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ECG Denoising using Wavelet Transform and Filters

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***Abstract*—ECG (Electrocardiography) is a technology used to measure the health of the heart. This paper describes various noises that contaminate the ECG signal and various techniques that are used to eliminate these noises. An efficient denoising method using wavelet transform is proposed. Results of 'sym8' wavelet transform is compared with results of digital filter using 'blackman window'. SNR (Signal to Noise Ratio) is the parameter used to measure the performance of the output. SNR of 'sym8' wavelet transform is seen to be greater than that of the digital filter using 'blackman window'.**

***Index Terms*—Denoising, ECG, wavelet transform, filters.**

I. Introduction

According to statistics, there are about 30 million heart patients in India and 2 lakh heart surgeries performed every year. There are about 17.3 million people dying in India due to heart diseases. Therefore, analysis of ECG plays a vital role. Critical situations require these signals to be recorded on a long time scale [example, 1 week] to identify disturbance in the signal. Hence, a cardiologist will require a lot of time to analyze these long ECG records. Automatic processing lessens this burden by automatically analyzing these long data. These signals need to be denoised prior to automatic processing to increase accuracy and avoid wrong detection of diseases.

ECG signal is a graphical representation of cardiac activity and is used to measure various cardiac diseases and abnormalities present in the heart. It is a process of measuring and recording electrical activity of heart by placing electrodes on the skin. The main purpose of ECG is to obtain information about the function of the heart. ECG signal is used to detect various types of diseases like arrhythmia, tachycardia, aberration, etc. The general structure of an ECG is shown in Fig. 1. It has a P wave, PR interval, QRS complex, ST interval and a T wave.

Raw ECG may be altered from the original structure due to interference of various biological and environmental noises. Hence, it is necessary to preprocess the ECG signal for accurate and reliable results. Denoising is the process used to separate original ECG signal from noise to obtain desired noise-free signal. There are various sources of noise such as powerline interference, electrode contact, motion artifact, muscle contractions and baseline wander.

Section II explains various noises present in the ECG signal and their sources. It consists of different denoising techniques used to eliminate these noises. Section III explains methods proposed in this paper which are wavelet transform and digital filters. Sections IV and V consists of results and discussions.

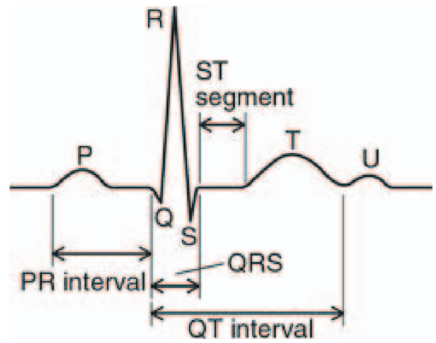

Fig. 1. Typical ECG signal.

II. Preprocessing of ECG

Signal processing is very important in the field of biomedical engineering, especially to detect and remove noises in ECG. A noisy ECG signal may lead to wrong diagnosis of the function of heart, which leads to wrong detection of diseases. Preprocessing of ECG is useful in applications such as finding the heart rate, QR interval, to extract features and distribution of QRS complexes [1]. This process removes the contamination in ECG signal caused by various factors like body movements, ECG leads, loose contact between skin and electrode, etc. ECG signal is corrupted by many types of noises [2]. Various filters have been designed to remove these noises [3]. Noises in ECG are segregated into various types based on the causes as follows.

A. Baseline Wander

Baseline wander is a low-frequency noise in the range 0.15 Hz to 0.3 Hz present in ECG. It may be caused by poor electrode contact, respiration, perspiration or body movements. It occurs when the patient breathes rapidly or coughs while ECG is being recorded.

B. Power Line Interference

Power Line interference is a high frequency noise whose value is 50 Hz/60 Hz. It is caused by loose contact of electrodes or due to dust in the electrodes. It can also be caused by improper grounding of nearby devices.

