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A Review on ECG Signal De-noising, QRS Complex, P and T Wave Detection Techniques

Naveen Ku. Dewangan[1], M. K. Kowar[2]

Research Scholar, Dept. of Electronics Engineering, MATS University, Raipur, C.G., India [1]

Director, Bhilai Institute of Technology, Durg, C.G., India [2]

Abstract: Electrocardiogram (ECG), a non-stationary signal, is extensively used as one of the important diagnostic tools for the detection of the health of a heart. Comparison of overall ECG waveform pattern and shape enables doctors to diagnose possible diseases. Currently there is computer based analysis which employs certain signal processing to diagnose a patient based on ECG recording. The Electrocardiogram may contain various artefacts, noise and baseline wander when ECG is recorded which severely limits the utility of the recorded ECG and thus needs to be removed for better clinical evaluation. Signal pre-processing helps us remove contaminants from the ECG signals. The baseline wander and other wideband noise are not suppressed by hardware equipments. Software schemes are more powerful and feasible for offline ECG signal processing. Automatic detection of R peaks in a QRS complex is a fundamental requirement for automatic disease identification. Recently, numerous research and techniques have been developed for processing, detection of QRS complex, P and T waves of ECG signal. All these techniques and algorithms have their advantages and limitations. This proposed paper discusses various techniques and transformations proposed earlier in literature for processing, QRS complex and P and T wave detection of ECG signals and make comparison among them.

Keywords: ECG, de-noising, pre-processing, feature extraction.

I.INTRODUCTION

Cardiac diseases are one of the leading killers all over the world. Thus, early diagnosis and quick treatment of these arrhythmias are the need of the hour. Preliminary assessment is basically done by interpreting electrocardiogram (ECG) which is a two dimensional plot of the electrical activity of the heart. The electrical activity portrays the mechanical activity of the heart as well. Hence, any abnormality in the functioning of the heart is always reflected in the ECG [1]. But growing number of cardiac patients has made it inevitable for the scientists and engineers to develop some automatic detection techniques which could not only assist but also share the load and pressure on the physicians. The Electrocardiogram may contain various artefacts, noise and baseline wander when ECG is recorded which severely limits the utility of the recorded ECG and thus needs to be removed for better clinical evaluation. In recent years, many researches have been made on ECG pre-processing and QRS complex, P and T wave detection techniques but still there is a need for a pre-processing and QRS complex, P and T wave detection techniques which provides accurate and faster result. ECG signal contain large amount of information as well as various noise, therefore it is advantageous to pre-process the signal to reconstruct the original signal. The central goal of ECG signal pre-processing is to remove noise, artefacts and baseline wander. As illustrated in figure 1 there are four major steps to the ECG signal recognition system, namely, the pre-processing of the signal, QRS complex and P and T wave detection, feature extraction and ECG signal classification [2].

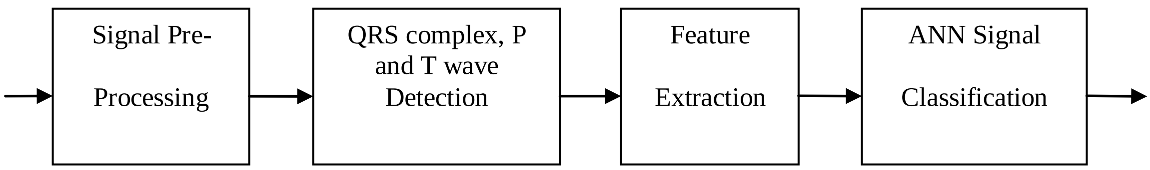

Fig. 1: Steps in ECG signal recognition system

II. LITERATURE SURVEY

The survey is divided into signal pre-processing, QRS complex, P and T wave detection. There are many sources of noise that can degrade the ECG signal. The literature survey begins by reviewing the different noises that may degrade the ECG signals. Then processing, QRS complex, P and T wave detection techniques of ECG signal is reviewed.

Different Noises in ECG Signals

There are many sources of noise in a clinical environment that can degrade the ECG signal. The high frequency noise in an ECG could be due to the instrumentation amplifiers, the recording system, pickup of ambient EM signals by the cables, and so on [3]. The signal may also be corrupted by power-line interference at 50 or 60 Hz and its harmonics [3]. Low-frequency artifacts and base-line

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drift may be caused in chest-lead ECG signals by coughing or breathing with large movement of the chest, or when an arm or leg is moved in the case of limb-lead ECG acquisition [3]. EMG related to coughing, breathing, or squirming may affect the ECG [3].
A brief description of these noises given by different researcher is given below:

Frankiewicz et al. (1985) reported that when an ECG is recorded, it would be contaminated with many kinds of noise, such as the following: (i) Base line wandering, which can be modeled by low pass noise (ii) 50 or 60 Hz power-line interference (iii) Electromyogram (EMG), which is an electric signal caused by the muscle motion during effort test (iv) Motion artefact, which comes from the variation of electrode-skin contact impedance produced by electrode movement during effort test [4].

