WAVELET FILTERING OF ECG SIGNALS USING PILOT ESTIMATION

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ABSTRACT

The paper deals with methods of denoising of ECG signals via wavelet transform. We focus on the method of pilot estimation. Our aim is to find optimal setting of input parameters for denoising in consideration of achieved signal-to-niose ratio (SNR) in output and deformation of output signal. Finally we present rules and recommendations which are needed to adhere to get quality results.

1. INTRODUCTION

Electrocardiograms scaned from human body are very often corrupted by noise. The most frequented sort of noise are myopotentials which arise in skeletal muscles. We have to reduce noise (that means increase SNR) to make ECG signal readable. The frequency spectrum of electrocardiograms coincides with spectrum of myopotentials. In this cases, it is suitable to use wavelet filtering instead of linear filtering.

2. WIENER FILTERING

We suppose that a corrupted additive signal is $x(n) = s(n) + w(n)$, where $s(n)$ is noise-free signal and $w(n)$ is noise, both uncorrelated. If we transform signal $x(n)$ by discreet time wavelet transform (DTWT) to wavelet domain we obtain wavelet coefficients $y_m(n) = u_m(n) + v_m(n)$, where $u_m(n)$ are coefficients of noise-free signal and $v_m(n)$ are coefficients of noise, m is level of decomposition and denotes m-th frequency band. We need to recover coefficients of noise-free signal $u_m(n)$ from $y_m(n)$. The idea of Wiener filtering of each wavelet coefficient can solve it. We are searching for such correction factor $g_m(n)$, so that modified coefficients DTWT are

$$^{\lambda}y_m(n) = y_m(n)g_m(n) = g_m(n)\left[u_m(n) + \nu_m(n)\right]. \qquad (1)$$

Modified coefficients $^{\lambda}y_m(n)$ are reqired to be optimal aproximation of noise-free signal coefficients $u_m(n)$. So: $^{\lambda}y_m(n) = s(n) + e(n)$, where $E\{e^2(n)\} \rightarrow min$. This Wiener correction factor is defined in [1,2,3,4] like

$$g_m(n) = \frac{u_m^2(n)}{u_m^2(n) + \sigma_{\nu_m}^2}, \qquad (2)$$

where $\sigma^2_{v_m}$ is variance of noise coefficients $v_m(n)$. Because the noise-free signal coefficients $u_m(n)$ are unknown, we use estimated values $\bar{u}_m(n)$, which we get by pilot estimation method. This method will be analysed in the next part.

3. PILOT ESTIMATION METHOD

By careful input signal preprocessing using wavelet transform and thresholding we obtain estimation of coefficients $u_m(n)$. Block diagram is in Figure 1. There is realized wavelet transform WT1 in the upper branch, modification of coeffients in the block H and inverse transform IWT1. Result is pilot signal $\bar{s}(n)$, which approximate noise-free signal $s(n)$. Input signal $x(n)$ and also pilot signal $\bar{s}(n)$ enter to the transform WT2. Block HW process both outputs from WT2 by correction factor

$$\bar{g}_m(n) = \frac{\bar{u}_m^2(n)}{\bar{u}_m^2(n) + \sigma^2_{v_m}}, \tag{3}$$

where $\bar{u}_m^2(n)$ are square DTWT coefficients obtained from pilot estimation $\bar{s}(n)$. We get final signal $y(n)$ by inverse transform IWT2 of modified coefficients $^{\lambda}y_m(n)$.

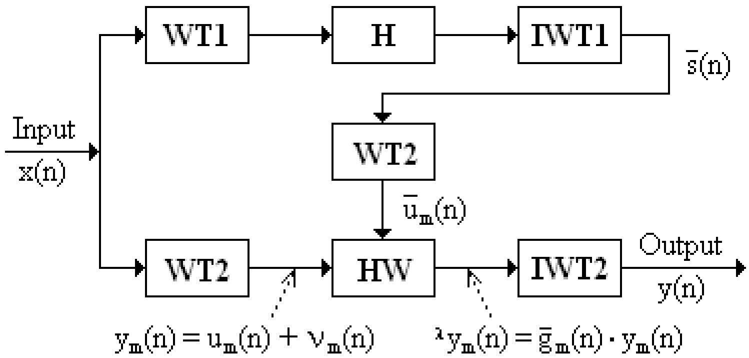

Figure 1: Block diagram of pilot estimation method.

The goal of our investigation will be to choose decomposition and reconstruction filters for WT1/WT2 and also suitable method for thresholding in block H.

