Implementation of HEFA for Feature Extraction and Classification of ECG signal

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Abstract: Conventionally every ECG signals are developed by ECG acquisition devices and these devices give a printout of the lead outputs. The printouts of ECG signal are analyzed by experts (cardiologists) for checking the abnormality or normality of patient health condition. But in recent years, automatic ECG processing has been of enormous focus to analyze ECG signal. Accurate measurement of ECG signal is a major requirement of quantitative ECG analysis, when the results of ECG signal analysis are to be used for clinical purposes. The accuracy with which parameters of ECG can be measured it mainly depends on the accuracy of the analysis algorithm. This paper presents an improved method of ECG feature extraction approach, based on the discrete wavelet transform (DWT) with Haar function being the mother wavelet. As wavelet transform is good representation for non-stationary signals, like ECG and dividing signal into different bands of frequency. To keep computational complexity low, Haar wavelet is chosen. The proposed algorithm is implemented using Hybrid Feature Extraction Algorithm (HFEA), as it is efficient and low complexity algorithm for ECG feature extraction and classification. The proposed algorithm is also measured instantaneous heart rate using the time interval between two consecutive R-waves.

Keywords: Hybrid Feature Extraction Algorithm (HFEA), Discrete Wavelet Transform (DWT), Electrocardiogram (ECG), Haar Wavelet.

I. Introduction

According to the World Health Organization, cardiovascular diseases (CVDs) are the number one cause of death worldwide [1]. Nowadays cardiac healthcare is the quickest developing area of research, as cardiovascular diseases are one of the leading causes of death in the world. Out of the several medical data sources, ECG is best way to measure and diagnose different abnormalities in functioning of the heart. So, study of Electrocardiogram is fundamental in primary diagnosis, forecast and survival analysis of heart diseases. So it is one of the most essential for life-sustaining research areas in the field of healthcare.

![Figure 1 Typical ECG signal with peaks and intervals identified](image)

The study of the waveform amplitudes and patterns constitutes the basis of the ECG signal analysis. Typical ECG signal with peaks and intervals shown in Figure. 1[2]. Mainly Fourier series and wavelets are used to introduce more accuracy in detection of local features of ECG signals. Wavelet Transform is a new technique used in non invasive ECG analysis providing improved methods for denoising, detection and delineation of cardiac arrhythmia signal. The commonly used wavelet transformation is the Discrete Wavelet Transformation (DWT).

II. Background And Motivation

Different approaches to QRS detection have been proposed during last decades, mainly involving artificial neural networks [3], real time approaches [4], genetic algorithms, and heuristic methods. Many of the detectors can be
divided into two stages: a pre-processor stage and a decision stage to threshold the QRS. The pre-processor stage consists of both linear and nonlinear filtering of the ECG. The main characteristic waves in ECG, viz. the QRS complexes, P and T waves. Detection of these fiducial points is necessary for ECG analysis. There are many difficulties in analysing ECG. i.e. oscillations in the baseline, frequency overlapping, irregular morphology etc. A substantial quantity of research work has been done to the automated detection of the fiducial points of the ECG. Most of these methods are filtering or adaptive thresholding based, which has restriction in real applications. Very less algorithms are beneficial for the detection of all fiducial points such as the onsets and offsets of the P wave, T wave and the QRS complex. The frequency variations is major drawback of filtering-based approach, affects its performance. The frequency variations of QRS complex generally overlaps with noise, leading in both false positive and false negative detections. The primary problems of the thresholding techniques are sensitivity to high noise and low efficiency. Therefore, more advanced signal processing techniques are needed to the growth of new detection schemes with more prominent detection accuracy. For ECG analysis many algorithms are being used, that proves to be very effective. These algorithms show high computing complexity, with effectiveness in ECG analysis, whether it is performed online or offline. Continuous ECG analysis is not suitable, as the energy consumption is highly dependent on the computational complexity of the algorithmic process. Thus algorithm with low complexity is necessary. The main task is to automatically detect ECG fiducial points like QRS onset and offset, P and T waves. The objective of this paper is to implement low complexity algorithm exploiting the advantage of discrete wavelet transform with Haar being mother wavelet. Further objective is to make ECG signal classification and heart rate measurement of ECG signal based on feature extraction.

