ECG Signal Baseline Wander Removal Using Wavelet Analysis

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Abstract— **One of the most common problems of ECG recordings is the baseline wandering in the ECG signals during data collection. Baseline wander elimination is considered as a classical problem in ECG signal filtering. This paper presents two wavelet analysis (WA) based ECG signal baseline wander removal methods, The Discrete Wavelet transform based method uses a high level decomposition and eliminates the lowest frequency component. The wavelet packet based searching algorithm uses the energy of the signal in different scales to identify the baseline wander. The algorithm calculates the corresponding energy of wavelet packet coefficients at each scale. After a comparison, the branch of the wavelet binary tree corresponding to higher energy wavelet spaces is chosen. These procedures are tested using specific data records.**

Keywords— **wavelet analysis, ECG signal processing, baseline wander removal.**

I. INTRODUCTION

The ECG signal is obtained by recording the potential difference between two electrodes placed on the body surface. A single normal cycle of the electrocardiogram represents the successive atrial and ventricular depolarization and repolarization. Baseline (isoelectric line) wander is considered as a perturbation which produces artifacts when in ECG parameters measuring, especially the ST segment and the R peak measurements could be strongly affected. The main causes of the baseline wandering are the respiration, electrode impedance change due to perspiration and increased body movements. Therefore, the elimination of the baseline wander can improve very much the accuracy of the clinical information. Figure 1 presents together a clean and a baseline wander affected ECG signal, the differences between them are obvious and the necessity of filtering also.

During the last years, the wavelet analysis has proven to be a very useful tool in many application areas for evaluation of non-stationary signals such as biomedical signals, the ECG signal in particular. The wavelet transform provides a time-frequency representation of the signal, and thus permits the inspection of characteristic waves of the ECG signal at different scales with different resolutions. This paper presents two wavelet analysis (WA) based ECG signal baseline wander removal methods, The Discrete Wavelet Transform (DWT) based method uses a high level decomposition and eliminates the lowest frequency component. The Wavelet Packet (WP) based searching algorithm uses the energy of the signal in different scales to identify the baseline wander.

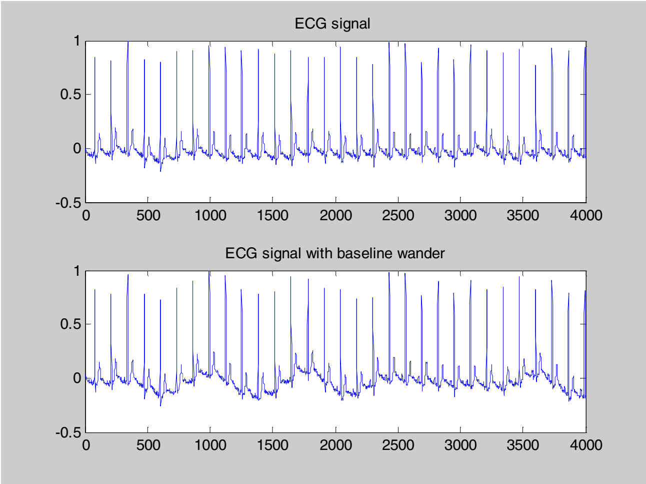

Fig. 1 ECG signal without and with baseline wander

The proposed algorithms are carried out in Matlab environment and are tested using specific ECG recordings from the MIT-BIH Arrhythmia Database, taken from a web-based resource for free access to study of physiological signals.

II. WAWELETS AND WAVELET PACKETS

The wavelet transform (WT) of signal x(t) is defined as a combination of a set of basis functions, obtained by means of dilation *a* and translation *b* of a mother wavelet [1].

$$W_a x(b) = \frac{1}{\sqrt{|a|}} \int_{-\infty}^{+\infty} x(t)\,\psi\left(\frac{t-b}{a}\right)dt \qquad (1)$$

The Discrete Wavelet Transform (DWT) is defined as a discrete dilations and translations of the mother (or analyzing) wavelet. In its most common form, the DWT employs a dyadic grid and orthonormal wavelet basis functions [4].

The Discrete Wavelet Transform (DWT) decomposition of the signal into different frequency bands can be obtained

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by successive high-pass and low-pass filtering of the time domain as shown in figure 2. Translation is accomplished by considering all possible integer translations of ψ(t) and dilation is obtained by multiplying t by a scaling factor which is usually factors of 2.

