An Investigation on The performance analysis of ECG Signal Denoising using Digital filters and Wavelet Family

Pinjala N Malleswari, Ch. Hima Bindu, K.Satya Prasad

Abstract : ***Electrocardiography is a technology used to identify the abnormalities in heart and noise free ECG data is often required for correct medication of cardiac disorders. Generally ECG signals are contaminated by noise and human artifacts during data acquisition. The denoising signal plays a major role in medical field. Electrocardiogram (ECG) signals represent important characteristics for diagnosing the disease or how the treatment works on the heart, which makes it necessary to design filters to weaken and eliminate these noises. This paper describes the denoising of ECG signal from baseline wander noise using digital filters and wavelet transform. The function of the filters has been tested on different cardiac signals. The results show that wavelet transform has the best performance in denoising ECG signals than digital filters such as IIR (Infinite Impulse Response) notch and window based FIR (Finite Impulse Response) filters. Finally the performance of the wavelet based approach is evaluated with SNR (Signal to Noise Ratio) value, PSNR (Peak Signal to Noise Ratio) value, Mean Square Error (MSE) value and Correlation Coefficient (CC) value and compared among various wavelet families. All simulations are carried out using MATLAB.***

Index Terms: ECG Signal, Denoising, Wavelet Decomposition, Reconstruction, digital filters.

I. INTRODUCTION

ECG signal is a graphical illustration of cardiac movements and is used to record various cardiac ailments and abnormalities with respect to time, present in the heart. In this process the electrical activity of heart is recorded by placing electrodes on the skin, which gives the information about the function of the heart and it detects various disorders such as arrhythmia, tachycardia, aberration, etc. Due to the presence of artifacts, the analysis of the ECG is difficult, because the noises created by sensors that can be confused with cardiovascular rhythms [13][14].

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Therefore, undesirable noise and signals should be removed or eliminated from the ECG in order to ensure proper analysis and diagnosis. Due to the interference of several biological and ecological noises, original ECG data is changed from its structure. To get the desired noise free ECG signal we need to preprocess the noisy signal by using denoising techniques which separate original signal from noise [2]. There are different types of noise sources like Power Line Interference (PLI), electrode contact, motion artifact, muscle contractions and Baseline Wanders (BW).

Different researchers have proposed various algorithms to get noise free ECG signal. Rishi Raj Sharma, et al. [1] discussed ECG denoising techniques to remove BW and PLI noises using eigen value based decomposition. Rashmi, et al. [2] have proposed ECG Denoising algorithm using digital filters and wavelet transform. Savita Chandel, et al. [3] have discussed ECG denoising using wavelet decompositoion, thresholding and wavelet reconstruction by making highest level coefficients as zero. The authors [4] proposed various algorithms for the removal of BW noise and EMI (Electro Myography Interference). W. Jenkal, et al. [5] discussed an efficient algorithm using the adaptive filter with dual threshold value and Discrete Wavelet Transform (DWT) to get noise free ECG data. Mavera Mazhar Butt, et al. [6] discussed various denoising processes of ECG signal. S.S.Bhogeshwar, et al. [9] addressed the advantages and disadvantages of FIR filters using different windows such as bartlet, kaiser, rectangular, hamming, hanning, and gaussian. They also discussed IIR digital filters like Butterworth, Chebychev Type-I & Type-II and Elliptic filters. Bhumika Chandrakar, [10] addressed noise less techniques for ECG signals.

II. PREPROCESSING OF ECG

Signal processing is an efficient mathematical tool in biomedical engineering, especially to identify and eliminate noises in ECG [2]. A corrupted ECG signal may lead to wrong diagnosis of the heart condition, which indications to erroneous detection of cardiac disorders. Preprocessing is widely used in the heart rate, QR interval, and extraction of features and distribution of QRS complexes [7]. It eliminates the contamination in ECG signal caused by many factors such as body activities, ECG leads, loose contact between skin and electrode, etc. Electrocardiogram signal is degraded by the following types of noises [6] [8].

A. Baseline Wander

It is a low-frequency noise which occurs in the range 0.15 Hz to 0.3 Hz in ECG. Due to poor contact of electrodes, respiration, and perspiration or body movements this kind of noise occurs when the patient breathes rapidly or coughs while ECG is being recorded.