4. RESULTS

We evaluated our results by achieved signal-to-niose ratio (SNR_{out}) of output signals according to equation

$$SNR_{out} = 10 \cdot \log_{10} \frac{\sum_{n=1}^{N-1} [s(n)]^2}{\sum_{n=1}^{N-1} [y(n) - s(n)]^2} \quad [dB]. \tag{4}$$

To use this equation we have to know noise-free signal $s(n)$. Conseguently, we choose only electrocardiograms with insignificant noise from the CSE database for tests, which we can consider as noise-free signals. This electrocardiograms we corrupt by synthetic noise $w(n)$. Noise $w(n)$ was made by such white Gaussian noise frequency limitation, so that approximates spectral characteristics of myopotentials [3]. All experiments was executed in Matlab environment.

4.1. THRESHOLDING OF PILOT ESTIMATION

The choice of thresholding in block H has essential influence on result. It is important to remove maximum of the noise. On the other hand it is not critical if we shrink or distort coefficients of *s(n)*, because following transform WT2 can repair this deformation. We tested three different methods for pilot estimation thresholding: hard, soft and hybrid. Table 1 summarizes achieved results.

Filters WT1/WT2: Haar/Db3

Signal ECG	SNR_{in} [dB]	SNR_{out} [dB]		
		Pilot estimation thresholding		
		Hard	Soft	Hybrid
s05-V4	10	19,33	20,68	20,34
	14	22,72	23,82	23,54
s11-0I	10	20,48	21,36	21,14
	14	23,64	24,16	24,06
s38-V3	10	21,62	22,91	22,72
	14	24,83	25,82	25,69
s63-03	10	22,97	24,56	24,24
	14	26,12	27,43	27,17

Table 1: Influence of different thresholding methods on results.

We can see from SNR_{out}, that better results are achieved using soft or hybrid thresholding. Results are about 1dB worse when we apply hard thresholding. The hard thresholding do not shrinks overthreshold values of noise coefficients. These are mistakenly consider as noise-free coefficients in the next step of algorithm. Thresholding influence is shown in Figure 2.

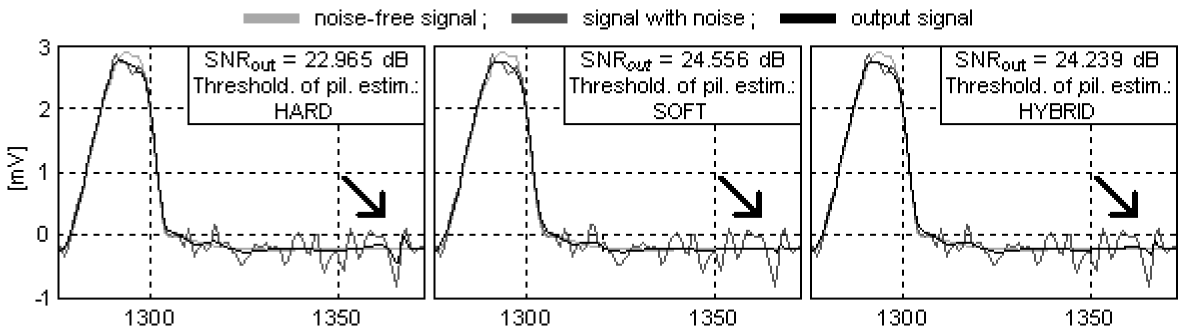

Figure 2: Influence of thresholding in block H on results. For signal s63-03, filters WT1/WT2: Haar/Db3, SNR_{in} = 10dB.

4.2. CHOICE OF FILTERS FOR TRANSFORM WT1 AND WT2

Our next investigation will be focused on choice of the filtres for transforms WT1 and WT2. We tested biorthogonal (Bior1.3, Bior3.9) and orthogonal (Db3, Db10) filters as well as filters with long impulse response (Bior3.9, Db10) and short impulse response (Bior1.3, Db3, Haar). Name of the filters come from Matlab database.

Soft thresholding in pilot estimation

Filtrs WT1/WT2	*s11-01*		*s38-V3*		*s05-V4*	
	SNR_{in} 10 dB	SNR_{in} 14 dB	SNR_{in} 10 dB	SNR_{in} 14 dB	SNR_{in} 10 dB	SNR_{in} 14 dB
	SNR_{out} [dB]					
Haar/Db3	21,36	24,16	22,91	25,82	20,68	23,82
Haar/Bior1.3	20,04	22,88	21,72	24,47	20,09	23,07
Haar/Bior3.9	21,31	24,39	22,90	25,96	20,35	23,72
Db3/Db3	21,66	24,23	22,75	25,74	19,86	23,39
Db3/Db10	20,83	23,25	21,25	24,39	18,51	21,88
Db10/Db3	21,61	24,29	21,89	25,07	19,43	22,79
Db10/Db10	19,87	22,35	19,86	22,61	17,33	20,56
Bior1.3/Haar	19,91	22,74	21,64	24,46	19,92	22,99
Bior1.3/Db3	21,37	24,11	22,96	25,78	20,65	23,79
Bior1.3/Bior3.9	21,45	24,44	23,05	26,03	20,48	23,81
Bior3.9/Db3	21,32	24,27	22,67	26,06	19,76	23,43
Bior3.9/Db10	19,54	22,53	20,51	24,06	17,92	21,48
Bior3.9/Bior3.9	18,58	21,85	20,74	24,73	17,70	21,67

Table 2: Influence of different filters WT1/WT2 on results.

