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Determination of Heart Rate from ECG Signal- A Simplified Approach

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Abstract

Electrocardiography is a non-invasive technique of registration of the electrical activity of the heart and is widely used as a diagnostic tool by the physicians. ECG signal yields information about the conditions of the heart. Among many morphological markers of the ECG, the QRS complex and the R-peaks are the most significant ones---with the contribution of the R-peak to RR interval being a driving factor. The number of R-peaks in a specified interval leads to the determination of the heart rate in beats per minute. This calls for an efficient R-peak detection algorithm. The authors have suggested here a straight-forward algorithm, the efficacy of which has been improved by enhancing the quality of the ECG signal by EMD method. The performance has been compared with Pan-Tompkins algorithm---a benchmark method and also against the original values obtained from MIT/BIH database.

Keywords: ECG signal, RR interval, Heart rate, Algorithm, EMD method.

Introduction

The clinical importance of the ECG signal in cardiology is well-established, being used for example, to determine heart rate, investigate abnormal heart rhythms and causes of chest pain. An ECG is generated by a nerve impulse stimulus to heart. The most important ECG signal features in a single cardiac cycle are labeled as shown in Fig.1.

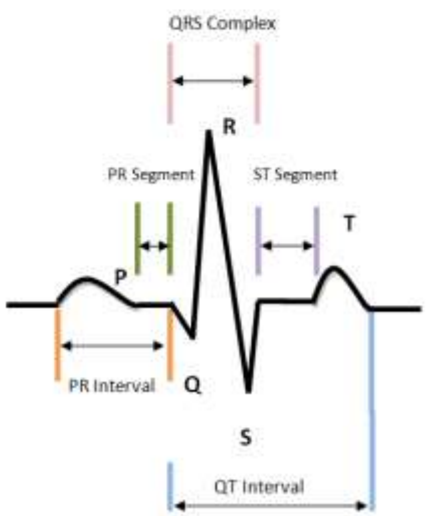

Fig 1 Normal ECG Signal

Abnormal patterns of ECG signal as obtained in practice may be due to various types of artifacts. Among these artifacts the power line interference (PLI) and the baseline wandering (BW) are the most significant ones. The signal voltage level is as low as 0.5 to 5 mV and is susceptible to artifacts that are larger than it. These signals are within the frequency range of 0.5 to 100 Hz [1]. Obviously, signal - conditioning for baseline wandering correction and noise suppression is typically the first step before analysis is carried out.

Literature review

Sahoo [2] has opined that the most important interval to be used for the determination of the cardio-vascular abnormality condition is RR interval (normal value is 600-1200 ns). Singh & Netala [3] measured RR interval using Pan-Tompkins algorithm---an optimized QRS detection algorithm in real time. Kulkarni & Patil [4] have determined bradycardia and tachycardia from ECG signal using wavelet transform. One of the steps to be followed is the detection of RR intervals. Nakaya & Nakamura [5] have improved adaptive sensing method for ECG signals by incorporating RR interval prediction. Joshi et al [6]

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have developed a peak detection algorithm to detect the R-peaks of the smoothened ECG waveform which is free from baseline wandering.

Alste & Schilder [7] used digital linear phase filtering to reduce BW and PLI in ECG signal. The major drawback of this method is the long computational time in the filtering in the time domain or frequency domain. FIR high pass zero phase forward backward filtering with a cut-off frequency of 0.5 Hz has been used to estimate and remove the BW in the ECG signal [8]. Sornmo [9] applied time-varying filtering technique to the problem of baseline wandering correction by letting the cut-off frequency of a linear filter be controlled by the low frequency properties of the ECG signal. Chavan et al [10] have advised the use of Kaiser window to design the digital filter for the removal of BW and PLI. Chouhan & Mehta [11] gave a technique for BW removal using median filtering on the ECG signal. This approach offers the advantage that the signal is not distorted in the absence of BW and is computationally efficient. Hargittai [12] has presented a multi-variable architecture with linear phase low pass filter working at low sampling rate for removal of BW. Mbachu et al [13] have discussed filtration of artifacts in ECG signal using rectangular window based digital filter. Sivkumar et al [14] have shown the way for the extraction of the cardiac component by rejecting the background noise with the help of filtering techniques. McManus et al [15] compared digital filtering methods while Dev[16] has presented a review of different techniques of filtering to remove BW from the ECG signal.

