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A Review: Algorithms for Electrocardiogram Signal Enhancement

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Abstract: This paper aims at studying the various techniques and algorithms available in literature for the cancellation of various types of artifacts occurring out of the noise present in the Electrocardiogram (ECG) signal. It further aims at the enhancement of the ECG signal for proper monitoring and diagnosis of the patient. In the process of the transfer of the signal information from the location of the patient to a remote location, certain kind of noise is introduced in the signal that results in the disturbance as well as interference of the signal. Hence, the information cannot be predicted accurately. Thus, it is important to remove the resulting noise and the artifacts in order to enhance the ECG signal for proper treatment of the patient.

Keywords: artifacts, Electrocardiogram (ECG), enhancement, remote location, interference.

I. INTRODUCTION

During the acquisition of ECG signal in clinical environment, it can encounter numerous types of artifacts. Power line interference, muscle artifact, motion artifact, respiration movements, baseline wander and instrumentation noise are the ones of primary interest. As a result, there is degradation in the quality of the signal. The other effects includes frequency resolution, the morphology of ECG signal is strongly affected which provides valuable information about heart diseases or arrhythmias. Hence, it is quite essential to reduce interferences in ECG signal and enhance the reliability as well as accuracy for better diagnosis.

The acquisition of ECG signal can be traced back in 1887 when Waller recorded the first ECG signal by capillary electrometer. An improvement in this method was seen with the introduction of string galvanometer and this was credited to Einthoven. Electronic amplifiers replaced the string-galvanometer that lead to the development of direct writing recorder or paper plotter to get ECG strips.

In modern times, the acquisition of ECG is carried out by the placement of electrodes at standardized locations on the surface of the skin of the patient. It is a non-invasive technique. The cardiac health of human heart can be well predicted from the heart rate and the ECG signal. Cardiac arrhythmia is a result of the rhythm or change in the morphological pattern of the heart. Basically, a disorder in heart rate causes cardiac arrhythmia. By the analysis of the ECG waveform, these arrhythmias can be detected as well as diagnosed. The characteristics of the P-QRS-T-U waveform that is the duration and amplitude of the wave can serve as the basis to diagnose and extract useful information about the nature of the disease.

This can be well illustrated by the figure shown alongside that shows the various segments of the ECG waveform

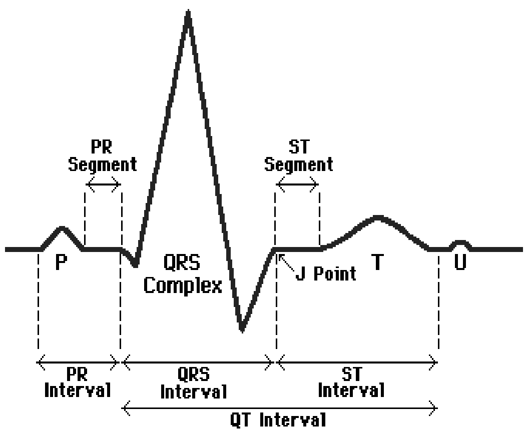

Figure 1: The schematic representation of normal ECG waveform

Section-II describes ECG morphology that defines the terms generally used in medical terminology. Section-III defines the various types of noises and artifacts appearing in the ECG signal. Section-IV discusses the review of various techniques and algorithms for ECG enhancement and removal of noise/artifacts in ECG. Section-V gives the conclusion and future scope of the work done.

II. ECG MORPHOLOGY

The ECG waveform of a normal individual constitutes various segments. These includes the P wave, PR interval, QRS complex, J point, ST interval, T wave, QT interval, U wave and RR interval. These segments provide valuable information about the constitution and working of the heart. The labels of Fig.1 are commonly used in medical terminology.

The various characteristic features of these segments are: *P wave* refers to the depolarization or contraction of the Atria, *QRS complex* relates with the depolarization of the ventricles, *T wave* is formed by the repolarisation of the ventricles, *U wave* results from the repolarisation of the papillary muscles and is a rare phenomenon.

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The time taken by the electrical impulses in travelling from the sinus node and entering the ventricles is represented by the *PR interval*. The period of depolarisation of ventricles represents the *ST interval*. *QT interval* can be better referred to as the addition of QRS and ST intervals and is measured from the QRS complex to the end of the T wave. A prolonged QT interval can result in ventricular tachy-arrhythmias and even sudden death. The *RR interval* is the interval between an R wave and the next R wave. The point where a QRS complex finishes is referred to as *J point*.

The typical features of an ECG signal along with their Amplitude and Duration are shown in table 1.

