ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 7, July 2015

Denoising of ECG Signals Using Framelet Transform

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ABSTRACT: Among the various medical signals, ECG signals are prone to noises when they are captured and displayed. Hence denoising of these signals is a necessity. Currently, the denoising techniques for medical signals are mostly available in the wavelet transform domain. In this paper, a new approach for denoising the signals in the Framelet domain is proposed. Initially, signals are decomposed using Framelet transform. After the decomposition, they are denoised using hard and soft thresholding approach. The denoised signal is then obtained and the performance evaluation is carried out by comparing the results with the wavelet transform.

KEYWORDS: ECG Signal Denoising; Framelet Transform; Wavelet Transform; Thresholding

1. INTRODUCTION

The Electrocardiogram (ECG) plays an important role in the process of monitoring and diagnosing cardiac behavior or irregularities in heart rate. Any change in the ECG characteristics and interval durations may reflect an abnormality in cardiac conduction. In general, an accurate ECG signal without any noise is rarely found. ECG signals are in general affected by low-frequency and high-frequency interferences. The most common source of disturbances are baseline wander, muscular noise and electrode motion artefacts. Power line interferences contains 60 Hz pickup (in U.S.) or 50 Hz pickup (in India) because of improper grounding. It is indicated as an impulse or spike at 60 Hz/50 Hz harmonics, and will appear as additional spikes at integral multiples of the fundamental frequency. Its frequency content is 60 Hz/50 Hz and its harmonics, amplitude is up to 50 percent of peak-to-peak ECG signal amplitude. Base-line drift may be caused in chest-lead ECG signals by coughing or breathing with large movement of the chest, or when an arm or leg is moved in the case of limb-lead ECG acquisition. Base-line drift can sometimes caused by variations in temperature and bias in the instrumentation and amplifiers. Its frequency range generally bellows 0.5 Hz. Motion artifacts are transient baseline change due to electrode skin impedance with electrode motion. It can generate larger amplitude signal in ECG waveform. The peak amplitude of this artifact is 500 percent of Peak to Peak ECG amplitude and its duration is about 100 – 500 mS. All these undesirable disturbances make the interpretation of the ECG signal difficult and sometimes even impossible.

During recent years, the wavelet transform has been proved to be a valuable tool for analyzing data from various domains such as mathematics, science, engineering, economics and also medicine and biology. Results of studies in the literature have demonstrated that the wavelet transform has the features that characterize the behavior of ECG signals for removing noises. Nagendra et al used wavelet transform as a tool for processing non-stationary signals like ECG signals. The variations of the wavelet techniques like Multi resolution DWT, Fast Wavelet Transform, Lifting Wavelets, Multi wavelet Transform, Stationary Wavelet Transform, Wavelet Packet Decomposition, Fractional wavelet transform were used. The different thresholding methods namely universal, minimax and heuristic methods were used for denoising the ECG signal. Poornachandra and Kumaravel described a sub band adaptive shrinkage method that generalizes hard and soft shrinkages. Wavelet technique was used for decomposing the ECG signal. The proposed sub band adaptive shrinkage is a nonlinear model that works on hyperbolic function, which will outperform the soft shrinkage. This method was then compared with hyper

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shrinkage, an optimized thresholding scheme based on universal threshold. Mikhled Alfaouri and Khaled Daqrouq proposed a method based on decomposing the signal into five levels of wavelet transform by using Daubechies wavelet(db4) and determining a threshold as the point where minimum error is achieved between the detailed coefficients of thresholded noisy signal and the original. This method was compared with Donoho's method of denoising.

David Donoho proposed an approach for the denoising using soft thresholding function. This approach provided better visual quality than procedures based on mean squared error, called the Visushrink , in reference to the good visual quality of reconstruction obtained by the simple "shrinkage" of wavelet coefficients. Yang proposed used wavelet transform with a high degree of scarcity. Various thresholding techniques such as Sure Shrink, VisuShrink and BayeShrink were used and its performance was compared. Michel and Thomas Ertl [6] proposed a method based on the vector wavelet transform and wavelet coefficient thresholding .This method was then compared with Gaussian filtering.

The existing wavelet technique has a disadvantage that they are shift variant and have poor directionality. The standard thresholding techniques described in the wavelet domain are VisuShrink and SureShrink. To improvise the denoising results using the wavelet transform, a new approach in the Framelet domain is proposed in this paper.

