the anatomic and other differences between atrium and ventriculum, it can be assumed that the spectral content of correctly extracted AA episodes should closely match those characteristics.

2. Database

Recordings of AF and AFL from 14 patients are enrolled in this study. All of them were provided by the Cardiac Electrophysiological Laboratory (Prucka Eng.)

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Computers in Cardiology 2002;29:605–608.

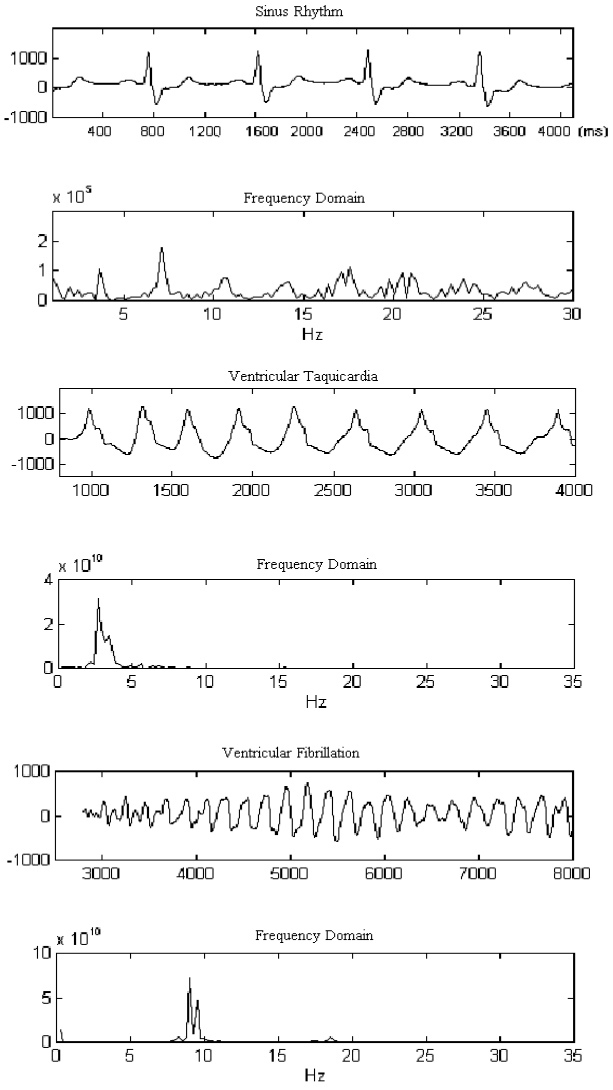


Fig. 1. Sinus Rhythm, Ventricular Tachycardia and Ventricular Fibrillation episodes with their corresponding spectral analysis.

from 'Hospital Clínico de Valencia'. These recordings consist of 8 seconds segments of standard 12-lead ECGs sampled (or resampled) at 1000Hz.

3. Methods

All records were pre-processed by means of a band-pass filter with cut-off frequencies of 0.5Hz and 60Hz. Notch filter was applied to remove power line interference. Each episode was introduced in a BSS model based on higher-order statistics. 12 Independent source signals were obtained, among of them there should be at least one AA candidate [8]. In fig.2 it is represented an example of AA extracted from AF and AFL recordings respectively.

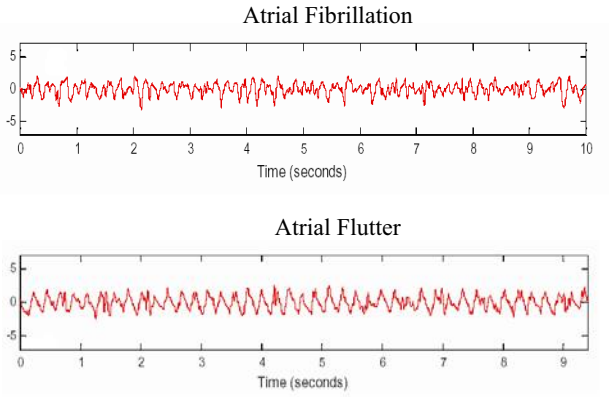


Fig. 2. Atrial activity extracted after BSS processing from atrial fibrillation and atrial flutter recordings.

