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Analysis of EMD Based QRS Detection Methods in Electrocardiogram (ECG) Signal

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Abstract— In this paper comparative study for QRS detection algorithms based on Empirical Mode Decomposition (EMD) are present. EMD is novel tool used for time-frequency analysis of any non-stationary signal. EMD decompose signal in to IMFs. In these study three different methods based on EMD is compared. In all three methods three different techniques are used, so their results are differ. The main objective of this paper is to understand how to use EMD for RS detection purpose. All three algorithms are tested on MIT-BIH arrhythmia database. The results are more promising compared to other methods. Even different methods based on EMD are giving different results.

Keywords— Electrocardiogram (ECG), EMD, IMF, QRS detection.

I. Introduction

The electrocardiogram (ECG) is an important tool for providing information regarding the heart activities. The detection of QRS complex, in particular R peak detection is very important task in the ECG signal analysis for monitoring heart rate and arrhythmia detection. Once QRS complex has been detected more details can be explored. Much research has been done to develop new algorithms or methods for the analysis of ECG signals in these past years. Empirical Mode Decomposition (EMD) is one of the results of these efforts [1-3].

EMD relies on a fully data-driven mechanism that does not require any priori known basis. It is suited for nonlinear and non-stationary signals, such as biomedical signals. Through a sifting process, the EMD can decompose the signal into a series of intrinsic mode function (IMFs). An IMF is defined as a function with equal number of extrema and zero crossings (or at most differed by one) with its envelopes, as defined by all the local maxima and minima, being symmetric with respect to zero. Basically IMFs represents the oscillatory modes of a signal. The lower order IMFs represents the fast or high frequency oscillations whereas upper order IMFs correspond to slow or low frequency oscillations. As per the characteristics of ECG, QRS complex is the high frequency component and P and T waves are the low frequency components of the signal. Hence lower order IMFs can be combined together to reconstruct the signal which highlights QRS region over the other waves and low frequency noises like baseline drift due to respiration etc [12].

In general R wave is the highest amplitude and smallest duration wave in the ECG signal. Being the high frequency part of the mother wave, it must be represented by the lower order IMFs as discussed earlier. Earlier studies [10-11] shows that QRS region is better captured in first three IMFs.

Any QRS detection algorithm involves many steps such as filtering, transformation and peak detection etc. So all algorithm can be categorized in three steps. These steps are

- **Preprocessing**: In QRS detection first step is band pass filtering to remove baseline drift and high frequency component specially 50 or 60 Hz interference of electric power line. This is more important to separate R peak to other artifacts.
- **Transformation**: To emphasis the QRS complex characteristics from the ECG signal we need transformation. Squaring, Averaging, Hilbert transform, Wavelet transform, Hilbert envelope (HE) is used as a transformation. These transform reduces the ambiguity in false detection and gives a large peak at the QRS complex compare to any other distortion.
- **Peak detection:** Different methods applied on the transformed signal to peak detection. The transformed signal used as a input for different signal processing tools, and applied some decision rules to find real R-peak.

In EMD based algorithms these steps may be merged or can be performed separately. EMD decompose signal in to IMFs. So filtering also can be performed by EMD. Because, first three IMFs contain all information about QRS complex, therefore it is used to eliminate QRS complex from rest of signal. So EMD can perform half role of transformation.

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II. Empirical Mode Decomposition Description

The EMD is defined by a process called sifting. It decomposes a given signal x(t) into a set of AM–FM components, called Intrinsic Mode Functions (IMF). Therefore, K modes $d_k(t)$ and a residual term r(t) [4,5] are obtained and expressed by:

$$x(t) = \sum_{k=0}^{K} d_k(t) + r(t), \quad k = 1,2, \ldots\ldots K \tag{1}$$

. The EMD algorithm is summarize by the following steps:

1. Start with the signal $d_l(t) = x(t)$, $k = 1$. Sifting process $h(t) = d_k(t)$, $j = 0$.
2. Identify all local extrema of *h (t)*.
3. Compute the upper *(EnvMax)* and the lower envelopes *(EnvMin)* by cubic spline lines interpolation of the maxima and the minima.

$$m(t)=1/M(EnvMin(t)+EnvMax(t)) \quad (2)$$

4. Calculate the mean of the lowe and upper envelopes.
5. Extract the details $h(t) = h(t) - m(t)$.
6. If h(t) is an IMF, go to step 7, else iterate step 2 to 5 upon the signal h(t), j=j+1.
7. Extract the mode $d_k(t) = h(t)$.
8. Calculate the residual $r_k(t) = x(t) - d_k(t)$.
9. If r_k (t) has less than 2 minima or 2 extrema, the extraction is finished r(t) = r_k(t) Else iterate the algorithm from step 1 upon the residual r_k(t), k = k + 1.

