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RESEARCH ARTICLE

A SURVEY ON ECG SIGNAL DENOISING USING S-TRANSFORM AND SG FILTERING

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Abstract

ECG is the cardiac recording of systematic electrical activity arising from the electro-physiological rhythm of the heart muscle and is a technology to identify the abnormalities in heart. Electrocardiogram (ECG) signal recording is one of the perplexing tasks in the field of biomedical engineering. The ECG signal is very delicate in nature, and even if small noise mixed with original ECG signal the various characteristics of the signal changes. A noise free data is always required for correct medication of cardiac disorders. But, during processing, the signal is contaminated with different types of noise like muscle noise, power line interference (PLI), baseline wandering (BW), EMG noise and motion artifacts (MA). Due to many noise sources, it is necessary that the signal has to be de-noised and presented in a clear waveform. This paper deliberates S transform and Savitzky-Golay filtering techniques used for preprocessing an Electrocardiographic signal.

Introduction:-

Electrocardiography is the method of producing an electrocardiogram. It is a graph representing the electrical voltage and time of the activity of the heart by means of electrodes. An electrocardiogram (ECG) signal processing is an important spectacle to the heart's electrical action. The three main sections of an ECG signal are the P wave, the QRS complex and T wave.

Atrial and ventricular actions are characterized on the ECG as a series of waves: the P wave followed by the QRS complex and the T wave. The first swing is the P wave associated with atrial depolarization and this wave is invisible because of low amplitude. The QRS complex characterizes the depolarization of the ventricles and includes Q wave, R wave and S wave that occurs in rapid succession. The T waverepresents the repolarization of the ventricles. The pact is that the Q wave is always negative, the R wave is the first positive wave of the QRS complex and the S wave is the first negative swerve after an R wave.

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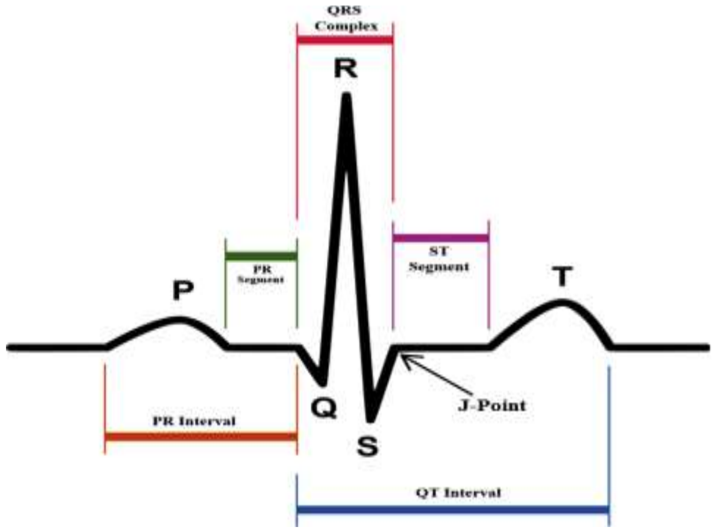

The J-point or Junction point is the point where the QRS complex and the ST segment meet. The J-point is significant because it can be used to diagnose an ST segment elevation myocardial infarction.

The objective of ECG signal processing is to mend the measurement accuracy and reproducibility. Therefore it is necessary that an ECG signal should be presented as clean and clear as possible to provision accurate decisions by physicians and doctors. As an electrical signal, ECG is vulnerable to different kinds of noise. The main sources of this noise are electrical activities of body muscles, baseline shift because of respiration, poor contact of electrodes, and equipment or electronic devices. The goal of ECG signal denoising is to distinct the usable signal components from the noise, so as to generate an ECG signal that eases an accurate interpretation [1]. In this paper, different noises present in ECG signal are discussed and some of the denoising methods are deliberated and studied.

The rest of the paper is organized as follows: Section II gives the review on various noises present in ECG signal, Section III illustrates the techniques used to filter the contaminated ECG signal, Section IV ewith Conclusion and section V ends with References.

A review on noises in ECG signals:
The major sources of noise that usually defile ECG signals are: Baseline wander (BW), Power line interference (PLI), Electromyography noise (EMG), Electrode contact noise, Motion artifacts and Instrumentation noise generated by electrosurgical noise. [2-3].

