Fars Samann * and Thomas Schanze

An efficient ECG Denoising method using Discrete Wavelet with Savitzky-Golay filter

Abstract: Electrocardiogram (ECG) is a widely used tool for the early diagnosis and evaluation of cardiac disorders. The ECG signal is usually distorted during recording by different types of noise which may lead to incorrect diagnosis. Therefore, clear ECG signals are required to support good cardiac disorder diagnosing. In this paper, an efficient ECG denoising method using combined discrete wavelet with Savitzky-Golay (S-G) filter is proposed. The performance of S-G filter is studied in terms of polynomial degree and frame size, i.e. signal section. In addition, the performance of denoising wavelet is studied in term of mother wavelet type and wavelet order. The advantage of S-G filter is combined with discrete wavelet denoising method to get better denoising performance. The performance of denoising ECG are evaluated using signal to noise ratio (SNR) and percentage root mean square difference (PRD). For this we used simulated and gaussian white noise surrogated ECG signals. Our results show that combined S-G and wavelet filter denoising is noticeable better than the respective individual procedures. In addition, we found that the selection of frame size, order of the S-G filter and the wavelet type and order should be done carefully in order to get optimal results. It also holds true for the new filter that the optimal choice of filter parameters is a compromise between noise reduction and distortion.

Keywords: Savitzky-Golay (S-G) filter, Discrete Wavelet Transform (DWT), ECG, Noise reduction

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1 Introduction

Electrocardiogram (ECG) is considered as one of the indispensable and low-cost tools for diagnosis and identifying cardiovascular diseases (CVD) by visual inspection of graphical representation of cardiac signal which is well-known

as ECG signal. However, in real life scenario, the recorded ECG signals are often contaminated or corrupted with different types of noise and interference like gaussian white noise, powerline interference and baseline wander noise, which are originated from external sources or physiological processes of human body [1]. Since the diagnosing of CVD is commonly achieved by visual inspection of ECG signals, therefore, clean ECG signals are significantly important to help cardiologists or physicians in identifying CVD [2].

Generally, the ECG signal is contaminated by baseline wandering noise which is caused by the patient motion and human respiratory system movements during recording phase. Besides, the powerline interference noise, produced mainly by electrical power line with a frequency of 50 Hz or 60 Hz, has also an impact on the ECG signals. Moreover, white gaussian noise is added to the ECG signals during transmission due to poor channel conditions. Hence, the denoising techniques of ECG signals become an active research area. Various research papers have developed denoising techniques to eliminate these noises [1, 2, 3]. The main interest of this paper is to investigate the performance of DWT and S-G filter in denoising ECG signals. The ECG signal is usually treated as non-stationary signal. The DWT is considered as powerful method for denoising non-stationary signals because this approach assumes that the non-stationary signal can be represented by stationary sections of the signal [4]. On the other hand, the S-G filter is known as polynomial smoothing or least-squares smoothing filter, and it can preserve the high-frequency components of the signal [2]. This means that S-G filter can smooth out the signal by maintaining relevant properties of the original signal [2]. In this paper, efficient ECG denoising method based on combining DWT and S-G filter is proposed.

2 Methodology

Since the ECG can be corrupted by different types of noise, it is essential to select a suitable filter to remove the noise. The proposed method based on applying three stages of filtering to denoise the ECG signals as shown in figure 1. The first stage is to eliminate the baseline wandering noise from the ECG signal by fitting low order polynomial (i.e polynomial order=6, it found to be more suitable to fit the data)

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to the signal and then subtract the result from the original signal. The second and third stage are S-G filter and DWT filter respectively to reduce the effect of white gaussian noise, which is added to the ECG during transmission.

Figure 1: block diagram of the proposed method.

2.1 Savitzky-Golay (S-G) filter

The Savitzky-Golay filter is finite impulse response (FIR), non-causal, smoothing filter which can smooth the data by fitting successive sub-sets of adjacent data points with low polynomial degree using linear least-square approach. The advantage of S-G filter is effective in preserving the high frequency components of the signal without destroying its original properties [2].