The rest of the paper is organized as follows: Section 2 describes the Framelet transform. Section 3 describes the proposed system, followed by results in Section 4. Section 5 concludes the paper.

II. FRAMELET TRANSFORM

Framelet transform has the multiresolution decomposition property similar to the wavelet transform [1-2]. While wavelets have one scaling function and a wavelet function, Framelet uses one scaling function $\varphi(t)$ and two wavelet functions $\psi_1(t)$ and $\psi_2(t)$. They are defined through these equations using the low pass filter $h_0(n)$ and the two high pass filters $h_1(n)$ and $h_2(n)$. The multiple high frequency filters provide better frequency localization. The coefficients in different sub bands are also correlated. Therefore, changes on one coefficient can be compensated by its related coefficient in the other sub band. This property helps in to remove noise more effectively from the corrupted image [3].

$$\Phi(t) = \sqrt{2}\sum_{n} h_0(n)\Phi(3t-n) \quad (1)$$

Any function f(t) could be expanded using the scaling function and the wavelet functions. When expanded like this, the scaling function give a low resolution or coarse approximation of f(t) [4]. The filters $h_i(n)$ and $h_i(-n)$ should satisfy the perfect reconstruction condition. For i=1,2 let Ki denote the number of zeros $H_i(ejw)$ has at w=0. The z-transform of each $h_i(n)$ is given as,

$$H_0(z) = Q_0(z)(z+1)^{K}{}_{0} \quad (3)$$

$$H_1(z) = Q_1z)(z-1)^{K}{}_{1} \quad (4)$$

$$H_2(z) = Q_2(z)(z+1)^{K}{}_{2} \quad (5)$$

K_0 gives the degree of polynomials representable by integer translates of $\varphi(t)$ and gives an idea about the smoothness of $\varphi(t)$ [5]. The number of zero moments of the wavelet filters is given by K_1 and K_2. A higher degree of smoothness can be achieved by making K_0 greater than the other two values. The values for the shortest analysis filters h0(n) , h1(n) and h2(n) are shown in Table 1. The generators of a Framelet frame with parameters K0 = 5, and $K_1 = K_2 = 2$ are shown in Figure 1.

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Table 1. Set of analysis filters

$h_0(n)$	$h_1(n)$	$h_2(n)$
0.076223	-0.020547	-0.027160
0.349088	-0.094105	-0.124388
0.602089	-0.122897	-0.130165
0.441941	0.061353	0.742137
0.060823	0.606332	-0.460423
-0.083923	-0.311319	
-0.032029	-0.118815	

