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Delineation of ECG Characteristics Points using Multi-resolution Wavelet Transform Approach

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Abstract: Accurate delineation of Electrocardiogram (ECG) characteristic's points is primarily required for computerized electrocardiography for diagnosis of heart diseases. The paper presents an algorithm for delineation of ECG characteristics points based on multi-resolution wavelet transform. The features of multi-resolution wavelet transform along with thresholding, window searching with minima/maxima pairs have been used. The measured values of characteristics waves of ECG are validated for European ST-T database records. The result shows 100% accurate detection rate along with onset and offset of P wave, QRS complex & T wave after removal of baseline drift and other artifacts.

I. INTRODUCTION

ECG plays vital role in diagnosis of heart functions for a human being which is consists of P wave, QRS complex, T wave has shown in figure (1). These waves represent the fields induced by specific electric phenomenon on the cardiac surface recorded by placing electrodes on specified position on the chest of human being using standard 12 lead ECG systems. All leads having different ECG signals. atrial depolarization is corresponds to the P wave, ventricular depolarization is due to QRS complex and ventricular repolarisation produces T wave. The shape and ECG polarity of different waves may change which depends on positions and leads used for recording [1]. During recording of ECG, many artifacts incorporated with ECG which makes interpretation and delineation more difficult as these artifacts distorts all segments of ECG. The most common artifacts are baseline wander, power line interference, muscle tremors and EMG noise, so for accurate and automatic delineation of computerized electrocardiography, removal of these artifacts are is essentially required [2]. The accurate delineation is further used in many medical prognosis and classification like heart rate variability, heart rate, tachycardia, bradycardia, tele-cardiology, ECG compression, myocardial ischemia, arrhythmia classification of ectopic beats, etc.

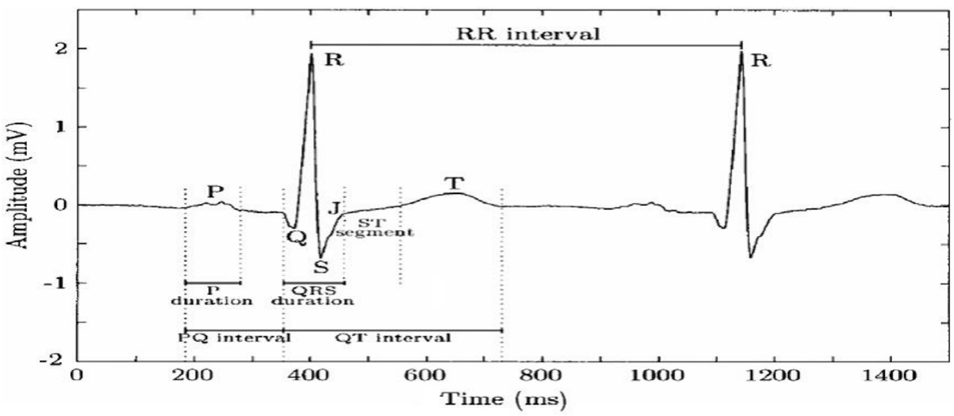

Figure 1: Basic ECG signal and its intervals & segments

A lot of algorithms have been reported for algorithms for the accurate extraction and delineation of characteristics points and features of ECG. Many algorithms are based on mathematical models. A new mathematical based QRS detection method based on continuous wavelet transform is proposed [3-5]. Another approaches includes matched filters [6], second order derivatives [7], ECG slope criteria [8], wavelet transforms [9,10]. For review of QRS detection techniques [11] may be referred. Method based on evolutionary optimization process [12] is having been reported for ECG wave detection. Classification of ECG Beats by neuro-fuzzy networks [13] with feature vector has been presented. A rule mining based method is developed [14], for ischemic beats identification and predictive coding in [15]. Feature extraction and measurement of ECG beats based on statistical classifier has explored in [16]. Independent component analysis (ICA) and neural networks (NN) for classification of ECG beats [17] may be refereed. Overview of ischemia detection techniques which review various methods for delineation of ECG characteristics waves [18] may be studied. So based on reviews, it is concluded the wavelets transform multi-resolution feature is boon for non stationary signals which decompose the non stationary signals used for accurate analysis in the required scales [19]. The size and dimension of the reconstructed signal is about the same as the decomposed signal, which shows wavelet transform very powerful potential in signal processing. Along with minima maxima, thresholding and multi-resolution feature of wavelet transform has become a very popular technique in feature extraction & detection, artifacts removal, signal compression, and image and video processing of biomedical signals.