Baseline Wander:
Baseline wander (BW) is one of the low-frequency artifacts present in electrocardiogram (ECG) signal recordings. This is mainly caused by the body movement of patient, change in the electrode resistance due to sweating or due to respiration. This variation is typically less than 1 Hz [4] and causes problem in detection and analysis of R peak and T peak.

One of the methods to remove BW artifacts is the high-pass filtering or low frequency elimination of ECG signals. However, it is not recommended for baseline wander removal as it can distort the ECG waveform because of variations in the frequency spectrum of the ECG signal. The other method to remove baseline wander is based on empirical mode decomposition (EMD) and mathematical morphology (MM) [6]. In this method, two basic morphological operators like opening and closing are utilized to realize a low-pass filter and this method decomposes a time varying signal into series of intrinsic mode functions. Hilbert vibration decomposition (HVD) has been proposed to eliminate BW [7]. This decomposition method extracts the mono-components of a signal by using its analytic form where the first component corresponds to the highest instantaneous amplitude.

Although the high-pass filter is capable of quashing the baseline wander, the ECG waveform distortion is unavoidable because of the frequency variations of the ECG signal. Thus a many number of advanced suppression algorithms includes linear low-pass filters, nonlinear filters, polynomial interpolation, wavelet filters, and mathematical morphological filters (MMF) are proposed. [7-12]

Powerline Interference:
The power line interference consists of 50/60Hz pickup and harmonics and the amplitude of PLI is nearly half of peak-to-peak ECG amplitude This is mainly caused by Power line Electromagnetic interference, Electromagnetic field by the proximate machines, stray effect of the current fields due to loops in the cable and improper grounding of the ECG machine. The electrical equipment's , like air conditioner, elevators and X-ray units which draw heavy power line current, make 50 Hz signals in the input circuits of the ECG machine.

Electromagnetic fields caused by a power-line (PL), is one of the common noise in all bioelectric signals recorded from the body surface such as ECG [4]. Such noise routs signal of interest and makes low-voltage measurement impractical [4,5]. This sinusoid noise is categorized 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].

Electromyography (EMG) Noise:
A muscle contraction by the movement of patient during recording is known as EMG noise and is responsible for artefactualmilivolt level potentials change in ECG signal. Segments of ECG may be corrupted by surface EMG which causes complications in data processing and analysis. The standard deviation of this type of noise has the frequency content of 10 KHz and is 10% of peak to peak of ECG amplitude with duration of 50ms.

Electrode Contact Potential and Motion Artifacts:
Electrode contact noise generally occurs when there is an improper contact of electrodes between patient and measuring system, which effectively disconnects the measurement system from the subject [4]. This noise has length of 1second and amplitude of maximum recorded output of ECG signal with frequency 60 Hz. When ECG signal is recorded, movement of the patient might cause changes in the electrode skin impedance. The duration of this noise is approximately 100-500ms and its amplitude is 500% peak-to-peak ECG amplitude.

Channel Noise:
Channel noise presents when ECG signal is transmitted through channels of poor channel conditions. It is mainly like white Gaussian noise which contains all frequency components.

Electrosurgical Noise:
Electrosurgical noise is usually generated by other medical equipment present in the patient care environment at frequencies between 100 KHz and 1 MHz .This noise residues roughly for 1 to 10 seconds.

Techniques for ECG Preprocessing:
Most of the ECG signal available in MIT-BIH database are degraded with different artifacts like power line interference, muscle interference, composite noise and so on, on contrary to baseline shift, which is low frequency noise and the power line interference of 50Hz which is of high frequency noise[11]. The R peak detection can be improved by various kinds of transforms as disused below:

S-Transform:
The limitations of frequency domain filtering techniques have inspired the development of alternative techniques, such as time-frequency distribution instead of the Fourier spectrum.

The S-Transform (or Stockwell Transform) is a linear time frequency analysis method. This transform was first derived as the "phase correction" of the continuous wavelet transform [11, 13] and thus it inherits the multi-scale resolution feature from the wavelet transform. But unlike the wavelet transform, the ST has the absolutely referenced phase information, i.e., the phase evidence at any time given by the ST is always oriented to the Fourier phase of the signal at zero time. This absolutely referenced phase guarantees that the time average of the ST spectrum yields the Fourier spectrum of the signal. The ST can be inferred as a modification of the short-timeFourier transform with a frequency-dependent window width. Thus the stockwell transform is derived from both CTFT and by WT.