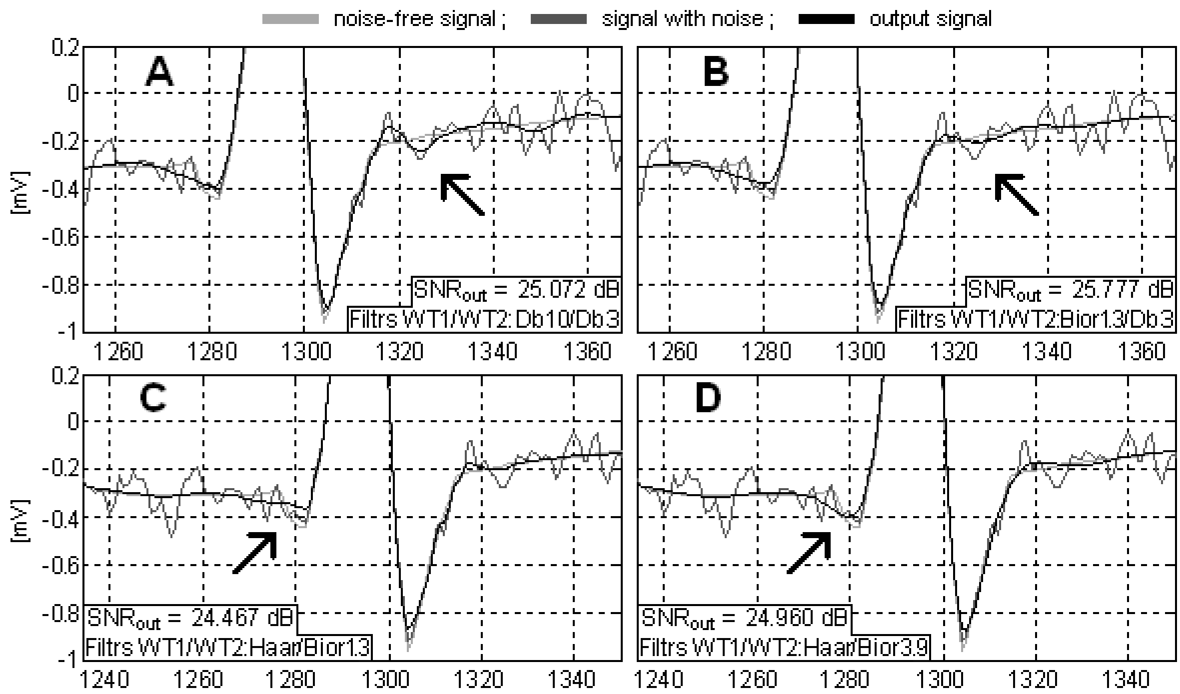

Figure 3: Influence of different filters WT1/WT2 on results. For signal s38-V3, soft thresholding in pilot estimation, SNR_{in} = 14dB.

Table 2 summarize achieved results. According to SNR_{out} we can say which filters combination is more or less suitable for particular electrocardiogram. Except achieved SNR_{out} are also output signal deformation important. Mainly, we can see damage of Q wave and oscillation nearby QRS complex. These deformations are shown in figure 3. We formulate next recommendations for design of filters WT1/WT2 based on Table 2 and Figure 3:

- In the transform WT1, do not use filters with long impulse response – genesis of the oscillation nearby QRS complexes which has impact on output signal (Figure 3A).
- In the transform WT2, do not use Haar filter nor short impulse response biorthogonal filters – damage of Q wave (Figure 3C) and bad P and T wave estimation.
- Do not use long impulse response filters combination (mainly filters Db) – genesis of the oscillation and QRS complex expansion.

5. CONCLUSION

In the firs part of our experiments, we tried to find which method is the most situable for the pilot estimation thresholding. We got globally smoothed signal by using soft thresholding. This is useful for pilot estimation, because it contains minimum of noise. We observed extensive amount of noise peaks in pilot estimation when we used hard thresholding. Using hybrid thresholding gave approximately the same results as soft thresholding.

Choice of decomposition and reconstruction filters for WT1/WT2 is not always clear. Contrary demands are often posed on the filters thereby choice of filters have to be some compromise. Results in table 2 and recommendation from chapter 4.2 can help with filters selection.

ACKNOWLEDGMENT

The research was supported by Research Programme of Brno University of Technology MSM 0021630513.

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