Park et al [17] proposed a wavelet adaptive filter for BW removal from the ECG signal to minimize the distortion of the ST segment . The noisy ECG signal is decomposed into seven levels, The 7th level approximation co-efficients are subjected to the adaptive filter with a cut-off frequency of 0.8 Hz. The work on the ECG beat detection using filter bank was carried out by Afonso et al [18]. Alfaowri & Daqrouq [19] suggested the use of WTT (wavelet transform with threshold) to process non-stationary signals such as ECG signals. Qawasmi & Daqrouq [20] advocated the use of DWT (discreet wavelet transform) in filtering high and low frequencies in the ECG signals.

Huang et al [21] introduced EMD (empirical mode decomposition) technique which is suitable for processing non-linear and non-stationary signals . EMD has the property of adaptive and signal dependency. Any signal can be represented as the sum of IMFs (intrinsic mode functions) and a residue. The method used by Zhao & Yu-Quan [22] to remove BW and PLI in the ECG signal based on EMD and notch filter. Pan et al [23] used EMD method for accurate removal of BW in the ECG signal. Hongyan & Minsong [24] proposed a new QRS complex detection algorithm based on EMD method. Sameni et al [25] presented an ECG denoising method employing EMD and wavelet transform method that is capable of overcoming the limitations of the existing methods. Sucheta & Kumaravel [26] have discussed various possible EMD based adaptive filtering techniques for denoising the contaminated signal. Anapagamini & Rajavel [27] have presented a new strategy for removal of artifacts in ECG using EMD. Adeyemo & Olayanju [28] have shown a way of using EMD for error correction of ECG signal corrupted by BW and PLI. Automatic detection of noisy IMFs is done by the help of statistical method. The IMFs containing BW are filtered by a bank of low pass filters and then passed through IIR notch filter. The authors claim that the method gives better SER (Signal error ratio).

Methods

Algorithms used for the determination of heart rate

A. **Pan –Tompkins algorithm:**

This algorithm can best be described by the block diagram as shown in the Fig.2

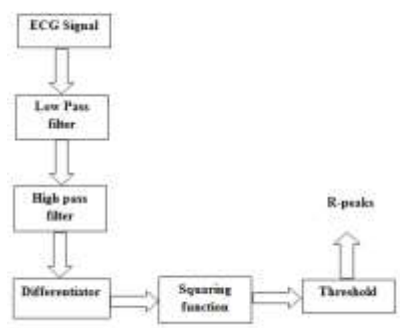

Fig 2 Block diagram representation of Pan-Tompkins algorithm

Heart rate is given by

Heart rate (beats per minute) = (1/RR-interval in seconds)x 60

B. **Proposed Algorithm**

Steps involved in this algorithm are as follows:

1. ECG data is passed through high pass filter and then notch filter.

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2. The R-R interval and the beat count are initialized.
3. Based on empirical search, appropriate threshold is specified.
4. A sample signal x(k) is checked against x(k-1), x(k+1) and threshold.
5. When x(k) becomes greater than x(k-1), x(k+1) and threshold, R-peak is detected.
6. Interval between two R-peaks is stored and beat count is incremented.
7. Once all the samples are run through the program, total beat count is noted.
8. The duration of the interval is determined from the total number of samples and the sampling frequency.
9. Then mean value of R-R interval and hence the heart rate is determined.

Removal of BW

The wavelet approach has the limitation that its basis functions are fixed and thus they do not necessarily match all real signals. Presently, the authors have taken recourse to EMD method. The flowchart shown in the Fig. 3 [28] clearly shows the process involved in the EMD method.

