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Automated Detection of R-peaks in Electrocardiogram

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Abstract— Electrocardiography is a method of picking up the biopotentials generated in the myocardium using electrodes put on the heart or body surface. The record of the biopotential is called as electrocardiogram (ECG). The ECG is characterized by P-wave, QRS complex, T-wave, S-T segment etc. The analysis of these characterized features can be used for estimation of cardiovascular function. An algorithm for detection of ECG peaks has been developed using Discrete Wavelet Transform (DWT). It was implemented for MIT/BIH ECG database. The ECG R-peak detection was automatically detected with tolerance variying from 0 to 6 ms. The sensitivity, positive predictivity and detection error was calculated for the investigated algorithm.

Index Terms— ECG, peak detection, DWT, MIT-BIH ECG arrhythmia database, sensitivity, positive predictivity and detection error

1 Introduction

Electrocardiography is a method of picking up the biopotentials generated in the myocardium using electrodes put on the heart or body surface. The record of these biopotentials is called as ECG. It is characterized by P wave, T wave, Q-R-S complex, ST segment, PQ segment. The P is associated with atrial depolarization and lasts for 80ms. The R wave is associated with ventricular depolarization and lasts for 0.06 to 0.10 ms. Normally the amplitude of R wave varies upto 5 mV in surface ECG. The T wave associated with ventricular repolarization. The ECG along with its characteristic wave is shown in Fig. 1. [1].

The changes in wave morphology, intervals and corresponding changes in the recorded ECG as compared to standard ECG can give insight into the diagnosis of cardiovascular disorders. The heart rate variability parameters estimated using beat-by-beat veriations in the cardiac events can be used for study of sympathetic and parasympathetic activity of nervous system. An estimation of short term and long term heart rate variability parameters need measurements of ECG R-peak-to-peak intervals. The measurement of ECG R peak to peak intervals manually using ECG signal recorded for long time is tedius and need more time. The method for automated detection of ECG R peaks and hence R-R interval is required. The threshold based method for ECG R peak detection may misdetect the R peaks if ECG T amplitude is larger the R peaks. Discrete wavelet transform method is frequency based operation which can be used for automated detection of ECG R peaks which further can be used for estimation of short term and long term heart rate variability parameters. [2]

The ECG signal is decomposed using db6 wavelet and the signal is reconstructed using level based thresholding. The peaks in reconstructed signal are observed in the vicinity of ECG R peaks with maximum tolerance of 6 samples. An automated detection of ECG R peaks was cerried out for 27 arrythemia ECG data base from MIT/BIH.The technique was tested for 2942 ECG R peaks from 27 ECG signals. In case of falt R peak an ambiguity was onercome in wavelet reconstructed signal.

2 Method

In wavelet decomposition the signal is decomposed into shifted and scaled versions of the original (or mother) wavelet. The low frequencies correspond to high scales and a dilated wavlet function. At high scales, the global information is obtained called as approximations. At low scales the fine information is obtained called as detail levels [5]. An analysis of signal using ECG includes decomposition of the signal, thresholding of the wavelet coefficients and reconstruction of the signal using modified wavelet coefficients.The wavelets of Daubechies family are shown in Fig.2. The wavelet db6 closely matches with the shape of ECG Q-R-S complex. The ECG signals from MIT/BIH data base were recorded at rate of 360 samples per minute. The ECG signal was decomposed into 10 levels using db6. Detailed levels and approximate levels are shown in Fig. 3 & Fig. 4 respectivly. Addition of 4th and 5th detail levels was taken as reconstructed signal. The prominent peaks in the reconstructed signal were observed in the vicinity of ECG R-peaks. An empirically determined threshold was used for detection of peaks in ECG.

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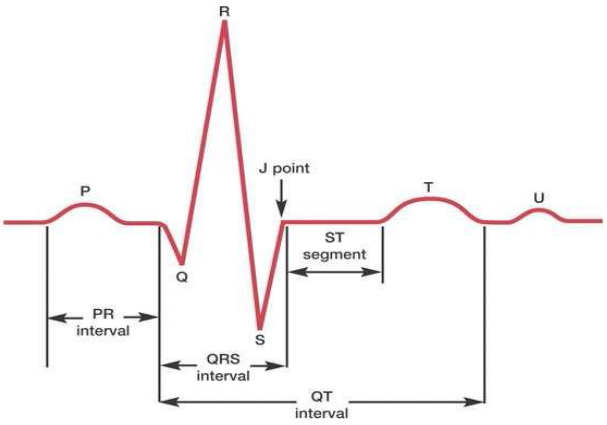