Haibing et al. (2010) described several kinds of noise in the process of collecting ECG signal mainly including electrical power frequency interference, which is caused by the electric power system. The interference frequency is composed of 50 Hz and its harmonic frequency. Next is electromyography (EMG), which is caused by irregular frequency interference generated by the activity muscle tension, usually including the single fibre muscle noise (500-10 KHz), drive unit signals (5-10 Hz), and surface muscle signal (0.01-500 Hz). The last is the base line drift, which is induced by the undesirable contact of electrode, the changes of skin resistance, breathing and other movement of the body, the frequency range of this interference is 0.05 Hz to 2 Hz and is close to the frequency component Q wave and ST segment of ECG signal [5].

Signal Processing and Filters

The first motivation clearly comprises the process of filtering to remove noise, most methods of signal processing implicitly provide some basis for discriminating desired from undesired signal component.

Thakor and Zhu (1991) proposed several adaptive filter structures for noise cancellation and arrhythmia detection. The adaptive filter essentially minimizes the mean-squared error between a primary input, which is the noisy ECG, and a reference input, which is either noise that is correlated in some way with the noise in the primary input or a signal that is correlated only with ECG in the primary input [6]. Their method allows estimation of the underlying signal in the absence of a priori knowledge of the statistical or spectral properties of the signal and noise. Method is easy to implement on modern microprocessors with numeric capabilities. Limitation of this method is that the reference impulse must be concident with the signal complex. Problem arises from unusual beat-by-beat variation that may prevent complete adaption form taking place.
Donoho (1995) proposed a de-noising method based on taking DWT of a signal, passing this transform through threshold, which removes the coefficients below a certain value, then taking the inverse DWT (IDWT). He proposed threshold to be applied on detail coefficients. The SNR at output up to 8.26 was achieved by this method [7].
Ziarani and Konrad (2002) presented a new method for elimination of power line noise in ECG signals. The proposed method employs, as its main building block, a recently developed signal processing algorithm capable of extracting a specified component of a signal and tracking its variations over time. Design considerations and performance of the proposed method are presented with the aid of computer simulations. Superior performance is observed in terms of varying PLI frequency. The proposed method presents a simple and robust structure which complies with practical constraints involved in the problem such as low computational resources availability and low sampling frequency [8].

Tinati et al. (2006) in the studies used wavelet transform based search algorithm to use the energy of the signal in different scales to isolate baseline wander from the ECG signal. They first removed the artifacts which is the noise that induced in the ECG signals that result from movements of electrodes. The baseline wanders that are considered as an artifact can affect inaccurate data when measuring the ECG parameters. Using the presented algorithm they could eliminate the baseline drifts from the ECG signals without introducing any deformation to the signal and also from losing any clinical information of the signal [9].

Alfaouri and Daqrouq (2008) proposed DWT based method based on decomposition of original and noisy ECG signals into level 5 using 'db4' wavelet. They proposed a new threshold value where optimum threshold was chosen by taking the minimum error between the detailed coefficients of noisy and those of original signal. This method has better performance than Donoho's discrete wavelet thresholding coefficients method. SNR at output up to 9.07 was achieved by this method [10]. Their method can effectively detect and suppress the presence of PLI in ECG without human operator supervision, even in the case of variant power-line frequency.

Zhang and Ge (2008) presented the use of wavelet based adaptive filters. Used level-dependent threshold estimator proposed by Johnstone and Silverman. This method provides better result than Donoho's discrete wavelet thresholding coefficients based method. Their method combines the theory of wavelet analysis and property of adaptation filter. Error between expected output signal and actual output achieved was 0.006324 [11]. Their method have improved extracting precision, speed and very effective in strong noisy environment.

Saritha et al. (2008) in their work first made an attempt to generate ECG waveforms by developing a suitable MATLAB simulator and in the second step, using wavelet transform; the ECG signal was de-noised by removing the corresponding wavelet coefficients at higher scales. They

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concluded that since the application of wavelet transformation in electro cardiology is relatively new field of research, many methodological aspects (Choice of the mother wavelet, values of the scale parameters) of the wavelet technique will require further investigations in order to improve the clinical usefulness of this novel signal processing technique [12].

