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Automation of ECG heart beat detection using Morphological filtering and Daubechies wavelet transform

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Abstract: - *The most specific diagnostic test for heart diseases is the Electrocardiogram (ECG). ECG is a graphical representation of the electrical activity of the heart. Analysis of an ECG signal starts with the detection of QRS complex. Detection of QRS complex is a difficult task as the signal is frequently corrupted by powerline interference, baseline drift, motion artifact and electromyographic interference. Therefore, reliable and accurate detection of QRS complex is gaining momentum nowadays.*
A novel QRS detection algorithm based on Mathematical Morphological (MM) filtering and Daubechies wavelet transform has been developed in this work. MM uses its hybrid opening-closing operations for impulsive noise suppression and baseline wander removal. Daubechies3 WT is used for signal analysis since it has a shape similar to the ECG signal. R peak is extracted as a first in the feature extraction since it is having highest amplitude, followed by Q peak and S peak extraction. Heart beat rate was calculated from the R-R peak interval. From the heart rate and R-R peak interval the diagnosis of the cardiac ailments is done.

Keywords: - *Baseline wander, Daubechies wavelet transform, ECG, Mathematical Morphology, QRS complex*

I. INTRODUCTION

Heart diseases are reported to have a major share in human death all over the world. Early diagnoses and medical treatment of heart diseases can prevent sudden death of the patient. The simplest and the most specific diagnostic test for cardiac ailments is the Electrocardiogram (ECG) test. ECG signals are generated by the ECG machine and these signals are analyzed for the presence of any heart abnormalities. Different computational tools and algorithms are being developed for the computer based analysis of the ECG to reduce time consumption and improve the accuracy of the extraction. The ECG heart beat detection involves the issue of extracting the QRS Complex, which is the main parameter that enables patient monitoring and further diagnosis of cardiac ailments.

An ECG signal is a bioelectric signal, which records the heart's electrical activity versus time. It is characterized by a series of waves whose morphology and timing provide information used for diagnosing diseases reflected by disturbances of the electrical activity of the heart. This activity is recorded on graph sheets or some kinds of monitors by placing the electrodes on specific locations of the body of a person. The recorded waves have peaks and valleys and are normally represented by the letters P, Q, R, S, T and U waves. Figure.1 shows a standard ECG waveform.

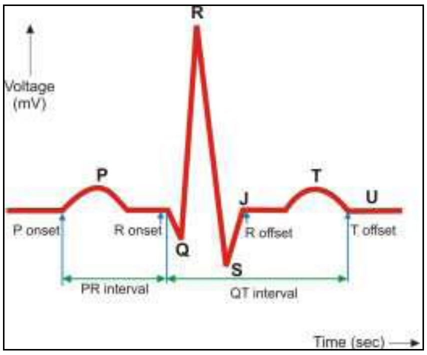

Fig.1 A standard ECG waveform

Computer based heart beat detection has mainly two challenges-Noise and the non-stationary nature of the ECG signal. Some of the noise and interferences affecting the ECG signal are baseline wandering, electromyographic noise, power line interference, motion artifacts. Baseline Wandering is a low frequency activity in the ECG which shifts the isoelectric line position of the signal. Electromyographic noise overlaps with the ECG signal which makes its filtering difficult. Power line interference is caused by data cables carrying

ECG signal from the patients to display devices are influenced by Electromagnetic interference (EMI) from the 50/60 Hz power line noise. This noise degrades the signal quality and affects the tiny features which can be critical for clinical diagnosis and monitoring and signal processing. Motion Artifacts are due to either the patient movement or loss of electrode contact, transient baseline changes caused by alterations in the electrode-skin impedance with electrode motion. Several filtering techniques are developed in the literature using moving average filtering [3], cubic splines [6], Mathematical Morphology [1, 2, 6, 7] and Wavelet transform [3, 4, 6] methods.