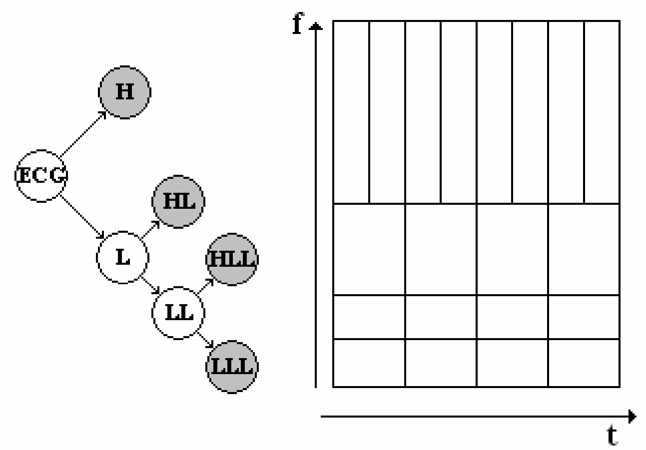

Fig. 2 FIR filter structure for dyadic scale decomposition

The following equation shows how wavelets are generated from the mother wavelet:

$$\psi_{j,k}(t) = 2^{j/2}\psi\left(2^{j/2}t - k\right) \tag{2}$$

Wavelet decomposition is a linear expansion and it is expressed as

$$x(t) = \sum_{k=-\infty}^{\infty} c_k \varphi(t-k) + \sum_{k=-\infty}^{\infty} d_k \psi\left(2^{j/2}t - k\right) \tag{3}$$

where φ(t) is called the scaling function and c_k and d_{jk} are the coarse and detail level expansion coefficients. In the field of signal processing, the implementation of wavelet theory is performed using filter banks. In applications one never has to deal directly with the scaling functions or wavelets, only with the coefficients of the associated filters in the filter banks. In a wavelet transform system, the signal is convolved with a pair of maximally decimated quadrature mirror filters (QMF). These filters are related to wavelet and scaling functions as expressed below [4]:

$$\varphi(t) = \sqrt{2}\sum_{k=-\infty}^{+\infty} h_k \varphi(2t+k) \tag{4}$$

$$\psi(t) = \sqrt{2}\sum_{k=-\infty}^{+\infty} g_k \varphi(2t+k) \tag{5}$$

The coefficients are ordered using two dominant patterns, one that works as a smoothing filter (like a moving average), and one pattern that works to bring out the data's detail information. These two orderings of the coefficients are called a quadrature mirror filter pair in signal processing language [6].

The wavelet packet method is a generalization of wavelet decomposition that offers a richer range of possibilities for signal analysis but is more redundant also. In wavelet analysis, a signal is split into an approximation and a detail [5]. The approximation is then itself split into a second-level approximation and detail, and the process is repeated. For n-level decomposition, there are n+1 possible ways to decompose or encode the signal. A single decomposition using wavelet packets generates a large number of bases.

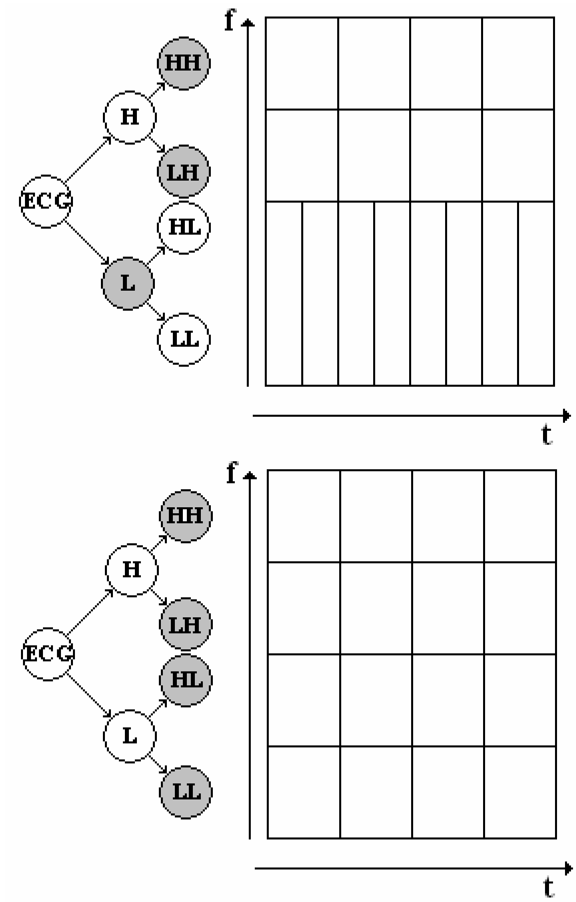

Fig. 3 Time-frequency blocks for second order dyadic wavelet packet decomposition and the corresponding filtering structure

