Wavelet Domain Blind Signal Separation to Analyze Supraventricular Arrhythmias from Holter Registers

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Abstract. Detection of atrial activity (AA) is quite important in the study and monitoring of supraventricular arrhythmias. This study shows the possibility of AA extraction from atrial fibrillation (AF) episodes in Holter registers using only two leads with a new technique, the Wavelet Domain in Blind Source Separation (WDBSS). Our principal aim is to join a processing stage with Blind Source Separation (BSS) with methodologies based on wavelet transform. A first stage with Discrete Wavelet Transform (DWT) increases the spectral information, decomposing the considered signal in a set of coefficients with different temporal and spectral features. A second stage with BSS uses this information to extract the AA. The obtained improvements are the increase of spectral concentration (in the band of 5-8 Hz) and the lack of residual complexes. In WDBSS, the use of several leads from the ECG is needless, which could be applied for to the detection of different arrhythmias in Holter registers, where the number of leads is reduced, like the paroxysmal atrial fibrillation.

1 Introduction

About 2-4% of people above 60 years suffers from AF. These numbers rise to 12% in people above 75 [1]. This arrhythmia (AF) is one of the most common and can be classified in three types: paroxysmal, permanent and persistent. The paroxysmal AF appears in episodes with lengths below 48 hours and in most cases have to be detected in Holter registers where the number of leads is reduced.

The isolated study of the registered atrial activity (AA) in the electrocardiogram (ECG) is necessary for the detection and characterization of AF in these cases. This study requires a previous extraction or cancellation of the ventricular activity (VA) which is spectrally overlapped and has larger amplitude level than AA.

Nowadays, there are several techniques that can extract the AA with a good performance- Blind Source Separation [2], Spatio-Temporal Cancellation [3,4]- but poor results are obtained when the number of used reference signals (leads) is less than three, or when the duration of these signals is reduced. On the other hand, classic techniques- Average Beat Subtraction (AVBS) [5]- have developed AA extraction from only one lead, but these systems are very sensitive to the presence of ectopic complexes.

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In previous works [6], the possibilities of Discrete Packet Wavelet Transform (DPWT) have been presented as a possible cancellation technique of VA in registers with synthesized AF and reduced number of leads. The obtained results showed an AA with spectral and temporal behaviour very similar to the expected AA. However, the presence of residual QRS complexes and the low performance in the case of real AF episodes required a second decomposition with Discrete Wavelet Transform (DWT). This second process obtained signals without QRS complexes, but the wave form of the extracted AA was distorted and it could not be identified as an AF by cardiologist.

In this paper, the WDBSS is presented as an improvement of the methodologies based on the DPWT and DWT for the AA extraction. The WDBSS consists of an analysis of several decomposition levels obtained with the wavelet transform using Blind Source Separation algorithms. The spectral concentration levels in the typical band of AF and the completed elimination of QRS complex justify the development of this new method.

2 Theory

The DPWT is a generalization of the wavelet transform that joins spectral and temporal analysis. The signal is decomposed in basic blocks corresponding to different frequency bands. Local and global parameters of the original signal can be identified using certain characteristics of these basic blocks.

The wavelet transform of a signal *f*(t) can be expressed as follows, in its most general form:

$$\begin{aligned} C(a,b) &= \int_R f(t)\psi_{a,b}(t)dt \\ \psi_{a,b}(t) &= \frac{1}{\sqrt{a}}\psi\left(\frac{t-b}{a}\right) \end{aligned} \tag{1}$$

The function $\psi_{a,b}$ is a dilated and displaced version of the "mother wavelet" ψ, where the parameters a and b indicate scale and translation respectively. The possibility of reconstruction of the original signal from some of the obtained basic blocks has been used for noise and interferences elimination in ECG, abnormal pattern recognition, complex detection, etc.

On the other hand, BSS, as a processing tool, is able to recover signals from a linear combination of these same signals. The simplest model of BSS takes on the presence of n statically independent signals and n observed linear and instantaneous mixtures. In this work, the independence and nongaussianity of the atria and ventricle as signal sources is taken on. Recent works have studied the propagation mechanisms and uncoordinated atrial activation of the AF to demonstrate this assumption [7].

