

C3IT-2012

R-peak detection algorithm for ECG using double difference and RR interval processing

Deboleena Sadhukhan^a, Madhuchhanda Mitra^a^a*Department of Applied Physics, University of Calcutta, 92, APC Road, Kolkata 700009, Calcutta, India*

Abstract

The paper proposes a simple algorithm for automatic detection of the R-peaks from a single lead digital ECG data. The squared double difference signal of the ECG data is used to localise the QRS regions. The proposed method consists of three stages: sorting and thresholding of the squared double difference signal of the ECG data to locate the approximate QRS regions, relative magnitude comparison in the QRS regions to detect the approximate R-peaks and RR interval processing to ensure accurate detection of peaks. The performance of the algorithm is tested on 12-lead ECG data from the PTB diagnostic ECG database, and a high detection sensitivity of 99.8% with low computational complexity and low sensitivity to low frequency noises is detected.

© 2011 Published by Elsevier Ltd. Selection and/or peer-review under responsibility of C3IT

Open access under [CC BY-NC-ND license](#).

Keywords: Electrocardiogram(ECG); double difference; sorting; thresholding;

1. Introduction

The electrocardiogram (ECG) is the recording of the electrical activity of the myocardium of the heart during one cardiac cycle and is characterised by a recurrent sequence of P, QRS, T and a conditional U wave (Fig.1) which represents the rhythmic depolarisation and repolarisation of the myocardium associated with the contractions of the atria and ventricles over each cardiac cycle. ECG is recorded by placing electrodes on the body surface and a standard 12 lead system is used to get an overall view of the hearts activity [1]. ECG is one of the most important diagnostic tools for various cardiac diseases. The different features of the ECG like the PR interval, QRS interval, QT interval, ST interval, PR segment, and ST segment (Fig.1) are used to infer about the cardiac condition [2,3]. The different computer aided analysis techniques aims at extracting these time plane features from digitised ECG data. Detection of QRS complexes and the R-peak provide the fundamentals for almost all automated ECG analysis algorithms. QRS complex reflects the electrical activity of the heart during the ventricular contraction and the time of its occurrence and its shape provide much information about the current state of the heart. QRS detection acts as the starting point of the other ECG feature extraction like the P, T waves ST segment [4, 5]. Accurate QRS detection is not only important for Heart Rate Variability analysis but also for diagnosing other cardiac diseases [2, 3]. Different QRS detection algorithms available in literature are broadly be classified as amplitude and derivative based, digital filter based, template matching techniques, non linear transformation based, wavelet based [6]. The derivative based approaches [7-9] are based on the high frequency content of the ECG signal which yields higher magnitudes of the derivatives and use different derivative operators. Due to ease of implementation and low computation complexity these methods are widely used. Template matching based approach [10] relies on cross correlation based comparing of standard QRS template with several ECG segments, though have low noise sensitivity but are computationally complex and needs manual segmentation of ECG data. In [11] a non linear Hilbert transform is used to enhance the QRS signature to increase its detection probability. The use of digital filter [12] to extract the QRS complex based on its frequency content is also computationally complex. In wavelet based techniques [13] the R peaks are localised by selective decomposition of the ECG signal and extracted by different scale comparison. These methods require availability of

suitable mother wavelet and scale values. A new and effective approach was implemented using a histogram and improved genetic algorithm to search and detect the QRS regions [14].

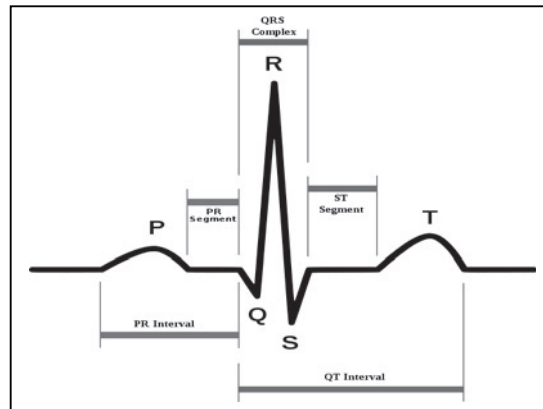


Fig. 1 Schematic representation of an ECG wave

ANN or SVM is also used as a classifier to detect the QRS complex [15-16]. A statistical based approach was used for detection of R-peaks and other time plane features of the ECG [17]. The detected R-peaks are not always accurate and can have false or missed peaks. Algorithms to increase detection sensitivity by processing the RR intervals were proposed [18, 19]. Difficulties in accurate QRS detections rise because of the physiological variability of the QRS complex and presence of different noises in the ECG signal. The noise sensitivities of 9 different algorithms were tested [20] to infer that the derivative based approaches had higher performance index for low frequency noises, while algorithms based on digital filtering performed well for high frequency noise.