III. Methodology

An ECG feature extraction method using Discrete Wavelet Transform (DWT) is proposed and is used to extract the information from the ECG input data and to perform classification. The proposed implementation model consists of four blocks, as shown in Figure 2 Below:

**Figure 2 ECG wave Feature Extraction Model**

The raw ECG wave is read from ECG Database as an input signal for features extraction. The ECG signal is divided into cardiac cycles, and detection of the intervals in each cycle is done. Features such as the QRS amplitude, R-R intervals and wave slope of ECG signal can be used as feature to create the mapping structure. The selection of appropriate wavelet is done before starting the detection procedure. It mainly depends upon the what type of signal to be analyzed. Wavelet having similar look to the signal being analyzed is one of the key criteria for selection of wavelet, due to its ability to fully reconstruct the signal from the wavelet without any pre-filtering. The Wavelet Transform (WT) is designed to solve the problem of non-stationary ECG signals. It is designed by generating function called the mother wavelet, by translation and dilation operations. The main advantage of the WT is that it becomes broad at low frequencies and narrow at high frequencies. Thus it gives an optimal time-frequency resolution in all frequency ranges. ECG fiducial points P, Q, R, S, T is extracted using threshold and more accurate analysis by using TDM. After detecting peaks, using standard deviation ECG signal is classified as normal or abnormal ECG.

**A. Block Diagram**

System block diagram is as shown in Figure 3. Before extracting ECG feature, de-noise the ECG signals for better feature extraction and to increase the system efficiency. By using DWT, frequency domain filtering is implicitly performed, making the system robust and allowing the direct application over raw ECG signals. DWT may also be considered as decomposition by wavelet filter banks. The DWT decomposes signal into the detail coefficients (high-pass) and approximation coefficients (low-pass). DWT application on the signal at multi-resolution gives decomposition of signals at successive frequency bands. Baseline noise is necessary to remove from ECG signal.
After the noise elimination from ECG signal, R peak is identified. Specific details of the signal are selected. R peak is the largest amplitude point which is greater than threshold points is located in the wave. Those maxima points are stored which denotes R peak locations. A process of removing the baseline drift of a signal is called as de-trending and removing the noise of a signal is called as de-noising. The proposed algorithm preprocess and to extract the features from ECG signal automatically by using Discrete Wavelet Transformation (DWT). The developed algorithm is implemented using MATLAB. Discrete Wavelet transform with Haar being mother wavelet decomposes original ECG signal into approximation coefficient up to 5 levels. At level 5 the signal becomes noise free. Detection of peaks P, Q, R, S, T are calculated from level 5. Heart rate is calculated using time difference between two consecutive R peaks. After finding PR and ST peaks using standard deviation and mean, the ECG is classified as normal and abnormal.

IV. Pseudocode Of Algorithm

The main aim is to formulate low complexity algorithm for analysis of ECG signal. Wavelets are mathematical functions that are local in time and frequency. A Wavelet Transformation gives multi resolution technique i.e. Different frequencies are examined with different resolutions. At high frequencies, it imparts good time resolution and poor frequency resolution and at low frequencies. The Wavelet Transform is a new anticipating technique used in non invasive ECG analysis providing improved methods for denoising, detection and delineation of cardiac arrhythmia signal.

A. Discrete Wavelet Transform

DWT transforms discrete time signal into discrete wavelet representation. The DWT of a signal is calculated by passing it through a series of filters, low pass to analyze low frequencies and high-pass to analyze high frequencies. The DWT decomposed signal into the detail coefficients (high-pass) and approximation coefficients (low-pass). Signal decomposition can mathematically be expressed as follows:

\[ y_{hi}[k] = \sum x[n].g[2k - n] \]  
\[ y_{lo}[k] = \sum x[n].h[2k - n] \]  

The decomposition has half the frequency band of the input so the frequency resolution has been doubled. As DWT output makes two times coefficients of original signal then it should be down sampled as shown in Figure 4.
The Discrete Wavelet Transform of a signal can be calculated by passing the signal through the low pass and high pass filters as shown in Figure 5. This algorithm is called Mallat algorithm. The decomposition is repeated to further increase the frequency resolution and the approximation coefficients are decomposed into high and low pass filters and then down-sampled. The signal is decomposed into low and high frequencies. Frequency domain representation is shown in Figure 6.

Haar wavelet is one of the simplest wavelet transform function. Haar wavelet and its corresponding scaling function is given in the Figure 7.

As frequency and time domain analysis are applying on PQRST complex, resulting algorithm is the hybrid feature extraction algorithm (HFEA). DWT decomposition on PQRST complex performs analysis in five dyadic space scales $(2^1 \cdots 2^5 \cdots)$ as shown in Figure 8. $2^5$ scale approximation coefficients are used for the extraction of QRS and P/T wave’s parameters as this scale gives noiseless signal. HFEA algorithm, based on the combination of wavelet transforms analysis and time-domain morphology principles.