The Continuous wavelet transform (CWT), $W(\tau,d)$ of a function $h(t)$ is given by,

$$W(\tau, d) = \int_{-\infty}^{\infty} h(t)w(t-\tau, d)dt$$

where, w(t,d) is the replica mother wavelet. The'd' represents the dilation which determines the width of the wavelet and controls the resolution of the signal.

The S transform of a function h(t) is obtained by the specific mother wavelet of CWT multiplied with the phase factor and thus S(τ,f) is given by,

$$S(\tau, f) = e^{i2\pi f\tau}W(\tau, d)f$$

Where the mother wavelet is represented as,

$$w(t, f) = \frac{|f|}{2\pi}e^{-\frac{t^2f^2}{2}}$$

One major limitation of using the ST for practical applications is its intensive computation. For a signal of length N, the full ST requires to compute N^2 ST coefficients and the total computational complexity is $O(N^3)$. This confines its use for large size or higher dimensional signals. This problem was stated by Brown et al. [23] combining parallel and vector computations to provide a 25-fold reduction in computation time and the S-spectrum contains high amount of information redundancy.

Savitzky-Golay Filter:

The SG filter approximates the ECG signal using local least square fitting and has significant performance for data smoothing problems. Savitzky and Golay proposed a method of data smoothing based on local least Squares polynomial approximation.[14] The lowpass filters obtained by this method are widely known as Savitzky-Golay filters. Savitzky and Golay were engrossed in smoothing noisy data obtained from chemical spectrum analyzers, and they demonstrated that least squares smoothing reduces noise while keeping the shape and height of waveform peaks.

They revealed that fitting a polynomial to a set of input samples and then estimating the resulting polynomial at a single point within the approximation interval is equivalent to discrete convolution with a fixed impulse response. The discrete convolution of a moving window is given by,

$$\mathbf{y[n]} = \sum_{\mathbf{m=-M}}^{\mathbf{M}} \mathbf{h(m)x(n-m)}$$

where h[m] is the fixed weighting coefficient. More specifically, to fit a polynomial of degree N within a window of length 2M + 1, the design matrix A

$A = \{A_{nk}\} = n^k$, $-M \leq n \leq M$, $k = 0, 1, ..., N$

Therefore, the coefficients of the fitted polynomial α using least square method can be evaluated by

$\alpha = (A^TA)^{-1}A T x = Hx$

where $x = \{x[-M], ...x[0], ..x[M]\}^T$ is the vector of the original data samples within the moving window and $H = (A^TA)^{-1}A$ is a (N + 1) by (2M + 1) matrix.

Since H is only determined by the order N and the half window width M and is independent from the input data samples in x[n], the corresponding row H_0 for computing α_0 is fixed and considered to be the weighting coefficients of a shift invariant discrete convolution process as,

$H_0 = \{h_{0,-M}, h_{0,-M+1}, ..., h_{0,0}, ..., h_{0,M}\}$.

Thus, the SG filtering is to apply the fixed weighted coefficients determined by the order of fitting polynomial and the width of the moving window to the discrete convolution of the original ECG signal.

From [11], [13-14] the Comparison table for different transforms is shown

S.No	Methods	Sensitivity	Predictivity
1	S-transform	99.2	99.42
2	SG Filtering	99.6	99.7

Conculusion:-

Heart diseases becoming the main reason of death nowadays and the ECG are the most important tool to diagnose the heart problems. But ECG signal is contaminated by many types of noises which affects the diagnosis and gives the coarse information. For a systematic analysis, it is important to pre-process ECG data with less distortion. Many types of filtering techniques were developed to eliminate the noise present in ECG and smoothing. In this paper S transform and SG filtering methods were studied. Using S-Transform the QRS complex detection and the peak detection is exact and accurate and the position of the R-peaks can be detected in both time and frequency axis. The Savitzky-Golay filtering methods used here removes noise and smooths the signal without much loss of information and signal features. The parameters of S-G Filter are the frame size and polynomial degree and whole performance is dependent on these parameters and the effects of change of these parameters are studied.

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