Fig. 1 A typical ECG with characteristic waves and intervals

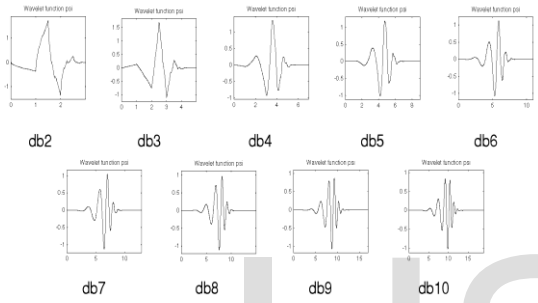

Fig. 2 Wavelets of Daubechies family

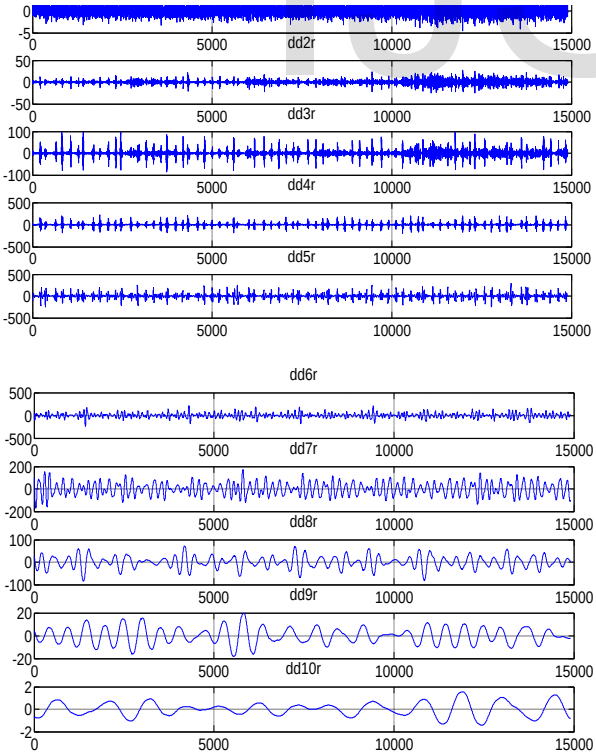

Fig.3The detailed level dd1r to dd10r using db6 wavelet decomposition of signal.wavelets

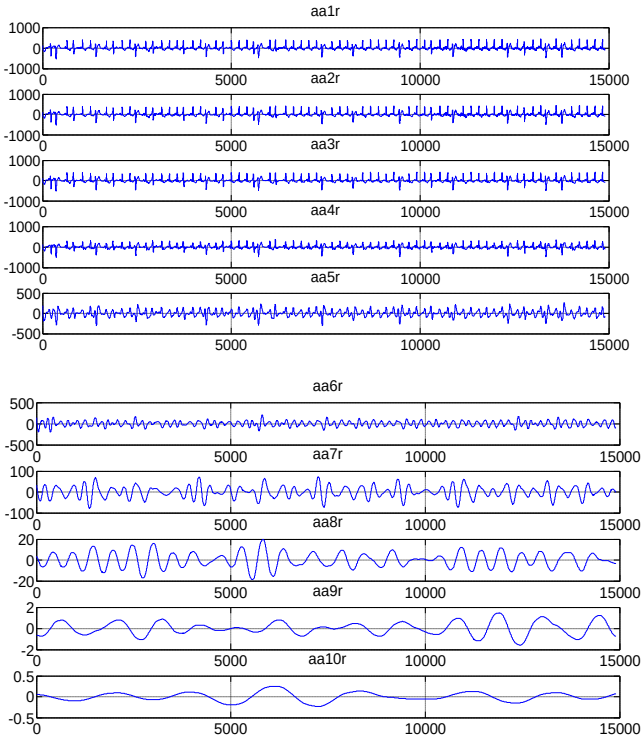

Fig.4 The approximation levels aa1r to aa10r using db6 wavelet decomposition of signal wavelets

All samples in reconstructed signal were scanned for peak. The amplitude of each sample is compared to next sample amplitude. If the condition y(i) > y(i-1) and y(i) > y(i+1), then y(i) is considered as a peak where y(i) is sample value of i th sample, y(i+1) is sample value of (i+1) th sample, and y(i-1) is sample value of (i-1) th sample. The sample number x (i) of i th sample is detected. The wavelet reconstructed signalis as shown in Fig. 5. In ECG the points are detected which is shown in Fig.7 and the zoomed version of ECG R-peaks are shown in Fig. 7 to Fig. 10.

The detected peaks using empirically derived threshold in the reconstructed signal are as shown in Fig. 5. In some cycles of ECG double R peak was observed. To overcome this difficulty detected R peaks were sampled for their sample numbers. If the difference between successive R peaks was less tha 100 samples then first R peak was selected. The reconstructed signal was having a single peak. There was no ambugity in selection of R peaks in case of flat R peak as shown in Fig. 10. The observed peak in the vicinity of ECG R for the ECG signal in file number 101 and 102 from MIT/IBH database are shown in Fig. 8 and Fig. 9 respectively. An accuracy of the method was estimated with reference to the sensitivity, positive predictivity and detection error which are defined as,

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$$\text{Sensitivity} = \frac{TP}{TP + FD} \quad (1)$$

$$\text{Positive Predicti vity} = \frac{TP}{TP + MD} \quad (2)$$

$$\text{Detection Error} = \frac{FD + MD}{TP + FD} \quad (3)$$

Where, TP is no. of true points, MD is no. od points misdeteted and FD is the no. of points failed to detect.

