ECG Signal De-Noising Techniques: A Review

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Abstract— Nowadays for de-noising the cardiac syndrome electrocardiogram (ECG) technique is used which record the result in form of waves or signal by using ECG tool but this includes various artifacts (motion) , noise and baseline wander which becomes very essential for us to extract or remove for better clinical result which helps in treatment of the patient. There are various techniques has been proposed or implemented for de-noising the signal for medical purpose such as wavelet transform, and neural network etc. In this we present the literature study of the previously developed technique and algorithm with their advantages and disadvantages. We also discuss the different performance measuring parameter of electrocardiogram.

Keywords— ECG, Wavelet transform, Neural Network, De-noising, Baseline Wander

INTRODUCTION

Heart disease is the major problem in human being nowadays which is the important part of the body and the cure of this is the major issue. The primary step for the patient of heart disease is the ECG (electrocardiogram). ECG and EKG are one and the same and used interchangeably for taping of the electrical commotion of the heart. "EKG" is from the original term "electrocardiogram," which is introduced by the well-known Dutch physiologist Willem Einthoven in the 1890s and early on 1900s. ECG is based on the English version of the word, "electrocardiogram", and is the version used most frequently today. EKG, conversely, is still regularly used and preferred by some populace, partly for historical causes, perhaps because that is basically the way they learned it, and/or somewhat to circumvent confusion with the analogous sounding EEG (from the brain) and EGG (from the reproductive system). I will typically use "ECG" from here on, with some "EKG" or together, as is usually done by others and in the literature (and you'll need to get used to it).

The heart itself is a multifarious organ and the electrical patterns coming from it can seem exceptionally complex, puzzling, and even overwhelming. ECGs are usually run in a medical/quantifiable environment involving abnormalities and tribulations. Most training and knowledge of ECGs and the associated terminology and jargon engrosses medically-related persons. On the other hand, most of the billions of hearts in the world keep ticking away day in and day out with their everyday standard patterns. Numerous biologists, biology teachers and students, and other people uncover the standard heart and its outputs to be interesting.

We recently switched to standard (clinical type) 12-lead and Holter PC-based units for pre-professional students who will eventually encounter the standard ECG machines as well as other students who might either be just plain interested or else encounter problems with their own hearts and end up getting 12-lead ECGs run on themselves in a clinical environment [2]. The range value for normal resting EKG is show in table.1

Standard ECGs, however, have a fairly steep learning curve, with most of the training and educational material focused on the medical student. It is possible, however, to introduce the subject to virtually anyone who is interested or needs to understand it to whatever degree. The main, typical waves of an ECG are identified as P, Q, R, S, and T (the symbols A, B, C, and X, Y, Z etc. had already been used for other physiologically-related items at the time when the system was first developed). Note: all of the waves do not appear on all recordings and there are also some other waves (with other names) that sometimes show up. The following recording, for example, does not show a "Q" wave, a downward wave just before the R wave, although the position of a Q wave (when present) is shown in fig.1.

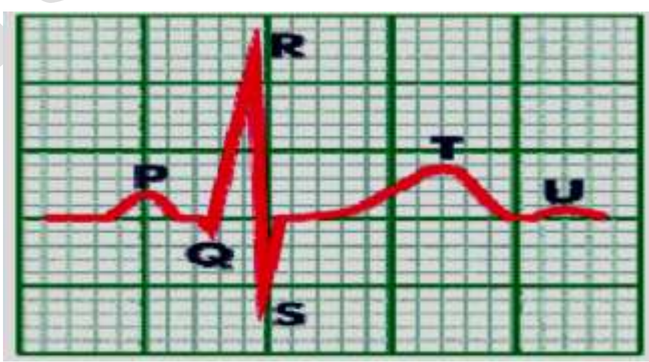

Fig.1 Different Signals of ECG

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The signals obtained from the ECG tools sometime do not appear clear which can be the harmful for the patient. This can be happen due to the injection of different types of noise such as electromyography noise, electrode contact noise and motion artifacts etc. The basicprinciple of it to get clear or visible results from the ECG tool by eliminating such noise and artifacts. To de-noising the signal of ECG a lots of techniques has been proposed or implemented such as DCT, DWT, DFT, Neural network, fuzzy set etc. In this paper we are presenting the literature study about the technique of de-noising the signal with their benefits and limitation. An organization of remaining section of the paper is done as follows: Section second of the paper present the different types of waves & Noise found in ECG. In section third present the literature work for de-noising the signal. In section fourth various techniques and algorithm of ECG signal de-noising is discussed with their advantages and disadvantages and last but not least this section gives overall conclusion about the paper.

ECG WAVES & TYPES OF ARTIFACTS

An ECG is performed by placing electrodes on the skin overlying the heart. As the electrical impulse moves from the atria, which are the top two chambers, to the ventricles down below, the voltage measurement between the electrodes varies, and this produces a graph of how your heart is performing. This provides the person running the test with valuable information based on the intensity of the heart's contractions and the time intervals between those contractions.

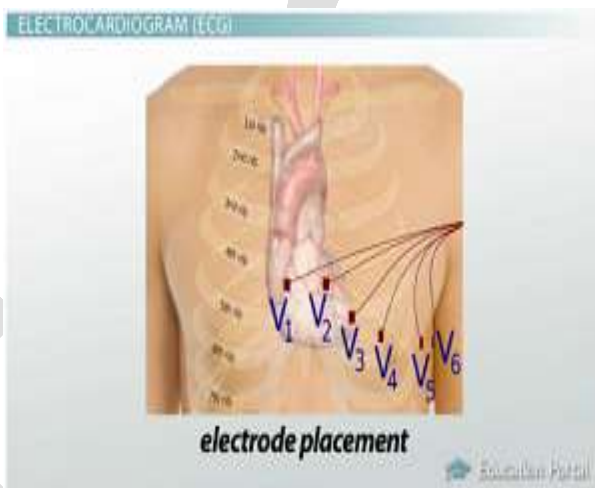

FIG.2 PLACEMENT OF ELECTRODES ON THE CHEST READ THE ELECTRICAL CURRENTS PRODUCED BY THE HEART

Types of Waves in ECG

In a normal ECG, there are three distinct waves: P-wave,QRS-wave and T-wave.

P-Wave

This is the primary wave or P wave [3] of the ECG which issimilar the salad course - it gets to the table hurriedly, and isn't predominantly bad for you. The primary wave moves quicker and arrives first. It's a longitudinal wave, meaning it throbs the ground parallel to the direction of motion - it basically shakes the ground up and down or side to side. In spite of having the highest frequency (the number of vibrations per second), P-waves cause comparatively minor damage.

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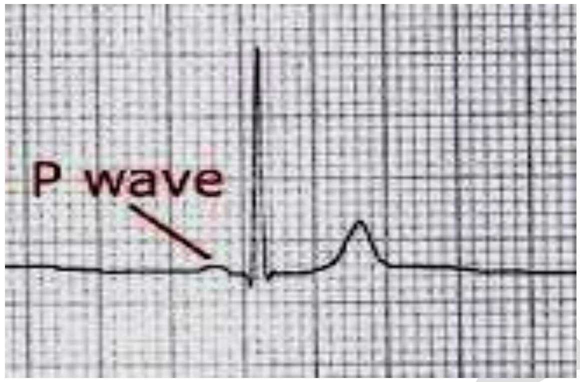

FIG.3 REPRESENTATION OF P WAVE

QRS Complex

A small dip followed by a large spike and another dip. This series is usually considered together, and it's called the QRS wave[3] and this puts the waves in alphabetical order. The QRS wave is sometimes called the QRS complex, and it represents the depolarization of the ventricles. This quickly leads to the contraction of the ventricles and ejection of blood out of the heart and into the large arteries exiting the heart.

FIG.4 REPRESENTATION OF QRS COMPLEX

T-Wave

The T wave is the furthermost labile wave in the ECG [4]. T wave deviations including low-amplitude T waves and abnormally inverted T waves may be the result of many cardiac and non-cardiac conditions. The normal T wave is typically in the similar direction as the QRS except in the right pre-cordial leads (see V2 below). Likewise, the normal T wave is asymmetric with the first half moving more gradually than the second half. In the normal ECG (see below) the T wave is always upright in leads I, II, V3-6, and continually inverted in lead aVR. The other leads are inconstant depending on the direction of the QRS and the age of the patient.

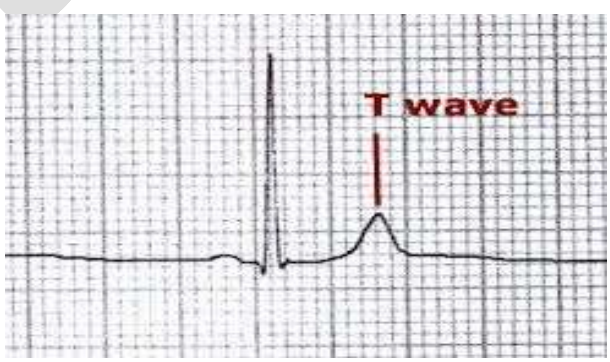

Fig. 4 Representation of T wave

Artifacts in ECG signal

The objectives of acquisition of ECG signal and signal processing system is to acquire the noise free signal. The major sources of noise are: power line interference, muscle contractions, motion artifacts, baseline wandering, high frequency noise in ECG, noise generated by electronics devices, high frequency noise in the ECG and breath, lung or bowel sounds tainting the heart sounds (PCG) and misplaced electrode, etc in which some artifacts is describing below [5]:

Baseline Wandering

In wandering baseline, the isoelectric line variations position. One probable cause is the cables moving during the reading. Patient movement, unclean lead wires/electrodes, loose electrodes, and a diversity of other things can source this as well.

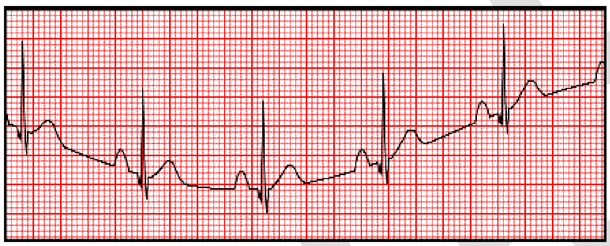

Fig. 5Baseline Wandering Artifacts

Muscle Artifacts

The heart is not the simply thing in the body that produces quantifiable electricity. When your skeletal muscles undergo tremors, the ECG is bombarded with seemingly haphazard activity. The term noise does not denote to sound but rather to electrical interference. Stumpy amplitude muscle tremor noise can imitator the baseline seen in atrial fibrillation. Muscle tremors are frequently a lot more understated than that shown in figure 6.

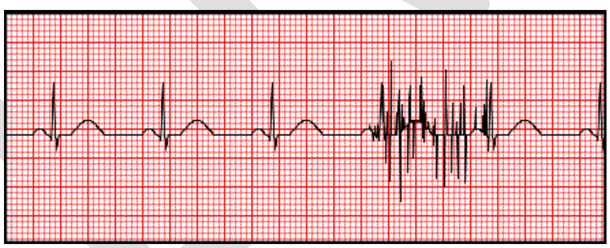

Fig. 6 Muscle Artifacts

Power line Interference

The power line interference is caused by using AC current which pronounces the type of electricity that we get from the wall. In the United States, the electricity "fluctuations direction" 60 times per second (i.e. 60 hertz). (Several places in Europe use 50 Hz AC electricity.) When an ECG machine is ailing grounded or not equipped to filter out this interference, you can get a profuse looking ECG line (as shown in figure 7). If one were to aspect at this ECG line narrowly, he would see 60 up-and-down wave patterns in a given second (25 squares).

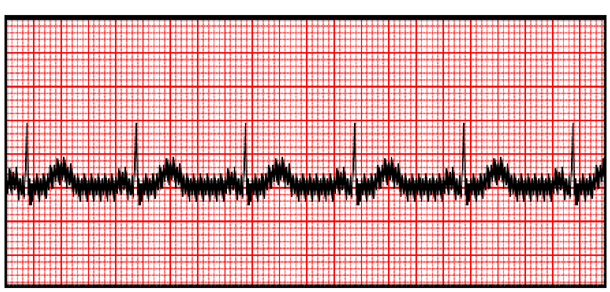

Fig.7 Power line Interference

RELATED WORK

CUOMO ET AL. [6] proposed a novel algorithm for ECG signal de-noising, pertinent in the contest of the real-time health supervising using mobile devices, where the signal processing effectiveness is theaustere requirement. The proposed algorithm is computationally inexpensive because it related to the class of Infinite Impulse Response (IIR) noise diminution algorithms. The major contribution of the proposed system is that confiscate the noise's frequencies exclusive of the implementation of the Fast Fourier Transform that would entail the use of special optimized libraries. It is composed by simply few code lines and thereforesuggests the prospect of implementation on mobile computing devices in an easy way. Additionally, the methodconsents to the local de-noising and therefore a real time visualization of the de-noised signal. The experiments on real datasets have been carried out in order to test the algorithm from correctness and computational point of vision.

KOWARET AL. [7] proposed an effectivealgorithm and its implementation details for de-noising ECG signals along with perfect detection of R peaks andhence the QRS complex of ECG signals using DWT .Main noises under consideration were the wide band EMG noise, PLI noise and low frequency BLD. When ECG signal is de-noised at level three, five and eight using DWT it was observed that at level three EMG, PLI noises areremoved and the signal has P, QRS, T waves and BLD. Inde-noised signal at level five the ECG signal has onlyrelatively slow P, T waves and BLD. The de-noised signalat level eight has only low frequency BLD. Noises suchas EMG, PLI and BLD were removed by subtracting thede-noised signal at level eight from de-noised signal atlevel three. When de-noised signal at level five issubtracted from the de-noised signal at level three, it wasobserved that the resulting signal has only QRS complex. Proposed method efficiently removed the different noisesembedded in the ECG signal and provided R-wavedetection sensitivity of more than 99%.**J**

AGTAP ET AL. [8] implemented the Chebyshev Type II digital filter to surmountdeprivation by improving ECG signal superiority for eminence clinical diagnosis. Dissimilar artifacts are the motive in corruption of the ECG signal. Eliminating noise from the biomedical signal is still challenging and a quickly expanding field with anextensive range of applications in ECG noise reduction. Presented paper deals with the design of Chebyshev Type II filters including low pass, high pass, notch filters. In addition the performance is tested using cascading of filters. For real time application 1711 add on card is used. Dissimilar ECG signals from MIT/BIH arrhythmia database are used for substantiation and compared with real time ECG signals. Finally consequences indicated noise reduction in the ECG.

MITRAET AL. [9] presented algorithm for de-noisingan ECG signal along with precise detection of Rpeaks and hence QRS complex using DWT where db6wavelet was selected as mother wavelet. Decomposition and selective reconstruction is used to de-noise the ECG signal. Thresholding together with slope inversion method isused for detection of QRS complex. Wavelet decomposition of ECG wave up to level 10 usingorthogonal daubechis 6 wavelet generates 10 scales ofapproximation coefficients. The baseline drift is obtainedas the lowest frequency signal and can be easily corrected. The detection of relatively high frequency QRS complexregion has become much easier because of thedecomposition of the signal. The enactment of thesystem is validated using the 12-lead ECG recordingscomposed from physionet PTB diagnostic database givingsensitivity of 99.4 %. The algorithm is evaluatedwith only two class of patient.

SUFI ET AL. [10] formulated a new ECG obfuscation technique for feature extraction and corruption detection. They described a new ECG obfuscation method which uses cross correlation based template matching scheme to differentiate all ECG features followed by corruption of those features with added noises. It is enormously complicated to restructure the obfuscated features without the knowledge of the templates used for feature matching and the noise. Therefore they measured three templates and three noises for P wave, QRS Complex and T wave includes the key which is only 0.4%-0.9% of the original ECG file size. The key allocation amid the authorized doctors is proficient and fast because of its small size. To finish off the experiments carried on with extremely high number of noise combinations the security influence of the presented method was very high.

SAWANTET AL. [11] wavelet de-noising method hasbeen examined to abolish noise from the ECG signal. Diverse thresholding algorithms are investigated boththeoretically and empirically. Ideal ECG signal and noisecorrupted ECG signal are evaluated using MATLAB.Elimination of noise because of muscle activity is intricate tohandle because of the substantial spectral overlieamongthe ECG and muscle noise. Averaging methods have beenprofitably applied to ECG signal for diminution of baselinewander noise. DWT has good capability to decompose the signaland wavelet thresholding is good in removing noise fromdecomposed signal. They applied wavelet transform on theinput vector, thresholded it, inverse transformed it to finallyaccomplish a signal with extremely low EMG noise. The analysis ofthresholding techniques has been compared based on signalto noise ratio. It is observed that "rigrsure" system givesoptimum performance.

TOSHNIWAL ET AL. [12] used the discrete wavelet transform at level 8 was functional to noisy ECG signals and decomposition of these ECG signals was accomplished. Subsequently removal of noise component using thresholdingmethod, decomposed signal is again reconstructed using Inverse discrete wavelet transform (IDWT). Now for de-noising the ECG signal, bi-orthogonal wavelet transform is used and the most effective idea for noise removal process is concluded with this wavelet transform. The simulation has been done in MATLAB toolbox with the help of SIMULINK. The experiments were carried out on MIT-BIH database. Performance analysis was performed by evaluating Mean Square Error (MSE), Signal-to-noise ratio (SNR), Peak Signal-to-noise ratio (PSNR) and visual inspection over the de-noised signal from each algorithm.

NOISE REMOVAL TECHNIQUE OF ECG

Discrete Wavelet Transform (DWT)

The DWT of a signal "x" is calculated by transient itthrough a series of filters i.e. low pass and high pass filters [13, 14]. The inner product of the signal x(t) and the waveletfunction ψm,k provides a set of coefficients XDWT(m,k)for m and k by applying DWT on signal x(t). DWT can beconsidered as one of the multi-rate signal processingsystems that use multiple sampling rates in the processingof discrete time signals. The DWT of a signal x(t) is givenby:

$$X_{DWT_k} = \int_{-\infty}^{\infty} x(t) 2^{m/2} \varphi(2^m t - k) dt$$

Where, ψm,k is the wavelet function. The discrete wavelet transform of a signal is consideredby passing it through a series of filters specifically low passfilter and high pass filter. The coefficients associated withlow pass filter is called approximation coefficients andhigh pass filtered coefficients are called meticulouscoefficients. This decomposition process is carried outuntil the required frequency response is accomplished from thegiven input signal.

Advantages:

- It is superior in conserving the energy in the presence of noise and in reconstructing the original ECG signal with a improved time resolution
- Increase the de-noising performance due to shift invariance property of SWT
- EMD and DWT domain will offer cleaner ECG signals

Disadvantages:

- It is not a shift1-invariant transform
- Lack of direction selectivity.

Empirical Mode Decomposition (EMD)

In this method the noisy ECG signal is decomposed in to different intrinsic mode functions (IMFs) .Then we must find the width of the QRS complex, to preserve it. Therefore sum of first 3 IMFs were taken and their sum is calculated. With the help of this and R point location QRS width is calculated. Then an adaptive window (Tapered cosine window) of size equal to width of the QRS complex is designed to preserve the QRS complex from the noisy IMFs. Mainly lower order IMFs are noisy. Then the signal can be reconstructed by adding these windowed IMFs and the remaining IMFs [15]
An enhancement to this method can be done by using a moving average filter for the smoothening of windowed IMFs. Thus we have to increase the QRS complex quality. Here residue got after empirical mode decomposition is also considered. EMD is an adaptive and data driven technique, thus suitable for any non stationary signal [16].And the de-noised ECG signal is very much similar to the original clean ECG signal. The ECG signal with high frequency Additive white Gaussian noise can be reduced using this technique.

Advantages:

- EMD is especially suitable for analyzing periodic signals like ECG that consists of both high and low frequency components.
- EMD and DWT domain will provide cleaner ECG signals

Disadvantages:

- It is not superior in preserving the energy in the presence of noise and in reconstructing the original ECG signal with a better time resolution

Soft and Hard Thresholding

A kind of signal estimation technique called wavelet thresholding have signal de-noising capabilities. Wavelet shrinkage operation is categorized in to two thresholding methods hard and soft. Performance of thresholding purely depends on the type of thresholding method and the thresholding rule used for the given application. In hard thresholding, the coefficients that are lesser than the threshold are vanished and the others are kept unchanged. However, the soft thresholding makes a continuous distribution of the remaining coefficients centered on zero by scaling them. Soft thresholding [17] is given as follows:

$$\hat{X} = \begin{cases} y, -sgn(y)T & if|y| \geq T \\ 0, & if|y| < T \end{cases}$$

Hard thresholding is given as following:

$$\hat{X} = \begin{cases} y, - & if|y| \geq T \\ 0, & if|y| < T \end{cases}$$

Advantages:

- It has the ability to perform local analysis
- Soft thresholding is best in preserving noise while not in good for edge vise-versa for hard thresholding.

Disadvantages:

- The hard threshold is not continuous at threshold whereas the soft threshold is not differentiable at this value; a pre-requisite for any optimization problem

Adaptive Filtering

An adaptive filter uses iterative computations to minimize the error "in modeling the relationship between two signals in real time" [18]. Fig. 4 shows a basic diagram of an adaptive filter. Here, the input S1 represents the ECG which is observed with the additive noiseS1. The reference signal n is either a pure noise generator or a signal relatedto n. Since the n and S1 are uncorrelated, then

$$E[e^e = E[(n-y)^2] + E[s_1^2]$$

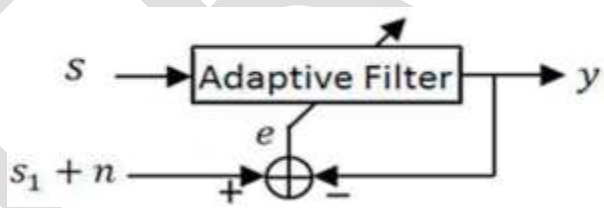

Fig. 8 Adaptive filter Process

Let the N coefficients of the filter at the Kth iteration denoted as W_k = [W_1(k),W_2(k), …..W_n(k)]^T vector X_k = [x(k), x(k-1), …..x(k-N)]^T, the output will be given as in Equation :

$$y(k) = \sum_{i=0}^{N} w_i(k)s(k-i) = W_k^T X_k$$

Advantages:

- Filtering response is fast
- Residual errors are small
- When working in time varying environment it has excellent performance

Disadvantages:

- This method necessitates reference signal (either signal or noise characteristics) information for the operational filtering process.[19]
- When RLS algorithm is used it has high computational complexity and stability problems.

CONCLUSION

The removal or extraction of noise from the biomedical signal is very essential for disease diagnosis which may contaminated by different artifacts like motion, power line, electrode movement during the recording etc. due to which bad result is generating. To de-noising the ECG signal from such artifacts various techniques has been implemented. In this paper, we discuss the literature about various proposed approach and techniques together with their benefits and drawbacks. After analyzing these techniques is it found that some are efficient in de-noising but they and good not for edge and lack of direction selectivity. So in future work need to develop such technique which can overcome all these limitations.

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