The independent component analysis based on higher order statistics is the support for the different methodologies that solve the problem of BSS. The BSS model in its more compact form is given by

$$\begin{aligned} x(t) &= \sum_{j=1}^{n} a_{ij}\cdot s_j(t) \\ x(t) &= A\cdot s(t) \end{aligned} \tag{2}$$

where, s(t) is a vector of $n \nabla 1$ columns which contains the estimated sources, x(t) is the vector of the mixtures and A is the square mixing matrix. As BSS tries to recover s(t) from the observations, x(t) is necessary to estimate the matrix A. If the ICA methods can estimate the separation matrix, the independent sources can be expressed as follows

$$y(t) = W \cdot s(t) \tag{3}$$

where y(t) is the estimated sources and W is the inverse matrix of A.

3 Database

The signals used are created from recordings of an own database of ECG, with signals obtained at the Cardiac Electrophysiology Laboratory of the University Clinical Hospital in Valencia and diagnosed by cardiologists. All the registers have been pre-processed and normalized to remove possible fluctuations of the base line, interferences, noises, etc. Leads V1 and V5 have been used from 12-lead ECG and from Holter system. The final configuration of the database is shown in Table 1.

Table 1. Registers in database.

	12-leads ECG.	Holter System
Number of registers	29	15

4 Method

The principal aim of this study is to provide enough useful information to the BSS implemented system, only from the V1 and V5 leads to achieve efficiently the AA extraction. This rise of useful information is obtained by increasing the observed mixtures of the signal from the decomposition of each lead into six transformed signals using a wavelet transform with the corresponding levels. This idea has been studied in several recent works that probe the increase of the quality blind source separation if the sparse representability of the sources is exploited [8].

This methodology can be expressed by

$$\begin{aligned} V1 &\Rightarrow \left[C\_V1_1, C\_V1_2, \ldots\ldots, C\_V1_6\right] \\ V5 &\Rightarrow \left[C\_V5_1, C\_V5_2, \ldots\ldots, C\_V5_6\right] \\ x(t) &= \left[C\_V1_i; C\_V5_i\right] = A \cdot s_{V1,V5}(t) \end{aligned} \tag{4}$$

where the coefficients C_Vi_j represent the six obtained signals from the original leads V1 and V5 yielding several spectral and temporal representations for each lead, that can be considered as different mixtures. This wavelet stage uses denoising techniques that intensify the AA in the sources.

The function *"symlet7"* and six levels of decomposition are the wavelet family and configuration that offers the best performance. Several BSS algorithms have been tested, but the *FastIca* is the most efficient for the BSS stage and offers the lowest computational load.

Spectral analyses have been used to identify the AA between the obtained signals, s_1 and s_2. The signal with a principal frequency peak in the band of 5-8 Hz and higher spectral concentration in this range –as it is usual in an AF episode- is identified as AA.

5 Results

The leads V1 and V5 of an example ECG from the used database and the final extraction using only DPWT and WDBSS are shown in Figure 1. In the results with DPWT, there are residual QRS complexes which are eliminated using the second stage with BSS. The characteristic *"f"* waves hold the form observed in the original lead perfectly. In the case of DPWT, the comparison of the signal fragments corresponding to the AA shows high values of correlation too, but the presence of the mentioned VA reduces the final performance.

The spectral concentrations of the estimated AA in the different methodologies are shown in figures 2 and 3. The dispersion of the spectral distribution is lower in the results obtained with WDBSS and a mean peak of frequency can be identified in the range between 5 and 8 Hz clearly. This fact makes it easier to identify this AA as an atrial fibrillation episode, from a spectral point of view.

In Figure 4, we can appreciate the differences between the wave form of the original leads and the form of the main extracted sources (identified as possible AA) using the WDBSS method and the extracted signals using only BSS algorithms (JADE, FastICA). As it can be observed, the stage implemented without the previous wavelet decomposition doesn´t work properly in any case, comparing with the WDBSS method. The obtained sources don´t show the typical and expected "f" waves and the spectral study can´t identify these signals as an atrial activity.