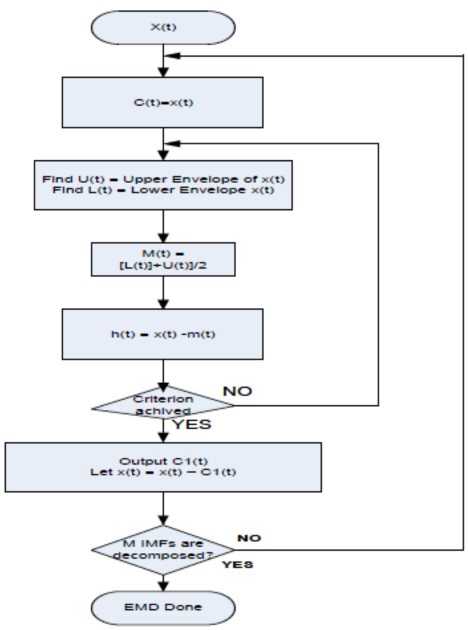


Fig 3 Flowchart for IMF decomposition

In order to validate the effectiveness of the method Record No.16272 (which has BW and does not possess PLI) from MIT/BIH normal sinus rhythm database has been considered. It is shown in the Fig.4.

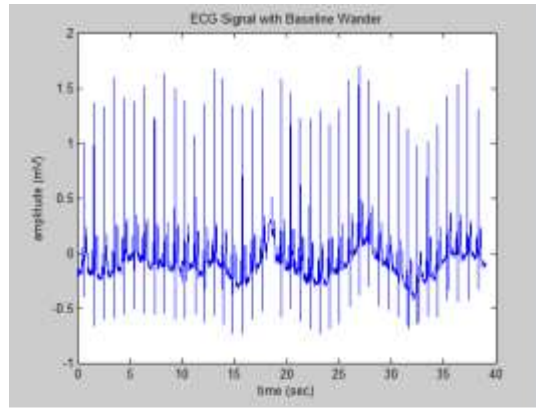
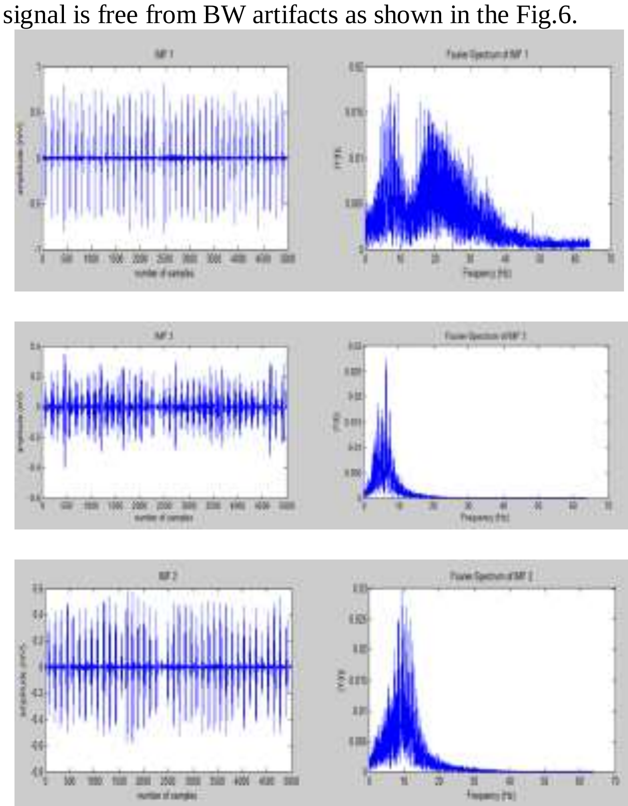


Fig.4: Signal of the record no. 16272

The ECG signal embedded with BW has been decomposed into 11 IMFs and one residue (IMF12) which are shown in Fig.5 left panels and corresponding Fourier Spectrum in right panels. Since BW noise occurs in the frequency range of 0.15 Hz to 0.3 Hz, the IMFs whose frequencies lie below 0.5 Hz can be considered to estimate BW noise. Hence, all the IMFs showing 0.5 Hz and below frequency are identified (IMFs 9, 10, 11 & 12 as shown in Fig.5).These IMFs are clubbed together and their sum is deducted from the noisy ECG signal. The resultant signal is free from BW artifacts as shown in the Fig.6.