**B. Pseudocode**

1. Initialize
2. Consider a PQRST complex
3. Apply HAAR DWT
4. $[c,l]=	ext{wavedec}(s,5,	ext{'haar'});$  
5. Calculate DWT Approximation coefficients
6. Choose CA_5 scale of approximation coefficients
7. Detection of P peak
8. Choose $m_1=\max(y_1)-\max(y_1) \times 60$
9. Using R location and R amplitude to find other peaks.
10. $a=\text{Rloc}(i,j)\pm X:R\text{loc}(i,j)\pm Y$
11. Take Standard deviation and mean of PR and ST peaks to classify ECG Wave
12. Time difference between R peaks gives Heart rate.

**V. Experimentation Results**

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A. Receiver Operating Characteristic (ROC) Analysis

The Receiver Operating Characteristic (ROC) analysis comes from statistical decision theory and was originally used during World War II for the analysis of radar images. ROC analysis is commonly used to evaluate medical tests and, in order to get an ROC it is very important to distinguish between disorder and diagnosis. The diagnosis of the disorder used to evaluate a medical test must be clinically valid. In general, four possible decisions and two types of errors are made when comparing result with a diagnosis as shown in Table I.

<table>
<thead>
<tr>
<th>Actual ECG Wave</th>
<th>(Diagnosis as)</th>
<th>Test Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abnormal ECG</td>
<td>Abnormal ECG</td>
<td>TP (True Positive)</td>
</tr>
<tr>
<td>Abnormal ECG</td>
<td>Normal ECG</td>
<td>FN (False Negative)</td>
</tr>
<tr>
<td>Normal ECG</td>
<td>Abnormal ECG</td>
<td>FP (False Positive)</td>
</tr>
<tr>
<td>Normal ECG</td>
<td>Normal ECG</td>
<td>TN (True Negative)</td>
</tr>
</tbody>
</table>

It is important to make out between disorder and diagnosis. Most medical tests are compared to the diagnosis of the disorder and the measure is how well the result of the test corresponds to the diagnosis made. First step to conduct medical test is to collect a sample group of patients, then diagnose and test the sampled data.

B. Calculate Efficiency of System

Table II.: Relations between the measurement probabilities of the outcome, prevalence and level of a test defined in the text.

<table>
<thead>
<tr>
<th>#Diagnosis</th>
<th>#Test result</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Positive</td>
</tr>
<tr>
<td>Positive</td>
<td>TP</td>
</tr>
<tr>
<td>Negative</td>
<td>FP</td>
</tr>
<tr>
<td>Q</td>
<td>Q’</td>
</tr>
</tbody>
</table>

Let “pi” be the probability of a positive diagnosis
“qi” be patient of a positive test.
P = mean (pi) and Q = mean (qi)
Sensitivity SE, probability of having a positive test among the patients who have a positive diagnosis:
SE = TP/P
Specificity SP, is the probability of having a negative test among the patients who have negative diagnosis:
SP = TN/P
The test result is used to calculate different measurements of the quality of the test. The efficiency of system is calculated using the following formula:
Efficiency = TP+TN/(TP+ FP +TN +FN)*100

VI. Conclusion and Future Scope
In this paper, HFEA - based on the combination of DWT analysis for extracting the ECG fiducial points as P, Q, R, S, and T. ECG classification as normal and abnormal and Heart rate measurement is proposed. The use of DWT with the Haar function as the basis allows for a significant reduction in the computational complexity compared to other WT-based approaches. Hence overall energy consumption is low. Due to inherent characteristics, noise induced in clinical environment is automatically eliminated. Experiments carried out on ECG signals from publicly available databases, covering both standard 12-lead (PTBDB) and ambulatory (QTDDB) recordings, the HFEA results are above 90% accuracy. The application area is considered remote cardiovascular monitoring system. The ECG feature extraction using proposed wavelet method acts substantial than other conventional system to find the proper detection of small abnormalities of the ECG signal. A MATLAB graphical user interface (GUI) is created for this implementation and to display the results.
As future work, the algorithm is extended to find particular cardiac diseases when result displayed as abnormal ECG. The algorithm has to test online ECG signals. The proposed method can be extended to larger numbers of ECG signals and with increased accuracy of the system.

VII. References
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