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Detection of Discontinuity in ECG

Using Wavelet Transform

N. Vasudha

Department of Mathematics
Vasavi College of Engineering
Ibrahimbagh, Hyderabad
Andhra Pradesh –500 031, India
nvasudha_raj@yahoo.co.in

N. Sundararajan

Department of Earth Science
Sultan Qaboos University
Post Box 36, Postal Code123
Al Khod, Muscat, Sultanate of Oman
Sundararajan_N@yahoo.com

Abstract

The Wavelet transform has emerged over recent years as a key time frequency analysis and coding tool for the Electrocardiogram (ECG). Its ability to separate out pertinent signal components has led to a number of wavelet based techniques which supersede those based on traditional Fourier methods. It is interesting to note that researchers in the field of Wavelet transform tend to take an approach to their study by either concentrating on the discrete Wavelet transform or the continuous Wavelet transform but relatively a few explore both in depth. Efficacy of Wavelet transform in highlighting small perturbations in an ECG which are not visible to the naked eye is presented in this paper using both CWT and DWT. On the other hand a new mother wavelet is presented for exclusive ECG analysis.

Keywords: Electrocardiogram, continuous Wavelet transform, discrete Wavelet transform

1. Significance of ECG

Electrical activity of the heart is well deciphered from the ECG. Millions of people undergo the ECG and the procedure has saved lives of innumerable patients by showing a serious condition like heart attack with a fair degree of accuracy. It is almost synonymous with a lifeline, as death is diagnosed when the ECG recording shows no activity or a straight line. Despite the progress made in cardiac investigation and development of sophisticated gadgets in cardiology, the ECG remains absolutely invaluable and inevitable in cardiac assessment.

2. Why Wavelet Analysis?

Although, ECG is an indispensable tool to analyze heart, diagnosis of ECG is complicated and can be done only by an expert. Further, as stated earlier it can mislead even well trained physicians and cardiologists and remain as a myth at times particularly while interpreting in the recorded domain. However, such a data when transformed to other domains say frequency, the interpretation is made easy. Thus, the Wavelet transform is not an exception. Wavelet analysis yields fairly good information pertaining to many cardiac problems which cannot be seen in the raw ECG. Wavelet analysis gives classical patterns that are unique to different diseases which differentiates normal from the abnormal at a glance.

3. Wavelet Analysis of ECG

A twelve lead normal ECG is scanned and digitized at a rate of 100 Hz. Figure 1a represents the first cycle in the second lead of a noisy ECG which may be due to dynamic nature of the source and the dynamic systems between the source and recording electrodes. The noisy segment of ECG is subjected to denoising using the DWT with the help of Daubechies wavelet 'db1' followed by the computation of 2D contours using the CWT.

The CWT is much more accurate measure of ECG pattern [1], [4]. Based on a previous extended survey on wavelets suitable to ECG analysis [2], the wavelets namely, The Morlet wavelet given by [3] as:

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

is found to be useful in such a study.

On the other hand, the following wavelet is proposed exclusively for the present study and thereby the feasibility/utility is investigated. The proposed wavelet namely the ECG is defined as:

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

The proposed wavelet qualifies to be standard wavelet as it satisfies the conditions of zero mean ($\int_{-\infty}^{\infty} \psi(t)\, dt = 0$) and compact support and is equally applicable in the study of ECG signal even in noisy environment.

The modulus of CWT of the noisy and the noise freed (denoised with ‘db1’) components of ECG were computed using two different complex valued wavelets namely ***Morlet*** and ***ECG wavelet*** and are shown in the form of 2D contoured images in Figures 3 and 4 respectively. The time scale plane in the figures corresponds to the same time segment of Figure 2. The amplitude of the CWT is useful here to visualize more details by increasing the image dynamics.
To study the ability of complex valued CWT in signal detection, the denoised ECG shown in Figure 2a has been artificially corrupted by a short time event called a discontinuity in the first derivative at t=16 msec and at 40 msec and shown in Figure 2b. Such a discontinuity which represents some sort of abnormal functioning of the heart can hardly be seen in time domain. That is, the ECGs with and without discontinuity are identical as shown in Figures (2a and 2b).
The ECGs in Figures 2a and 2b have been transformed to wavelet domain using Morlet and ECG wavelets. The resulting amplitude of CWT of the ECGs with and without discontinuity are shown in the form of 2D contour images in Figures 3a , 3b and Figures 4a , 4b respectively. As it is known that CWT is capable of detecting short time events regardless of their frequency contents, one can expect significant differences between resulting time scale images.
On the other hand, the corresponding phase of CWT of the ECG (Figures 5a, b and 6a, b) are computed for possible detection of discontinuities as discussed in the case of the amplitude of CWT