In this paper a simple algorithm based on the double derivative has been proposed. The algorithm includes three stages. First, the squared double differences of the ECG signal are sorted in descending order and compared to a threshold to extract the approximate QRS regions. Second, by magnitude comparison in the detected QRS regions the R peaks are detected. Lastly, the RR intervals obtained are processed according to some criteria to ensure accuracy of detection. The algorithm is tested on 10 sec ECG data from the PTB diagnostic ECG database (PTB-db) available under Physionet [21] and a detection sensitivity of 99.8% is achieved. The proposed algorithm yields high performance with lesser computational complexity as it does not need any segmentation of data, training of algorithms, or complex calculations.

2. Methodology

The proposed algorithm is based on the derivative based approach and operates on digitised ECG data from a single lead. The digital ECG data from a single lead is read as a 2-d array of the time instants and the sample points. The method involves four different stages for the accurate detection of the R peaks.

2.1. Smoothing and filtering of raw data

The derivative based approach amplifies the high frequency noises, which leads to high difference signals due to noise. So, initial smoothing and filtering of the ECG data is done to eliminate power frequencies and high frequency noise in the ECG.

2.2. Detection of QRS Regions

Owing to the high frequency content of the QRS region [5-15 Hz] the derivative of these regions of ECG have higher amplitudes. As the sampling instants of digital ECG data remains constant the amplitude differences are proportional to the derivatives which can be used to detect the QRS regions. Double differencing and squaring intensifies the magnitudes of the difference signal in the QRS regions which aids in the localisation of the QRS regions as in Fig. 2 (b). The process involves the following steps-

- i. From the ECG data array $e(n)$ the squared double differences are calculated at all points to yield the difference array $d(j)$.

$$d1(i) = e(i+1) - e(i), i = 1, 2, \dots, n-1 \quad (1)$$

$$d2(j) = d1(j+1) - d1(j), j = 1, 2, \dots, n-2 \quad (2)$$

$$d(j) = [d2(j)]^2 \quad (3)$$

where $e(n)$ is the ECG data array with total n points, and $d(j)$ is the squared double difference array.

- ii. The difference array is sorted in descending order of magnitude and the difference peaks above a constant threshold value of 3% of the maximum are selected.
- iii. Since the maximum duration of the QRS regions is 150 ms, to eliminate possibility of detection of several peaks in the same QRS region all the difference peaks within an interval of ± 75 ms of each selected difference peaks are eliminated.
- iv. The QRS regions are identified to be within a window of ± 75 ms of each selected peaks on the ECG data array as shown in Fig 2 (c).

2.3 Detection of R peaks

The R peaks are the positive peaks of the QRS regions. These are detected by relative magnitude comparison in each QRS regions. A search for maximum was done on the relative magnitudes for each window to eliminate errors due to baseline wander.

- i. For each detected QRS window the maximum and minimum amplitude values of the ECG data array are calculated.
- ii. The mean of the maximum and minimum values are subtracted from all data points of that window to get the relative magnitudes.
- iii. The position of the maximum of the relative magnitudes is the R point locations of the corresponding QRS window. The absolute maximum value of the QRS window is not selected as the R-point location to eliminate possibility of detection of the S point

2.4 Processing of RR intervals

The R peaks thus obtained may not be accurate. There can be missed peaks or false detections. To ensure detection accuracy the RR intervals are processed according to certain criteria.

- i. It is considered that the minimum difference between two successive R peaks can be 200 ms. Any peaks detected within 200 ms of the first is considered as noise peak and eliminated
- ii. The average RR interval for 5 successive R peaks, two on either side of the R peak corresponding to the highest difference peak is calculated and taken as reference for the RR interval processing.
- iii. All the successive RR intervals are processed by comparing with the calculated average RR interval.

CASE 1- If the RR interval between any two detected peaks is less than 70% of the average RR interval then the 2nd peak is eliminated.

CASE 2- If the RR interval between any two detected peaks is more than 180% of the average interval then a search for another R peak in that interval is initiated with decreased threshold for the difference signal.

TABLE 2. Test results for some diseased patients

LEADS	I	II	III	aVR	aVL	aVF	V1	V2	V3	V4	V5	V6
Total R	507	507	507	507	507	507	507	507	507	507	507	507
Detected R	507	505	506	506	504	506	506	505	506	506	506	506
TP	507	505	506	506	504	506	506	505	506	506	506	506
FN	0	2	1	1	3	1	1	2	1	1	2	1
Sensitivity (%)	100	99.6	99.8	99.8	99.4	99.8	99.8	99.6	99.8	99.8	99.8	99.8

The overall detection sensitivity is 99.8%. Detection of false peaks is almost negligible. The algorithm shows good performance for data affected with low frequency noises like base-line wander.