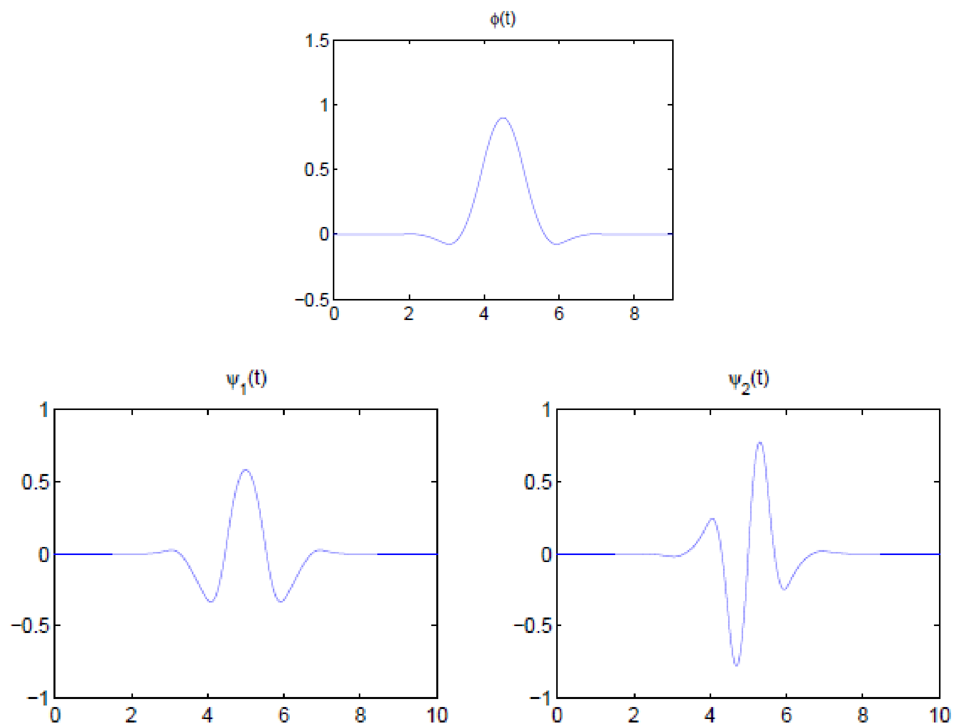

Figure 1. The generators of a Framelet frame

III. THE PROPOSED SYSTEM

In the proposed system, the Framelet transform is used for decomposing the ECG signals [6]. It is also called double density discrete wavelet transform (DDWT) because it has exactly twice the number of wavelet coefficients compared to the Discrete Wavelet Transform (DWT). The Framelet transform is implemented on discrete-time signals using the analysis and synthesis filter bank .The analysis filter bank consists of three analysis filters- one low pass filter denoted by h0(n) and two high pass filters denoted by h1(n) and h2(n). As the input signal travels through the system, the analysis filter bank decomposes it into three sub bands, each of which is then down-sampled by 2. The sub bands decomposed from Framelet transform are then thresholded using a median based, hard and soft threshold approach [7-8]. The thresholded coefficients are then passed into inverse Framelet transform which makes use of synthesis filter bank to reconstruct the denoised signal. Figure 2 shows the analysis filters.

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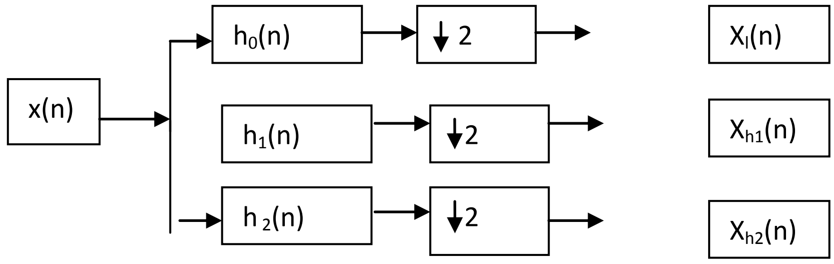

Figure 5.1 Analysis filter

Figure 2. Analysis filters

3.1 Noisy Signal Generation

Ten healthy ECG signals are obtained from the Physiobank database [9]. These signals are affected by various kinds of noises like Gaussian noise, power line interference, baseline wanders, and muscle contraction. Here, we focused only on addition of Gaussian noise. A noisy signal is generated by adding Gaussian noise to the healthy signal. Gaussian noise is signal independent and each sample will be changed from the normal by a small amount [10]. The PDF of a Gaussian random variable x, is given by

$$p(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{1}{2}(\frac{x-\mu}{\sigma})^2} \qquad (6)$$

Where x is the gray level, μ is the mean, σ is the standard deviation.

3.2 Denoising

The Framelet transform is applied to the noisy ECG signal for decomposing the signal. The decomposed sub band signals are stored in the cell array [11]. The decomposed sub bands are then passed into thresholding function which involves two processes: first, the calculation of threshold value (T) and then comparing the value of T with the Framelet coefficients. For calculating the value of T, three standard techniques were used namely, SureShrink method, VisuShrink method and Median based thresholding. In SureShrink method, value of threshold, T is calculated as

$$T=\sqrt{(2\log(N \log N/ \log 2))} \qquad (7)$$

where N is the length of the sub band. For VisuShrink method, threshold is calculated as, T= σ√2logN, where σ is the noise variance. For median based threshold method, threshold is given by T= σ√2logN where σ- median of Framelet coefficients in each sub band [13-14].

Thresholding are of two types; hard threshold and soft threshold. In a hard threshold, if Framelet coefficients are greater than the threshold, then the coefficients are retained else the coefficients are made zero. In soft thresholding, if the Framelet coefficients are greater than or equal to the threshold, then the coefficients are subtracted from threshold and if coefficients are less than or equal to threshold, the coefficients are added to the threshold, else the coefficients are made zero.