B. Power Line Interference

This is a high frequency noise whose value is 50 Hz/60 Hz. Due to loose contact or dust in the electrodes this type of noise occurs and it can also be produced by improper grounding of adjacent devices.

C. Electromyographic (EMG) Noise

EMG noise is a high frequency noise of ten thousand Hz. It is affected by muscular actions except heart. ECG picks up the depolarization and repolarization produced by sudden body actions. All these noises need to be removed from ECG for exact investigation. Many number of techniques are available to denoise ECG signals.

III. METHODOLOGY

The proposed technique includes denoising ECG waveforms by wavelet family such as Daubechies, Haar, Symlet [2] and BiorSplines, digital filters like IIR notch and window based FIR Filters using Hanning, Hamming, and Blackman and Rectangular windows.

Step 1: Decompose the noisy data by choosing particular wavelet from its family for '7' levels, which gives many number of coefficients of different lengths.

Step 2: Make the uppermost level coefficients a7 and d7 as zeroes.

Step 3: Apply soft thresholding to the remaining coefficients [3] (d6, d5, d4, d3, d2 and d1).

Step 4: Reconstruct the signal using modified coefficients, with the same wavelet family up to '7' levels.

Step 5: Apply noisy ecg signal to the IIR notch filter to get the denoised signal.

Step 6: Apply noisy signal to the window based FIR filter to get the noise free signal.

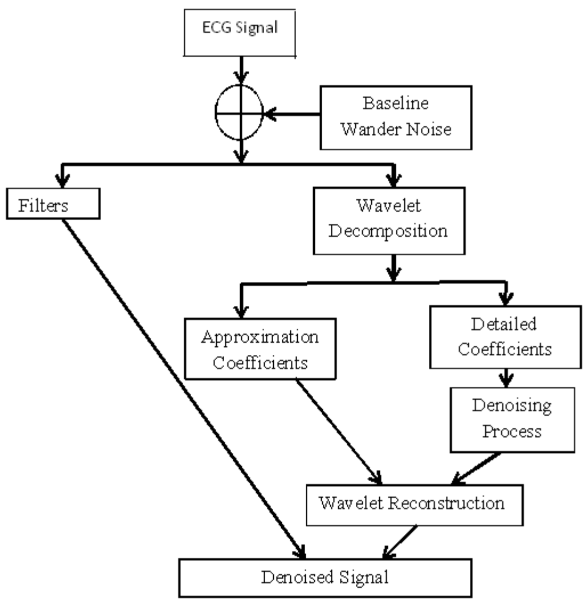

Fig. 1 Flow Chart of Proposed Method

The work flow of proposed method is shown in Fig.1. It clearly describes the step by step procedure.

IV. IMPLEMENTATION RESULTS AND DISCUSSIONS

This article presents the comparative analysis of wavelet based approach and window based FIR digital filters to eliminate baseline wander noise in the electrocardiogram signal. Sample ecg data is collected from MIT BIH Arrhythmia Database [11]. It consists of a collection of ecg data records with sampling rate 360 Hz, 11 bit resolution over 10 mV range. Figure 2 shows that the sampled original ecg data. In this survey the orthogonal wavelet functions: haar, db2, db4, bior1.3 and sym8 are studied and the noisy signal is generated by adding baseline wander to the original signal and it is clearly observed in Figure 3. Wavelet decomposition is applied to the corrupted signal for seven levels which gives eight coefficients with different lengths. (a7, d7, d6, d5, d4, d3, d2, and d1). In the next step the minimum length coefficients a7 and d7 are made zeroes and Rigrsure and Sqtwolog thresholding schemes are applied to the remaining coefficients. Then ecg signal is recovered using the new wavelet coefficients and the corresponding results for sample record 101 is displayed in Fig.4.

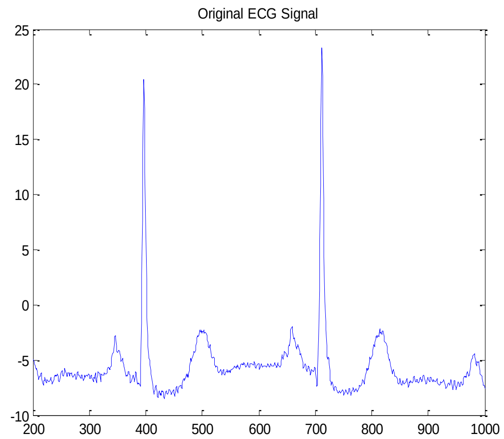

Fig. 2: Raw ECG data of record 101.