This paper deals with the accurate and automatic delineation of characteristics points of ECG using multi-resolution wavelet transform and window searching methods implemented in MATLAB. The developed algorithm for the detection of P, QRS and T wave has been validated using European ST-T database record. The paper is organized as follows; the first section introduced the ECG & noises and related methods, second section deals with materials and methods which describes the wavelet transforms, third section describes the implementation of the algorithm, fourth section is having results and discussions and last section includes conclusion and future scope.

II. MATERIALS AND METHODS

Wavelet Transform

ECG signals are having statistical characteristics non-stationary. In particular, so for accurate delineation and analysis of ECG signals should exhibit good resolution in both frequency domains as well as in time domain. Many frequency-time analysis methods available in literature to represent the ECG signals in both time and frequency domains at the same time not found suitable. An only way to analyze the non-stationary ECG signals is the use of wavelet transform, which have the feature of variable time-frequency resolution over the time frequency plane [21]. The wavelet transform decomposes a signal into elementary frequency bands that are localized in both space frequency and scale with time. The high scale is having low frequency component for the transformed signals where as low scale holds high frequency components or provides good time resolution for high frequencies and good frequency resolution at low frequencies. Because of the localization properties of wavelets are good in isolating the singularities and irregular structures in the ECG signals. Another advantage of wavelet transform includes smaller storage space.

The mother wavelet of any signal f(x) which is known as continuous wavelet transforms [20] as expressed by equation (1)

$$W_s f(x) = f(x)\,\Psi(x) = \frac{1}{s}\int f(t)\,\Psi\left(\frac{x-t}{s}\right)dt \quad \text{--(1)}$$

Where s is a scaling factor

$\Psi_s(x) = \frac{1}{s}\Psi(\frac{x}{s})$ is pre dilation of mother wavelet Ψ(x) by s scaling factor.
For $s=2^J$, the particular wavelet transform is known as digital wavelet transform (DWT). The digital wavelet transform of a digital Signal f(n) may find out using mallet algorithm, as shown in equation (2) and equation (3) as follows

$S_2^J f(n) = \Sigma h_k S_2^{J-1} f(n-2^{J-1}k)$--(2)

$W_2^J f(n) = \Sigma g_k W_2^{J-1} f(n-2^{J-1}k)$---(3)

Where S_2^J is Smoothing operator & $S_2^0 f(n) = dn$, where dn is the digital signal to be analyzed, here ECG signal is to be processed and analyzed in this paper. $W_2^J f(n)$is the referred as wavelet transform of the digital Signal f(n).

Σh_k & Σg_k are the coefficients of a low pass filter H(w) & high pass filter G(w) respectively as shown in equation (4).

i.e. $H(w)= \Sigma h_k e^{-jkw}$ & $G(w)= \Sigma g_k e^{-jkw}$ --(4)

Wavelet functions are defined in a space of measureable functions that are absolute and square integral-able i.e.

In such space, they should satisfy following conditions of zero mean and one for square norm. The DWT having advantage of linearity, shift covariance, scale, computational complexity, redundancy as compared to CWT. As per mallat's algorithm, discrete wavelet transform may be implemented as a cascade of identical cells for low pass & high pass FIR filters using an octave filtering bank [21]. The low pass filter's coefficients produced approximation coefficients (CA) and the high pas filter's coefficients produces detailed coefficients (CD). Each consecutively wavelet scale decomposition divides the approximation coefficients in to detail and approximation coefficients and process is performed till the desired frequency response is attained and known as decomposition tree. The various wavelet families are available in MATLAB in wavelet toolbox and each wavelet function is having its own shape. The db families of wavelet transforms are preferred for non stationary ECG signals because of their high number of vanishing moments [19].

III. PROPOSED METHOD

We have used wavelet functions for the removal of noises contaminated during the recording of ECG like baseline wanders, muscle noise and power line interference etc. These noises are necessary to remove for accurate delineation of ECG characteristics points. The flow chart for proposed method has been shown in figure (2). The proposed method has been implemented in wavelet toolbox in MATLAB.

