Automated Detection of QRS Complex in ECG Signal using Wavelet Transform

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Summary
Heart failure is number one cause of mortality surpassing other diseases. The percentage of people having heart disease has increased from 1-2% to 3-5% in rural India and from 2-3 % to 10-11% percent in India alone i.e. 300% over the past 30 years. The number of risk factors related to heart diseases like high blood pressure, high cholesterol and physical inactivity. The morphology and rhythm of ECG signal contains vital information about the status of cardiac health. The presence or absence of P-wave, QRS complexes, T-wave and duration and amplitude of these waveforms depict the type of abnormalities present in the signal. This paper presents timely and accurate detection of QRS complexes present in the ECG signal.

Key words:
CWT, Denoising, ECG signal, Wavelets, Wavelet coefficients.

1. Introduction
Signals play important role in the field of Medical, Electrical, Electronic and Communication Engineering. The signals related to medical are known as biomedical signals such as ECG, EEG and EMG and contain lots of information. The biomedical signals can be classified with regard to their source, application or in terms of the signal characteristics. These signals can be considered to be continuous or discrete. Continuous signals include temperature, pressure and chemical concentration, while discrete signals include electrical impulses generated by individual nerve cells. ECG signal is non-invasive and non-stationary in nature recorded by placing electrode on different locations on body surface.
P wave is generated due to electrical potential generated by atrial depolarization. The propagation of the SA action potential through atria result in contraction of the atria. The magnitude of P wave is normally low (50-100µv) and 100 msec.
QRS Complex is generated when the ventricles depolarize before contraction or when the depolarization wave spreads through the ventricle. Therefore, both the P wave and components of QRS complex are depolarization wave.
Q - Wave is initial negative deflection resulting from ventricular depolarization.
R- Wave is first positive deflection resulting from ventricular depolarization.
S -Wave is first negative deflection of the ventricular depolarization that follows the first positive deflection.
T-Wave is produced by ventricular repolarization and is of longer duration than the QRS complex. Because ventricular repolarization is slower than depolarization. The T wave is caused by potentials generated when the ventricles recover from the state of depolarization. This process normally occurs in ventricular muscles 0.25-0.35 sec after depolarization. This wave is known as repolarization wave.


2. Toolbox used

Wavelet Toolbox software is a collection of functions built on the MATLAB® technical computing environment. It provides tools for the analysis and synthesis of signals and images, and tools for statistical applications, using wavelets and wavelet packets within the framework of MATLAB.

Wavelet analysis represents the next logical step: a windowing technique with variable-sized regions. Wavelet analysis allows the use of long time intervals where we want more precise low-frequency information, and shorter regions where we want high-frequency information. Wavelet analysis is capable of revealing aspects of data that other signal analysis techniques miss, aspects like trends, breakdown points, discontinuities in higher derivatives, and self-similarity. A wavelet time limited wave is chosen as the “mother wavelet”. This mother wavelet is limited in time and frequency. Scaling and translation of the “mother wavelet” gives a family of basis functions called “daughter wavelets”.

The wavelet transform of a time signal at any scale is the convolution of the signal and a time–scaled daughter wavelet. Scaling and translating the mother wavelet is the mechanism by which the transform adapts to the spectral and temporal changes in the signal being analyzed. Wavelets are generally orthogonal basis functions, though biorthogonal wavelet functions are now also being used. Orthogonality is considered an important property for the purpose of conserving the energy of the signal, an important property for reconstruction of the signal from the coefficients. The approximations are the high-scale, low-frequency components of the signal. The details are the low-scale, high-frequency components.

Scaling means stretching or compressing it. The scale factor works exactly the same with wavelets. The smaller the scale factor, the more "compressed" the wavelet. Shifting means delaying or hastening its onset.

Wavelet Reconstruction

The components can be assembled back into the original signal without loss of information is called reconstruction, or synthesis. The mathematical manipulation that effects synthesis is called the inverse discrete wavelet transform (IDWT). The main criteria are:

- Speed of convergence
- Symmetry
- Number of Vanishing Moment
- Regularity
- Fast algorithm
- Space Saving Coding

Daubechies Wavelet: Ingrid Daubechies invented compactly supported orthonormal wavelets making discrete wavelet analysis practicable. The names of the Daubechies family wavelets are written dbN, where N is the order, and db the “surname” of the wavelet.

Complex Shannon Wavelets - Shannon - is obtained from the frequency B-spline wavelets by setting m to 1. A complex Shannon wavelet is defined by:

\[ F(x) = \sqrt{f_b} \text{sinc}(f_b) e^{2\pi j f_c x} \]  

Where \( f_b \) : Bandwidth parameter  
\( f_c \) : Wavelet center frequency.

3. Signal used

The real ECG data used in the present work has been picked up from ECG databank, “Common Standard for Electrocardiography” (CSE) library. The data taken is first digitized at 500 Hz with quantization level of 5μV. The ECGs of all the 12 leads are simultaneous recorded for recording length of 10 sec for each lead.[1]

4. Methodology used

1. Load Raw ECG signal of 12- lead of 125 patients.
2. Daubachie discrete wavelet transformation ‘db3’ applied to decompose the ECG signal up to level 10 and computed the approximations and detail coefficients for each level.
3. Shifted the signal by approximations of level 9 to get baseline drift free signal.
4. This signal is again decomposed using Daubachie wavelet ‘db4’ up to level 6 and approximation and detail coefficients are computed.
5. The detail coefficients at level 1, 2, and 3 reduces to zero value. The signal is reconstructed using approximation at level 6 and details at level 4, 5, 6 to obtained noise free ECG signal.
6. Detected and marked the Rpeaks by applying Complex Gaussian wavelet transformation at scale of 1:1:1 to ECG signal.

5. Test result

The graphical results for preprocessing of signal and QRS detection are as follow:

![Fig.3 (a) Original signal, (b) Baseline approximation, (c) Baseline drift free ECG signal](image)

![Fig.4 (a) Original Signal, (b) Denoised Signal](image)

![Figure 5(a) Original Signal, (b) QRS detection in ECG](image)

The test results for detection of QRS complexes in ECG signal for mentioned patients are as under:

<table>
<thead>
<tr>
<th>Sr no.</th>
<th>Patient Number</th>
<th>QRS Detected</th>
<th>QRS Actual</th>
<th>FP</th>
<th>FN</th>
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</tbody>
</table>

Table 1: Tabulated test result
**Conclusion**

The combination of wavelets like Daubachie at level 3 and Complex Gaussian at scale 1:1:1 is implemented for QRS complex detection in ECG signal. The denoising and baseline drift reduce near to zero using above said algorithm. The actual QRS peaks for 125-patients is 1511 out of which 1485 QRS detected and detection rate is 98.28%. The False positive value are 3.2% and False negative values are 0.86%.

**References**


H.P. Sinha is presently working as an Associate Director in MMEC, MMU, Mullana, Ambala. He graduated in year 1965, did his ME in 1974 and Ph.D in year 1986. He has 48 years of total teaching experience in India and abroad. He has more than 30 research papers in various national and international journals. He has also chaired technical sessions in Halifax Canada, Durban and other places. He has guided one Ph.D with 8 in progress. He has been Executive Secretary and Program Director for ISTE for 5 years. His area of research is biomedical engineering.

Vijay S. Chouhan was born in India in 1960. He received B.E. degree Electronics & Communication Engineering and M.E. degree in Digital Communication Engineering and Ph.D. from J. N. V. University, Jodhpur (India). He has publication in reputed journals and conferences. His research interest includes fields of Biomedical Signal Processing, Soft Computing and Digital Communications.