In general, the performance of the S-G filter depends on two parameters: frame length n and polynomial order m . The frame length of S-G filter should be always odd, $n \geq m+1$ [5]. The S-G filter replaces the data point x_i , noisy signal, by a linear combination of itself and some nearby neighbors [6]:

$$y_i = \sum_{n=-n_L}^{n_R} c_n x_{i+n} \quad (1)$$

Where n_L is the number of the samples considered to the left side of data point i , while the number of samples to the right side of position i is denoted as n_R . It means for each point x_i , least-squares polynomial is used to fit all points $n_L + n_R + 1$ in the shifted window (for symmetric window $n_L = n_R$), then replaced with the polynomial value y_i at position i [6]. The convolution coefficients matrix, $\mathbf{c}$, can be calculated as follow $\mathbf{C} = \mathbf{G} \mathbf{S}^T$. Where $\mathbf{G} = (\mathbf{S}^T \mathbf{S})^{-1}$, and $\mathbf{S} = \mathbf{k}^j$. Where $\mathbf{k} = -n_L, \dots, n_R$ and $\mathbf{j} = 0, \dots, m$.

2.2 Discrete Wavelet Transform (DWT)

The discrete wavelet transform is widely used to decompose the signal to time and frequency domain information in a simultaneous manner. The mother wavelet is a signal, which may have tiny oscillations, controlled by scaling factor 'a' and shifting factor 'b'. It is expressed [7] by

$$\psi_{ab}(t) = \frac{1}{\sqrt{a}} \psi\left(\frac{t-b}{a}\right) \quad (2)$$

There are several types of mother wavelets such as 'Haar', 'Daubechies', 'Symlets', 'Biorthogonal', etc. To denoise any signal using DWT, it requires to decompose the signal into L levels and selecting a specific mother wavelet function [4]. Then, universal threshold method is applied to the detailed

coefficients of each level L using soft or hard thresholding approach. In hard thresholding approach, the coefficients below the threshold value is reduced to zero, above the threshold value is kept the same. The approach of soft thresholding is achieved by shrinking the coefficients above the threshold value a little bit toward zero and making the coefficients below the threshold value equal to zero [8].

2.3 Quantitative Performance analysis

The quantitative performance of DWT, S-G filter and the proposed denoising technique are evaluated using two performance metrics: SNR_{out} and PRD [4]:

$$\text{SNR}_{\text{out}}[\text{dB}] = 10 \log_{10} \sum_{i=1}^n \frac{(x'[i])^2}{(x[i] - x'[i])^2} \quad (3)$$

$$\text{PRD}\% = \sqrt{\frac{\sum_{i=1}^n (x[i] - x'[i])^2}{\sum_{i=1}^n x^2[i]}} \quad (4)$$

Where $x[i]$ denotes the original ECG signal, and $x'[i]$ is the denoised ECG signal. The denoising method with highest SNR_{out} and lowest PRD is considered as the best performance.

3 Results

The MIT-BIM arrhythmia database has been considered to evaluate the performance of DWT filter, S-G filter and proposed method in denoising ECG signal [9]. In this paper, thirteen ECG signals are considered from the database (100m to 112m), which contain different time-varying QRS morphology, and both normal/abnormal ECG beats. These recordings have sampling rate of 360 samples/sec and duration of 10 sec. The 100m is considered as a reference ECG signal, because it has normal beat rhythm, to investigate the best parameters of S-G and DWT filters. These parameters are considered for all other ECG signals, and the SNR_{out} are calculated overall data sets and then averaged as in table 1.

The simulated gaussian white noise is added to the ECG signals to generate corrupted signal at different input SNR levels (0 dB, 5 dB, 10 dB and 15 dB). The performance of S-G filter is investigated with respect to two parameters: polynomial degree and frame size. Moreover, the performance of DWT filter is studied in term of two parameters: mother wavelet types and wavelet level. To select the best parameters for both S-G and DWT filter, we vary one parameter whereas another is kept constant. A combined of S-G filter and DWT filter with best parameters is proposed in this paper. The effectiveness of the proposed method in comparison with both S-G and DWT filter is presented in the following. Note, All the simulations are carried out using MATLAB R2018b.