III. BASELINE WANDER REMOVAL PROCEDURE

The baseline wandering removal is carried out by identifying the low (or the lowest) frequency (large scale) components in the ECG signal. The proposed algorithms are based on the assumption that the baseline wandering and the ECG signal constitute a mixture of two independent signals, obtained as a linear superposition. Usually the typical baseline variation means 15 percent of peak-to-peak ECG amplitude variation of 0.15 to 0.3 Hz [3]. There are two methods to be presented, the first is based on an n-level Discrete Wavelet Transform (DWT) and the other uses the Wavelet Packet (WP) decomposition to find the low frequency component corresponding to the baseline variation. In first case the DWT level is estimated starting from the sampling frequency (which gives the maximum frequency of the ECG signal) and the estimated baseline wander frequency domain $\Delta f_{BLw} = f_{BWH} - f_{BWL}$ as follows:

$$n = round\left[\frac{1}{2}\left(\log_2 \frac{f_{\max}}{\Delta f_{BWH}} + \log_2 \frac{f_{\max}}{\Delta f_{BWL}}\right)\right] \quad (6)$$

The lowest frequency components are identified in the DWT structure and extracted from the original signal (after a selective reconstruction) in a way illustrated on figure 4.

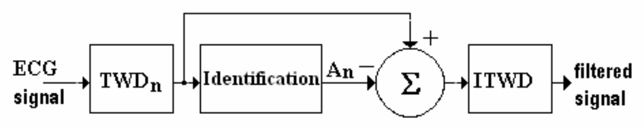

Fig. 4 Wavelet decomposition, lowest frequency component identification and baseline wander removal

A full wavelet packet decomposition binary tree for three scale wavelet packet ECG Baseline Wander Elimination using Wavelet Packets transform is shown in figure 5.

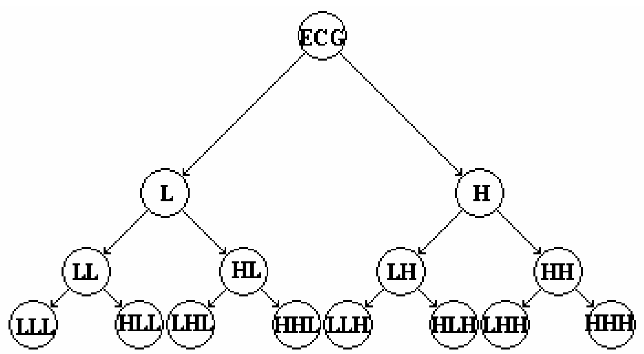

Fig. 5 Third level Wavelet Packet decomposition

In wavelet packet analysis, the details as well as the approximations can be split. This yields more than 2^{2^n-1} different ways to encode the signal [1]. Usually the components which are responsible to baseline wander placed in low frequency but have a relatively great energy. The energy of the signal is given in terms of the WT coefficients by Parseval's relation as:

$$E = \int |x(t)|^2 = \sum_{k=1}^{n} |a_k|^2 + \sum_{k=1}^{n} |d_k|^2 \quad (7)$$

Simple and efficient algorithms exist for both wavelet packets decomposition and optimal decomposition selection. The search for baseline wander causing components is focused on great energy and low frequency structures in the Wavelet Packet decomposition tree. After a Wavelet Packet decomposition these components are identified, removed and the signal is recomposed without them. In fact, that leads to a nonlinear filtering of the signal. In order to eliminate the baseline drift, the estimated baseline wander is subtracted from the original data record and a baseline wander free ECG signal is identified [5].

IV. RESULTS

The test database was extracted from the MITBIH database, results are shown in figures 6 to 8. The measurements were carried out by adding gaussisan white noise to the test signal. The used analyzing function was "db4" (Daubechies) both for DWT or WP decomposition. The estimation is relatively good, the results after extraction show a satisfying baseline wander elimination .

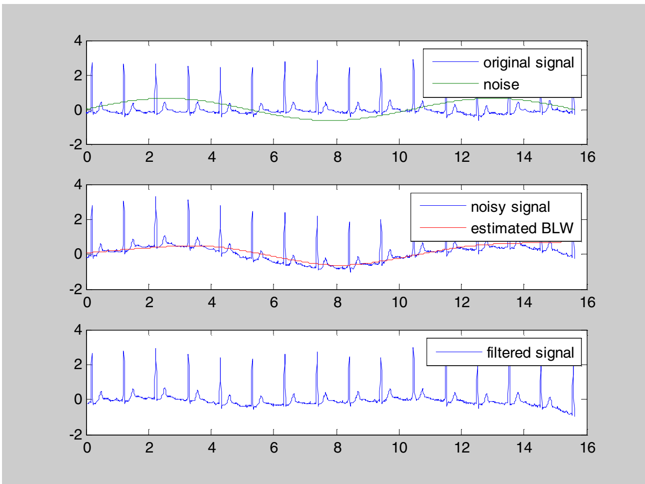

Fig. 6 Results obtained with n^{th} level DWT decomposition

In the corresponding wavelet packets situation, each detail coefficient vector is also decomposed into two parts using the same approach as in approximation vector splitting. Results obtained with the use of this method and applied to the same signal, are represented in figures 7.

