Application of Wavelet Transform to Atrial Activity Extraction

RAQUEL CERVIGÓN¹, CÉSAR SÁNCHEZ¹, FRANCISCO CASTELLS², JOSÉ MILLET²
¹Department of Engineering Electronically, Electronic and Automatic
²Bioengineering, Electronic and Telemedicine Research Group
University of Castilla-la Mancha
Campus Universitario 16071 Cuenca
SPAIN

Abstract- Atrial fibrillation (AF) is the most common cardiac arrhythmia. It is also the one that contribute to more days of hospitalisation. Its incidence increases with age (17% in people above 70 years) and the presence of structural heart disease. The proper analysis and characterization of Atrial Activity (AA) from Electrocardiographic (ECG) recordings requires, as a first step, the cancellation of ventricular activity (VA). The present study demonstrates the appropriateness of the Discrete Packet Wavelet Transform (DPWT) and the Continuous Wavelet Transform (CWT). With certain components provenience from the decomposition DPWT we reconstruct the AA source, and this reconstruction is also possible with the combination of some of the coefficients of the decomposition by means of CWT. After these algorithms applications, we prove the coincidence of the dominant frequency from Frequency Power Spectrum of the AA. The advantage of this method is that only it is necessary one lead.

Key-Words: - atrial fibrillation, ECG signal processing, atrial activity, f waves, wavelet transform

1. Introduction
Atrial fibrillation (AF) is the most common arrhythmia encountered in clinical practice. The works published have shown that its prevalence and incidence doubles with each advancing decade beyond 50 years reaching 17% in septuagenarians [1]. AF is responsible for frequent physician visits and hospitalisations leading to high cost, that are markedly greater than for any other arrhythmia.

One normal cardiac cycle is started when the heart beat begins at sinoatrial (SA) node, located in the right atrium. When the SA node fires, electrical activity spreads through the right and left atria, causing them to contract. The impulses travel to atrioventricular node, which is the bridge that allows the impulses to go from the atrial to the ventricles. The impulse then travels through the walls of the ventricles, causing them to contract [13].

This arrhythmia is characterized because many impulses begin and spread through the atria [9]. The resulting rhythm is disorganized, rapid and irregular. Because the impulses are travelling through the atria in a disorderly fashion, the atria are not able to contract in a regular rhythm. On the Electrocardiogram (ECG), AF is described by the replacement of consistent P waves by rapid oscillations or fibrillatory waves (f waves) that vary in size, shape, and timing associated with an irregular, frequently rapid ventricular response (ranging from about 50 to 150 beats per minute).

2. Problem Formulation
The proper analysis and characterization of AF from ECG recordings requires the extraction or cancellation of the signal components associated to ventricular activity (VA), that are the QRS complex and the T wave (QRS-T). Unfortunately, a number of facts hinder this operation: atrial activity (AA) presents much lower amplitude than VA, and both possess spectral contents notably overlapped, rendering linear filtering solutions unsuccessful.

Methods reported in the literature to extract the AA in the ECG involve two different techniques of process: the first consist to cancel out VA in the ECG and the other is based on statistic arguments. Techniques that cancel the VA in the ECG involve: direct suppression of QRS-T complex through the subtraction of a fixed template [2], also the correct spatiotemporal alignment of every complex associated to the use of an adaptive template before cancellation has proven to be very effective [3] and recently, methods that extract the VA from the ECG using artificial neural networks [4].

Methods belong to the second group are based on AV and AA are generated by physically independent sources, and these contributions appear mixed on the ECG and can be separated via a suitable blind signal separation (BSS) method [8]. Nevertheless, one common limitation of all the previously mentioned method is their inability to
obtain AA from a one-lead ECG, limitation for the use of Holter register, that it is used in different cardiac arrhythmias to evaluate the type and amount of irregular heart beats during regular activities, exercise and sleep [13]. This study proposes a new method of noninvasive extraction of AA in AF episodes recorded from a one-lead surface ECG.

2.1. Wavelet Transform

The wavelet transform has become a valuable analysis tool in the last years because of its ability to localize simultaneously local spectral and temporal information within a signal. It overcomes some of the limitations of the more widely used Fourier transform, which only contains globally averaged information and has the potential to lose transient or location-specific features within the signal [12].

Wavelet analysis is essentially comparing the signal with a chosen wavelet; and recording the coefficients that indicate the correlation of the signal to the wavelet. The reference function is called the mother wavelet \( \psi(t) \), which is appropriately dilated (a) and translated (b) to different scales before comparing with the time domain signal.

\[
\psi_{a,b}(t) = a^{-\frac{1}{2}} \psi \left( \frac{t-b}{a} \right) \quad (1)
\]

The wavelet coefficients are plotted against a two dimensional plane with one axis (y-axis) representing the dilation (scaling factor) of the wavelet, and the other (x-axis), its translation (shift along the time axis). In the Continuous time Wavelet Transform (CWT) the wavelet coefficients are evaluated for infinitesimally small shifts of translation as well as scale factors. This approach provides a more accurate time localization of the abnormality or the defect in the signal. The evaluation of Continuous time Wavelet Transform (CWT) coefficients is a highly computation intensive process. Discrete time Wavelet Transform (DWT), is a sampled version of the CWT in a dyadic grid. The argument in favour of the DWT is that, though it makes use of fewer coefficients than CWT, it is possible to synthesize the original signal using these coefficients. The following representation is called a multiresolution representation that means if we add the signal detail at an arbitrary scale (index m) to approximation at that scale we get the signal approximation at an increased resolution (i.e. at a smaller scale, index m-1). The DWT is computed by successive lowpass and highpass filtering of the discrete time-domain signal as shown in figure 1. This is called the Mallat algorithm or Mallat-tree decomposition. Its significance is in the manner it connects the continuous-time multiresolution to discrete-time filters.