Figure 2: the performance of S-G filter where polynomial degree is varied and frame size= 21, (a) SNR output and (b) PRD %

Figure 5: the performance of DWT filter for mother wavelet sym4 and level is varied, (a) SNR output and (b) PRD %

Figure 3: the performance of S-G filter where polynomial degree=6 and frame size is varied, (a) SNR output and (b) PRD %

Figure 6: the comparison between S-G filter, DWT filter and the proposed method, (a) SNR output and (b) PRD %

Figure 4: the performance of DWT filter for different mother wavelet and level= 3, (a) SNR output and (b) PRD %

Table 1: Average SNR performance of thirteen ECG signals

SNR Input	SNR output in dB		
	G-S filter	DWT filter	Proposed filter
15 dB	18.67	17.90	19.60
10 dB	15.56	14.78	16.73
5 dB	10.98	11.64	12.52
0 dB	7.06	7.78	8.63

Figure 7: Denoised ECG signal 100m corrupted by white Gaussian noise at input SNR 10 dB

The variation of polynomial degree and frame size of S-G filter illustrates that S-G filter of polynomial degree equal to 6 and highest frame size has the best performance in terms of SNR_{out} and PRD% as shown in figures 2 and 3. The performance of DWT filter in denoising ECG signal is found to be the best using mother wavelet type (sym4) and level = 3 (see figures 4 and 5). The proposed method is based on denoising ECG signals using S-G and DWT filter together with the best parameters for each filter. Figure 6 shows that the proposed method has better performance in comparison with S-G filter and DWT filter separately. Table 1 indicates that the enhancement in the SNR_{out} performance obtained by the proposed method is notably improved comparing with S-G filter and DWT filter performance. It is clear from figure 7 that the DWT filter tends to distort the shape of QRS complex of ECG signal, while the S-G filter retains the high frequency such as QRS complex, but the low frequency components like P and T wave are distorted. In addition, figure 7 indicates that the denoised ECG signal by the proposed method is more smoother and less noisy, and most of relevant properties of the original signal is preserved comparing with S-G and DWT filter separately.

4 Discussion and Conclusions

In this paper, the performance of G-S filter and DWT in denoising ECG signal was studied in regard to polynomial degree/frame size and mother wavelet type/level respectively. In order to obtain the optimal performance for each filter, the parameters of G-S filter and DWT filter were selected carefully. The parameters with best performance for both G-S filter and DWT filter were considered in the proposed method which is based on combining these two methods. The results show that our proposed method has better SNR_{out} and PRD% comparing with G-S filter and DWT filter. Regardless of mount of improvements in terms of SNR_{out} and PRD%, the proposed method promises advantages in denoising ECG signal smoothly and efficiently by maintaining the relevant details of QRS complex, P wave and T wave. In future work, we want to include optimization methods to find the best or at least well-suited parameters for DWT and G-S filter automatically, so we can get the best desnoising performance for any biosignals.

Author Statement

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References

- [1] M. Rakshit and S. Das (2018). An efficient ECG denoising methodology using empirical mode decomposition and adaptive switching mean filter. *Biomedical Signal Processing and Control*, vol. 40(1), pp. 140-148.
- [2] M. A. Awal, S. Mostafa und M. Ahmad (2011). Performance Analysis of Savitzky-Golay Smoothing Filter Using ECG Signal. *International Journal of Civil Engineering and Technology*, vol. 1(2), pp. 24-29.
- [3] M. Bahaz and R. Benzid (2018). Efficient algorithm for baseline wander and powerline noise removal from ECG signals based on discrete Fourier series. *Australasian Physical & Engineering Sciences in Medicine*, vol. 41(1), pp. 143-160.
- [4] M. Alfaouri and . K. Daqrouq (2008). ECG Signal Denoising By Wavelet Transform Thresholding. *American Journal of Applied Sciences*, vol. 5(3), pp. 276-281.
- [5] J. L. Guíñón, E. Ortega, J. García-Antón and V. Pérez-Herranz. Moving Average and Savitzki-Golay Smoothing Filters Using Mathcad. in *International Conference on Engineering Education*, Coimbra, Portugal, 2007.
- [6] W. H. Press, B. P. Flannery, S. A. Teukolsky, and W. T. Vetterling, "Numerical recipes in C: the art of scientific computing," in Chapter 14. *Statistical Description of Data*, New York: Cambridge University Press, 1986, p. 735.
- [7] N. Rastogi and R. Mehra (2013). Analysis of Savitzky-Golay Filter for Baseline Wander Cancellation in ECG using Wavelets. *International Journal of Engineering Sciences & Emerging Technologies*, vol. 6(1), pp. 15-23.
- [8] David L. Donoho (1995). De-Noising by Soft-Thresholding. *IEEE Transactions on Information Theory*, vol. 41(3), pp. 613-627.
- [9] "PhysioNet," MIT-BIH Arrhythmia Database, [Online]. Available: <https://physionet.org/physiobank/database/mitdb/>. [Accessed 14 3 2019].