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COMPARATIVE ANALYSIS OF AWGN FILTERING IN WRIST PULSE SIGNAL

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Abstract:

Health is all about maintaining balance in human body. Wrist Pulse Signal (WPS) represents state of different organs such as heart, liver, kidney and can be used as a tool for health diagnosis. At the time of acquisition, WPS are often embedded with noise which results in abnormal feature extraction. Denoising WPS has become a topic of extensive research. This paper focuses on denoising non stationary signal such as WPS using different algorithms. A database has been created consisting of 5 subjects. AWGN noise of signal-to-noise (SNR) 5dB and 10dB has been introduced using MATLAB tool. Algorithms such as LPF, MAF, Wavelet Transform (WT), fusion of Wavelet & Gaussian filter (WT+G) were employed. Comparative analysis of algorithm was done on the basis of MSE, PSNR, Sm, SDE and CC. Experimental results illustrated that WT outsmarted in comparison with other algorithms. It was proved that WT was a powerful and consistent tool for noise removal in WPS.

Keywords: Wrist Pulse, Noises, AWGN, MSE, PSNR, SM, SDE, CC etc

1. Introduction

Ayurveda is an authentic branch of Traditional Indian Medicine which deals with maintaining equilibrium between body, mind and soul[1]. This authentic method has been practiced by sages in olden times to physicians in present era. The pulse can be felt at any point on the body where the arterial beat is transmitted to the skin by pressurizing it with fingers[2]. These radial pulses help experts to evaluate pulses in detail so that different body conditions can be studied. Pulse segment consists of 3 waves: Percussion, Tidal and Dicrotic waves as demonstrated in Fig.1. Variation in amplitude and time interval of these waves signifies abnormalities in body. The WPS not only captures cardiac muscle activity but are also influenced by characteristics of blood, muscles, nerves and skin. In short, WPS provide more information compared to ECG[3].

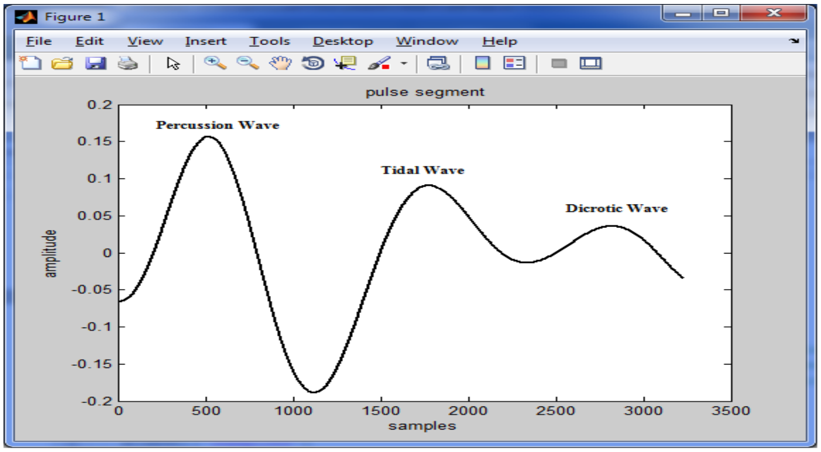


Fig.1: Wrist pulse segment.

The whole process of quantification is non-invasive i.e. sensors are placed on standardized positions on the radial artery of the subject[4]. Noise addition during acquisition process has been an obstacle in pulse analysis. In real situations, noises such as baseline wandering, powerline interference and high frequency noise are also acquired along with signal which reduces the clinical importance of WPS[5]. Therefore, denoising is essential in pre-processing step to conserve the time and frequency information of signal. Prior to denoising, it is necessary to study about different sources of noises as described in Fig.2.