Table I: Features of ECG Signal

Features	Amplitude	Duration
P wave	0.1-0.2mv	60-80 ms
QRS Complex	1.0-1.2mv	80-120ms
T wave	0.12-0.3mv	120-160ms
U wave	25%of R wave	-
PR interval	-	120-200ms
ST interval	-	80-120ms
QT interval	-	300-430ms
RR interval	-	0.2-1.2s
J point	-	-

III. NOISES AND ARTIFACTS IN ECG

The recorded ECG signals at output are often contaminated by various kinds of noise and artifacts that generally interfere with the quality of the signal and it becomes difficult to extract the necessary information. These noises and artifacts can be characterized as:

3.1 Power Line Interference

This is the basic cause of noise in ECG signals. Power Line Interference (PLI) contains 50/60 Hz (50 Hz-India, 60 Hz-U.S) pickup due to improper grounding. In electro-cardiology inductive coupling is the basic cause of PLI. It is caused by mutual conductance between two conductors. On the flow of current through wires, a magnetic flux is produced which can induce a current in adjacent circuits An impulse or spike at 50/60 Hz harmonics indicates PLI and appears at integral multiples of the fundamental frequency as additional spikes.

3.2 Baseline Wander

This may be caused in chest-lead ECG signals and may result from the enlargement or large movements of the chest through activities like coughing and breathing. It may also result from the movement of arm or leg in case of the acquisition of limb-lead ECG. A bias in instrumentation and amplifiers or variation in temperature can also be a cause of Baseline Wander. It generally ranges below 0.5 Hz.

3.3 Muscle Artifact

This is caused by the contraction of other muscles besides the heart. Due to the muscle contraction in the vicinity of the electrodes, depolarization and repolarisation waves are created that are picked up by the ECG signal resulting in interference. The extent of interference is determined by the amount of contraction better referred to as subject movement in medical terminology and the quality of the probes. The resulting signals are assumed to be zero mean band-limited Gaussian noise. These cause rapid fluctuations generally faster than the ECG signal. Muscle artifact lies in the frequency band of 100-500 Hz.

3.4 Motion Artifact

These are transient baseline changes that occur due to the electrode skin impedance with the motion of the electrode. Large amplitude signals are generated in the waveform as a result. The duration of this artifact is about 100-500ms and the peak amplitude is proportional to the 500% duration of the peak to peak amplitude.

3.5 Instrumentation Noise

The electrical instruments (electrode probes, analog-to-digital converter, signal processors and cables) used in the process of measurement of ECG signal are also the contributors to noise. This type of noise can be reduced by a careful circuit design and the use of better quality equipment. Flicker noise is another contributor to noise in ECG.

IV. REVIEW OF VARIOUS TECHNIQUES AND ALGORITHMS FOR THE CANCELLATION OF NOISE/ARTIFACTS IN ECG

In order to remove these artifacts from the ECG signal, various adaptive and non-adaptive filtering algorithms were proposed. Initially, the use of deterministic functions as the reference inputs in addition to the time variant correlation matrix was proposed and the steady state mean square error (MSE) convergence of the Least Mean Square (LMS) algorithm was analysed [1]. However, the steady state convergence analysis showed that the weight vector is biased, so the adaptive estimate fails to approach the Weiner solution. To overcome this, another strategy for estimating the linear expansion coefficients namely, the Block LMS (BLMS) algorithm came into being.

The BLMS algorithm is the solution of the steepest descent strategy in order to minimise the mean square error that shows to be steady state unbiased and has a lower variance as compared to the LMS algorithm. In BLMS, the coefficient vector is updated only once for every new occurrence being based on the estimation of block gradient as opposed to the LMS algorithm in which the updating takes place for every new sample based on an instantaneous gradient estimate. Hence, BLMS algorithm performs better than LMS algorithm [2].

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A robust Variable Step-Size Normalised LMS (VSS-NLMS) algorithm was proposed to relax the trade-off between the convergence speed of the algorithm and the residual error. In this, the time varying Step Size parameter is changed in such a manner that the change varies in proportion to the negative gradient of the square of the estimation error with respect to the parameter of convergence. Thus, VSS-LMS converges to a lower steady state value and is computationally efficient [3]. An improved version of VSS-LMS was proposed referred to as Robust Variable Step-Size (RVSS). The improved version is less sensitive to the power of the measured noise than VSS-LMS with only a small increase in Computational Complexity [5].

