Detection of T-Wave Alternans in ECGs by Wavelet Analysis

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Abstract

T wave alternans (TWA) is an acute and serious problem associated with the heart and mostly they are reflected in Electrocardiogram (ECG). It is identified as an alteration of the amplitude and morphology of the T wave that occurs in every other beat indicating electrical instability in acute ischemia, where it may precede ventricular tachyarrhythmia. The analysis of TWA is introduced recently as a new diagnostic tool for identification of patients with an increased risk of ventricular tachyarrhythmia or sudden cardiac death. ECGs recorded by sophisticated equipment with specific software can only diagnose TWA. The hard and software are exorbitantly costlier and therefore not available everywhere. In the present study, the TWA is brought out very well from the amplitude of continuous Wavelet transform (CWT) which is not only cheap and simple but also highly reliable and may be considered as an alternate tool for such investigations. This study is also substantiated by the exclusively proposed new mother wavelet namely ECG wavelet. The results are presented highlighting the salient features.

Keywords: T wave alternans; Electrocardiogram; continuous Wavelet transform; discrete Wavelet transform

1. Introduction

Electrical alternans of the T wave describe an alternating beat-to-beat amplitude change in the T wave. It was reported as a marker for ventricular arrhythmias Rosenbaum et al. (1994). Considerable interest has recently been shown in the detection of microvolt TWA as a noninvasive marker of the risk of ventricular tachyarrhythmia in patients with chronic heart disease.
Macroscopic alternans of the T wave is a rare appearance and it is not only linked to malignant ventricular arrhythmias more frequently in the long QT syndrome Khalameizer et al. (2005), but also after administration of some drugs Tan and Wilde (1998). TWA can be found even in Normal ECGs and is generally known that the variation of magnitude and/or shape of T wave in the microvolt domain involve the same arrhythmic risk as do macroscopic alternans. The exact mechanism of alternans is yet to be known. However, it can be determined by spatial and/or temporal differences in repolarization of different regions of myocardium Chinushi et al. (1998) generating unidirectional block and re-entrant arrhythmias or Ventricular Fibrillation (VF) Pastore et al. (1999).

2. Electrocardiogram (ECG)

To interpret an ECG it is necessary to understand the components making up the ECG signal. Each wave and interval appears on ECG is a result of particular electrical function of the heart. Each of three major waves of electric signals appears on ECG represents a different part of the heartbeat. The first wave that appears on ECG is called P wave which records the electrical activity of the heart's two upper chambers (atria). The second and largest wave, the QRS, records the electrical activity of the two lower chambers (ventricles) of the heart. The third wave is the T wave that records the returning to the resting state of heart.

The time interval (duration), or distances between two points in the ECG is as significant as identifying these waves themselves. In other words, the onset and offset of P, QRS and T waves are of great significance in deciphering the health of a heart Sundararajan et al. (2011). They provide information about the progression of impulses through the cardiac cycle. The basic component known as cycle of ECG rhythm is given hereunder in Figure 1.

![Figure 1 Cycle of ECG](image)

3. Wavelet Transform

Over the last two decades, the Wavelet transform (WT) has proven to be a valuable tool in many applications of non-stationary signals including the biomedical signals in general and ECG in particular. The WT provides a time frequency representation of the signal, and thus suitable for the inspection of characteristic waves of the ECG signal at different scales with different resolutions. WT has already been used successfully in various areas of electro
cardiology namely to identify the markers from a multi-scale approach Sahambi et al. (1997), detection of ischemia in the QRS complex Gramatikov and Thakor (1993) and to characterize the time frequency signature of HRV Thurner et al. (1998). The time series pertaining to inter-beat interval (distance between two consecutive R waves) of the human heart exhibits scaling behavior, multiresolution wavelet analysis etc. Mallat (1989), Meyer (1990) and Daubechies (1992) provides an ideal means of decomposing ECG signal into its components at different scales, and at the same time has the salutary effect of eliminating non stationarities Arneodo et al. (1988), Abry and Flandrin (1996) and Teich et al. (1996). Wavelet based methods for compression of ECG signals has been proved to perform well Lu et al. (2000) and Miaou et al. (2002).

4. Materials and Methodology

Wavelets and all their variants result in two dimensional continuous and discretized outputs of two parameters namely the scale and time shift. While the time shift corresponds to time axis of the signal to be analyzed, scale corresponds but is not equal to frequency. However, in wavelet analysis of a given signal, we have to take into account the type of the Wavelet transform, type of the mother wavelet and the desired scale.