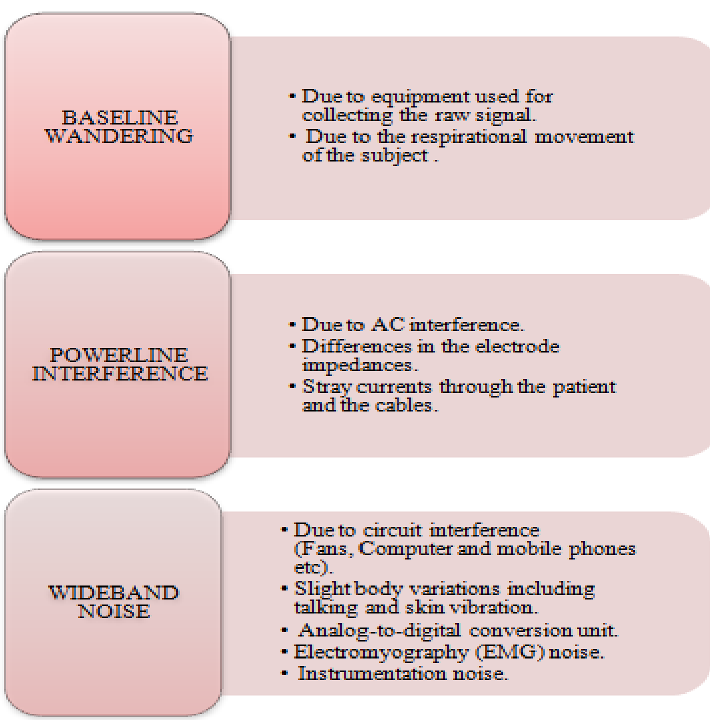


Fig.2: Sources of noise.

Various algorithms has been enlisted in literature for cleaning and enhancement of WPS and other biomedical signal such as FIR/IIR filters[6], Moving Average filter, Adaptive filter[7,8], Zero phase filter[9] and Wavelet Transform[10,11]. These digital and adaptive filters show better response for signals whose statistical properties remains stationary. Out of all these, wavelet based methods are preferred more for non stationary signal as it provides long time intervals for low frequency information and vice versa for high frequency information[12,13]. This paper has been focusing to find an optimal denoising algorithm which removes AWGN noise at 5dB and 10dB efficiently and satisfying the evaluation parameters such as MSE, PSNR, Sm, SDE and CC[14, 15]. This paper is divided into five different sections as mentioned. Section II describes Database and noise addition. In section III, material and methods has been discussed. It also illustrates evaluation parameters for comparative analysis. Section IV briefly describes experimental results. Section V concludes the paper.

2. Database

A pressure sensor is used to collect pulses from 5 subject and ®LabVIEW software is used for recording them. Then using notch filters and wavelet transform, a reference signal (clean) is created as illustrated in Fig.3. Thereafter, AWGN noise of SNR 5dB and 10dB is added to reference signal. For denoising, whole processing is done in MATLAB software. Different algorithms and parameters have been computed for efficient noise removal.

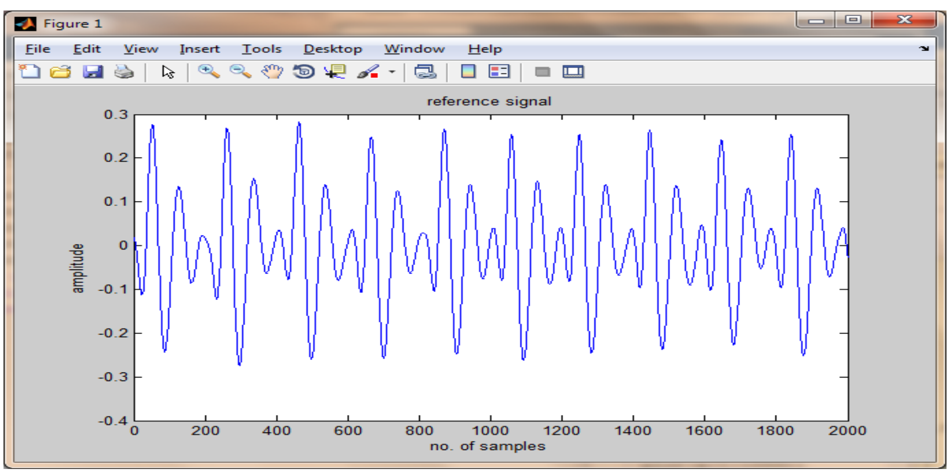


Fig.3: Reference Signal.

