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An efficient wavelet-based automated *R*-peaks detection method using Hilbert transform

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ABSTRACT

Machine-aided detection of *R*-peaks is becoming a vital task to automate the diagnosis of critical cardiovascular ailments. *R*-peaks in Electrocardiogram (ECG) is one of the key segments for diagnosis of the cardiac disorder. By recognizing *R*-peaks, heart rate of the patient can be computed and from that point onwards heart rate variability (HRV), tachycardia, and bradycardia can also be determined. Most of the *R*-peaks detectors suffer due to non-stationary behaviors of the ECG signal. In this work, a wavelet transform based automated *R*-peaks detection method has been proposed. A wavelet-based multiresolution approach along with Shannon energy envelope estimator is utilized to eliminate the noises in ECG signal and enhance the QRS complexes. Then a Hilbert transform based peak finding logic is used to detect the *R*-peaks without employing any amplitude threshold. The efficiency of the proposed work is validated using all the ECG signals of MIT-BIH arrhythmia database, and it attains an average accuracy of 99.83%, sensitivity of 99.93%, positive predictivity of 99.91%, error rate of 0.17% and an average *F*-score of 0.9992. A close observation of the simulation and validation indicates that the suggested technique achieves superior performance indices compared to the existing methods for real ECG signal.

1. Introduction

Electrocardiogram (ECG) is one of the essential tools for diagnosing cardiac illnesses. It reflects the electrical activities of the heart. The primary segments of a typical ECG signal are *P*-wave, QRS complex, and *T*-wave [1]. Numerous medical information on the cardiac system can be accessed by determining the amplitude and duration of ECG segments. By detecting the *R*-peaks in ECG signal heart rate can be calculated and from that point various cardiac disorders in particular heart rate variability (HRV), bradycardia, tachycardia can be determined [2,3]. Hence, proper detection of *R*-peaks in ECG signal is essential for the better treatment of cardiac diseases. When a pathological ECG signal is collected from a patient's body, various noises contaminate with it, in

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particular baseline wander noise, power line interference, muscle artifact etc. [4]. As a result, visual detection of R-peaks for long-term monitoring is a laborious task for a clinician. To the end, the requirement of a computer-based ECG analyzer is essential. Due to the non-stationary behavior of ECG signal computer-based R-peak detection is a challenging task in biomedical engineering.

Various researchers contribute a number of research articles on computer based R-peak detection technique. These techniques are mainly based on digital filtering [5–8], Hilbert transform [9], artificial neural network (ANN) [10], empirical mode decomposition (EMD) [11], short-time Fourier transform (STFT) [12], wavelet multiresolution technique [13–15]. Pan and Tompkins [5] developed an automatic R-peak detection algorithm based on differentiation, squaring and integration method. Though the algorithm is less complex, it yields low accuracy. Moreover, for peak detection, it uses amplitude threshold which degrades the performance of the algorithm. The efficiency of the heuristic method [6] relies on the suitable selection of bandwidth of the band-pass filter. In [9], the authors have proposed a Hilbert transform based R-peak detection algorithm. It employs the fact that, Hilbert transform generates a peak in the transformed signal when there is a zero crossing between two consecutive positive and negative inflexion points in the test signal. Since, the Hilbert transform is applied on the differentiated ECG signal, to isolate the true R-peaks from false peaks suitable amplitude threshold is required. Arzeno et al. [7] employed first order differentiation for R-peaks detection. For first order derivative, high-frequency noise components are amplified that leads toward false detection. ANN based technique [10] requires additional training stage hence, not suitable for real time application. EMD based method [11] provides a satisfactory response, but only a limited number of ECG signals of MIT-BIH arrhythmia database. A technique based on Shannon energy with Hilbert transform (SEHT) [8] detects plenty of false peaks as R-peaks for long pause ECG signals. Wavelet transformed based multiresolution approach is popular for processing of non-stationary signals. A methodology based on continuous wavelet transform (CWT) is described in [13]. The CWT contains redundant signal information that increases the computational complexity. Dyadic wavelet transform (DWT) based methods employ multiple amplitude thresholds for R-peak detection. Thus the efficiency of these techniques is solely dependent on the suitable selection of amplitude threshold values [14,15].

After a detailed survey of important research articles on R-peak detection technique spanning over three decades, it is clear that R-peak detection method has mainly two stages, preprocessing and detection. In the preprocessing stage, noises in the ECG signal are removed, and QRS complexes are enhanced and in the detection stage, by considering some decision rules, R-peaks are detected. Most of the existing techniques in literature employ some set of amplitude threshold value for detection of R-peaks. Hence, for successful detection of R-peaks, a suitable amplitude threshold is desired. Though some research articles utilize some adaptive threshold values which are adapted periodically, these threshold values are determined based on the maximum amplitude of ECG signal over a window, the amplitude of previously detected R-peaks, R–R interval of the past detected peaks etc. In all these situations, the efficiency of the method is highly dependent on the proper selection of initial parameters. In [9], the technique utilizes a single threshold value for R-peak detection. For small and wide QRS complex ECG signals, the method fails to detect numerous R-peaks. In [7], it is tested that by employing another secondary threshold value, the performance of the previous method can be improved, but it detects some false peaks as true R-peaks. Hence, overall efficiency is reduced.

Considering the aforementioned constraints, in this work, a wavelet assisted automated R-peaks detection method has been proposed. In the preprocessing stage, by utilizing the powerful features of time-frequency localization of discrete wavelet transform, the QRS complexes in the ECG signal are enhanced and employing the Shannon energy transform the energy envelopes of QRS complexes are estimated. In the detection stage, by using Hilbert transform, the R-peaks are detected without employing any amplitude threshold value. The efficiency of the proposed technique is validated using standard MIT-BIH arrhythmia database [16]. The performance of the described method is compared with other existing works.

The outline of the paper is presented as follows. In Section 2 a brief description of the described work has been explained. The performance comparison of the proposed work is presented in Section 3. Finally, a conclusive discussion is given in Section 4.

2. Materials and methods

The process flow diagram of the proposed R-peaks detection method is exhibited in Fig. 1. A detailed discussion on each stage is presented in the following sections.

2.1. *Preprocessing*

In this stage, ECG signal is decomposed by using Daubechies wavelet of order 10 (*db10*) and the coefficients associated with the QRS frequency band are extracted.

2.1.1. *Wavelet transform*

Wavelet transform (WT) is a well-known signal processing tool that decomposes a signal into different time-frequency levels [17]. By decomposing the signal into different time-frequency levels, important features can be obtained. Though Fourier transform provides the spectral information of a signal, it is not suitable for processing of non-stationary signal (e.g. ECG signal). Unlike Fourier transform, the wavelet transform decomposes the signal into different time-frequency levels which make it efficient for dealing with non-stationary signals.

The WT controlled by two parameters namely, scaling parameter and translation parameter. Scaling parameter is related to frequency localization and translation parameter is for time localization [18,19].

WT can be classified mainly into two categories, continuous wavelet transform (CWT) and discrete wavelet transform (DWT). The mathematical formula of CWT is expressed as

$$Wx(a,b) = \int_{-\infty}^{\infty} x(t)\psi^*_{a,b}(t)\,dt, \tag{1}$$