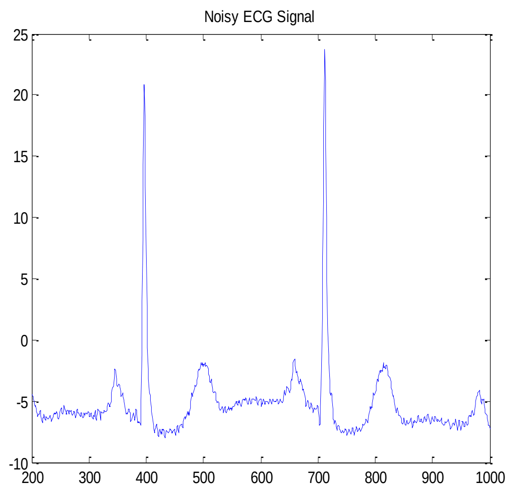

Fig. 3: Noisy ECG signal.

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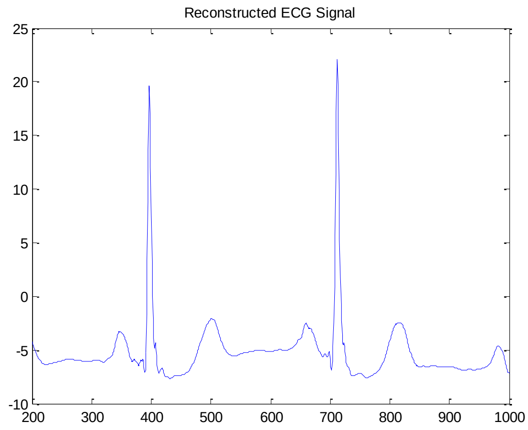

Fig. 4: Denoised signal using wavelet transforms.

It is clearly observed that the noise component is completely detached. Table I and II shows that the SNR, PSNR, MSE and CC values for different records using IIR notch and FIR filter with Blackman window.

Table I: Denoising results of IIR notch filter

IIR notch	MSE	SNR	PSNR	CC
101	4.9948	4.6751	10.1810	0.7878
102	2.2489	6.9213	10.8646	0.9223
104	3.0703	4.3575	11.6634	0.9213
105	7.3539	4.2917	9.6986	0.8922
106	5.2080	3.5793	9.7208	0.8468
107	17.1103	5.7019	9.1613	0.9598
108	1.3033	6.5039	4.0488	0.9128
109	9.5886	4.9359	9.8624	0.9360
111	2.6029	4.8583	8.4535	0.8772
112	4.4634	8.8121	2.6623	0.8457
117	4.4426	8.9336	-5.4567	0.8847
119	21.7021	6.8271	9.7717	0.9295
124	13.1029	6.0733	9.2276	0.8956
208	15.8514	2.1169	10.0419	0.7905
228	1.8493	7.5950	8.5327	0.9721
Avg	7.8498	5.82198	7.73235	0.8990

Table II: Denoising results of Blackman window

Blackman	MSE	SNR	PSNR	CC
101	0.9833	8.2042	13.7100	0.9683
102	0.8068	9.1474	13.0907	0.9774
104	0.9429	6.9209	14.2269	0.9800
105	0.8699	8.9269	14.3338	0.9903
106	0.7916	7.6701	13.8116	0.9829
107	2.4335	9.9370	13.3963	0.9948
108	0.5635	8.3248	5.8697	0.9715
109	1.0302	9.7801	14.7066	0.9945
111	0.5050	8.4192	12.0144	0.9848
112	0.7032	12.8251	6.6753	0.9828
117	0.7077	12.9224	-1.4678	0.9868
119	3.3101	10.9103	13.8550	0.9901
124	1.5079	10.7682	13.9225	0.9899
208	2.2841	6.3237	14.2487	0.9747
228	0.4110	10.8610	11.7988	0.9963
Avg	1.2058	9.55265	11.4630	0.9854

The SNR, PSNR, MSE and CC values are calculated for 15 records of ECG data with sym8 wavelet transform using Rigrsure and Sqtwolog threshold values [12] are shown in Table III and IV.