C. Electromyographic (EMG) Noise

EMG noise is a high frequency noise of ten thousand Hz. It is caused by muscular movements other than heart. ECG picks

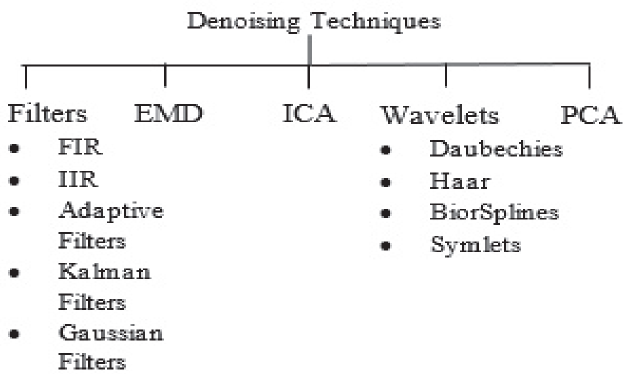

Fig. 2. Denoising techniques.

up the depolarization and repolarization caused by sudden body movements.

D. Electrode Pop or Contact Noise

Electrode Contact Noise is caused due to disturbance in the contact between electrodes and skin. The noise occurs for a duration of 1 s as spiky alterations.

E. Motion Artifacts

Motion Artifacts is caused due to changes in electrode-skin impedance when the patient moves. It results in partial baseline drift.

Such noises need to be eliminated from ECG for accurate analysis. Various methods are used to denoise ECG signals. These methods are segregated into various techniques as shown in Fig. 2.

Different researchers have proposed various methods of ECG denoising. Sande Seema Bhogeshwar, M.K. Soni and Dipali Bansal [4] discussed various FIR filters like Kaiser, Rectangular, Hamming, Hanning, Gaussian, Bartllet and Equiripple Filter. They also presented IIR filters like Butterworth, Chebychev I & II and Elliptic Filters. Baby Paul and P. Mythili [5] have proposed an adaptive filtering technique for denoising the ECG based on Genetic Algorithm (GA) tuned Sign-Data Least Mean Square (SD-LMS) algorithm. The adaptive filter requires a reference input that is uncorrelated with the signal of interest, but closely correlated with the interference or noise in some manner. It removes baseline wander and powerline interference from the ECG signal. Mahsa Akhbari, *et al.* [6] proposed the method of extended Kalman Filter. There are two cases considered in this paper. In one case they have assumed a corresponding observation to angular velocity state and in the other case, they have not assumed any observations for it. Abdolkarim Hashemi, *et al.* [7] discuss dynamic Gaussian filter which suppresses EMG noise outside the QRS region by applying variable smoothing effects in different parts of the signal. This method improves the SNR of the signal compared to low-pass filters.

Jaffery Z.A., Ahmad K. and Afroz [8] discussed various wavelet threshold estimators for denoising of ECG signal. Mean square errors are computed for different values of SNR of noisy ECG signal. Pradnya B. Patil and Dr. Mahesh S. Chavan [9] discussed Daubechies wavelet analysis method to eliminate powerline interference from ECG signal. Signal to Noise Ratio is the parameter used to measure the signal noise. Soft and hard thresholding techniques have been implemented in this paper. M. Suchetha, N. Kumaravel and B. Benisha [10] used Empirical Mode Decomposition to remove 50 Hz power line interference and baseline wandering from the ECG signal. Mrinal Phegade and P. Mukherji [11] discussed Independent Component Analysis (ICA). They apply different ICA schemes such as JADE algorithm, fast ICA and constrained ICA for ECG denoising. Savitha R.V., S.R. Breesha and X. Felix Joseph [12] proposed a combination of FIR Filter and Principal Component Analysis (PCA) to remove interferences in ECG. They also compared the results of proposed method with FIR Filter, PCA and Butterworth filter and proved that the proposed method provides better result. Sarang L. Joshi, Rambabu A. Vatti and Rupali V. Tornekar [13] described various noises present in ECG and compared various denoising techniques such as FIR filtering, EMD and wavelets.