ECG being a non-stationary signal, the irregularities may not be periodic and may show up at different intervals. Selection of an efficient technique to analyze these types of signals is an important task. Wavelet transformation has proven to be an effective tool for non-stationary signal analysis [3].Mathematical Morphology is found effective for impulsive noise reduction as it preserves the original shape of the wanted signal [2]. Since physiologists are interested to the shape of ECG signal, it is reasonable to use MM filtering for ECG waveforms. It is essential to develop an algorithm which enables accurate analysis of the ECG signal. A novel algorithm combining Mathematical Morphology and Daubechies wavelet transform for ECG analysis is developed in this work.

II. SYSTEM MODELLING

The proposed algorithm for the ECG analysis consists of three stages- Preprocessing, Transformation and Feature extraction. Block diagram of Heart beat detection is shown in Figure.2. The digitized ECG is obtained from MIT-BIH database. The obtained signal is polluted with noise which is filtered by a sequence of Morphological operations. In the transformation stage, Daubechies wavelet transform is performed on the ECG signal to facilitate heart beat detection. The feature extraction stage is to recognize the positive maximum negative-minimum pair with adequate amplitude in the wavelet coefficients from the previous stage. This is done through zero crossing detectors, peak detectors and decision making circuits. Finally, identification of QRS complex and heart beat is done.

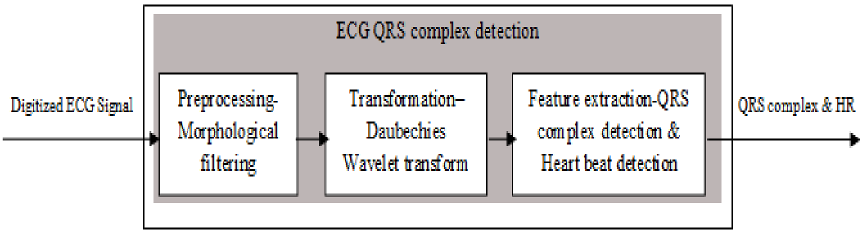

Fig.2. System Architecture of ECG Heart Beat Detection

A. PRE-PROCESSING

It is essential to purify the contaminated ECG signal before any processing is done on the signal. This is done in the Preprocessing stage. In this work, Preprocessing is done based on mathematical morphology, by employing morphological operators for baseline wandering elimination and impulsive noise suppression.

Mathematical Morphology (MM)

A morphological operation is actually the interaction of a set or function representing the object or shape of interest with another set or function of simpler shape called structuring element. The shape of the structuring element determines the shape information of the signal that is extracted under such an operation. The basic morphological operations are erosion 'Θ' and dilation '$\oplus$'. Two other operations are derived from the basic ones, opening '$\circ$' and closing '$\bullet$'. Opening and Closing operations are intuitively simple and mathematically formal way for peak or valley extraction. The operators exploited are shown below:

Dilation: $f \oplus s\,(n) = \max\,(f\,(n-i) + s\,(i))$ Eqn.(1)

Erosion: $f\,\Theta\, s\,(n) = \min\,(f\,(n+i) - s\,(i))$ Eqn.(2)

Opening: $f \circ s = (f\,\Theta s) \oplus s$ Eqn.(3)

Closing: $f \bullet s = (f \oplus s)\,\Theta s$ Eqn.(4)

Here *f* is the signal for filtering and *s* is the structuring element designed for the processing.

Algorithm for Noise suppression and Baseline wander removal

Morphological technique uses a sequence of opening and closing operations on the digitized data for Noise suppression and Baseline wander removal.

Noise Suppression

Opening operation of MM followed by closing operation is done on the digitized data and the reverse operation is also done. Taking the average of the two gives the impulse noise suppressed ECG signal. Subtracting it from initial data will give the impulse noise.

Baseline Wander Removal

For Baseline wander removal, baseline estimation is calculated. To get the baseline estimation, the signal is first opened by a structuring element, s1, for removing peaks in the signal. Then, the resultant waveforms with pits are removed by a closing operation using the other structuring element, s2. The two structuring elements, s1 and s2, are defined as two horizontal line segments of zero amplitude but with different lengths. The result of this compound operation is then an estimate of the baseline drift. The correction of the baseline is then done by subtracting baseline estimation from the original signal.