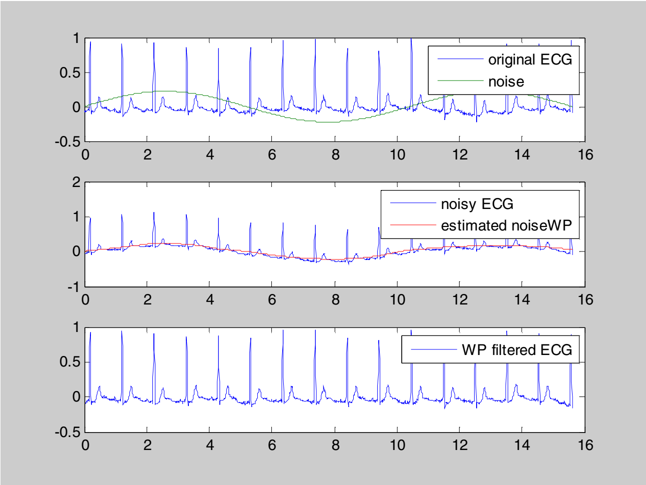

Fig. 7 Results obtained with nth level WP decomposition

To estimate the obtained results the following parameters were measured, :

$$SNR = \log_{10} \frac{P_{filteredECG}}{P_{originalECG} - P_{filteredECG}} \quad (8)$$

$$Gain = SNR - \log_{10}\left(\frac{P_{originalECG}}{P_{noise}}\right) \quad (9)$$

The obtained results are presented on figure 8 and 9.

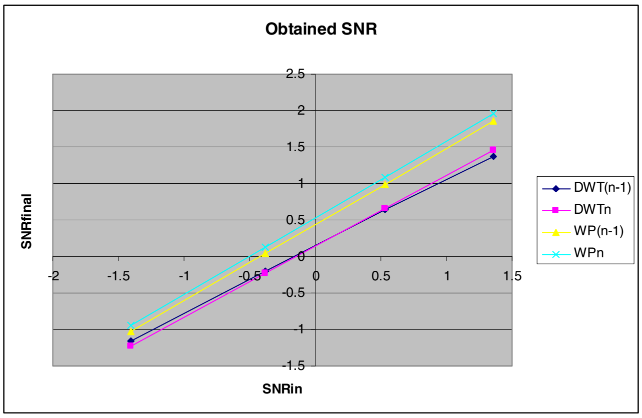

Fig. 8 Results obtained on test signal (Signal to Noise Ratio)

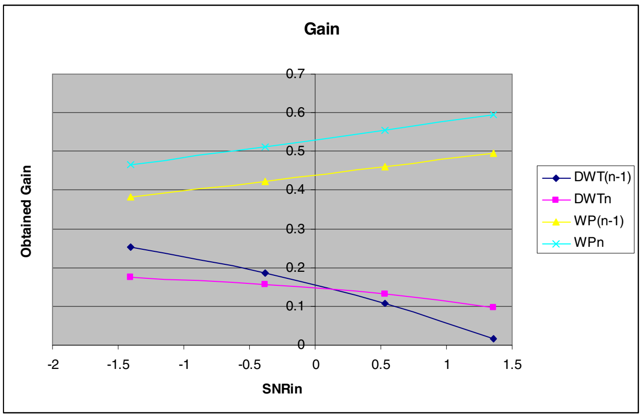

Fig. 9 The obtained gain for different DWT and WP decompositions

V. CONCLUSIONS

In this paper were presented two algorithms based on wavelet analysis for canceling baseline wandering in ECG signals. The WP decomposition offers a particular way of decomposing signals, the filtering results are slightly better than in case of using classical DWT. The presented algorithms can eliminate ECG baseline wandering without introducing major deformation in the signal structure. As further work is possible to study the opportunity to extract a weighted sum of low frequency components from the DWT or WP decompositions in order to have a better accuracy of baseline wander identification.

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