3. MATERIAL AND METHODS:

3.1. Denoising Methods

In this section different algorithm used for AWGN noise removal has been detailed. Here we have used LPF, MAF, WT and WT+G algorithms.

- **Low Pass Filter (LPF)**

A FIR- Equiripple Low Pass filter with pass band frequency of 10 Hz and stop band frequency of 12 Hz is used. Although, the LPF brings in distortion with the denoised signal because of difference in ideal and actual filter response. Filtering has been performed using Filter Design & Analysis (FDA) toolbox in MATLAB. Parameters were adjusted as: Fp=10Hz, Fst=12HZ, Ap=1dB, Ast=60dB, fs= 250Hz.

- **Moving Average Filter (MAF)**

A Moving average filter, which is a poor low pass filter, has been used. The first element has been calculated by taking the average of a particular subset of data (window). Then the window is slided in forward direction and denoised signal is obtained. A moving average is used to smooth out short-term fluctuations and highlight longer-term trends. Using for loop and sum function, MAF has been implemented.

- **Wavelet Transform (WT)**

Wavelet transform (WT) is a multi-resolution analysis technique which is very convenient for analysis of non-stationary signals such as the WPS. Here we are using db9 level 4 wavelet where a4 coefficient (within range of 10 Hz) was used for reconstruction. Open wavelet toolbox using wavemenu, select Wavelet 1-D tool. After loading signal, select type of wavelet and no. of levels followed by denoise option.

- **Fusion of Wavelet & Gaussian Filter (WT+G)**

Even though we are using WT to remove high frequency noise but one drawback of this technique has been observed that the signal we get is not smooth. To overcome this drawback a fusion of wavelet transform and Gaussian filter has been implemented. Gaussian filter modifies the input signal by convoluting wavelet Transform output with a Gaussian function. For Gaussian window, use gausswin function to select a window of length 32 and convolute it using conv function.

3.2. Evaluation Measures

To discover an efficient technique best suited for AWGN removal, we have compared denoised WPS with reference (cleaned) WPS on the basis of following criterion:

If $x(n)$ = reference signal; $\hat{x}(n)$= denoised signal.

- **Mean Square Error (MSE):** MSE is also used to evaluate the quality of the information which is preserved in the denoised WPS waveform. MSE is defined as follows:

$$MSE = \frac{1}{N}\sum_{n=0}^{N-1}\left[x(n) - \hat{x}(n)\right]^2$$

- **Peak Signal to Noise Ratio (PSNR):**

PSNR is mathematically described as:

$$PSNR = 10\log_{10}\frac{MAX^2}{MSE}$$

where, MAX is the maximum fluctuation in the input WPS data and MSE is Mean Square Error. The PSNR value approaches infinity as the MSE approaches zero. Higher value of PSNR represents higher signal quality. Small value of PSNR represents high numerical differences between signals.

- **Smoothness (S_m) :**

The S_m parameter is to measure the smoothness of the de-noised pulse waveform in contrast to the reference pulse, correlated with continuity of the derivative

$$S_m = \frac{\left\|\left[x(n) - \hat{x}(n)\right]'\right\|}{\left\|\left[x(n)\right]'\right\|}$$

Where, x′ represents the first-order derivation vector and is calculated by using the function $f' = [f_2 - f_1, f_3 - f_2, \ldots, f_n - f_{n-1}]$. The smaller the parameter, the better is the pulse de-noising performance.

- **Standard Deviation Error (SDE):**

PSDE is mathematically described as:

$$SDE = \frac{\left\|\left[\hat{x}(n) - \hat{m}\right]\right\| - \left\|\left[x(n) - m\right]\right\|}{\left\|\left[x(n) - m\right]\right\|}$$

Where, m is mean of x (n) and $\hat{m}$ is the mean of $\bar{x}$ (n). The smaller the parameter, the better is the pulse de-noising performance.