B.TRANSFORMATION

Transformation technique used here is Wavelet transform (WT). WT is a linear operation that decomposes the signal into a number of scales related to frequency components and analyses each scale with a certain resolution. The WT uses a short time interval for evaluating higher frequencies and a long time interval for lower frequencies. The signal at different frequency bands and at different resolutions is decomposed into 'approximations' and 'details'. Two sets of functions are employed by the WT, the scaling functions (associated with the low pass filter) and the wavelet functions (associated with the high pass filter). The signal is filtered by passing it through successive high pass and low pass filters to obtain versions of the signal in different frequency bands. The fundamental idea behind wavelets is to analyze according to scale. Figure 3 shows wavelet packet decomposition over 3 levels.

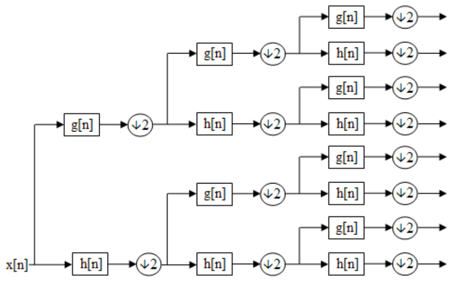

Fig.3. Wavelet Packet decomposition over 3 levels. g[n] is the low-pass approximation coefficients, h[n] is the high-pass detail coefficients

Wavelet Transform of a signal f (t) is defined by:

$$W(a,b) = \int_{-\infty}^{\infty} f(t)\psi_{a,b}(t)dt \qquad \text{Eqn. (5)}$$

$$\psi_{a,b}(t) = \frac{1}{\sqrt{a}}\psi^*\left(\frac{t-b}{a}\right), \qquad \text{Eqn.(6)}$$

Where * denotes complex conjugation and $\psi_{a,b}(t)$ is a window function and is called mother wavelet, '***a***' is a scale factor and '***b***' is a translation factor. Here $\psi^*\left(\frac{t-b}{a}\right)$ is a shifted and scaled version of a mother wavelet which is used as bases for wavelet decomposition of the input signal. One of the key criteria of a good mother wavelet is its ability to fully reconstruct the signal from the wavelet decompositions. Selection of the type of the wavelet depends on the application it is being used. There are different types of wavelets- Harr, Daubechies, Biorthogonal, Coiflets, Symlets, Morlet, Mexican Hat, Meyer etc. and several other Real and Complex wavelets. However, Daubechies (Db3) Wavelet has been found to give details more accurately than others [4]. Moreover, this Wavelet shows similarity with QRS complexes and energy spectrum is concentrated around low frequencies. Therefore, we have chosen Daubechies (Db3) Wavelet for extracting ECG features in our application.

Daubechies WT applied to Preprocessed ECG signal

Daubechies WT is applied to the pre-processed ECG signal. The signal is decomposed into the low-pass approximations (g[n]) and high-pass detail coefficients (h[n]). The high pass detail coefficients are maintained while the low pass approximations are discarded.

C. FEATURE EXTRACTION

R peak Detection and Heart beat rate

For R peak detection, first step is finding the zero-crossing points, zero-derivative points (peaks) from the wavelet transformed signal. Setting negative and positive thresholds to find R peak position is the next step. Peaks of the R waves have the largest amplitude. If two detected R-peak are located less than 0.25 second then discard the corresponding coefficient as it is a pseudo R-peak. If the two detected R-peak are located greater than 0.25 second, then register the coefficient as an R-peak. This is done so, as no subsequent beats happen less than 0.25 second and thus pseudo-beats are also removed. Detection of R peaks is very important because they define the cardiac beats and the exactness of all forthcoming detections is dependent on this. Minimum of the signal within 0.1 second about the R peak is formally detected from the WT coefficients to find the position of Q and S points. The left minimum point from the R peak denotes Q peak and the right minimum point denotes S peak. For heart beat rate calculation, RR interval in seconds is determined from the R-peak positions. Heart beat rate in beats per minute (bpm) is equal to 60/RR interval.

III. RESULTS AND DISCUSSIONS

ECG signal analysis has been done in MATLAB 7.9. Digitized ECG signal was obtained from MIT-BIH database. Various results obtained during the analysis are discussed below.