Fig. 1 shows the original ECG (record 219) decomposition using the EMD. IMFs are represented from high to low frequencies.

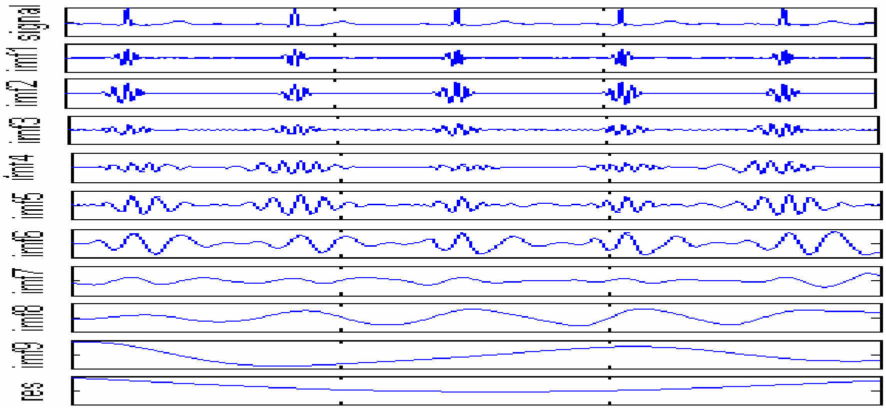

Fig.1: The original ECG and all the IMFs from first to ninth order obtained after Empirical Modal Decomposition

III. METHODOLOGY

In this section three different QRS detection algorithms based on EMD are presented. These methods are recently presented. All three methods are used basic EMD techniques.

A. Method – I

In this method as the first several IMFs are mainly caused by the QRS complex and the high frequency noise, this indicates that denoising on the first several IMFs can filter out the noise and preserve the QRS content. In our method, the first three IMFs are treated with soft thresholds to eliminate high-frequency noise and then are summed together to yield a new signal d(t) . The new signal d(t) can be seen in Fig.3 and Fig. 4 for the clean ECG signal and the noisy signal respectively. The corresponding relationship between the modulus maxima of d(t) and the feature points of the QRS complex connected by the dash lines are also shown in the two figures. From the two figures, we can see clearly that the peaks of QRS correspond to the modulus maxima of d(t) and the QRS is bounded by two zero-crossing points. Such a discovery reminds us that the QRS complex can be easily detected with the modulus maxima method [6]. As most of the QRS are detected in d(t) in our algorithm, d(t) is named the detection layer. In case of false negative detection of the R wave, a leakage detection layer w(t) and a verification layer v(t) are constructed.,

The detail QRS complex detection procedure can be as follows [1]:

1. Read the ECG signal and segment it in every 5 seconds length. Apply the EMD to each segment. Denoise the first three IMFs with the soft threshold method respectively and sum the denoised IMFs to obtain the detection layer d(t) . Sum the detection layer d(t) and the 4^{th} IMF to form the verification layer v(t);
2. The last two IMFs are given to zero and reconstruct the signal with the new IMFs, which forms the leakage detection layer w(t) .
3. With an adaptive amplitude threshold ε to detect all the modulus maxima point in the detection layer d(t) . The point meets the threshold condition can be considered as an R wave.
4. Calculate the average RR interval T_{rr} in the current segment. If there is an RR interval in the current segment longer than 1.5* T_{rr}, such an RR interval will be regarded as a leakage interval. Then half the threshold ε and detect the modulus maxima of the leakage interval in the detection layer d(t) again. If no QRS then switch to leakage layer. Find the maxima point using modified threshold. If detected maxima are not in range of 10-20

ms from the R point in detection layer, it will be consider as new QRS and repeat for three different modified threshold.

5. Utilizing the refractory period, if there is an RR interval shorter than the refractory period, the smaller amplitude of the R wave in w(t) will be treated as a false positive point and discarded.