- **Correlation Coefficient (CC):**

It describes the strength and the direction of a linear relationship between two signals.

$$CC = \frac{\operatorname{cov}(x,\bar{x})}{\sigma(x).\sigma(\bar{x})}$$

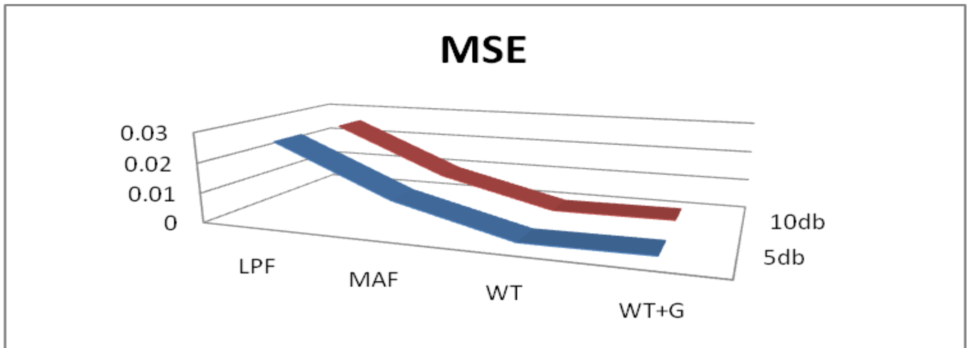
Where, cov represents covariance between two signal and σ denotes standard deviation. Higher the value of Correlation Coefficient, more similar is denoised signal to reference signal.

4. Experimental Results

The LPF, MAF, WT and WT + G techniques are applied to database so as to obtain denoised WPS. In this section, comparison between denoising techniques for eliminating AWGN has been shown. AWGN with different input SNR of 5dB and 10 dB have been added for analysis.

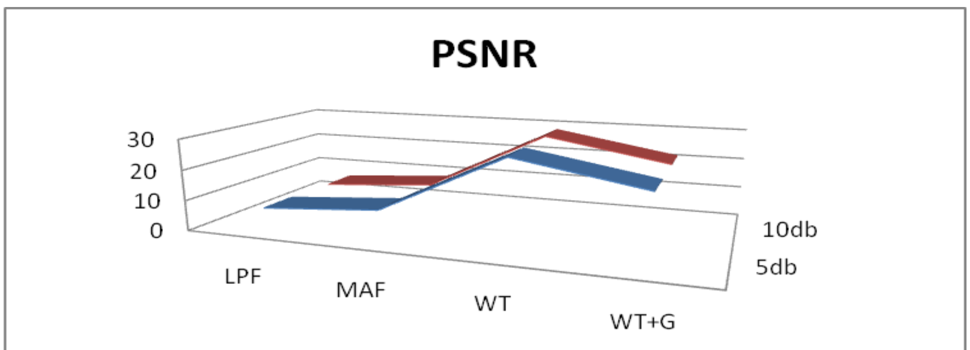
4.1. AWGN Removal:

The graphical data depicts comparison between denoising techniques to remove AWGN of different SNR added to signals in our database. Fig.4 illustrates averaged response of MSE parameters computed for each technique (LPF, MAF, WT and WT + G). A lowest value has been achieved by WT.



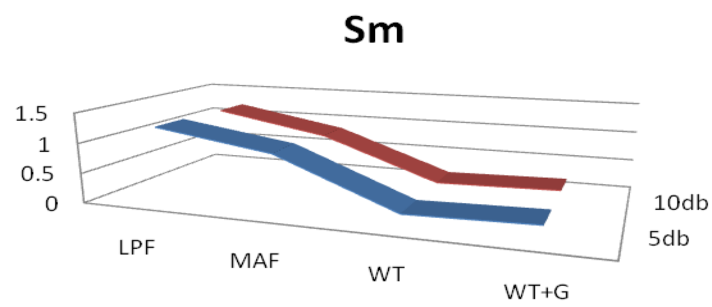
	LPF	MAF	WT	WT+G
5db	0.02628	0.00986	0.00012	0.00046
10db	0.02576	0.00966	0.00012	0.00046

Fig. 4: MSE response.