A. DETECTED FEATURES OF THE ECG DATA-RECORD NO. 100

Details of various findings of the ECG data Record No.100 are given below:

1. The number of R-peaks detected is 11 in 10s duration.
2. Q and S peak positions are found to be approximately .25second left and right of R-peak. Q peak positions are found as an extrema of the signal as the last zero crossing of the differential Daubechies wavelet transformed signal, before an R peak. S peak is accordingly found by the first extrema after an R peak.
3. R-R interval: The R-R intervals in terms of second of the record 100 are varying from minimum 0.79 second to maximum 0.85 second at 10s duration. The normal range of R-R interval is 0.6 to 1 second. So, the R-R interval is on the normal level. The amplitudes of R peak are minimum 0.44 mV to maximum 0.75 mV.
4. Heart rate: 73.940 bit per minute.

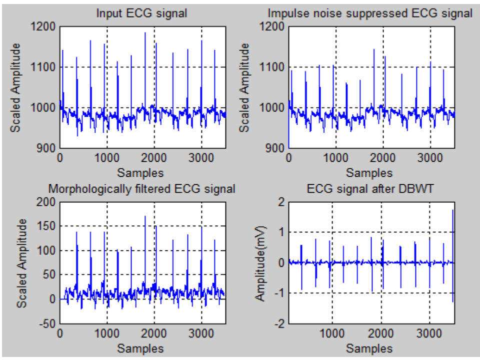

Fig.4.ECG signal at different stages of analysis

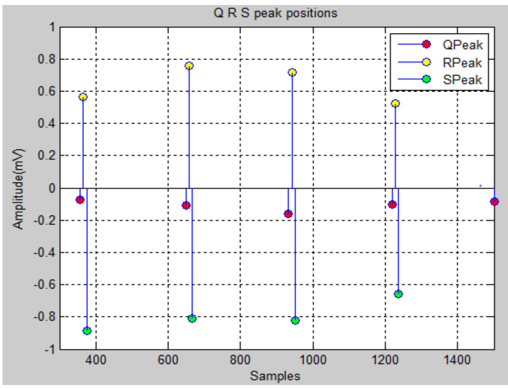

Fig.5.Representation of Q,R,S peak positions

B. DIAGNOSIS OF CARDIAC AILMENT

Diagnosis of Cardiac ailment was done on the basis of heart beat rate calculated from R-R interval of various ECG data. Normal range of R-R interval is 0.6 second to 1 second. Table 1 gives heart beat rate and corresponding Cardiac ailments and Table 2 gives Cardiac Ailments diagnosed for various ECG records.

Table 1. Heart beat rate and corresponding Cardiac ailments

Heart rate (beats per min)	Cardiac ailment
>60 bpm	Bradycardia
60-100 bpm	Normal
150–250 bpm	Tachycardia
250–350 bpm	Flutter
350–500 bpm	Fibrillation

Table 2: Cardiac Ailment diagnosed for various ECG records

Record No.	Average R-R interval(sec)	HR	Cardiac ailment
100	0.811	73.940	Normal
102	0.530	113.301	Tachycardia
103	0.861	69.706	Normal
104	0.465	128.907	Tachycardia
105	0.724	82.854	Normal
106	1.019	58.901	Bradycardia
109	0.134	447.795	Fibrillation
200	0.186	322.045	Flutter

IV. CONCLUSIONS AND FUTURE SCOPE

Heartbeat detection via Mathematical Morphology and Daubechies wavelet transform provide an effective algorithm for automated analysis of ECG. Baseline wander and impulse noise was appreciably removed by MM filtering. Db3 WT was used for signal analysis. From the wavelet coefficient, high pass details were kept for feature extraction discarding the low pass approximations. R peaks were detected first because R peaks has high dominated amplitude and this peak detection is easy than other peaks. On the either negative extremas of the R peak, Q and S peaks was found and extracted. RR interval in seconds was calculated and was used for Heart beat rate calculation. Further cardiac ailments were diagnosed by correlating the extracted features with normal range of these features and decision was taken if patient have any type of abnormality or none. Future work will be on the extraction of more features from the ECG, thereby expanding the detection to wider scale.

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