Table III: Denoising results of sym8 wavelet using Rigrsure threshold

Sym8	MSE	SNR	PSNR	CC
101	0.2794	10.9366	16.4424	0.9966
102	0.2773	11.4668	15.4101	0.9967
104	0.2990	9.4150	16.7210	0.9972
105	0.2931	11.2894	16.6963	0.9986
106	0.2931	9.8276	15.9692	0.9973
107	0.3379	14.2243	17.6836	0.9997
108	0.4961	8.6014	6.1464	0.9767
109	0.2874	12.5524	17.4789	0.9993
111	0.2923	9.6065	13.2016	0.9953
112	0.3269	14.4885	8.3388	0.9959
117	0.3168	14.6676	0.2774	0.9968
119	0.3346	15.8871	18.8317	0.9995
124	0.2805	14.4207	17.5750	0.9993
208	0.3923	10.1493	18.0743	0.9976
228	0.3603	11.1468	12.0846	0.9971
Avg	0.3276	11.9816	13.8921	0.9962

Table IV: Denoising results of sym8 wavelet using Sqtwolog threshold

Sym8	MSE	SNR	PSNR	CC
101	0.8092	8.6273	14.1332	0.9835
102	0.9353	8.8265	12.7698	0.9797
104	0.8566	7.1296	14.4356	0.9863
105	0.9131	8.8218	14.2287	0.9924
106	0.9047	7.3802	13.5217	0.9863
107	1.3112	11.2799	14.7393	0.9978
108	1.1246	6.8241	4.3690	0.9317
109	0.9120	10.0447	14.9712	0.9963
111	0.7889	7.4506	11.0457	0.9788
112	0.9119	12.2607	6.1110	0.9842
117	0.7158	12.8978	-1.4924	0.9894
119	0.9928	13.5253	16.4700	0.9978
124	0.7742	12.2160	15.3703	0.9966
208	1.3365	7.4874	15.4125	0.9895
228	0.7575	9.5332	10.4709	0.9912
Avg	0.9453	9.6912	11.6016	0.9855

The average SNR, PSNR, MSE and CCs of these wavelet transforms for 15 samples of data is taken and compared in Table V for wavelet family using soft thresholding schemes such as Rigrsure and Sqtwolog and the performance analysis of sym8 gives better results than digital filters and other wavelets.

Table V: Comparative Analysis of digital filters and wavelet family

Various filters	MSE	SNR	PSNR	CC
IIR Notch	7.8498	5.82198	7.73235	0.8990

Rectangular	1.3515	9.33732	11.2477	0.9834
Hamming	1.3109	9.39427	11.3046	0.9723
Hanning	1.2291	9.51497	11.4253	0.9851
Blackman	1.2058	9.55265	11.4630	0.9854
Wavelet family	Rigrsure Threshold			
haar	0.4065	11.5089	13.4193	0.9946
bior1.3	0.3914	11.5939	13.5042	0.9948
db2	0.3453	11.8591	13.7695	0.9959
db4	0.3247	11.9636	13.9040	0.9962
sym8	0.3276	11.9816	13.8921	0.9965
Wavelet family	Sqtwolog Threshold			
haar	1.3475	8.9521	10.3407	0.9789
bior1.3	1.2021	9.2081	11.118	0.9803
db2	0.9744	9.6220	11.5324	0.9847
db4	0.9533	9.6685	11.5789	0.9855
sym8	0.9453	9.6912	11.6016	0.9855

From Fig. 5 to 8 shows that the graphical representation of SNR, PSNR, MSE and CC values.