3.1. Spectral parameters computation

Once the spectrum frequency has been calculated, it should be parameterized in order to find specific characteristics for each atrial arrhythmia. In this study we propose a set of spectral parameters [3-7] that have already shown their effectiveness in the characterization and discrimination of ventricular arrhythmias. These parameters are:

a) Main Frequency Peak (F_p): Spectral component with maximal power content.

b) Spectral Content below the main peak (A1):

$$A1 = \frac{\sum_{i=0.7324}^{F_p/2} xi}{\sum_{i=0.7324}^{20F_p} xi} \quad (1)$$

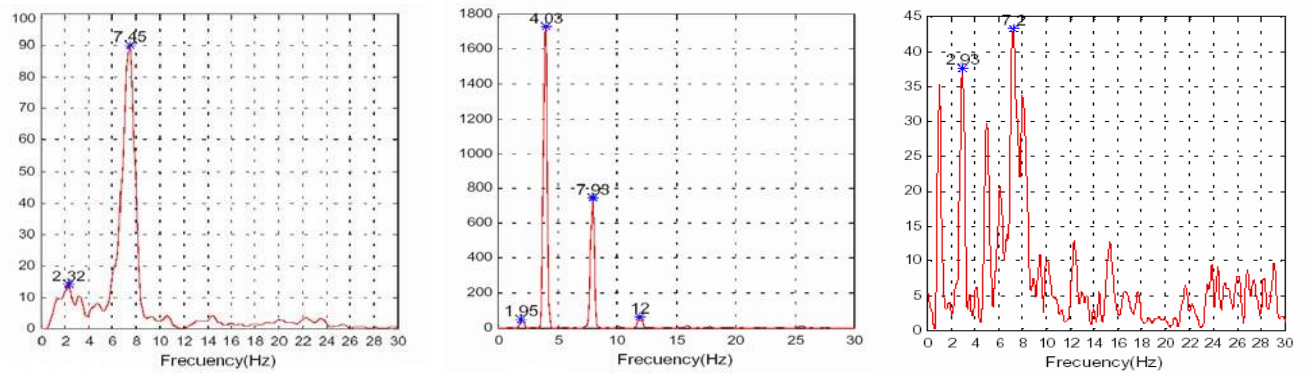
c) Spectral Concentration in the Band of the Peak (SCBP):

$$SCBP = \frac{\sum_{i=0.7F}^{1.4F} xi}{\sum_{i=0.7324}^{20F} xi} \quad (2)$$

d) First Order Moment (M1):

$$M1 = \frac{\sum_{i=0.7324}^{20F} xi \cdot fi}{\sum_{i=0.7325}^{20F} xi} \quad (3)$$

e) Normalized First Order Spectral Moment (NFSM):



a b c

Fig.2: a) Spectrum of the estimated atrial source during an AF episode. b) Spectrum of the estimated atrial source during an AFl episode. c) Spectrum of a normal sinus rhythm.

$$\mathrm{NFSM} = \frac{1}{F_p} \frac{\sum_{i=0.7324}^{20F} xi \cdot fi}{\sum_{i=0.7325}^{20F} xi} \quad (4)$$

f) Second Order Moment (M2):

$$M2 = \frac{\sum_{i=fsub}^{f\,\sup} xi \cdot (fi - \mathrm{M1})^2}{\sum_{i=fsub}^{f\,\sup} xi} \quad (5)$$

g) Main Peak Amplitude to First Harmonic Amplitude Ratio (MPFHR):

$$\mathrm{MPFHR} = \frac{x(F_p)}{x(2F_p)} \quad (6)$$

where *xi* is the spectral amplitude at the frequency *fi*.

3.2. Statistical analysis

Statistical description (mean value, standard deviation, range, etc.) has been computed for each parameter and for each rhythm by means of SPSS program tool. Box Whisker & Dot Plots has been displayed to quick illustrate performance of each parameter between NSR vs Atrial arrhythmias (AFl & AF) and AF vs AFl. Statistical significance analysis for each parameter and for both groups has also been done.

4. Results and discussion

Once spectral analysis of different episodes was computed they were checked. As it was expected, ventricular sources presented a spectrum very close to the spectrum of a normal sinus rhythm (NSR), i.e. with high spectral content in the frequency range [0.5..60]Hz. Meanwhile atrial sources showed a spectrum that differs from the spectra of ventricular sources.

Inspection of spectrum atrial sources (fig. 2 as an special example) confirm what we expected:

- Narrowband for AF-AFl vs. Wideband for NSR.
- Main peak amplitude vs several peaks amplitude.
- Harmonic presence for AFl vs absence for AF.

And some others not so expected:

- Main frequency peak is overlapped against NSR-Atrial Arrhythmias in some records. Mainly in AFl vs NSR episodes. As we can see in fig. 2, main frequency peak was located around 4.3Hz in the case of AFl and within the interval [6..8] Hz in the case of AF.
- Peak amplitude strongly higher in AFl episodes than AF.