III. Methodology

ECG signals are taken from MIT-BIH Arrhythmia Database. It has forty eight different records. The recordings are sampled at 360 Hz per channel with 11 bit resolution over a 10 mV range. The proposed method involves denoising ECG waveforms by wavelet transform like Daubechies, Haar, Symlet [14] and BiorSplines and FIR Filters like Hanning, Hamming, Blackman and Rectangular windows.

Two different denoising techniques are used in this paper.

A. Wavelet Transform

It is one of the efficient methods to remove noises in ECG. There are many types of wavelets such as Daubechies, Haar, Symlet and BiorSplines [9].

Wavelet transform consists of 3 main steps

(1) Decompose the signal by choosing wavelet ‘sym8’ and level ‘7’. This results in many coefficients of various lengths.
(2) Make the highest coefficients with minimum length as zeroes. i.e., make CA7 and CD7 as zeroes. Apply soft thresholding to rest of the coefficients [15] (CD6, CD5, CD4, CD3, CD2, and CD1).
(3) Reconstruct the wavelet using modified coefficients, and same wavelet ‘sym8’ and level ‘7’.

The above three steps are represented in Fig. 3.

Soft Thresholding is calculated using (1), (2) and (3).

$$signal = \begin{cases} signal, & |signal| \le \delta \\ signal - \delta, & |signal| > \delta \end{cases} \tag{1}$$

$$\delta = \sigma * \sqrt{2 * \log_{10} n} \tag{2}$$

$$\sigma = standard\ deviation\ (C) \tag{3}$$

where n is window length and C is Coefficients.

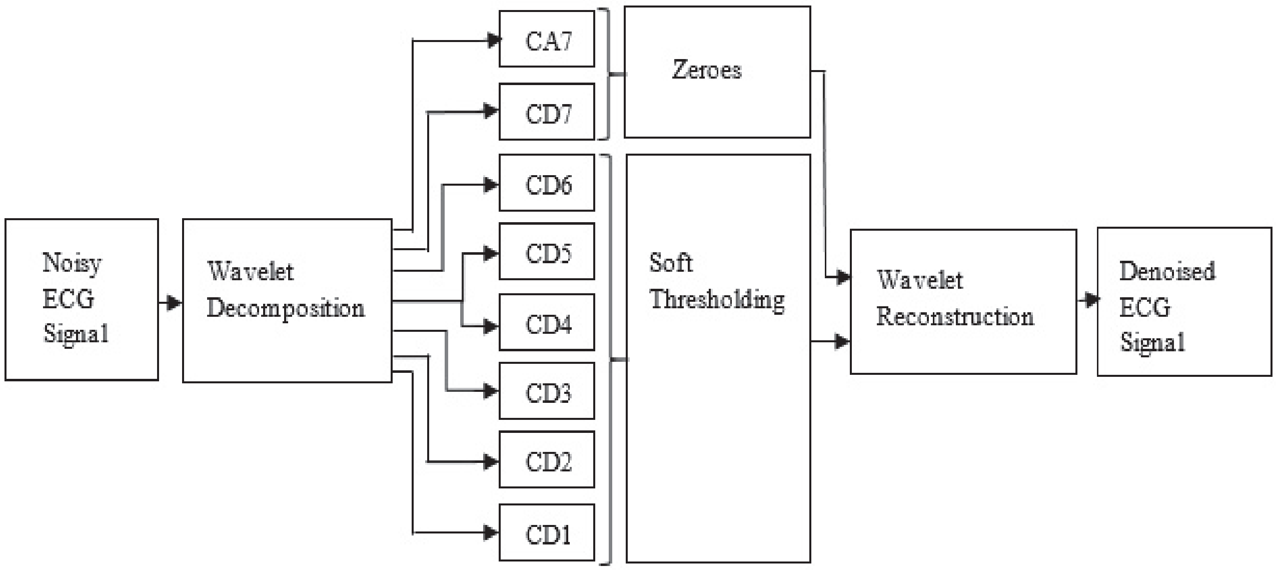

Fig. 3. Denoising of ECG signal using wavelet transform.