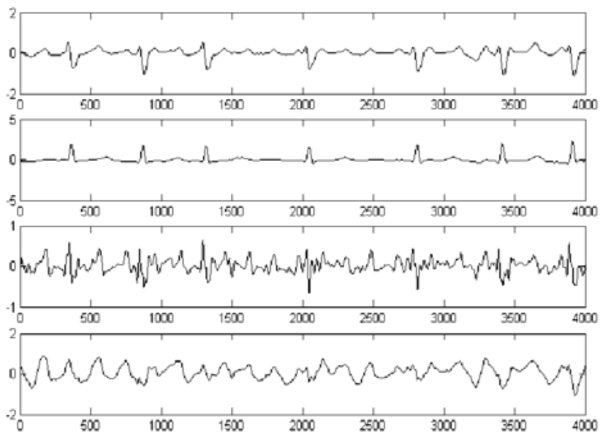

Fig. 1. Original leads V1 and V5 (upper) and extracted AA using DPWT (middle) and WDBSS (low).

The previous methodologies have been applied to the registers of Table 1. The obtained results of principal frequency peak and spectral concentration in the typical band of AF, with mean values and standard deviation, are shown in Table 2.

Table 2. Spectral parameters obtained with DPWT and WDBSS.

	WDBSS	DPWT
Principal Peak (Hz)	5.62 ± 1.02	5.84 ± 1.98
Spect.Concentration	0.43 ± 0.04	0.14 ± 0.05

The spectral concentration in the band 5-8 Hz is much lower in the case of DPWT (<15%). If the WDBSS is used, these values increase more than 200%. The analysis with higher order statistics allows the processing of signals with abnormal beats, and the high values of standard deviation of the principal peak show the lower reliability of the DPWT system in the case of real AF episodes.

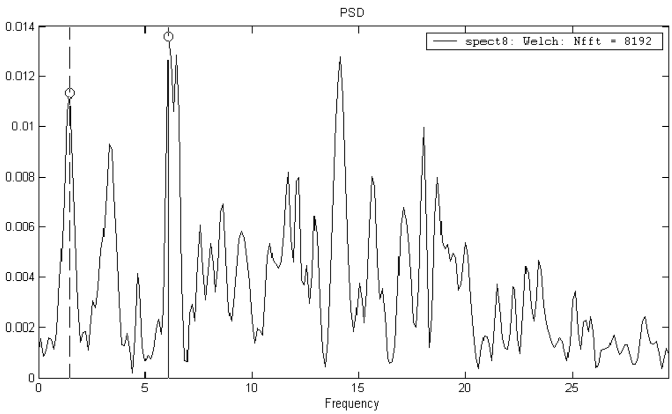

Fig. 2. AA spectral distribution estimated with DPWT.

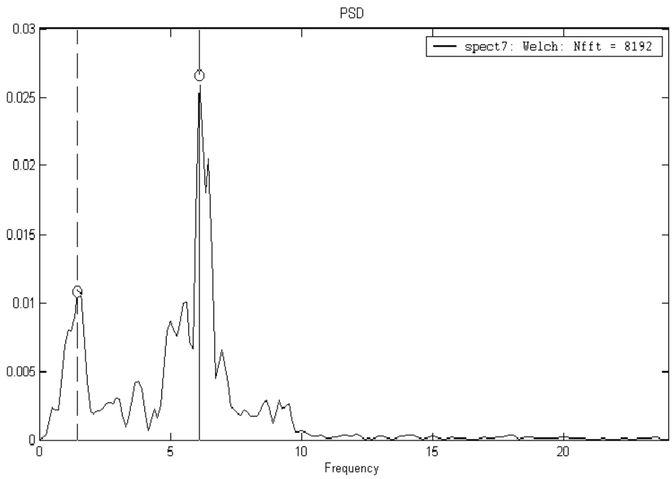

Fig. 3. AA spectral distribution estimated with WDBSS.