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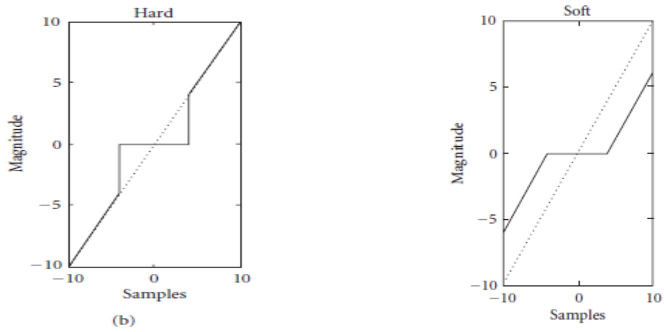
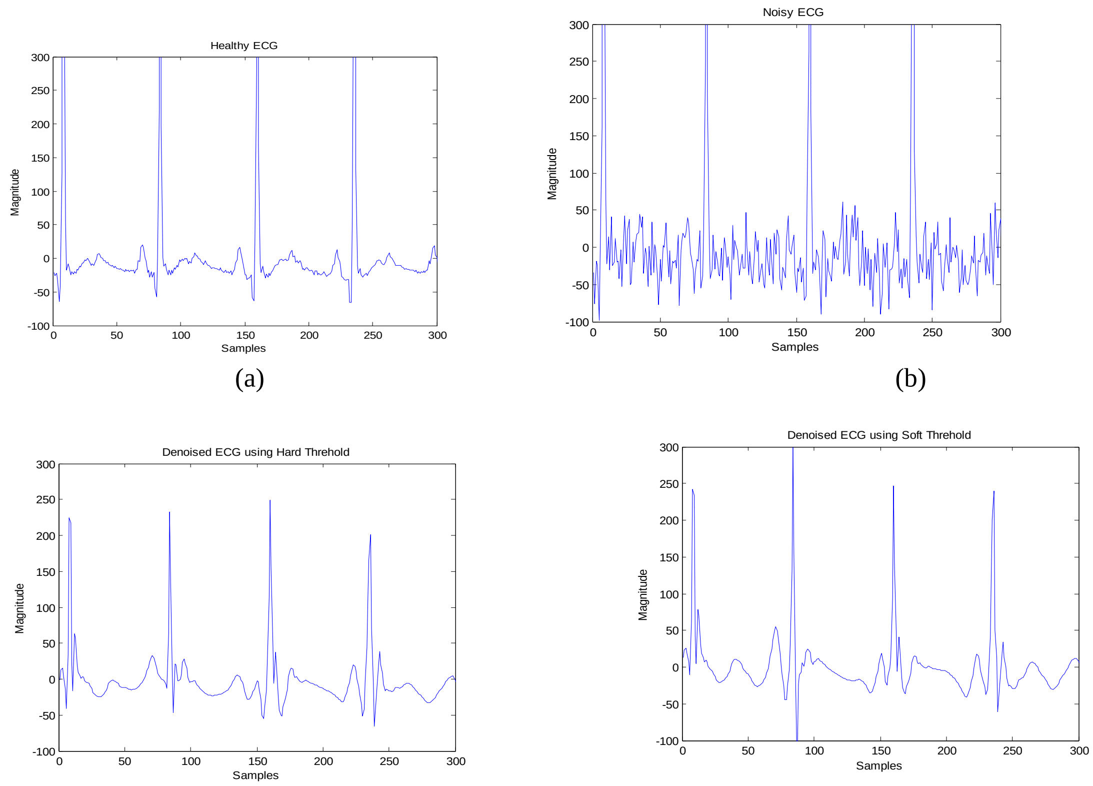


(a) (b)

Figure 3. (a)) Hard Threshold (b)Soft Threshold

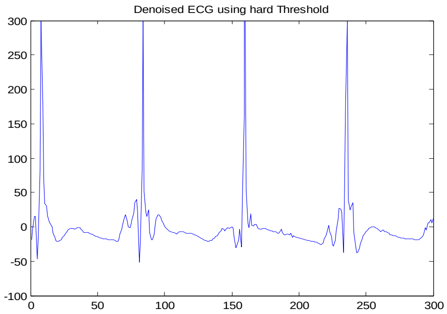
IV. RESULTS

In order to evaluate the results, the ECG signals corrupted by the Gaussian noise are used. Each signal is having duration of 1 min [12]. The percentage of Gaussian noise added to the noise free ECG signal is varied. Experiments were conducted for various noise levels from 0%-50%. After the addition of the noise, signals are decomposed both in the wavelet and the Framelet transform domains using single level decomposition. Then, denoising is conducted using Visushrink and the proposed thresholding method. A sample ECG signal used for denoising is shown in Figure 4.