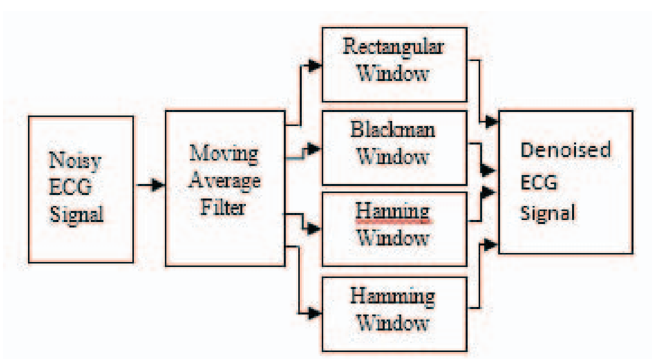

Fig. 4. Denoising of ECG signal using digital filters.

B. Digital Filter

Digital filters are divided into two types, FIR (Finite Impulse Response) and IIR (Infinite Impulse Response). FIR filters include median filter, moving average filter and different Windowing methods. Windowing methods include rectangular, blackman, hanning and hamming window [16]. Fig. 4 shows the block diagram for FIR Filtering technique used. The noisy ECG signal is passed through moving average filter to remove Baseline wander [17]. This filter replaces the first sample in the output with the average of samples taken. The window shifts rightwards to replace each element in this manner. It is given by (4).

$$Y\left[j\right] = \frac{1}{p}\sum\nolimits_{k=0}^{p-1} x(j+k) \tag{4}$$

where p is the window length.

This result is then passed through rectangular, blackman, hanning and hamming windows to remove other types of noises. These windows are described as follows.

- Rectangular window:
  It is the simplest window which replaces all but N values of a data sequence by zeroes. It is given by (5).

$$w\left(n\right) = \begin{cases} 1, & n \le N \\ 0, & n > N. \end{cases} \tag{5}$$

- Blackman window:
  A blackman window of length N is defined by (6).

$$w\left(n\right) = 0.42 - 0.5\cos\left(\frac{2\pi n}{N-1}\right) + 0.8\cos\left(\frac{4\pi n}{N-1}\right)$$
$$0 \le n \le M-1 \tag{6}$$

  where,
  M is $N/2$ for even N and $(N+1)/2$ for odd N.
- Hanning window:
  Equation of hanning window is given by (7).

$$w\left(n\right) = 0.5\left(1 - \cos\left(2\pi\frac{n}{N}\right)\right), \quad 0 \le n \le N \tag{7}$$

  where window length L is given by (8).

$$L = N + 1. \tag{8}$$

- Hamming window:
  Equation of hamming window is given by (9).

$$w\left(n\right) = 0.54 - 0.46\cos\left(2\pi\frac{n}{N}\right), \quad 0 \le n \le N \tag{9}$$

  where window length L is given by (8).

Filter order N is taken as 100 and window length L is 101.

TABLE I
SNR VALUES (IN DB) FOR BLACKMAN WINDOW AND SYM8 WAVELETS.

Record	Blackman window	Sym8
101	56.1981	56.5390
102	58.7234	60.4967
104	52.035	56.0800
105	48.3577	50.2822
106	48.4722	49.5094
107	31.7667	36.9499
108	60.725	67.2200
109	43.3542	45.3900
111	57.0627	58.4472
112	55.0042	59.0674
117	51.2244	58.0902
119	34.9459	40.6822
124	43.7859	47.1008
208	42.1804	46.5196
228	47.3602	52.7608
Average	48.7464	52.3423

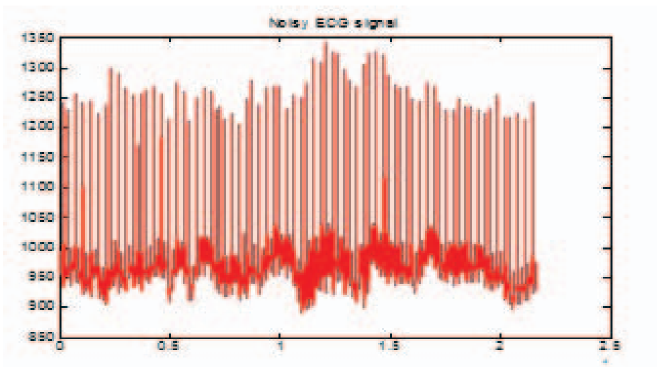

Fig. 5. Raw ECG data of record 101.

