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.

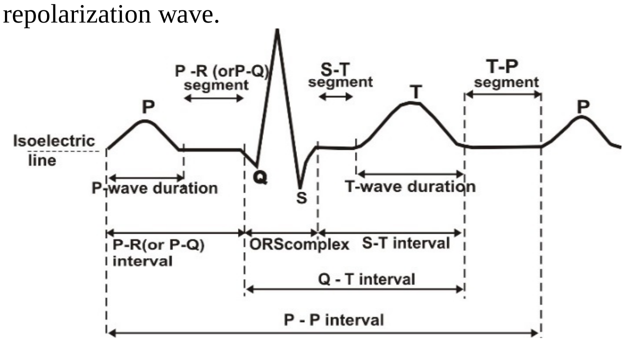

Fig. 1 Normal ECG Cycle

Kohler [2] provided brief description of many algorithms used for QRS–complexes like slope and derivative based, digital filters based, wavelet based, Artificial Neural Network based. Chouhan et al [3, 10] presented a method to determine QRS complex using Adaptive Quantized Threshold and P&T wave detection using threshold. Mehta & Lingayat [4, 12] presented Support Vector Method for Cardiac Beat Detection and detection of P and T. In the literature, Lingayat & Mehta [5] provided methods for biomedical signal processing based on support vector machine. Zheng et al [6] presented sorting method for ECG signal based on neural network.

Cohen [7] used Fuzzy method for detection of QRS complexes. Chawla & Verma [8] presented ECG modelling and QRS detection using Principle Component Analysis. Shuo & Desong [9] presented automatic detection of QRS onset. Mehta et al [11] presented recognition of P and T in ECG signal using Fuzzy theory. Chouhan [13] presented method for delineation of QRS complexes. Pablo et al [14] presented wavelet based delineation. Banerjee et al [15] presented Delineation of

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ECG signal using Multi Resolution Wavelets. C. Saritha et al [16] presented ECG analysis using Wavelets. J. Pan [17] presented method for real time QRS detection. C. Li [18] presented method for ECG characteristic point using Wavelet Transform. Sahambi et al [19] use wavelet transform for ECG Characterization. Daubachie [20] presented time frequency localization and signal analysis.

This paper is organized as follow: Brief introduction in section I, Toolbox used in section II, Signal used in section III, Methodology used in section IV, Test Results in V and conclusions are presented in section VI.

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.

Fig. 2 Daubachie 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 :

$$\boldsymbol{F(x)} = \sqrt{\boldsymbol{f_b}}\{\boldsymbol{sinc(f_b)e^{2ipifc\,x}} \qquad (1)$$

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:

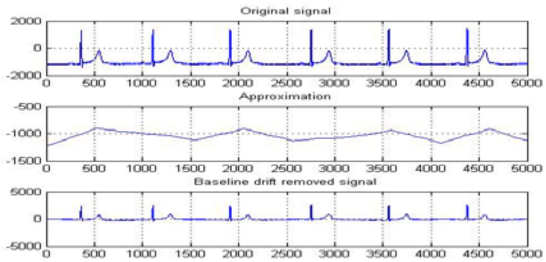

Fig.3 (a) Original signal, (b) Baseline approximation, (c) Baseline drift free ECG signal