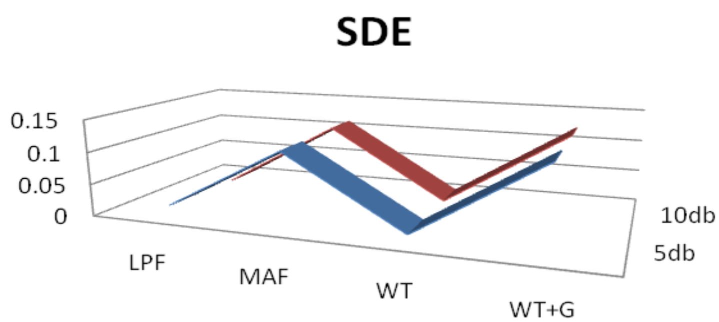
	LPF	MAF	WT	WT+G
5db	6.44882	9.28302	28.61932	21.7477
10db	5.99228	8.83742	28.61932	21.7477

Fig. 5: PSNR response.



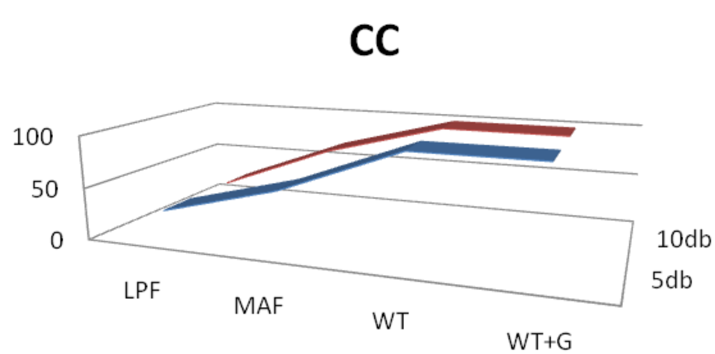
	LPF	MAF	WT	WT+G
5db	1.23058	0.93416	0.15338	0.19864
10db	1.20624	0.85276	0.15338	0.19864

Fig. 6: Sm response.



	LPF	MAF	WT	WT+G
5db	0.0109	0.11132	0.00468	0.12498
10db	0.00736	0.11342	0.00468	0.12498

Fig. 7: SDE response.



	LPF	MAF	WT	WT+G
5db	24.878	54.712	99.616	99.376
10db	25.162	69.052	99.616	99.376

Fig. 8: CC response.

Similarly, averaged response for PSNR, S_m, SDE and CC are plotted in Fig. 5, 6, 7 and 8 respectively. A high value of PSNR, CC and a small value of MSE, S_m, and SDE is observed for wavelet transform which clearly demonstrates wavelet results (highlighted bold) are far much better than other 3 techniques for removal of AWGN noise of different SNR. However, it is also observed that evaluation parameters for WT and WT+G technique remain invariable for different AWGN noise levels which bring to light the regularity (independent of noise level) of both techniques.

5. Conclusion

Denoising WPS has become a topic of extensive research. WT have emerged as a powerful and effective tool widely used for denoising purpose. In this paper, we have presented a comparative study related to denoising algorithms and their effect on increasing noise level. With the success of WT in efficient removal of noise in different applications, we have compared it with LPF, MAF and WT+G algorithms for removal of added AWGN of 5dB and 10dB SNR. It was observed that performance of WT and WT+G was invariable for different SNR levels which signified consistent performance. However, the worst performance was shown by LPF. Overall, WT demonstrated its dominance by attaining lowest value of MSE (0.00012), Sm (0.15338), SDE (0.00468) and highest value of PSNR (28.61932), SNR (20.97155), CC (99.616%) outmaneuvering other algorithms. In future work, extension of database along with outlier removal methods would be focused to enhance the classification rate.

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