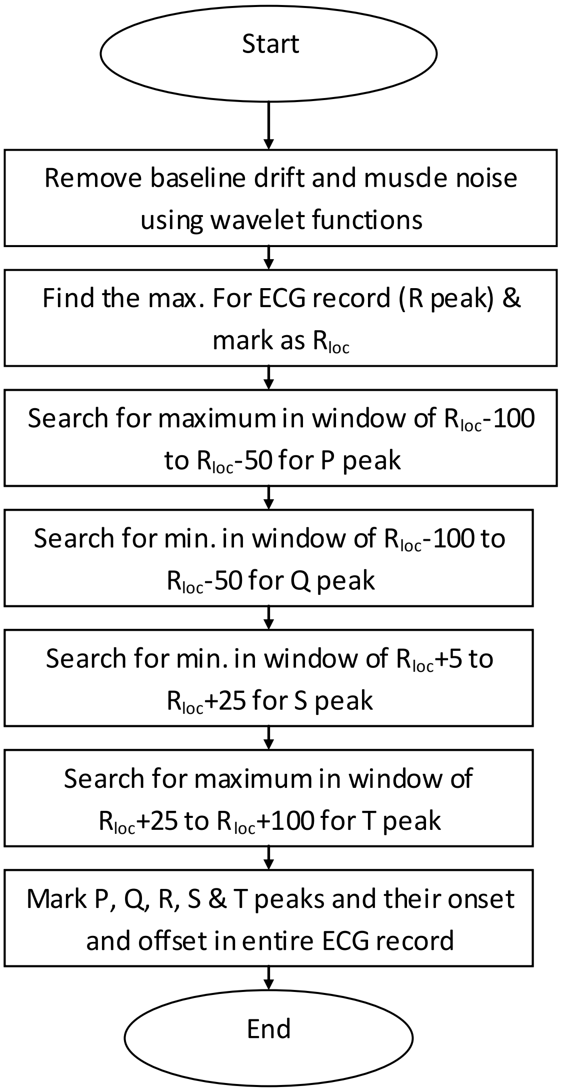

Figure (2), flow chart for delineation of ECG characteristics points' algorithm

A) Denoising of ECG

Removal of artifacts and denoising of the ECG signal for the accurate delineation stage is carried out in following steps, baseline wander correction, high frequency noise removal and then delineation of characteristics points.

a) *Baseline Wanders Removal*

In wandering baseline, the position of iso-electric line changes. One possible cause is the cables moving during the recording of ECG. Dirty lead wires/electrodes, patient movement, loose electrodes are possible causes of this artifact as well. The baseline wandering is of two types viz; drift, which is low frequency noise and another is D.C. components which affects the iso-electrical line of recorded ECG signal. For normalization with respect to iso-electric line, mean of entire ECG has been taken. The baseline wander frequency is of approximately 0.5Hz– 1 Hz. This artifact is eliminated after decomposition of the ECG signal by db4 wavelet transform followed by removal of the lowest frequency component, discarding the approximation coefficients at level of 8^{th} eliminates these artifacts. The result for removal of baseline wandering is shown in figure (3).