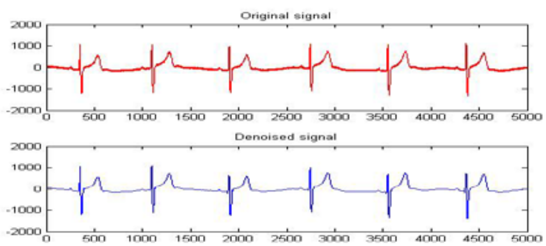

Fig.4 (a) Original Signal, (b) Denoised Signal

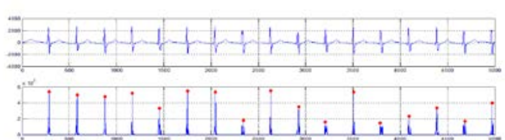

Figure 5(a) Original Signal, (b) QRS detection in ECG

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

Table 1: Tabulated test result

Sr no.	Patient Number	QRS Detected	QRS Actual	FP	FN
1	MO1_001	11	11	0	0
2	MO1_002	20	19	1	0
3	MO1_003	17	17	0	0
4	MO1_004	13	12	1	0
5	MO1_005	16	17	0	1
6	MO1_006	13	16	0	3
7	MO1_007	16	16	0	0
8	MO1_008	9	10	0	1
9	MO1_009	12	12	0	0
10	MO1_010	10	7	3	0
11	MO1_011	14	15	0	1
12	MO1_012	13	13	0	0
13	MO1_013	12	12	0	0
14	MO1_014	8	8	0	0
15	MO1_015	6	6	0	0
16	MO1_016	16	16	0	0
17	MO1_017	10	10	0	0
18	MO1_018	15	15	0	0
19	MO1_019	13	13	0	0
20	MO1_020	19	22	0	3
21	MO1_021	8	7	1	0
22	MO1_022	12	12	0	0
23	MO1_023	11	8	3	0
24	MO1_024	9	9	0	0
25	MO1_025	10	10	0	0
26	MO1_026	13	13	0	0
27	MO1_027	14	14	0	0
28	MO1_028	11	10	1	0
29	MO1_029	10	10	0	0
30	MO1_030	12	12	0	0
31	MO1_031	11	11	0	0
32	MO1_032	14	14	0	0
33	MO1_033	10	9	1	0
34	MO1_034	13	13	0	0
35	MO1_035	11	11	0	0
36	MO1_036	12	12	0	0
37	MO1_037	13	13	0	0
38	MO1_038	12	11	0	1
39	MO1_039	9	9	0	0
40	MO1_040	12	11	1	0
41	MO1_041	11	11	0	0
42	MO1_042	11	11	0	0
43	MO1_043	11	10	1	0
44	MO1_044	8	8	0	0
45	MO1_045	13	13	0	0
46	MO1_046	12	12	0	0
47	MO1_047	16	16	0	0
48	MO1_048	10	10	0	0
49	MO1_049	11	10	1	0
50	MO1_050	8	8	0	0
51	MO1_051	20	20	0	0
52	MO1_052	15	15	0	0
53	MO1_053	17	17	0	0
54	MO1_054	10	7	3	0
55	MO1_055	9	9	0	0
56	MO1_056	11	10	1	0
57	MO1_057	12	10	2	0
58	MO1_058	15	15	0	0
59	MO1_059	9	8	1	0
60	MO1_060	12	12	0	0
61	MO1_061	13	12	1	0
62	MO1_062	11	11	0	0
63	MO1_063	9	9	0	0
64	MO1_064	11	11	0	0
65	MO1_065	12	12	0	0
66	MO1_066	10	10	0	0
67	MO1_067	12	12	0	0
68	MO1_068	17	16	1	0
69	MO1_069	13	13	0	0
70	MO1_070	12	24	0	0
71	MO1_071	14	14	0	0
72	MO1_072	12	11	1	0
73	MO1_073	13	13	0	0
74	MO1_074	10	10	0	0
75	MO1_075	13	13	0	0
76	MO1_076	13	13	0	0
77	MO1_077	12	12	0	0
78	MO1_078	7	7	0	0
79	MO1_079	9	9	0	0
80	MO1_080	9	9	0	0
81	MO1_081	12	12	0	0
82	MO1_082	11	9	2	0
83	MO1_083	15	15	0	0
84	MO1_084	10	10	0	0
85	MO1_085	12	11	0	0
86	MO1_086	9	9	1	0

87	MO1_087	10	9	1	0
88	MO1_088	11	9	2	0
89	MO1_089	9	6	3	0
90	MO1_090	9	8	1	0
91	MO1_091	10	9	1	0
92	MO1_092	12	11	1	0
93	MO1_093	11	9	2	0
94	MO1_094	11	10	1	0
95	MO1_095	9	8	1	0
96	MO1_096	9	9	0	0
97	MO1_097	11	11	0	0
98	MO1_098	11	10	1	0
99	MO1_099	10	10	0	0
100	MO1_100	15	16	0	1
101	MO1_101	16	16	0	0
102	MO1_102	16	16	0	0
103	MO1_103	11	11	0	0
104	MO1_104	8	8	0	0
105	MO1_105	11	11	0	0
106	MO1_106	11	10	1	0
107	MO1_107	15	14	1	0
108	MO1_108	16	16	0	0
109	MO1_109	13	13	0	0
110	MO1_110	15	15	0	0
111	MO1_111	18	20	0	2
112	MO1_112	14	14	0	0
113	MO1_113	17	17	0	0
114	MO1_114	11	11	0	0
115	MO1_115	11	11	0	0
116	MO1_116	13	13	0	0
117	MO1_117	12	12	0	0
118	MO1_118	12	11	1	0
119	MO1_119	18	18	0	0
120	MO1_120	10	8	2	0
121	MO1_121	10	10	0	0
122	MO1_122	15	14	1	0
123	MO1_123	13	13	0	0
124	MO1_124	12	11	1	0
125	MO1_125	13	12	1	0
Total		**1511**	**1485**	**49**	**13**

Conclusion

The combination of wavelets like Daubachie at level 3 and 4 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%.

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