An infinite number of options are available in wavelet analysis involving the above aspects which are closely related and must be considered at the same time. However, the present study confines to a few limited options. The first step usually is the type of the Wavelet transform to be considered leading to decide whether to use continuous Wavelet transform (CWT) or discrete Wavelet transform (DWT). The CWT is much more accurate measure of ECG pattern Aldroubi and Unser (1996) and Rajendra Acharya et al. (2002). The type of mother wavelet (here after called wavelet) should be set according to the signal being analyzed and/or the event being detected in the signal. Based on a previous extended survey on wavelets suitable to ECG analysis Andreao (2004) the wavelet namely, complex Gaussian wavelet given as

\[
\psi(t) = \frac{d^2}{dt^2} \left( e^{-i\omega_0 t^2} \right) \quad \omega_0 \geq 5
\]  

is found to be most useful in such a study. Real and imaginary parts of complex Gaussian wavelet are given in Figure 2.
On the other hand, the proposed wavelet namely the ECG wavelet Vasudha (2008) exclusively for the present study is investigated. The proposed wavelet is somewhat similar to Morlet wavelet and is defined as

$$\psi(t) = \frac{2}{\sqrt{3}} \pi^{-\frac{1}{4}} (1-t^4) e^{i\omega_0 t} e^{-t^2/2} \quad \omega_0 \geq 5$$

(2)

The real and imaginary parts of ECG wavelet are given in Figure 3.

The proposed ECG wavelet was established based on trial and error basis and equally applicable in the study of ECG signal even in noisy environment. This wavelet qualify to be standard wavelets as it satisfy the conditions of zero mean ($\int \psi(t) dt = 0$) and compact support. The requirement of zero mean is called the admissibility condition of the wavelet. The selection of scale is based on the number of details in what frequency range is needed for a particular application.

4.1 Denoising of ECG using DWT

ECGs are invariably contaminated by drift and interference caused by several bioelectric phenomena, or by various types of noise, like intrinsic noise from the recorder and noise from electrode skin contact etc. Unfortunately there is no universal method to reduce noise, since the probability distributions of noise are different. However, wavelet analysis ensures minimization of such noise background associated with ECGs and the process is known as wavelet ‘denoising’ Li et al. (1995), Hardle et al. (1997) and Jansen (2001). In this study an eighth lead (V2) of ECG was digitized at the rate of 100 Hz which is adequate enough to accommodate the useful information in an ECG. It was denoised using the DWT with the biorthogonal wavelet ‘bior1.1’ before subjecting for further analysis. The wavelet ‘bior1.1’ is given in Figure 4.
In DWT, a time scale representation of a digital signal is obtained using digital filtering techniques. Further, filters of different cut-off frequencies are used to analyse the signal at different scales. The signal is passed through a series of high-pass filters to analyse high frequencies, and then it is passed through a series of low-pass filters to analyse low frequencies. The resolution of the signal, which is a measure of the amount of detail information in the signal, is changed by the filtering operations, and the scale is changed by up-sampling and down-sampling (sub-sampling) operations. While up-sampling of the signal corresponds to increasing the sampling rate of a signal by adding new samples to the signal and sub-sampling of a signal corresponds to reducing the sampling rate, or removing some of the samples of the signal. A denoised three cycles of an eighth lead from ECG of a normal person with an obscured T wave located at 40, 100 and 160 milli seconds is given in Figure 5.

4.2 Detection of TWA by CWT

On computing the CWT of the denoised lead results amplitude and phase for further analysis. The CWT of a signal is computed by changing the scale of the mother wavelet, shifting it along the time and convolving it with the signal. The amplitude of CWT coefficients was obtained using the complex Gaussian wavelet and shown in the form of 2D contoured images in Figure 6.
Figure 6 Amplitude of the CWT with the Gaussian wavelet

Figure 7 shows the computed amplitude of CWT in the form of 2D contour image using the ECG wavelet.

Figure 7 Amplitude of the CWT with the ECG wavelet

5. Results and Discussions

The study of TWA of normal ECG although results three prominent QRS complexes, the presence of T wave is obscure in time domain (Figure (5)). However, the amplitude of CWT with both the Gaussian and the ECG wavelets has brought out very explicitly the T phases. It is to be noticed that the amplitude level of T wave vary marginally in time domain but prominent variation is observed in Figures (6 and 7) based on CWT analysis. This suggests that the subject although is normal ECG, evidences of TWA is clear and is suggestive of either an existing problem with heart or it may also be due to the side effect of drugs. It may be ascertained that the proposed wavelet viz. the ECG wavelet is found to be reliable in the detection of TWA and may be a potent tool to study wavelet analysis of ECG.

References