With reference to manually detected ECG R peaks, the true points (TP), the no of points failed to detect (FD), and the no of point's misdetected (MD) using ECG from 27 files of MIT/BIH data base are tabulated in Table 1. The corresponding sensitivity, positive predictivity and detection error of the method used is also tabulated in the same table.The manually detected ECG peks in 2942 ECG cycIn case of flat R peak an ambugity was solved An ambugity in selection of R peak The R peaks of 27 ECG files from MIT/BIH database are automatically as well as manually detected as shown in Table 1.

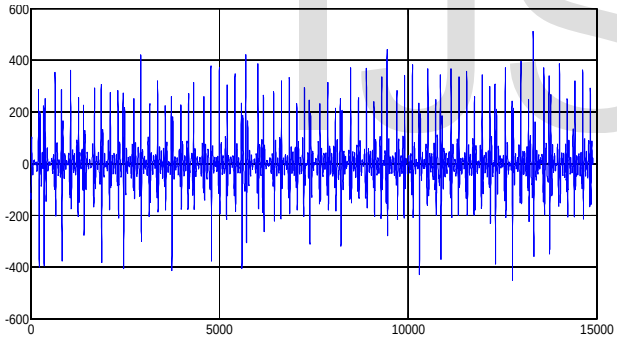

Fig.5 The reconstructed signal using dd4r and dd5r.

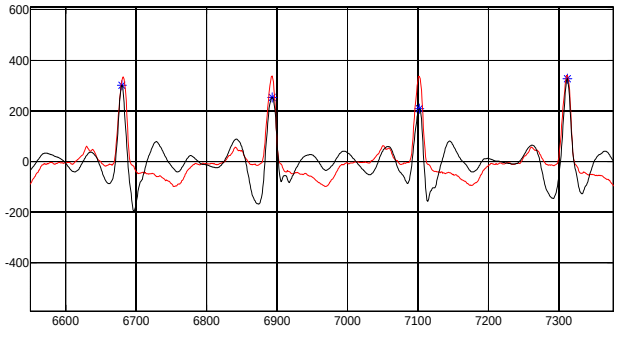

Fig.6 The detected R-peaks in ECG

The accuracy of algorithm was also tested for 10 ECG recordings from MIT/BIH arrhythmia data base. The exact peak location in ECG and wavelet derived signal was identified. The difference between these locations was calculated. The location of peak in ECG signal and wavelet derived signal for MIT/BIH ECG data file 101 is shown in Fig. 7.

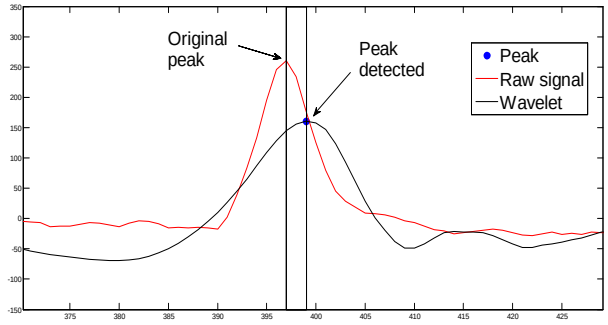

Fig.7.Peak Verification of first peak from 101.dat file

The peak in raw ECG was at 397th sample and in wavelet derived signal it was at 399th sample. So the detection error was calculated as absolute value of the difference between peak locations. In this case the absolute difference was found to be 2 sample values which is equivalent to 2.77 ms error at the sampling frequency of 360 Hz. From 10 files of data base 100 peaks from 10 different ECG were tested. The sample examples of error in peak detection are as shown in Fig. 7 to 10. The test results are tabulated in Table.2