Table 1 summarizes mean and standard deviation of some of spectral parameters described above for AF and AFl.

Table 1. Spectral Parameters

	AF		AFl	
	Mean	Std	Mean	Std
F_p (Hz)	6.32	0.9	4.27	0.3
A1	0.21	0.096	0.055	0.028
SCBP	0.47	0.12	0.59	0.05
M1	6.18	0.95	4.13	0.25
NFSM	1.46	0.47	1.6	0.12
M2	0.695	0.087	0.49	0.016
MPFHR	43.52	50.33	2.88	0.31

As it can be observed, some of them show strong differences, i.e. the main peak frequency, the spectral content below the main peak, the main peak to first harmonic ratio, etc. In the case of main peak frequency the range is [2.3,6.83] for NSR, [5.13,7.32] for AF and [4.03,4.64] for AFl. So Fp is very good localized for AFl

but completed overlapped with NSR. So, on one hand this parameter by itself is not able to discriminate between NSR and AFl, while on the other hand it is perfect to discriminate between AF vs AFl. Other parameters as MPFHR are not consistent since ranges for AF and AFl are overlapped.

First and second order moments arise to be parameters with no overlapped ranges and hence, appropiated for characterization and further discrimination.

Significant analysis corroborate the observation for AF vs Atrial Arrhtymias: SCBP, M1, M2 parameters are significant ($p<0.05$). Meanwhile this is not the case for Fp ($p=0.43$). For AF vs AFl: Fp, M2, A1,SCBP,MPFHR and M1 parameters are significant ($p<0.05$). Fp or M2 parameters are enough for completed discrimination (100% of accuracy).

It has been remarked that some parameters could be redundant. For example, the main peak frequency and the first order moment are strongly correlated for AF vs AFl study.

5. Conclusions

Spectral characterization proves a straightforward, efficient methodology for validating the effectiveness of AA extraction techniques (both local and global contribution) from the surface ECG. In addition, the proposed methodology substantiates the suitability of BSS to this problem and offers simple guidelines for the implementation of future BSS-based automatic AA-extraction algorithms.

Furthermore, the spectral parameterization proposed in this study show a different characterization for different atrial arrhythmias: AF and AFl. These parameters have also proven their success for the classification of other ventricular arrhytmias. All these considerations lead the authors to anticipate promising prospects for the further characterization of other existing atrial arrythmias as well as for their automatic identification.

Acknowledgements

This work was partly supported by research grants TIC2002-00957 and 'Programa Incentivo a la Investigación' UPV.

References

[1] Clayton RH, Murray A, Campbell RWF. Analysis of the Body Surface ECG measured in independent leads during ventricular fibrillation in humans. PACE 1995; 18: 1876-1881.

[2] Chorro FJ, Guerrero J, Cánoves J, Martínez-Sober M, Mainar L, Sanchis J, et al. Quantification of the modifications in the dominant frequency of ventricular fibrillation under conditions of ischemia and reperfusion: an experimental study. PACE 1998; 21: 1716-1723.

[3] Nygards ME, Hulting J. Recognition of ventricular fibrillation from the power spectrum of the ECG. Comput Cardiol 1977: 393-397.

[4] Forster FK, Weaver WD. Recognition of ventricular fibrillation, other rhythms and noise in patients developing the sudden cardiac death syndrome. Comput Cardiology 1982: 245-248.

[5] Barro S, Ruiz R, Cabello D, Mira J. Algorithmic sequential decision-making in the frequency domain for life threatening ventricular arrhythmias and imitiative artifacts: a diagnostic system. Journal Biomedical Engineering 1989; 11: 320-328.

[6] Nolle FM, Bowser RW, Badura FK, et al. Evaluation of a frequency-domain algorithm to detect ventricular fibrillation in the surface electrocardiogram. Computers in Cardiology 1989: 337-340.

[7] Millet-Roig J., López JJ, Mocholí A., Ruiz R., Chorro F.J. Study of frequency and Time domain parameters extracted by means of wavelet transform applied to ECG to distnguish between VF and other arrhytmias. *Computers in Cardiology, vol. 25; Cleveland, 1998, pp. 17-20.*

[8] J. J. Rieta, V. Zarzoso, J. Millet-Roig, R. García-Civera and R. Ruiz-Granell, "Atrial Activity Extraction Based on Blind Source Separation as an Alternative to QRST Cancellation for Atrial Fibrillation Analysis" in: *Computers in Cardiology, Vol. 27, Boston, MA, September 24-27, 2000, pp. 69-72.*

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