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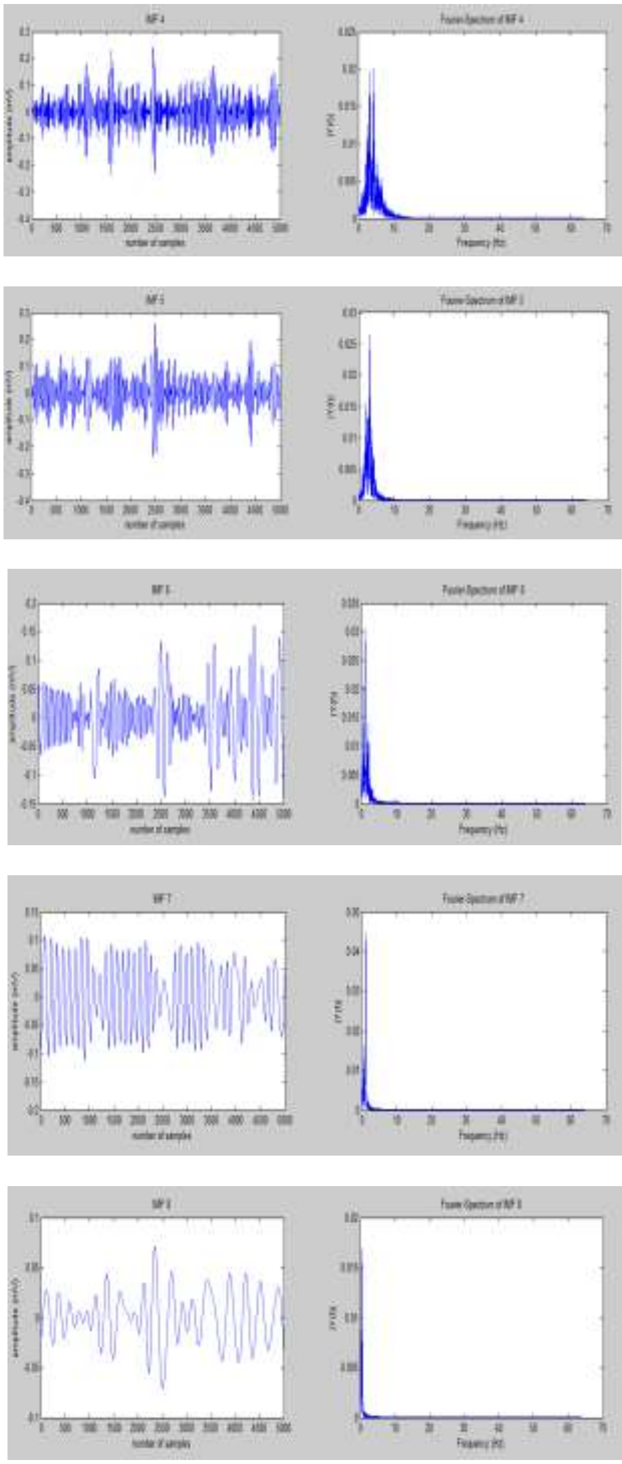

