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IRBM 38 (2017) 56–61
IRBM

Original Article

Enhanced and Optimal Algorithm for QRS Detection

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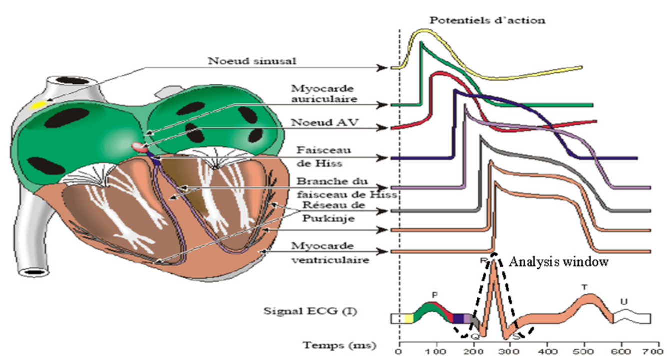
Received 5 October 2015; received in revised form 25 June 2016; accepted 11 November 2016

Available online 14 December 2016

Graphical abstract



Abstract

Purpose: The electrocardiogram (ECG) segmentation step establishes the basis of the cardiac pathologies' classification. We propose here to detect the essential basic forms of this signal to optimize the cost calculation and ensure real-time application.

Methods: An automatic approach for R wave's location of the ECG signal based on the Entropy Criterion (EC) of the Wavelet Transform (WT) is introduced in this paper and implemented on MATLAB platform. The method uses automatic placement of analysis window and adjusting its width by measuring entropy for signal in three localized sub-windows. The WT is applied to the ECG signal at analysis window with a first derivative Gaussian wavelet. The R-wave corresponds to the zero crossing between the two maxima of the WT.

Results: The above-mentioned method (EC-WT) was tested with most noisy signals within QT databases and compared with two methods: the R wave detection method proposed by Martinez et al. and Zhang and Yong. EC-WT achieved good results attaining a sensitivity about 99.94% and a predictivity over 99.8%.

Conclusion: Through this method, the problem of adjustable thresholds for R wave detection is resolved as we apply a dynamic window that fits R peak's parameters. This ensures optimization and efficiency detection in terms of computational cost and complexity.

Keywords: ECG; QRS complex; Entropy; Wavelet transform; Modulus maxima

1. Introduction

QRS complex detectors are extremely useful tools for the analysis of ECG signals. They are used for finding the fiducial

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http://dx.doi.org/10.1016/j.irbm.2016.11.004
1959-0318/

points for averaging methods and to calculate the RR time series in Heart Rate Variability techniques [1]. There are currently a number of QRS detection algorithms available which use a variety of signal analysis methods [2,3]. The most common of these are based on signal matched filters or time–frequency decomposition methods. It is on this basis, entropic measures provide an indication in variations of a signal but the diagnostic of segmentation sets the limits. Diagnosis is thus based on a number of a priori on the breaks to be detected [4,5]. In contrast to conventional techniques, the wavelet transform provides a new dimension to signal processing and event detection.

The ability of wavelet transform to extract ECG features has been demonstrated by several researchers [6]. The majority of them are based on singularity detection via local maxima of the wavelet coefficients signal; therein the correspondence between singularities of a function and local maxima in its wavelet transform is investigated [7,8].

The QRS detection technique proposed by Li et al. [9] is based on finding the modulus maxima larger than a threshold obtained with the preprocessing of some initial beats, using quadratic spline wavelet. Martinez et al. [10] apply a Dyadic Wavelet Transform to a robust ECG delineation system which identifies the peaks, onsets, and offsets of the QRS complexes, P and T waves.

The algorithm presented by Josko [11] is based on Discrete Wavelet Transform (DWT), computed at selected characteristic scales, where QRS complex spectrum energy is the largest. For each transient present in the input signal coefficients of DWT produce localized extremes at several consecutive scales. This property is used in detection process. As characteristic scales are analyzed, the QRS waves can be found. Aligned positions of local extremes at characteristic scales determine the instant of QRS complex in the input signal. Zhang and Yong [12] present a novel algorithm based on continuous wavelet transform (CWT) to accurately detect QRS. It employs a first-order derivative based differentiator to suppress noise and baseline drift and uses high-scale continuous wavelet transform to peak the zero crossing R point produced by differentiator to ease the task of QRS detection.

We present here a new method for QRS wave's locations using the entropy function [13] calculated from the discrete Fourier transform. For the singularity detection through local maxima, we rely on the approach Mallet and Hwang [14] using a first derivative Gaussian function as prototype wavelet. This article is organized as follows: firstly, we introduce the theory of continuous wavelet transform and the notion of entropy. Secondly, we present and explain the detection method. Thereafter, we interpret the results of QRS detection. Finally, we give a conclusion.

2. Entropy and wavelet transform modulus maxima

This article proposes a method combining entropic criterion and Wavelet Transform Modulus Maxima to detect QRS complex. The two theories are introduced in the following.

2.1. Entropic local criterion

In general, the entropy is a quantitative measure of the disorder, and in this context, it defines a measured quantity of information contained in the signal. In the case of the representation of the signal, it comes to measuring the fineness and precision of the location information, location in both time and frequency.

Entropy will allow us to see where the signal energy is localized in the time–frequency plane. Specifically, it will allow us to know what time–frequency representation allows the best location information in the plan.

The entropy associated with a discrete scalar random variable with X achievements $\{x_1, \dots, x_N\}$ and the probability distribution $\{p_1, \dots, p_N\}$ measures its mess [15]. It is defined by:

$$\mathrm{H}[X] = -\sum_{k=1}^{N} p_k \ln p_k, \quad \text{with} \sum_{k=1}^{N} p_k = 1 \tag{1}$$

Since entropy operator will be applied to a channel signal $\{x[n]\}$, $n \in [0, N-1]$, it has implicitly been normalized to 1, so that:

$$\sum_{k=0}^{N-1} \left|X[k]\right|^2 = 1, \quad \text{where} \sum_{k=0}^{N-1} \left|X[k]\right|^2 = \sum_{n=0}^{N-1} x[n]^2 \tag{2}$$

with $X[k]$ the Discrete Fourier Transform DFT of $x[n]$ for $n \in [0, N-1]$ defined for $k \in [0, N-1]$ by:

$$X[k] = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} x[k].e^{-2i\pi k \frac{n}{N}} \tag{3}$$

For any signal $\{x[n]\}$, $n \in [0, N-1]$, the entropy in the sense of the energy distribution of frequencies is legitimate with the following definition:

$$H_{[0,N-1]}(x) = \sum_{k=0}^{N-1} \left(\frac{|X[k]|}{\upsilon}\right)^2 \cdot \log\left(\frac{|X[k]|}{\upsilon}\right)^2 \tag{4}$$

where

$$\upsilon = \sqrt{\sum_{n=0}^{N-1} x[n]^2}$$

2.2. Wavelet transform modulus maxima

Most of the information in a signal is carried by its irregular structures and its transient phenomena, called singularities. A method that excels in finding and identifying these singularities is the Wavelet Transform; because of its capability of decomposing a signal into elementary building blocks that are well localized in both time and frequency. Because of this capability, the Wavelet Transform is capable of defining the local regularity of a signal.

The local regularity of a function is often measured with the Lipschitz exponents [16], also called the Hölder exponent. We define what we mean by a local maximum of the wavelet transform modulus [7].