IV. RESULTS AND DISCUSSIONS

The proposed algorithm is implemented in MATLAB. The real data is taken from MIT BIH Arrhythmia Database. Digital filers and Wavelet transforms are applied on 15 records as shown in Table I. Fig. 5 shows the raw ECG data of record 101.

A. Wavelet Transformation

Different wavelet transforms such as db6, db3, haar, bior1.3 and sym8 are applied on raw ECG data. The ECG signal is decomposed into 7 levels using the symlet wavelet ‘sym8’. The plot of resulting coefficients are as shown in Fig. 6. Eight coefficients of different lengths are obtained (CA7, CD7, CD6, CD5, CD4, CD3, CD2, and CD1). Coefficients CA7 and CD7 are made zeroes and the rest are subjected to soft thresholding. The signal is then reconstructed using the new coefficients. Result of this technique for record 101 is shown in Fig. 7. It is clearly seen that the baseline drift is completely removed. The SNR obtained proves that other noises are eliminated as well. SNR calculated for different records are shown in Table I. The average SNRs of these wavelet transforms are compared and SNR of sym8 proves to be greater.

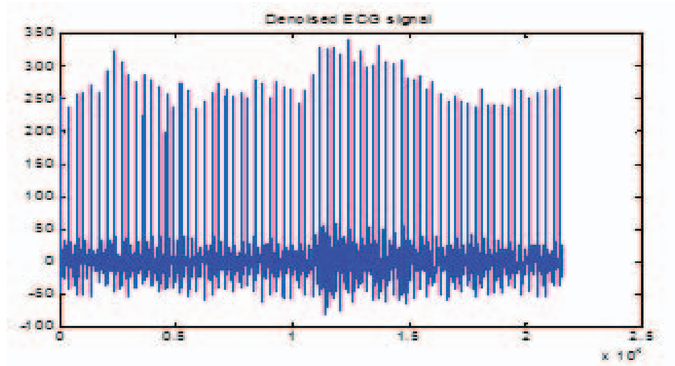

Fig. 6. Denoised signal using wavelet transform.

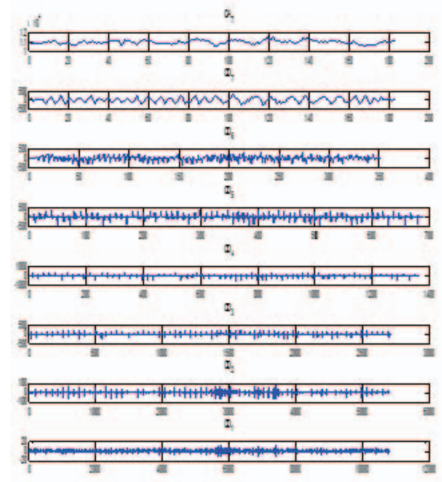

Fig. 7. Coefficients obtained from wavelet decomposition. From top: CA_7, CD_7, CD_6, CD_5, CD_4, CD_3, CD_2, CD_1.

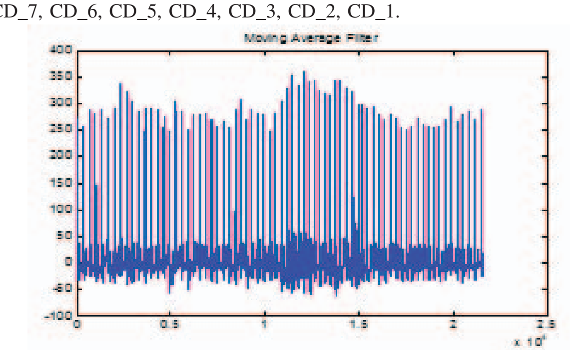

Fig. 8. ECG signal passed through moving average filter.