Lin and Hu (2008) proposed a novel power-line interference (PLI) detection and suppression algorithm to pre-process the ECG signal. A distinct feature of this proposed algorithm is its ability to detect the presence of PLI in the ECG signal before applying the PLI suppression algorithm. No PLI suppression operation would be performed if PLI is not detected. They proposed a PLI detector that employs an optimal linear discriminant analysis (LDA) algorithm to make a decision for the PLI presence. An efficient recursive least-squares (RLS) adaptive notch filter is also developed to serve the purpose of PLI suppression. Experimental results demonstrate superior performance of this proposed algorithm [13]. Their algorithm effectively detect and suppress the presence of PLI in ECG without human operator supervision, even in the case of variant power-line frequency.

Qawasmi and Daqrouq (2010) proposed a new approach to filter the ECG signal from noise is proposed using Wavelet Transform WT. Different ECG signals are used and the method evaluated using MATLAB' software. The method adapts the discrete wavelet transform (DWT) to enhance the (ECG) signal. The presented method showed good results comparing to conventional methods particularly in ECG signal case. This method has better performance than Donoho's discrete wavelet thresholding coefficients and FIR filter [14].

Dewangan and Kowar (2011) proposed method based on DWT to de-noise three kind of noises present in the ECG signals. After the decomposition of the signal using wavelet as the mother wavelet, a selective reconstruction gives the signal without high frequency noise, PLI and baseline drift. A comparative study has been done among different wavelets to find which wavelet offers better SNR, correlation coefficient and computation time [15].

QRS, P and T Wave Detection

The QRS complex is the most striking waveform within the ECG. Since it reflects the electrical activity within the heart during the ventricular contraction, the time of its occurrence as well as its shape provide much information about the current state of the heart. Due to its characteristics shape, it serves as the basis for the automated determination of the heart rate, as an entry point for classification scheme of the cardiac cycle, and it is often used in ECG data compression algorithms. In that sense, QRS detection provides the fundamentals for the almost all automated ECG analysis [16].

Pan and Tompkins (1985) developed a real time QRS detection algorithm and includes band pass filter, differentiator, squaring operation, moving window integration and adaptive thresholding and search procedures. It reliably recognizes QRS complexes based upon digital analyses of slope, amplitude, and width. A special digital band-pass filter reduces false detections caused by the various types of interference present in ECG signals. This filtering permits use of low thresholds, thereby increasing detection sensitivity. The algorithm automatically adjusts thresholds and parameters periodically to adapt to such ECG changes as QRS morphology and heart rate. For the standard 24 h MIT/BIH arrhythmia database, this algorithm correctly detects 99.3 percent of the QRS complexes [17]. Computation time is more if number of ECG beats is more and all samples are processed at once.

Daskalov and Christov (1999) said that automatic detection of QRS onset and offset points with reasonable accuracy has been a difficult task, approached since the first attempts at computerised electrocardiogram interpretation. The problem is additionally complicated by the usual presence of PLI, EMG artefacts and baseline fluctuation in the original signal, especially in multiphase complexes with small *q*, *r*, *r*9, or *s*9 waves. They proposed a pre-processing method guaranteeing accurate preservation of the QRS boundaries, even in the existence of strong PLI or EMG noise [18].

Mahmoodabadi et al. (2005) developed feature extraction system based on multi-resolution wavelet transform using Daubechies wavelets. In the first step, the ECG signal was de-noised by removing the corresponding wavelet coefficients at higher scales. Then QRS complexes are detected and each complex is used to locate the peaks of the individual waves, including onset and offset of the P and T waves which are present in one cardiac cycle. They noticed that P and T waves are more noticeable when keeping details 24-28. At these levels lower frequencies and high frequency ripple of the signal are removed. The extremes of the signal before and after the zero crossings about the R peak which are formerly detected denote P and T peaks. The proposed QRS detector achieved sensitivity of 99.18% ± 2.75 and a positive predictivity of 98%±4.45 over the validation database [19]. Main advantage of their work is that whole signal samples are processed all at once, taking the possibility of each kind of beats into account.

Sarita et al. (2008) used WT for ECG signal de-noising by removing the corresponding wavelet coefficients at higher scales. Then QRS complexes were detected and each complex was used to find the peaks of the individual waves like P and T, and also their deviations. Abnormal signal coefficient's plots are compared with those of the normal ECG. Different abnormalities result in different changes in coefficients [12]. Method is simple and easy to implement. They plotted and showed wavelet coefficients to differentiate normal and abnormal ECG beats.