4. Conclusion

The proposed algorithm is simple with low computational overhead and fairly good detection sensitivity. For this the algorithm can be easily implemented in an embedded platform for use in wearable cardio-respiratory systems. As it was insensitive to low frequency noise like baseline wander, baseline elimination is not required. Conventional derivative based methods are sensitive to high frequency noise leading to false detections, in this method some false detection could be eliminated by processing the RR intervals. The proposed algorithm can be extended to extract other time plane features of the ECG [5, 17].

References:

- Webster J.G. *Medical instrumentation- Application and Design*. 4th ed. Boston: John Wiley & Sons, Inc; 1978.
- Schamroth L, *An Introduction to Electrocardiography*. 7th ed. Oxford: Blackwell Science Ltd; 1990.
- Chan H.L, Chou W.S., Chen S.W, Fang S.C, Liou C.S, Hwang Y.S. Continuous and online analysis of heart rate variability. *J Med Eng Technol*. 2005; vol. 29(5): 227-34.
- Zhu Y. , Thakor N.V, P-wave detection by adaptive cancellation of QRS-T complex, *IEEE Ann. Conf. Eng. Med. Biol. Soc.* 1986; 329–331.
- Gritzali F, Frangakis G, Papakonstantinou G, Detection of the P and T waves in ECG, *Comp. Biomed. Res.* 22; 1989, 83–91.
- Kohler B.U, Hennig C, Orglmeister R, The principles of software QRS detection, *IEEE Eng Med. Biol. Mag.* 2002, 42-57.
- W.P. Holsinger, K.M. Kempner, and M.H. Miller, A QRS pre processor based on digital differentiation, *IEEE Transactions on Biomed. Eng.*, vol. 18, no. 3; 1971, 212-217.
- Pan J, Tompkins W.J, A real-time QRS detection algorithm, *IEEE Trans on Biomed. Eng.* 1985, Vol. 32(3), 230–236.
- Yeha Y.C, Wang W.J, QRS complexes detection for ECG signal: The Difference Operation Method, *Comp. Methods and programs in biomed.* 2008, vol. 92; 245–254
- Dobbs S.E, Schmitt N.M, Ozemek H.S, QRS detection by template matching using real-time correlation on a microcomputer, *Journal in Clin. Eng.* 1984, Vol-9(3); 197–212.
- Benitez D, Gaydecki PA, Zaidi A, Fitzpatrick AP, The use of the Hilbert transform in ECG Signal analysis, *Comp. in Bio. and Med.* 2001, vol. 31, no. 5; 399-406.
- Okada M, A Digital filter for the QRS complex Detection, *IEEE Trans. on BME.* 1983, Vol.-30, 651-657.
- Li C.W, Zheng C.X, Tai C.F, Detection of ECG characteristic points using wavelet Transforms, *IEEE Trans. Biomed. Eng.* 1995, vol. 42; 21–28.
- Tu C, Zeng Y, Yang X, A new approach to detect QRS complexes based on a histogram and genetic algorithm, *J. of Med Eng & Technol.* 2005, Vol. 29, No. 4; 176 –180.
- Suzuki Y, Self organising QRS-wave recognition in ECG using Neural Net-works, *IEEE Trans. on Neural Net.* 1995, vol. 6(6); pp 1469–1477.
- Mehta S. S, Lingayat N. S, Detection of QRS complexes in electrocardiogram using support vector machine, *J. of Med. Eng. & Technol.* 2008, Vol. 32, No. 3, 206 – 215.
- Chatterjee H.K, Gupta R, Mitra, A statistical approach for determination of time plane features from digitized ECG, *Comp. in Bio and Med.* 2011, vol 41; 278–284.
- Widjaja D, Vandeput S, Taelman J, Bracker M, Otte R.A. et. al., Accurate R peak detection and advanced preprocessing of normal ECG for heart rate variability analysis, *Computers in cardiology.* 2011, 533-536.
- Adnane M, Jiang Z, Choi S, Development of QRS detection algorithm designed for wearable cardio-respiratory system, *Comp. Methods in Biomed.* 2009, vol. 93, 20-31.
- Friesen G. M, Janet T. C, Jadallah M.A, Yates S. L, Quint S. R, Nagle H. T, A Comparison of the noise sensitivity of nine QRS detection Algorithms, *IEEE Trans. of Biomed. Eng.* 1990, Vol. 37 no. 1, No. 1, 85-98.
- <http://www.physionet.org/physiobank/database/mitdb/>