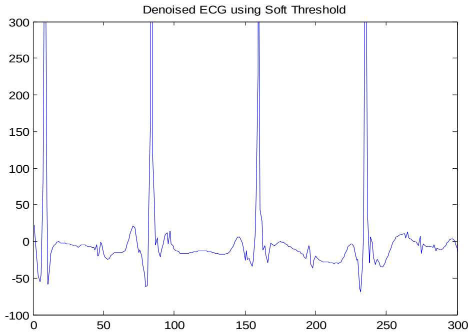


(a) (b)

(c) (d)



(e)



(f)

Figure 4. Noise level=30% (a) Healthy ECG Signal (b) Noisy ECG Signal c)Denoised ECG(dwt-hard threshold) (d)Denoised ECG (dwt- soft threshold) (e) Denoised ECG (Framelet-hard threshold) (f) Denoised ECG (Framelet-soft threshold)

The signal denoised after single level decomposition had poor visual quality but better SNR [15-16]. Then, multi level decomposition (level=2,3,4) was conducted and the denoising procedure was repeated in both domains. It was observed that the proposed thresholding method gave better SNR as well as good visual quality of the signal in the Framelet domain than wavelet under multilevel decomposition. The quality of the denoised signal is measured by calculating the Signal-to-Noise ratio (SNR), which is given by,

$$SNR(dB)= 20*\log10\ (\sigma/\sigma_n) \quad (8)$$

where σ - Standard deviation of denoised signal and σ_n - Standard deviation of noise.

From the results, it is observed that the Median based technique using soft thresholding function in the Framelet transform yielded better SNR than the Sureshrink technique using soft thresholding function in the wavelet transform.

SIGNAL	NOISE LEVEL (Variance %)	WAVELETS (sure shrink)		FRAMELETS (median based)	
		HARD THRESHOLD	SOFT THRESHOLD	HARD THRESHOLD	SOFT THRESHOLD
		SNR(dB)	SNR(dB)	SNR(dB)	SNR(dB)
a04m	20	8.0700	8.0415	6.7788	9.6893
	30	3.8719	3.1212	3.4868	5.8379
	40	-0.4398	0.0537	1.1871	2.9104
a05m	20	9.9568	10.4509	7.7635	11.6813
	30	5.6188	5.8705	4.7486	7.9287
	40	2.5726	2.3156	2.0301	5.2459
a07m	20	12.3860	12.3379	10.4902	13.6283
	30	8.1033	7.5376	6.5900	9.7609
	40	4.4922	4.7543	4.3741	6.7358

Table 2 Comparison of SNR of various ECG signals for different noise level

A graph has been plotted by taking signals with noise variance level (30%)on X-axis and SNR values on Y-axis for both wavelet and the Framelet technique as shown in Figure 5

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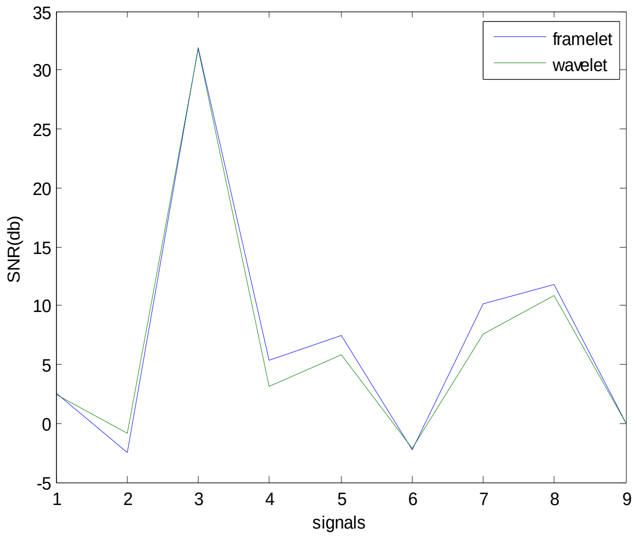

Figure 5. Comparison of SNR for Framelet and Wavelet

V. CONCLUSION

An approach for denoising of the ECG signal in the Framelet domain is implemented. The noisy ECG signal is decomposed using Framelet transform. The decomposed signal is then denosied in the Framelet domain using a new thresholding technique. Performance evaluation shows that the SNR results are better than Visushrink and the SureShrink algorithms. This technique also shows that multilevel Framelet decomposition with soft thresholding gives better results than the hard thresholding. Experimental results further show that the technique is able to achieve SNR superior than the wavelet based denoising techniques.

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