B. Method-II

It has been observed that compared to the clean case, the most component of the first IMF (IMF1) is high frequency noise which may seriously disturb the QRS complex detection. But the amplitude of IMF1 is small, that is to say, the energy of IMF1 is small. In such case, IMF1 will be omitted and the second IMF (IMF2), the third IMF (IMF3), and the fourth IMF (IMF4) are used to detect QRS complex. The steps for this algorithm are following [2]:

1. Segment the ECG signal and decompose in to its IMFs and residual.
2. Calculate the energy of IMF1 and the ECG signal. if the ratio of the energy is less than 5%, the ECG signal is noisy and IMF1 should be removed, and then IMF2, IMF3, IMF4 are the selected IMFs; else IMF1, IMF2, IMF3 are the selected IMFs;
3. Denoise the selected IMFs with soft threshold method [13] respectively and sum the denoised IMFs to reconstruct the detection layer;
4. Detect all the local maxima points in the detection layer with an adaptive amplitude threshold, ε = 0.3*(0.375*AA+0.125*MA) where AA is the average value of the R wave amplitudes in the previous segment and MA is the maximum amplitude in the current segment. These points are candidates of the main waves of the QRS complex.
5. If current RR interval is shorter than refractory period it means it has false point and if it is longer than 1.5 times, then half the threshold and find the new R peak.

C. Method-III

This algorithm requires the following stages: High-pass filter, Empirical Mode Decomposition signal, nonlinear transform, integration and finally, a low-pass filter

1. *Baseline wander cancellation:* Frequencies in the range of 0–1 Hz should be removed to reduce the influence of the baseline wander. This is achieved by the implementation of a fifth-order high-pass Butterworth filter.
2. IMF estimation of the ECG signal.
3. Nonlinear transform: After IMF estimation, we applied a nonlinear transform [6,7], as follows:

$$y(t) = \begin{cases} \mathrm{abs}(x(n) * x(n-1) * x(n-2), & \text{if } x(n), x(n-1), x(n-2) \\ 0 & \text{otherwise} \end{cases} \quad (3)$$

Where *x(n)* is IMF of ECG signal.

4. Integration: In order to produce a signal that includes information about the slope and the QRS with, a moving window integrator is used [8,9]. This is calculated from as average of output from IMF 1,2 and 3.
5. Low-pass filter and R-position definition: In order to obtain a unique maximum for each QRS complex, we use a first-order low-pass Butterworth filter [12, 13]. The cut-off frequency at −3 dB is about 1 Hz or 2 Hz. The resulting signal z(n), contains only the R-position Rp.

TABLE I
COMPARISON BETWEEN DIFFERENT EMD BASED ALGORITHMS

Method	**Filtering**	**IMF used**	**Transformation**
Method-I	Using soft threshold	IMF 1, IMF 2 and IMF 3	No
Method-II	Soft threshold and removing IMF 1	IMF1, IMF 2 and IMF 3 Or IMF 2, IMF 3 and IMF 4	No
Method-III	High pass Filter	IMF1, IMF 2 and IMF 3	Non Linear Transform

IV. RESULT

All three algorithms are applied on MIT-BIH arrhythmia database. In Table-II we can easily see the performance of different methods on the some ECG records. In this Method –III is giving best performance. Table-III shows the error rate between these QRS detection methods. Again overall performance of Method-III, which is based on non-linear transform, is giving best results.

TABLE III
COMPARISON BETWEEN RESULTS FOR DIFFERENT EMD BASED ALGORITHMS ON MIT-BIH ARRHYTHMIA DATABASE

Record	Method-I		Method-II		Method-III	
	FP	FN	FP	FN	FP	FN
100	1	0	0	0	0	0
103	0	0	0	0	0	0
105	35	14	22	13	15	09
203	23	95	25	20	2	36
223	28	1	2	5	1	0
233	1	7	1	4	0	1

TABLE IIIII
OVERALL PERFORMANCE OF EMD BASED METHODS

Method	% Error rate
Method-I	0.66
Method-II	0.38
Method-III	0.23

V. CONCLUSION

In this paper, the comparative study of three different QRS detection algorithms based on EMD are presented. Method – I and Method-II are giving % error rate 0.66 and 0.38 respectively and Method-II is giving 0.23 % error rate. In method-II a non-linear transform is used. So we can say that any transform can increase the accuracy of QRS detection algorithms. Even EMD is a very useful tool to find QRS complex in ECG signal. It is giving more accurate results compare to other methods.

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