A new rule based rough set decision system used for developing a disease inference engine was introduced [4]. For this engine, image processing techniques are used to develop an offline data acquisition system of paper ECG. Firstly, noise removal process is carried out on the extracted ECG. For the detection of RR interval of ECG waves, a QRS detector is developed. Once, the RR waves are detected, the P and T waves are detected with the use of a syntactic approach. For the accurate analysis of different attributes of P, QRS and T waves, the baseline wander correction and iso-electric level detection are carried out. Then, the knowledge base is developed from a variety of medical books and the feedback of reputed cardiologists in terms of ECG interpretation and necessary time domain features of the ECG signal. Lastly, the rule based rough set decision system is implemented from the time domain features regarding the disease identification. Hence, the complexity of neural networks was avoided.

For the filtering of single channel noisy ECG recordings, a Nonlinear Bayesian Filtering framework came into being. The proposed scheme can effectively track the ECG signal in such conditions where the cardiac signal is overlapped by background noises i.e., in very low Signal to noise ratio (SNR) conditions. This is due to the fact that these filters accurately separate nonlinear and non-stationary signals and in-band noise. Another feature of these filters is the introduction of automatic parameter selection method by which the model parameters can be adapted to a variety of ECGs. It serves as an excellent framework for model based filtering of high resolution ECG signals from noisy environment [6].

Unfortunately, the present technologies lacks in effectively transmitting the data of compressed ECG over text messaging communication. Thus, new ECG compression algorithms for ECG tele-cardiology were proposed that works effectively in transmitting ECG compressed data over wireless links that are constrained in relation with bandwidth. These serve as an efficient tool for cardiovascular abnormality detection from ECG data that was compressed. This not only provides faster diagnosis but also maintains end to end security and the privacy of the patient [9].

A prime issue that still needs to be investigated is the extraction of ECG signals from the background noise contaminated ECG signals. In wireless biotelemetry, there is a need to investigate an important issue that is to reduce the complexity of noise cancellation systems. As the ECG transmission rate increases, there is an increase in the channel impulse response length. Thus, there is an increase in the order of the filter resulting in the increased computation complexity making the real time operation quite difficult. This is clear from the simultaneous shortening of the symbol period. In other words, very less time will be available for carrying out the computations while the computation volume increases. Thus, no effort has been made so far in the direction of reducing the computation complexity while still maintaining the signal quality [7].

In order to cope with the issue of increasing computation complexity, novice algorithms using the signum of either the input signal or the error signal or both were presented and were derived from the LMS algorithm enabling the simple implementation in addition to a significant reduction in the time required for “Multiply and Accumulate” (MAC) operations. The signed algorithm (SA) proves its effectiveness in not only providing simple implementation but also assured convergence and robustness. A comparison of three effective algorithms i.e., LMS, NLMS and SA shows that SA proves to be efficient than LMS in terms of less computation complexity but comparatively inferior convergence rate and steady state error. NLMS on the other hand is better than LMS in terms of superior convergence rate and steady state error but increased computation complexity [7].

In order to cope with the trade-off between the complexity and the convergence issues, sign based normalized adaptive filtering algorithms were proposed. These include the Normalized Signed Least Mean Square (NSLMS) algorithm and Normalized Signed Regressor Least Mean Square (NSRLMS) algorithm. These algorithms can be employed for the effective elimination of different artifacts and noise present in ECG signal. The proposed scheme achieves considerable speed over other conventional LMS based algorithms as it employs simple addition and shift operations (L+1 MACs as compared to NLMS requiring 2L+1 MACs). These are quite suitable for applications that require less computation complexity with large signal to noise ratio. The less computation complexity results from the sign present in the algorithm and the normalized term provides for the good filtering capability [8].

Further various improved algorithms were proposed namely Error Nonlinear Sign Regressor LMS (ENSRLMS), Error Nonlinear Sign LMS (ENSLMS), Error Nonlinear Sign-Sign LMS (ENSSLMS) and Block ENSRLMS (BB ENSRLMS), Block ENSLMS (BB ENSLMS), Block ENSSLMS (BB ENSSLMS) for various artifacts like PLI, Baseline wander, Muscle artifact and Motion artifact in terms of SNR. These algorithms enjoy faster convergence with less computation complexity [10].

V. CONCLUSION

In this paper, a study of the various noise cancellation techniques for the removal of artifacts and ECG signal enhancement techniques available in literature are presented. Out of all the algorithms reviewed, the

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BBENSRLMS performs better than the others in terms of SNR. Certain issues in the process of noise cancellation in ECG still remains and new and improved techniques are required in order to tackle the issues.

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