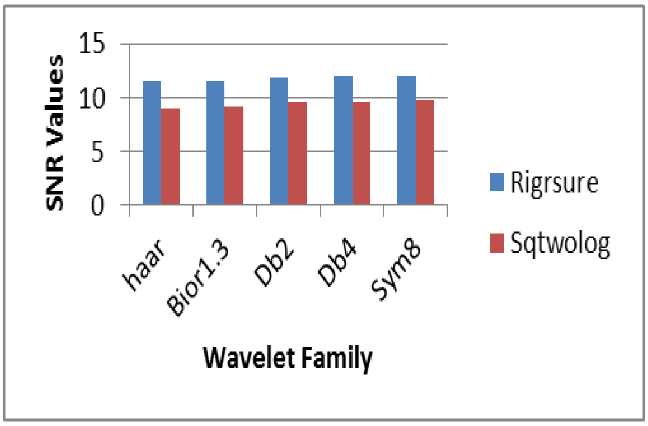

Fig. 5. SNR vs. Wavelet Family.

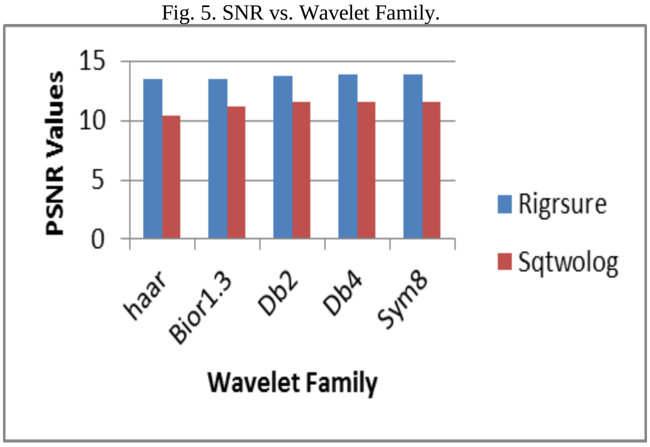

Fig. 6: PSNR vs. Wavelet Family.

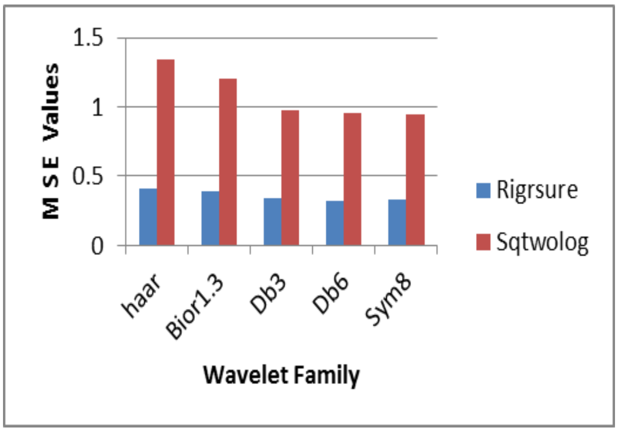

Fig. 7: MSE vs. Wavelet Family.

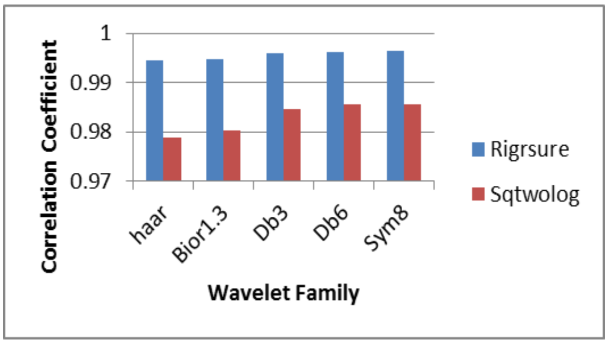

Fig. 8: CC vs. Wavelet Family.

The performance analysis of various digital filters such as IIR notch filter and FIR filter using rectangular, hamming, hanning and blackmann window in terms of MSE, SNR, PSNR and CC values are shown from Fig. 9 to 12. Blackman window gives better results than the remaining filters. The MSE function is defined as:

$$MSE = \frac{1}{N}\sum_{n=1}^{N}[x(n) - y(n)]^2 \qquad (1)$$

Where $x(n)$ is the actual signal and $y(n)$ is the reconstucted signal.