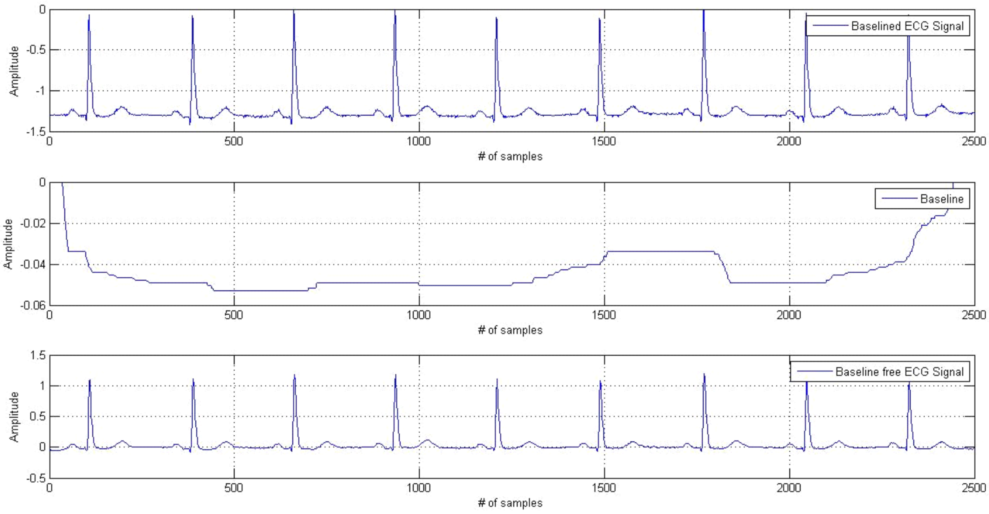

Figure 3: Results for removal of baseline wander

b) *High frequency (muscle tremor) noise removal*

The heart is not the only responsible in the body which produces measurable electricity. When our skeletal muscles undergo tremors, the ECG is contaminated with seemingly random activity. Low amplitude muscle tremor noise can mimic the baseline seen in atrial fibrillation. Muscle tremors are often a lot more subtle than that shown in original ECG. Muscle contraction noise and electrosurgical noise are high frequency noise which completely destroys the ECG segments and the removal of this noise is necessary for an accurate delineation and feature extraction. This noise is lie in between 100 kHz–10 MHz frequency and muscle contraction noise has a frequency of 10 kHz. These two noises are removed by discarding the detail coefficients at lower stages i.e. D1, D2 by using coif3 wavelet. After removal of these noises the ECG signal has the range of 0 to 125 Hz. The result of removal of high frequency (muscle noise) has been shown in figure (4).

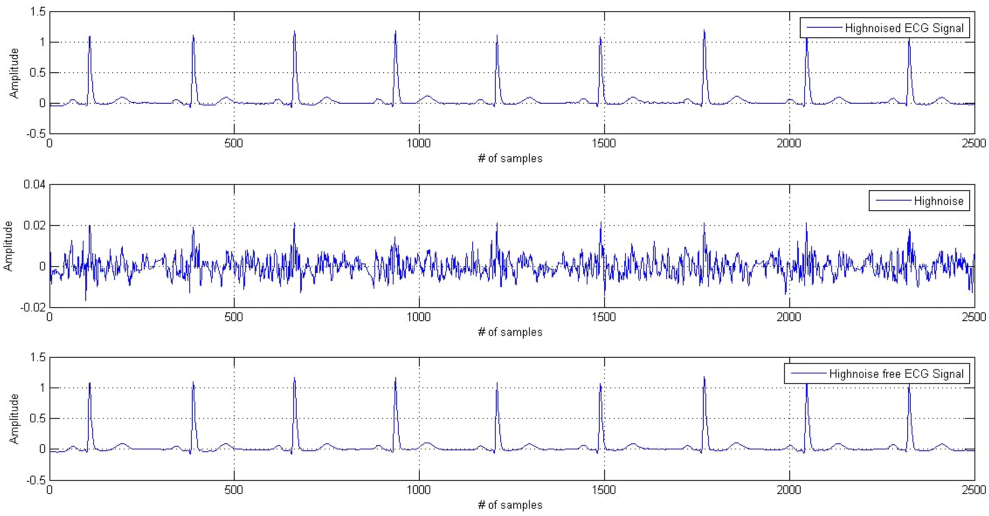

Figure 4: Results for removal of high frequency in ECG

B) Delineation of ECG characteristics points

After removal of artifacts present in the acquired ECG signal, we append the zeros to left and right hand side of the denoised ECG samples in order to overcome the possibility of window crossing the signal boundaries while looking for peak locations. Firstly, searching of maximum bumps was carried out for entire ECG record. A threshold of 0.6 was multiplied with maximum searched value for the R peaks. R peaks was marked as Ramp and Rloc that represents the R peak amplitude and location at the original ECG record. Now detection of other characteristics points or peaks with reference to R peaks was carried out. From R-peak traverse forth and back search for minima and maxima for P, Q, T, S peaks respectively. This is mentioned here that, searching in the window of Rloc-100 to Rloc-50 for maxima represents the P peak. Similarly minima in the window of Rloc-500 to Rloc-10 detects should essentially be the Q peak. With similar logic we have detected the S and T peaks in window of Rloc+10 to Rloc+25 and Rloc+25 to Rloc+100. The mark the peaks of P, QRS and T waves with respect to the location and amplitude for all waves. A flow chart has been presented in figure (2). The detected characteristics waves have been validated for the annotated European ST-T database for different records of ECG of 10 seconds (2500 samples at sampling frequency of 250). The detected characteristics waves are having exact values for time and amplitude as mentioned annotations in European ST-T database. As shown in figure(5), red stars represent R peaks, green star corresponds to P peaks, pink represents to Q waves and cap represents T waves.