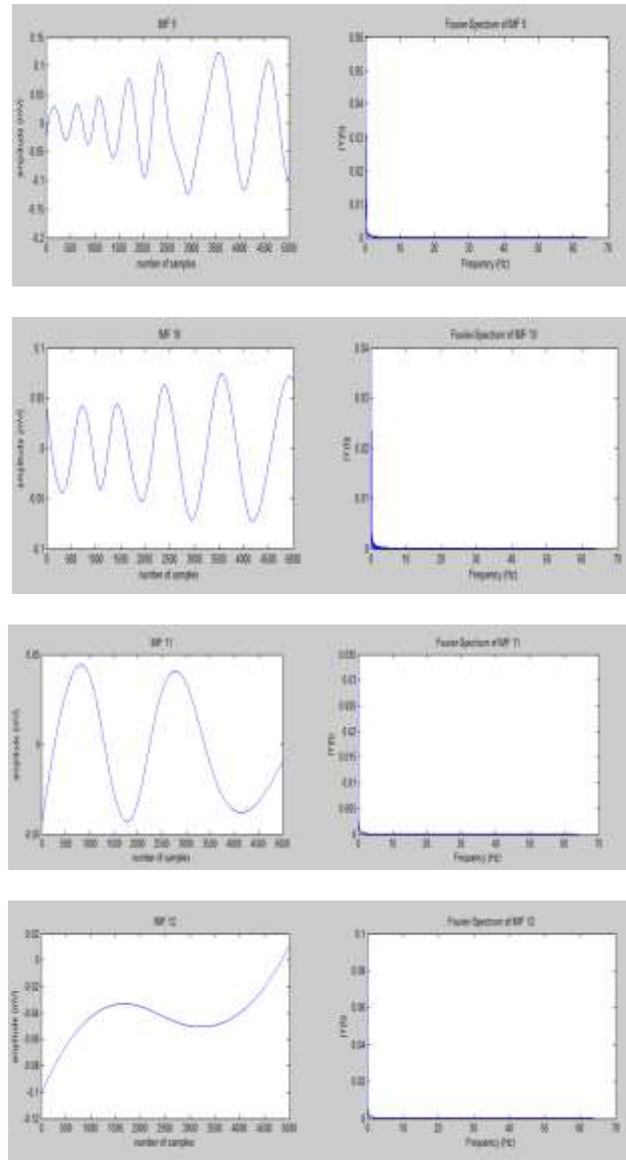

Fig.5: 12 IMFs and corresponding Fourier spectrum

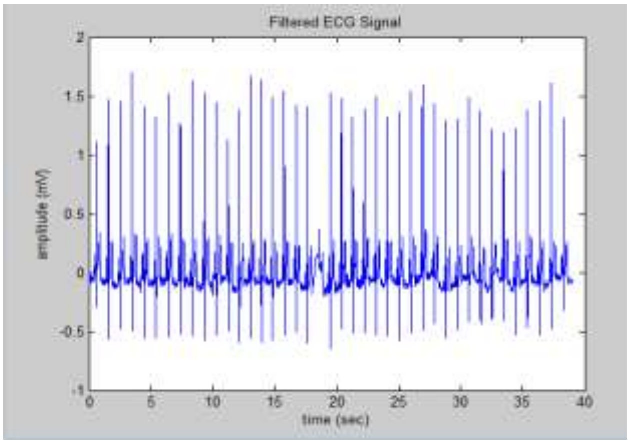

Fig.6: BW free record no.16272

Experimental works and results

Five records of ECG signals were acquired from Normal sinus rhythm data base. The subjects included in the database were found to have no significant arrhythmias. Each signal was sampled at 128 Hz with 12 bits ADC. Each record consists of .dat file,.hea file and .ari file.

The quality of each signal has been enhanced by EMD method as illustrated in the case of record No.16272. Afterwards, the signal is subjected to Pan-Tompkins algorithm and the algorithm proposed by the authors.

Comparison of the values of heart rate

Record No.	Original Values	Pan-Tomkins Algorithm	Proposed Algorithm	Proposed Algorithm using EMD
16272	63.32	63.47	62.32	63.34
16420	96.65	96.00	94.46	95.45
16483	97.76	93.66	96.73	96.74
16773	75.85	80.00	75.51	75.50
16786	71.80	70.46	70.65	70.65

Discussion

It is obvious from the above Table that there is close agreement in the result showing the heart rate determined in three different ways and its original value. Barring one case the result obtained by using Pan-Tompkins algorithm is poor. This may be due to wrong choice of the threshold, as its accuracy is highly dependent on the value of threshold. In this respect the technique applied in the proposed algorithm minimizes the effect of threshold to a lot extent. The proposed algorithm is simple, straight forward, less time consuming and also less complex. The efficiency of EMD method is validated again as the results obtained by the proposed algorithm combined with EMD are much better.

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