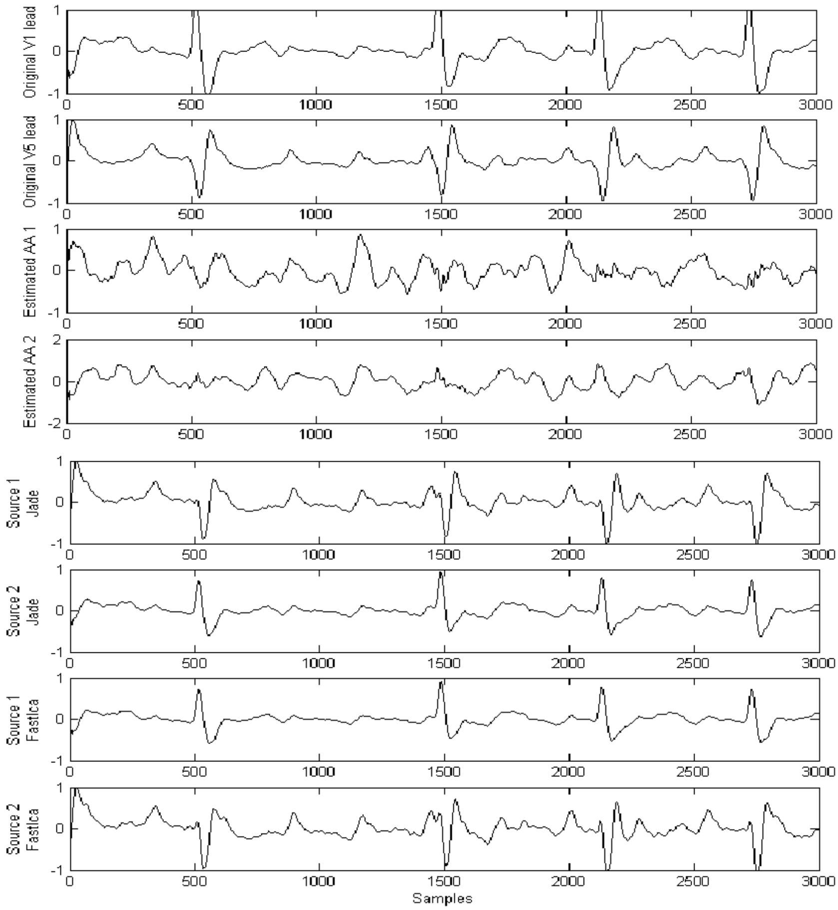

Fig. 4. Wave form comparisons between original V1 and V5 leads, main extracted sources with WDBSS and extracted sources using JADE and FastIca methods without wavelet decomposition.

6 Conclusions

Throughout this paper, the possibilities, as an AA extraction technique, of the system that implement the DPWT and BSS jointly have been shown. The initial hypothesis of statistical independence atria-ventricle and the increase of useful information obtaining from the wavelet decomposition have been demonstrated.

The reliability of this method in the case of real AF episodes has been probed, in contrast with the results of the DPWT method or the use of BSS methodologies without a previous decomposition .

This is an important step to find an atrial extraction method applicable in short duration registers with a reduced number of leads. In this sense, this process should be applicable in arrhythmia detection and analysis, like paroxysmal atrial fibrillation, which have to be usually detected from Holter systems.

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References

1. Falk RH. Medical progress: Atrial fibrillation. New England Journal of Medicine 2001; 344(14):1067-1078.
2. Rieta JJ, Castells F, Sanchez C, Igual J. ICA applied to atrial fibrillation analysis. International Conference on Independent Component Analysis and Blind Signal Separation (ICA) 2003; 4:59-64.
3. Stridh M, Sörnmo L. Spatiotemporal QRST cancellation techniques for analysis of atrial fibrillation. IEEE Trans Biomed Eng 2001;48(1):105-111.
4. Langley P, Stridh M, Rieta JJ, Sörnmo L, Millet-Roig J, Murray A. Comparison of Atrial Rhythms Extraction Techniques for the Estimation of the Main Atrial Frequency from the 12-lead Electrocardiogram in Atrial Fibrillation . IEEE Computers in Cardiology 2002;29:29-32.
5. Shkurovich S, Sahakian AV, Swiryn S. Detection of atrial activity from high-voltage leads of implantable ventricular defibrillators using a cancellation technique. IEEE Trans Biomed Eng 1998;45(2):229-234.
6. Sánchez C, Millet J, Rieta JJ, Ródenas J, Castells F. Packet Wavelet Decomposition: An Approach to Atrial Activity Extraction. IEEE Computers in Cardiology 2002;29: 33-36.
7. Rieta J.J., Millet J., Zarzoso V., Castells F., Sánchez C., Garcia R., Morell S. Atrial Fibrillation, Atrial Flutter And Normal Sinus Rhythm Discrimination By Means of Blind Source Separation And Spectral Parameters Extraction. IEEE Computers in Cardiology 2002;29:25-28.
8. Zibulesvsky M., Pearlmutter B.A., Blind Source Separation by Sparse Decomposition. Neural Computations 2001;13(4).