Detection of Onset and offset points

After validation of ECG characteristics points taken from European ST-T Database which proves that the R peak is detected accurately in terms of time and amplitude, the P, Q, S and T wave onset and offset points are detected. To detect the onset of P, QRS and T waves, window search has been initiated from P peak towards left (Right) within a window of P: P-20 (P: P+20) to check the slope sign inversion. For each point with in defined window, the slope is computed by three point differentiation formula. Similarly for Qonset and Soffset has been searched in +-20 window samples. Then Tonset and Toffset have been searched using same logic.

IV. RESULTS AND DISCUSSION

The validation for the ST-Segment classification was carried out using European ST-T database. In order to validate, the proposed algorithm was run on different types of ECG records. The advantage of the proposed method is its ability of making the noise reduction, QRS point's detection with the help of wavelet transform only. The sensitivity and positive predictivity achieved from proposed method is better than the other methodologies. The results for detected characteristics waves of ECG records have been shown in table 1. The table shows 100% sensitivity and positive predictivity for 10 records. The sensitivity is defined as below

$$\text{Sensitivity } (S_E) = TP/(TP+FN) \text{ and positive predictivity } P+ = TP/(TP+FP)$$

Where TP denotes true positive, FP denotes false positive & FN denotes false negative detection. An equation (1) & (2) denotes the sensitivity and the positive predictivity. The figure 5 shows results for validated delineation of ECG record (e0105m) as peaks are marked as red, onset points shown by magenta and offset of all waves are marked by blue color.

Sr. No.	ECG record	P wave	QRS wave	T wave	Sensitivity (%)	+ve Predictivity (%)
1	e0103m	1990	1990	1990	100	100
2	e0104m	1974	1974	1974	100	100
3	e0105m	1984	1984	1984	100	100

4	e0106m	1987	1987	1987	100	100
5	e0108m	1982	1982	1982	100	100
7	e0110m	1981	1981	1981	100	100
8	e0111m	1988	1988	1988	100	100
9	e0113m	1992	1992	1992	100	100
10	e0114m	1991	1991	1991	100	100

Table 1: Results for sensitivity and positive predictivity for various European ST-T database ECG records

Detection rate=100% for all waves

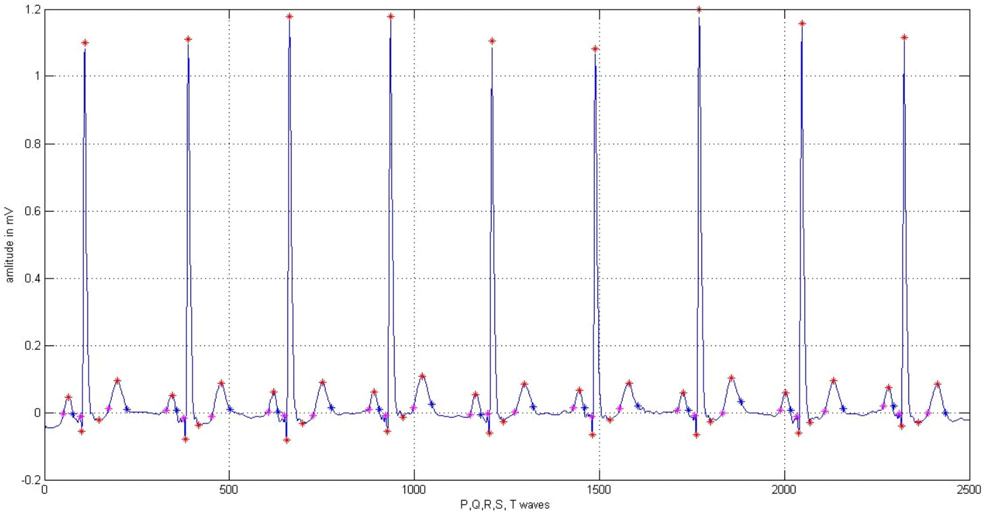

Figure 5: Detected characteristics waves (P, QRS, T) peaks-red, onset-magenta, offset- blue

V. CONCLUSION AND FUTURE SCOPE

We have successfully implemented an algorithm research for delineation of ECG characteristics points followed by removal of artifacts & noises based on multi-resolution feature with window searching feature of wavelet transform. The measured and detected values of characteristics waves of ECG are validated for European ST-T database records. The result shows over 100% accurate detection rate, sensitivity and positive predictivity for all records. The future scope includes the classification of Arrhythmia and heart diseases using the values of intervals with hybrid algorithms like wavelet transform and support vector machines or with genetic algorithms.

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