B. Digital Filters

The raw ECG data is first passed through moving average filter and median filter to eliminate baseline wander. Output of moving average filter is shown in Fig. 8. SNR of moving average filter is seen to be greater. Hence, the output of this filter is passed through different windows such as rectangular, blackman, hanning and hamming. Among these windows, blackman window is seen to provide a better SNR. Output

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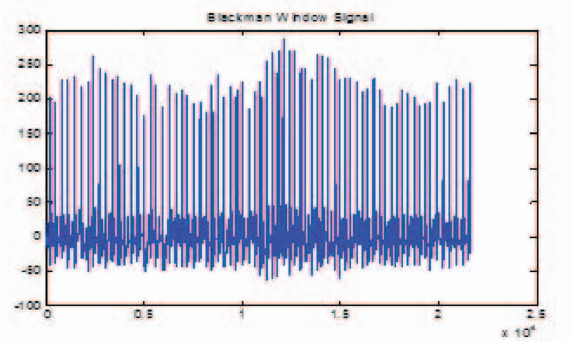

Fig. 9. Denoised signal using blackman window.

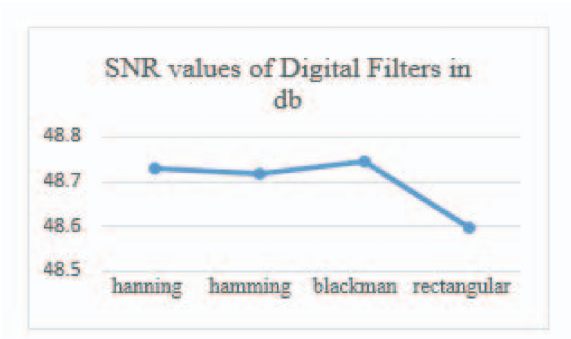

Fig. 10. Comparison of SNR values of digital filters.

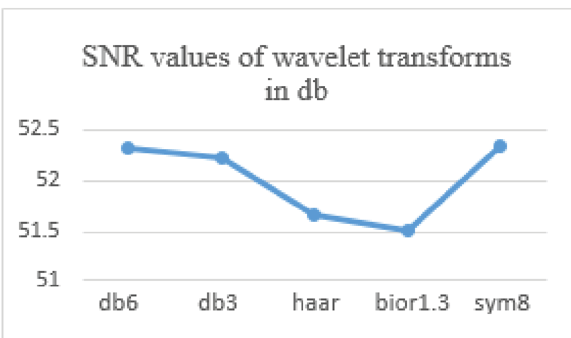

Fig. 11. Comparison of SNR values of wavelet families.

of blackman window is shown in Fig. 9. SNR calculated for different records are shown in Table I.

SNR is calculated using (10).

$$SNR = 20 * \log_{10}\left(mean \frac{(raw\ signal)^2}{(processed\ signal)^2} \right). \quad (10)$$

Comparison of average SNR values of each window in digital filters is shown in Fig. 10. It is clearly seen that blackman window has greater SNR than hanning, hamming and rectangular. Comparison of average SNR values of each family in wavelet transform is shown in Fig. 11. It is evident that sym8 has the highest SNR comparatively.

V. Conclusion

ECG data is denoised using wavelet transform and digital filters. Various wavelet families such as Daubechies, Haar, BiorSplines and Symlet are studied. SNR of each technique is calculated for various records. Wavelet transform using 'sym8' gives better SNR (average SNR of 48.7464) amongst these techniques. Identically, different windowing methods such as rectangular, blackman, hanning and hamming are studied among digital filters. 'Blackman window' is seen to provide a greater SNR (average SNR of 52.3424 dB) in digital filters. The comparison proves that SNR of wavelet transform 'sym8' is greater than that of the digital filter using 'blackman window'. The proposed method is able to remove baseline wander and powerline interference effectively.

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