The SNR function is defined as:

$$SNR\, in\, dB = 10 * \log\left[\frac{\frac{1}{N}\sum_{n=0}^{N-1}[x(n)]^2}{MSE}\right] \qquad (2)$$

The PSNR value is defined as:

$$PSNR = 10 * \log_{10}\left(\frac{MAX_{input}^{\;2}}{MSE}\right) \qquad (3)$$

The Correlation Coefficient (CC) value of two signals x and y is defined as:

$$Corr(x/y) = \frac{\sum_{i=1}^{N} x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{N} (x_i - \bar{x})^2 (y_i - \bar{y})^2}} \quad (4)$$

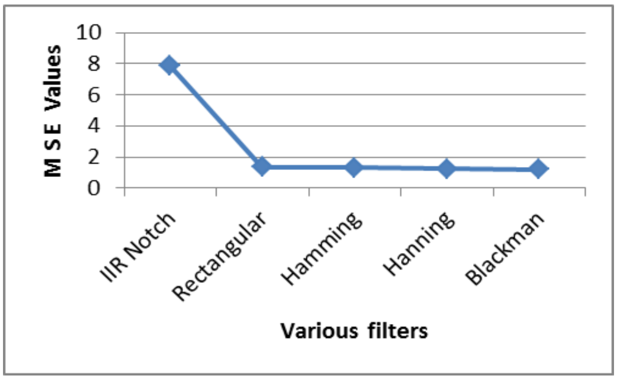

Fig. 9: MSE vs. digital filters.

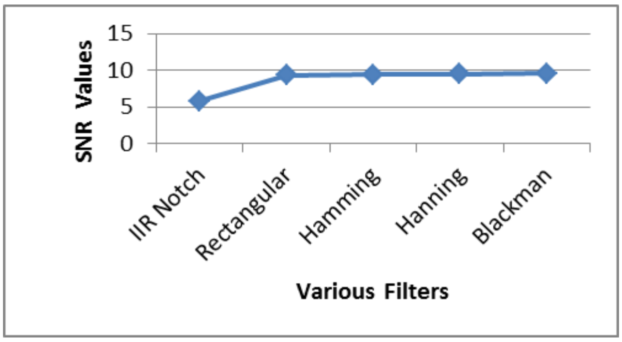

Fig. 10: SNR values vs. digital filters.

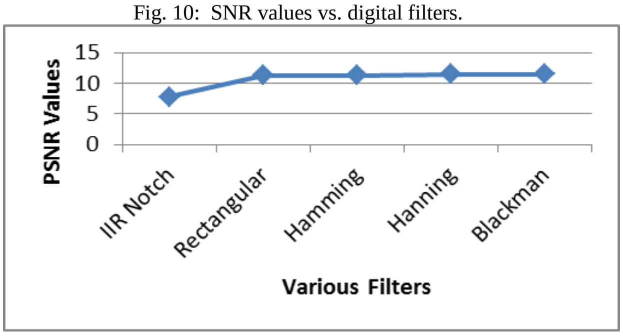

Fig. 11: PSNR values vs. digital filters.

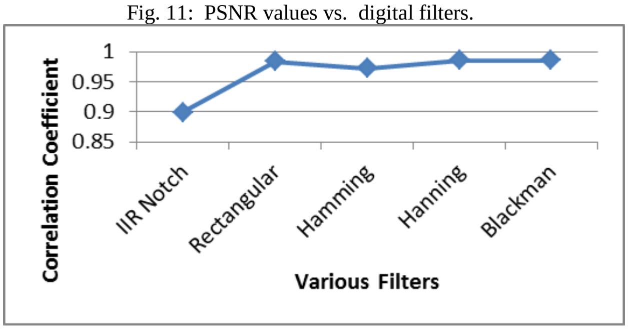

Fig. 12: CC values vs. digital filters.

V. CONCLUSION

In order to improve the denoising performance of an ECG signal, decomposition of wavelet family like Daubechies, Haar, BiorSplines and Symlet and suitable thresholding is applied on new detailed coefficients then reconstructed. Similarly the noisy signal is transmitted through digital filters. SNR, PSNR, MSE and CC of each technique are measured for total 15 records. DWT using 'sym8' gives superior results than the remaining functions. In digital filters several windowing techniques like rectangular, blackman, hanning and hamming are applied to the noisy ecg data. 'Blackman window' gives better performance in digital filters. This paper clearly shows that the comparative analysis of wavelet transform 'sym8' gives better results than the digital filter using 'blackman window'. The projected technique is able to eliminate BW noise efficiently. This work can be extended by changing the thresholding with advanced techniques to enhance the ECG signal.

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