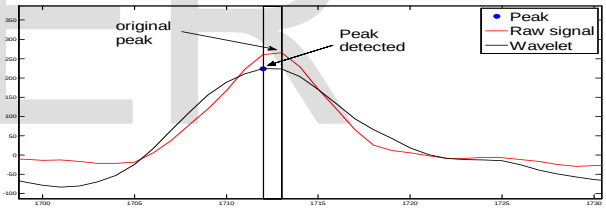

Fig.8 Peak Verification of 5th peak from 101.dat file

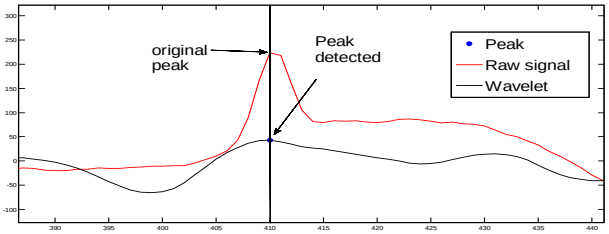

Fig.9 Peak Verification of 1st peak from 102.dat file

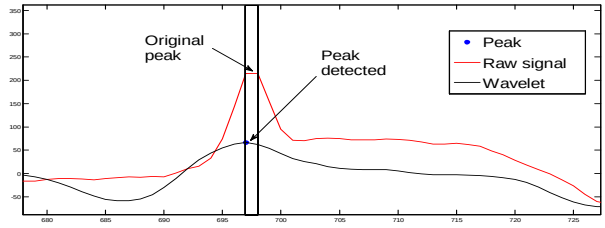

Fig.10 Peak Verification of 2nd peak from 102.dat file

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TABLE 1
TABLE OF STATISTICAL ANALYSIS

FILE NAME	TP	FD	MD	%SS	% PP	%DE
100	102	1	0	99.03	100	0.97
101	96	2	0	97.96	100	2.04
102	100	1	0	99.01	100	0.99
103	97	3	0	97	100	3
105	114	5	0	95.8	100	4.2
106	91	8	0	91.92	100	8.08
107	97	0	4	100	96.04	4.12
111	95	12	0	88.79	100	11.21
115	86	3	0	96.63	100	3.37
116	109	2	0	98.2	100	1.8
119	90	1	0	98.9	100	1.1
122	120	16	0	88.24	100	11.76
201	123	9	0	93.18	100	6.82
205	123	1	0	99.19	100	0.81
209	129	7	0	94.85	100	5.15
210	117	10	0	92.13	100	7.87
212	124	6	0	95.38	100	4.62
213	152	7	0	95.6	100	4.4
214	104	11	0	90.43	100	9.57
217	99	0	19	100	83.9	19.19
219	104	10	0	91.23	100	8.77
220	99	2	0	98.02	100	1.98
223	109	6	0	94.78	100	5.22
230	107	9	0	92.24	100	7.76
231	87	1	0	98.86	100	1.14
233	141	24	0	85.45	100	14.55
234	127	4	0	96.95	100	3.05
MEAN				95.18	99.26	5.69

T.P- no. of true points (R peaks in ECG were manually counted),
F.D- no. of points not detected automatically,
M.D -no. of R peaks misdetected by program

3 RESULTS & DISCUSSION

The statistical analysis is carried for 27 ECG signals which are taken from MIT/BIH data base. We had detected the R peak manually in raw ECG & after that R peaks detected automatically by the program. From automatic and manual analysis of the ECG the quantities are determined as T.P i.e no. of true points, which are manually counted R peaks in ECG; F.D i.e no. of points not detected automatically, M.D i.e no. of R peaks misdetected by program. Using these quantities following parameters are calculated,

The average values of 27 files of ECG for sensitivity, positive predictivity and detection error are 95.18%, 99.26% & 5.69% respectively.

The accuracy test is carried out on the 10 files of MIT/BIH arrhythmia data base. From each file first 10 peaks are analyzed. Table.2 corresponds the results of accuracy test carried out for ECG signal. Hence we decided the tolerance of about 0, ±1, ±2, ±3, ±5, ±6 samples (0 ms, 2.7 ms, 5.4 ms, 8.1 ms, 13.5 ms, 16.2 ms,) etc. Therefore for each tolerance we have calculated the positive predictivity & detection error.

TABLE 2
Statistical analysis of accuracy test of ECG with different tolerance

	No. of Missdetected points	**PP%**	**DE%**
MD0	73	58%	73%
MD1	38	72%	38%
MD2	14	88%	14%
MD3	5	95%	5%
MD5	2	98%	2%
MD6	0	100%	0%

MD (misdetection) with different tolerance level are shown in table. 3
MD0 = no. of R-peaks detected with 0 samples (0 ms) tolerance
MD1 = no. of R-peaks detected with 1 samples (2.7 ms) tolerance
MD2 = no. of R-peak detected with 2 samples (5.4 ms) tolerance
MD3 = no. of R-peak detected with 3 samples (8.1 ms) tolerance
MD5 = no. of R-peak detected with 4 samples (13.5 ms) tolerance
MD6 = no. of R-peak detected with 6 samples (16.2 ms) tolerance

4 CONCLUSION

Using investigated algorithm for automatic detection of ECG R-peaks, the detection parameter with ±6 numbers of samples (±16.2 ms) tolerance shows improvement of 4.59% in sensitivity, 0.24% in positive predictivity and detection error is reduced. The peaks are detected with small detection error, high positive predictivity and sensitivity.

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