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Sumathi and Sanavullah (2009) proposed work, based on DWT, where signal is decomposed up to level 4 where QRS complex is dominant at that level of approximation and R-peak is detected by finding the points of highest amplitude. They used adaptive threshold to eliminate PVC beats. Cubic spline, haar and db4 wavelets are compared for R detection [20].

Gautam and Sharma (2010) described a QRS complex detector based on the Dyadic wavelet transform (DyWT) which is robust in comparison with time- varying QRS complex morphology and to noise. They illustrated the performance of the DyWT-based QRS detector by considering problematic ECG signals from Common Standard for Electrocardiography (CSE) database. They also compared and analysed its performance to some of the QRS detectors developed in the past [21]. The main advantages of the DyWT over existing techniques are its robust noise performance and its flexibility in analysing non-stationary ECG data.

Banerjee and Mitra (2010) presented algorithm for de-noising an ECG signal along with accurate detection of R peaks and hence QRS complex using DWT where db6 wavelet was selected as mother wavelet. Decomposition and selective reconstruction is used to de-noise the ECG signal. Thresholding along with slope inversion method is used for detection of QRS complex. Wavelet decomposition of ECG wave up to level 10 using orthogonal daubechis 6 wavelet generates 10 scales of approximation coefficients. The baseline drift is obtained as the lowest frequency signal and can be easily corrected. The detection of relatively high frequency QRS complex region has become much easier because of the decomposition of the signal. The performance of the system is validated using the 12-lead ECG recordings collected from physionet PTB diagnostic database giving sensitivity of 99.4 % [22]. The algorithm is evaluated with only two class of patient.

Narayana and Rao (2011) dealt with the detection of QRS complexes of ECG signals using derivative based/Pan-Tompkins/wavelet transform based algorithms. Different ECG signals from MIT/BIH Arrhythmia data base were used to verify the various algorithms using MATLAB software. Wavelet based algorithm presented in their paper was compared with the AF2 algorithm/Pan-Tompkins algorithms for signal de-noising and detection of QRS complexes meanwhile better results are obtained for ECG signals by the wavelet based algorithm. In the wavelet based algorithm, the ECG signal has been denoised by removing the corresponding wavelet coefficients at higher scales. Then QRS complexes are detected and each complex is used to find the peaks of the individual waves like P and T, and also their deviations. They concluded, since the application of WT in electro cardiology is relatively new field of research, many methodological aspects (Choice of the mother wavelet, values of the scale parameters) of the wavelet technique will require further investigations in order to improve the clinical usefulness of this novel signal processing technique [23].

Sasikala and Wahidabanu (2011) published paper in which they focus on the detection of the P wave and T wave. Determining the position of P and T wave is complicated due to its low amplitude. In this paper they used WT for extracting the features in ECG data, since WT is an effective tool for analysing transient signals. The desired output is the location of the P and T wave. The accuracy of location of features is essential for the performance of other ECG processing such as signal analysis, diagnosis, authentication and identification. The method was tested using MIT-BIH arrhythmia database [24].

Dewangan and Kowar (2013) proposed an effective algorithm and its implementation details for de-noising ECG signals along with accurate detection of R peaks and hence 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 denoised at level three, five and eight using DWT it was observed that at level three EMG, PLI noises are removed and the signal has P, QRS, T waves and BLD. In de-noised signal at level five the ECG signal has only relatively slow P, T waves and BLD. The de-noised signal at level eight has only low frequency BLD. Noises such as EMG, PLI and BLD were removed by subtracting the de-noised signal at level eight from de-noised signal at level three. When de-noised signal at level five is subtracted from the de-noised signal at level three, it was observed that the resulting signal has only QRS complex. Proposed method efficiently removed the different noises embedded in the ECG signal and provided R-wave detection sensitivity of more than 99% [25].

III.CONCLUSION

Biomedical signals are often contaminated by noise from sources such as power line interference and disturbances due to movements of the recording electrodes. In addition, biomedical signals often interfere with one another, e.g., signals due to muscle contractions often contaminated electroencephalograms (EEG`s) and electrocardiograms (ECG`s). Often, the techniques and methods for removing noise and interference are important in the medical practice. The pre-processing of ECG signal plays an important role in feature extraction and classification of ECG signals. The development of accurate and quick methods for automatic ECG pre-processing and QRS complex detection is of major importance. The future enhancement eye on utilizing different technique that provides higher accuracy, faster in pre-processing and QRS complex detection.

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