![Fig 1. Three-level wavelet decomposition tree](image)

Discrete Packet Wavelet Transform (DPWT) is a generalization of the discrete wavelet transform (DWT). Wavelet packet decomposition of a signal is performed in a manner similar to the multiresolution algorithm for the DWT, the difference is that in the DWT signal decomposition both, the approximation and detailed coefficients are further decomposed at each level.

Over recent years, wavelet transforms have played an increasingly important role in the medical signal analysis. Wavelet transform analysis has been applied to a wide variety of biomedical signals including: the ECG, EEG, EMG, Echocardiograms, MRI Images, clinical sounds-arterial bruits, heart sounds, breath sounds, respiratory patterns, blood pressure trends, and DNA sequences [11]. Last years this tool has led to study the structure of a number of cardiac pathologies, including AF that it is the main argument of the current study.

2.2. Material and acquisition

The method was evaluated on a database including 51 recordings from patients diagnosed with AF from the Cardiac Electrophysiological Laboratory of the University Clinic Hospital of Valencia. Each recording was of one minute duration and all of them were sampled at 1 kHz.

3. Problem Solution

The ECG is pre-processed and normalized to remove possible fluctuations of the baseline, noise and interferences by a band-pass FIR filter with cut off frequencies of 0.5 and 40Hz, since the spectral content of interest in the residual ECG is well below 40 Hz. The AF frequency is investigated in the 3–12 Hz range where the f-wave repetition rate is commonly found [5][6]; the spectral content beyond 12 Hz is primarily constituted by harmonics which reflect the shape of the f-waves.
From a multi-lead ECG register, we select the lead V1 and we apply two different methods to extract the AA.

### 3.1. Reconstruction with Wavelet coefficients

We apply wavelet packet decomposition to the lead V1. In this decomposition conform go down in the tree generated by the wavelet transform, the original signal is suffering modifications with the different filters, but to a determinate level the f-waves are invariants. From this level the signal correspondence to the AA localized between QRST complex start to vary, it happens as consequence when we filter their spectral components below that are below 40 Hz [5]. It is observed also with DWT with the sampling frequency used to approximation at scale 5 observed where it is not variant AA, as from this level, below levels have AA, and with some of this coefficients the AA signal is reconstructed.

In this study has been employed like mother wavelet ‘sym5’, because its similarity with QRST complex, the results are also very similar with ‘sym7’, ‘bior3.9’ for the similarity of the different filters.

### 3.2. Reconstruction with Wavelet coefficients

Wavelet decomposition analysis was used to interrogate the ECG in an attempt to find features that correspond to atrial contraction during AF. A continuous Morlet wavelet was employed as it provides amplitude information about local features within the signal. To extract the AA we employed the combination lineal of two scales of the coefficients that have been observed in the scalogram. In the current study for the frequency used, we did the subtraction of the coefficients belonging to two different scales to cancel the AV and the resultant signal is very similar to the one obtained with the previous method.

### 3.3. Results

The results obtained with the two procedure are very similar and these signals coincide with AA signal in the time domain, smoothed by the filters, it has been demonstrated with the superposition of the signal obtained with the original one (Fig 2), and in the frequency domain analysis using Fast Fourier Transformation of 8196 points, was performed and a power frequency spectrum generated in the 3-12 Hz, using a Welch periodogram of 4096 points and a Hamming window with an overlap of 50% [7]. The peak frequency in this spectrum is in the 4-9 Hz range and in our analysis, in the first method this frequency is coincident in a range of 7% with the one obtain with ICA method, and in a range of 3% in the second one compared also with the previous method (Fig 3). The main frequency is very closed with the obtained with other methods, and the spectral concentration in the band 5-8 Hz is also comparable (table 1). The obtained results show this technique as an alternative by its speed and ease of implementation.

![Fig 2. Register ECG (top), superposed AA with ECG signal (middle) AA signal (bottom).](image)

![Fig 3. Power spectral densities associated with the AA in AF episodes extracted with different methods: DPWT (top), CWT (bottom).](image)

<table>
<thead>
<tr>
<th></th>
<th>DPWT</th>
<th>CWT</th>
<th>ICA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Principal peak (Hz)</td>
<td>5.69±2.01</td>
<td>5.47±1.51</td>
<td>5.32±1.12</td>
</tr>
<tr>
<td>Spectral Concentration</td>
<td>0.34±0.05</td>
<td>0.29±0.15</td>
<td>0.44±0.17</td>
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Table 1. Spectral parameters obtained with, DPWT, CWT and ICA.
4. Conclusion

The present contribution has shown a new biomedical engineering application for wavelet transform. The preliminary results are very similar with those obtained with traditionally methods of the AA extraction. The advantages of this method are its easy implementation, its low computational cost and its ability to obtain a unified AA signal from a only-lead ECG of short duration. These considerations make feasible the application of this methodology to solve the AA extraction problem and to contribute in the development of diagnosis for this cardiac pathology, allowing a better knowledge of AF patterns.

References:


