ISSN: 2278 – 909X
International Journal of Advanced Research in Electronics and Communication Engineering (IJARECE)
Volume 6, Issue 4, April 2017

Efficient Method For ECG Denoising - Survey

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***Abstract*— Electrocardiogram (ECG) signal processing is a challenging field which has to deal with several issues. ECG plays a vital role in the diagnosis of the heart related problems. During the acquisition of ECG, various interference distorts the signal. Good quality of ECG is needed for the physicians for the identification of physiological and pathological phenomena. ECG is very sensitive in nature and even if small amount of noise interferes with it, the characteristics of signal changes. ECG signal is corrupted by presence of different noises like power line interference (PLI), channel noise, baseline wander, electromyogram (EMG) noise, electrode contact noise, and motion artifacts that may lead to wrong interpretation in diagnosis. Efficient denoising techniques are required for accurate diagnosis of cardiac problems. This paper describes about different methods for ECG denoising.**

***Index Terms*—Electrocardiogram, Denoising, Adaptive Filtering, DWT, EMD, Morphological filtering, SWT.**

I. INTRODUCTION

The electrocardiogram (ECG) is a record of electric potential generated by different actions of heart. It is a biopotential signal that records the heart's electrical potential verses time. ECG recordings obtained by noninvasive technique is a harmless, safe and quick method of cardiovascular diagnosis. The accuracy and content of information extracted from a recording require proper characterization of waveform morphologies, which in turn, require the preservation of phase and amplitude, important clinical features and high attenuation of noise.

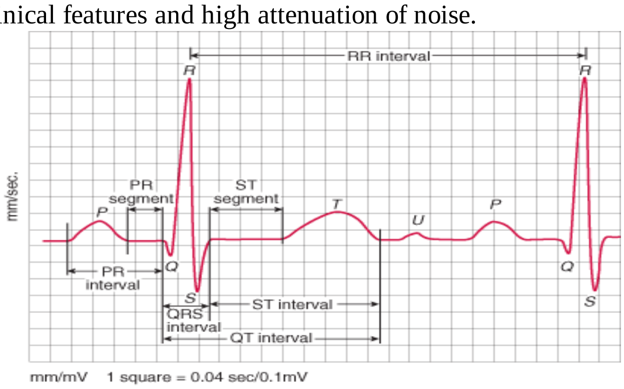

Figure.1 Standard ECG Signal

Manuscript received April, 2017.

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Fig.1 depicts a standard ECG signal. ECG signals are collected using the electrodes. The electrodes are placed on the body's surface. An electrode lead, or patch, is placed on both arm and legs and six leads are placed across the chest wall. The signals generated at the electrodes are recorded [1].

The signal consists of six continuous electromagnetic peaks i.e. P,Q,R,S,T and U. The amplitude and timing of these peaks viz. P,Q,R,S,T and U gives the vital information about heart's working. The P wave reflects the activation of right and left atria. The QRS complex shows depolarization of right and left ventricals. The T wave, which is generated after QRS complex shows ventricular activation [2]. The interval between S wave and the beginning of T wave is called ST segment. In some ECG an extra wave can be seen at the end of T wave, called as U wave [3].

In frequency domain ECG signal varies from 0.05 Hz to 100 Hz whereas the associated amplitude values vary from 0.02 mV and 5 mV. The amplitude values of the human body bioelectric signals are measured in microvolts [4]. The ECG signal gets corrupted due to the presence of different types of artifacts and interference such as PLI, line drift, instrumentation noise generated by electronic and mechanical devices, electrosurgical noise. The goal of ECG denoising is to separate the valid signal components from the noise, so as to create an ECG signal that facilitates an easy and accurate interpretation [5].

The rest of the paper organized as follows : Section II- Noises in the ECG signals. This section describes about the different types of noise interfering with the ECG signals. Section III- ECG denoising methods. This section explains about different denoising methods.

II. NOISES IN ECG SIGNALS:

During the acquisition of ECG signal it may get corrupted by different types of noises. The noises that commonly contaminate signals are: Baseline wander (BW), Electromyographic Interference (EMG), Power line interference (PLI) Electrode contact noise, Motion artifacts, Muscle contraction, Instrumentation noise generated by electronic devices and Electrosurgical noise [6].

1.*BASELINE WANDER*: Baseline wander mainly caused by the movement of the patient, change in the electrode resistance due to perspiration or due to respiration, and is typically below 0.5 Hz [7]. Due the presence of wander, T peak would be higher than R peak which might lead to misinterpretation of detected T peak as R peak. Amplitude variation is 15% of peak to peak ECG amplitude [6].

2.*ELECTROMYOGRAPHY NOISE*: Muscle contractions also known as EMG (electromyography) noise which is produced by patient's movement and is responsible for artefactual milivolt level potentials change in ECG signal. The standard deviation of this type of noise is 10% of peak to peak ECG amplitude with duration of 50ms and the frequency content being dc to 10 KHz [6].

3. *POWERLINE INTERFERENCE*: Electromagnetic fields caused by a power-line (PL), represents a common noise in all bioelectric signals recorded from the body surface such as ECG [8]. Such noise overwhelms signal of interest and makes sensitive or low-voltage measurement impractical [8,9]. This sinusoid noise is characterized by 50-60 Hz depending on the location, for example 50 Hz AC power is used in Europe and Asia, whereas 60 Hz power is used in North America[10].

Amplitude of PLI is half of peak-to-peak ECG amplitude. Common cause for 50 Hz interferences are the following:

1. Stray effect created due to loops in cables
2. Improper grounding of ECG machine or disconnected electrode on patient's body
3. Electromagnetic interference produced from the power lines
4. 50 Hz signal is induced in the input circuit of the ECG machine due to the presence of electrical equipment such as air conditioner, elevators, and X-ray units draw heavy PL current [11].

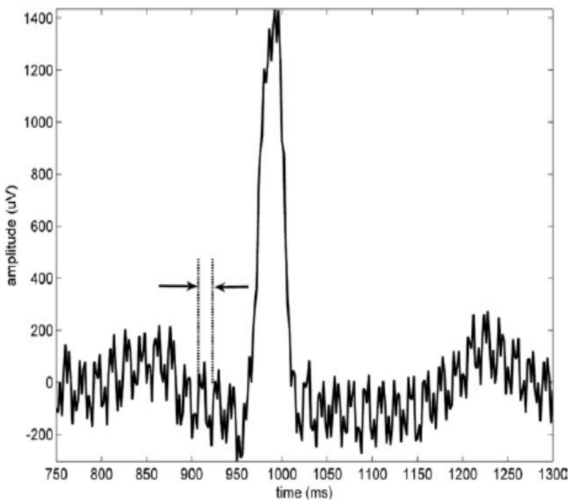

Figure.2 Power Line Interference

4. *ELECTRODE CONTACT POTENTIAL*: The improper contact of electrodes between patient and measuring system creates electrode contact noise. It has duration of 1second and amplitude of which is maximum recorded output of ECG signal with frequency 60 Hz [6].

5. *MOTION ARTIFACTS*: When ECG is recorded, movement of the patient cause changes in the electrode skin impedance. Duration of this noise is 100-500 ms and its amplitude is 500% peak-to-peak ECG amplitude [6].

III. ECG DENOISING METHODS :

The various methods of ECG denoising which results removal of noise present in ECG signals are discussed below:

1. *WAVELET BASED TECHNIQUES*:

Based on wavelet theory for ECG signal denoising, MM Elena, JM Quero, I Borrego [12] introduced the optimal method SGM that uses the global universal threshold modified using standard deviation, to estimate the value and to apply this to complete wavelet co-efficient vector. The algorithm tries to improve the compression ratio of the captured signal by means of an optimal noise threshold in terms of hardware complexity and memory requirements. The quality of recovered signal found to be good for the clinical diagnosis, obtaining a superior compression rate inspite of using instantaneously captured signals. The results obtained shows that the use of the standard deviation in the estimation of the threshold allows a simplification in the complexity of the hardware and resources required in the electronic implementation.

Z. German –Sallo [13] used Discrete Wavelet Transform (DWT) for ECG denoising ECG signal. The time-frequency representation of DWT is performed by repeated filtering of the input signal with a pair of low pass filter (LPF) and high pass filter (HPF). LPF coefficients are called Approximation Co-efficients (CA) and similarly, HPF co-efficients are called as Detailed Co-efficients (CD). This decomposition process is carried out until the required subband achieved from the given signal [5,14].

Manuel Blanco- Velascoa, Binwei Wengh, Kenneth E. Barnerce [15] used Stationary Wavelet Transform (SWT) for ECG denoising. SWT is also called undecimated wavelet transform. LPF and HPF are applied at each stage of SWT decomposition. In the SWT, the output signal is not decimated. Insread, the filters are up sampled at each level. Modification of filters done at each level, by padding them with zeroes. Reconstruction after thresholding signal is reconstructed by using original approximate co-efficients and modified detail co-efficients [14].

Anupama Kumari, Dr.(Mrs.) Lini Mathew [16] compared the performance of DWT and SWT in terms of Signal to Noise ratio (SNR) and Minimum Square Error (MSE), and concluded that SWT gives the superior results compared to DWT because it retains complete information at the time of signal decomposition, but it also uses high order of redundancy.

Donghui Zang in [17] proposed an approach on DWT for baseline wander correction and denoising. In order to reduce the high frequency noise, wavelet shrinkage method using Empirical Bayes posterior median is used. The symmlet wavelet with order 8 and decomposition upto 6 is used as the mother wavelet.

ISSN: 2278 – 909X
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2. *EMPERICAL MODE DECOMPOSITION*:

Empirical Mode Decomposition (EMD) is proposed in [18] method to remove high frequency noise and baseline wander. The signal is decomposed as a sum of several intrinsic mode functions which represents simple oscillatory mode. In order to achieve baseline wander removal, different Intrinsic Mode Functions (IMF) are processed. Partial signal reconstruction causes high frequency denoising. The method is suitable for real noise cases too.

Md. Ashfanoor Kabir et. Al. in [19] proposed a new windowing method in Empirical Mode Decomposition domain. This method preserves the QRS complex information in the first three high frequency intrinsic mode functions. The intrinsic oscillatory modes are identified and then signal is decomposes into IMF. The noisy signal is enhanced in the EMD domain and then transformed into the wavelet domain in which adaptive thresholding scheme is applied to the wavelet co-efficients to preserve the QRS information. In order to reduce the noise that remains after the EMD, an adaptive soft thresholding is performed in DWT domain.

Abdul Qayoom Bhat [20] proposed a new method which combines EMD with wavelet. This method to some extent minimizes the limitation of EMD alone or Wavelet alone. The proposed noise removal method using EMD is as, the different steps are explained below:

Step 1: The ECG signal are taken from MIT/BIH arrhythmia data base. Every file in the database consists of two lead recordings sampled at 360 Hz sampling frequency with 11 bits per sample of resolution. The noisy signal s(t) is obtained as s(t) = x(t) + n(t) where, x(t) is orifinal ECG and n(t) is the noise signal.

Step 2: The noisy ECG is decomposed into IMFs using EMD method.

Step 3: The number of noisy IMFs, n, is obtained using a bank of LPFs.

Step 4: The noisy IMFs are filtered using Wavelet Transform (WT), by selecting a proper threshold.

Step 5: After these IMFs are filtered, the signal is reconstructed by adding the filtered IMFs with noise free IMFs.

From the results obtained, the author concluded that the EMD method used with WT filtering removes the baseline wander noise effectively.

3. MORPHOLOGICAL FILTERING:

Morphological image processing is a collection of non-linear operations related to the shape or morphology of features in an image. Morphological operations can be performed on both binary and gray scale images [4]. Structuring element is a pixel window used to scan the image, it plays critical role in morphological operation since it decides the pixel value should change or not. Morphology operations are dialation, erosion, opening and closing.

Erosion removes small-scale details from a binary image but reduces the size of regions of interest. Boundaries of each region can be found by subtracting the eroded image from the original image.

Dialation is opposite process from erosion. It adds a layer of pixels to both the inner and outer boundries of regions. The size and shape of structuring element influences the results of dialation or erosion. Dialation and erosion are dual operations in that they have opposite effects.

Opening of a data sequence means to slide a structural element along the data sequence from beneath and the result will be the highest point reached by structural element.

Closing of data sequence is done by sliding an inverted or flipped version of the structural element from above and the result will be the lowest point reached by structural element. These two operations are equally important for noise filtering in ECG signal as opening suppresses peaks and closing suppresses pits.

Opening and closing operations are used for baseline correction and noise suppression in conditioning of ECG signal. Some sequences of both the operations are used for conditioning the signal. Different structural elements and different morphological operators are used depending on the characteristics of the ECG signal.[16]

4. ADAPTIVE FILTERING:

Soumyadipta Acharya, Dale H. Mugler, Bruce C. Taylor in [21] proposed a new adaptive filter structure to reduce power line interference from ECGs. It is based on principle of continuously tracking the frequency, amplitude and phase of the noise, using a modified form of Short Time Fourier Transform. This information is used to reconstruct the noise signal, which is then subtracted from the noisy ECG. The proposed method is very effective in tracking relatively large and sudden changes in frequency, phase and amplitude of PLI, without distorting the underlying ECG. It is computationally simple enough for real time implementation. However with ECGs sampled at a higher rate than usual, real time implementation might not be feasible owing to increased computational time.

Yong Lian and Jiang Hong Yu in [22] presented a way to remove the noises using the computational efficient linear phase FIR digital filters. The filter is developed based on the frequency response masking technique [23-25]. The proposed filter requires considerable less delay components compared to a recursive running sum based filter. The filter is suitable for the VLSI implementation of portable ECG device.

Sigi Hussain and Babitha. M. S in [7] implemented adaptive algorithms viz. LMS, NLMS, CSLMS for noise removal from cardiac signals. They concluded that CSLMS based filter shows an improved simulation result compared to LMS and NLMS algorithm. The best least square estimate of original signal is obtained by modification in weight update formula. This algorithm has an ability to remove both stationary and non- stationary noise in an ECG signal at a time. The simulation results confirms that the performance of CSLMS is better than LMS and NLMS in terms of MSE and SNR improvement.

A novel power- line interference (PLI) detection and suppression algorithm is presented by Yue-Der Lin and Yu Hen Hu [26] to preprocess the ECG signals. A distinct feature of this proposed algorithm is its ability to detect the presence of PLI in ECG signal before applying the PLI suppression algorithm. They proposed a PLI detector that employs an optimal linear discriminant analysis (LDA) algorithm to make a decision for the PLI presence. Experimental results indicated that the proposed algorithm can effectively detect and suppress the presence of PLI in ECG without human operator supervision, even in the case of variant power line frequency.

Syed Ateequr Rehman and R. Ranjith Kumar [27] has presented a comparison based on SNR of adaptive filter algorithms LMS, NLMS, DLMS, SRLMS, NSRLMS. Simulation studies showed that the proposed novel algorithms like NLMS and DLMS based adaptive system present better performance compared to existing realization LMS, SRLMS and NSRLMS based procedures in terms of SNR.

Siddappaji and K.L. Sudha [28] presented a performance analysis of their proposed NTVLMS algorithm with other well-known algorithms such as LMS, NLMS, RVSSLMS, NVSSLMS and TVLMS. The computer simulation result showed that the performance of proposed NTVLMS algorithm is better compared to the other algorithms under white Gaussian noise environment.

IV.CONCLUSION

This paper presents a survey which includes the work by different researchers on signal denoising methods. During the acquisition of ECG signal it may get corrupted by different types of noises like Baseline Wander (BW), Electromyographic interference (EMG), Power- Line Interference (PLI), Electrode contact noise, motion artifacts, Muscle contraction. Wavelet based methods found to be good for removing BW noise. Wavelet technique can be used if signal beat to beat variation is high.EMD method has offered a powerful method for non-stationary data analysis. EMD can be used to remove high frequency noise. Adaptive filtering has found to be best suited for removing PLI noise.

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