5. Results and Discussions

Comparison of Figure 1a with that of Figure 1b , it is observed that the first cycle in the second lead of noisy ECG has improved by the process of denoising using the mother wavelet ‘db1’. It is to be emphasized here that the choice of wavelets ‘db1’ is based on trial and error basis. That is the signal enhancement in this case is found to be maximum in the case of wavelet ‘db1’. In the case of other wavelets, the results are similar and however not shown here. On the other hand, the discontinuity was brought out well in the amplitude of CWT using Morlet and ECG wavelets. Further, in the corresponding phase of CWT, the discontinuity is explicit in the case of all the two wavelets.
Wavelet analysis using two different mother wavelets in the study of denoising and detection of discontinuities associated with heart are illustrated based on the amplitude and phase of the continuous Wavelet transform (CWT). A discontinuity in any segment of the ECG can be brought out fairly well by the the amplitude and the phase of the CWT using existing Morlet and newly proposed ECG wavelet. Hence proposed ECG wavelet is potent tool to study wavelet analysis of ECG.

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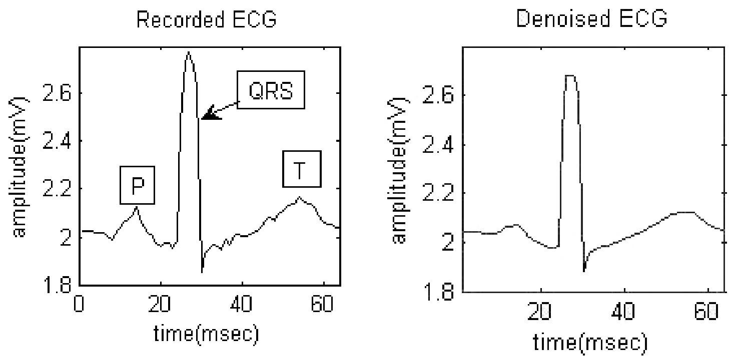

Figure 1a: First cycle from the second lead of a recorded ECG
Figure 1b: The denoised ECG using the Daubechies ('db1') wavelet

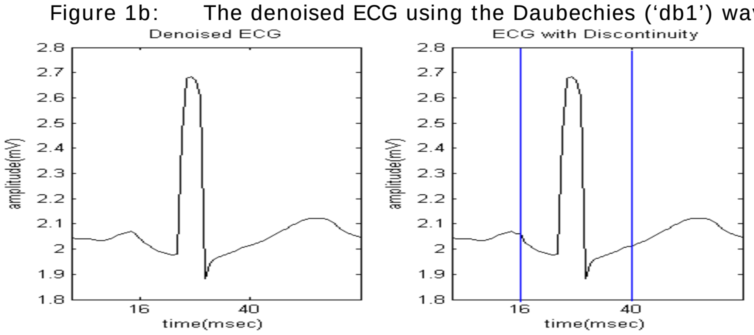

Figure 2: (a) The denoised first cycle from the second lead of ECG
(b) With artificial discontinuity at t=16msec and at t= 40msec

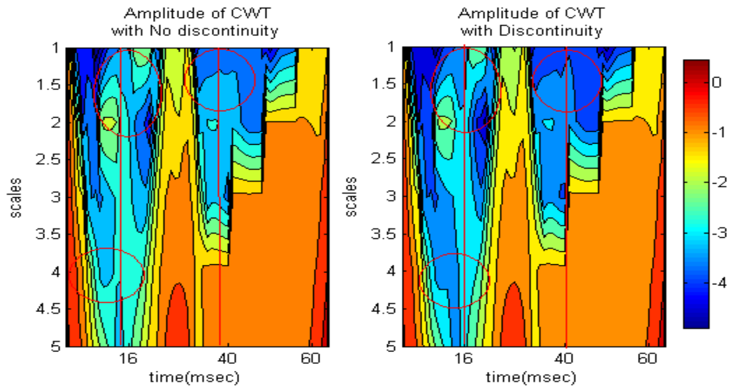

Figure 3: The amplitude of CWT of denoised ECG using the complex Morle wavelet
(a) With no discontinuity and
(b) With discontinuity at t=16msec and at t= 40msec

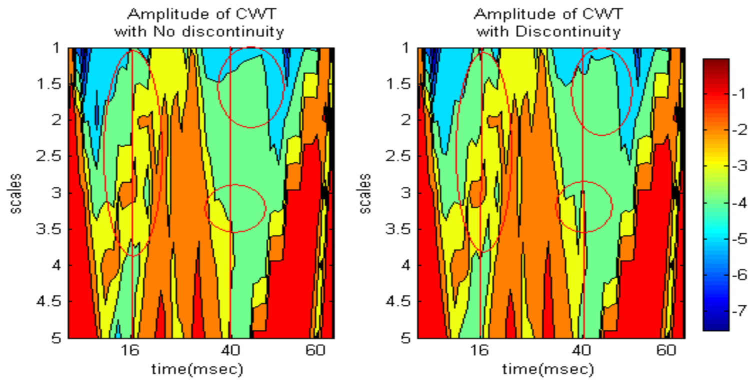

Figure 4: The amplitude of CWT of denoised ECG using the complex wavelet
(a) With no discontinuity and
(b) With discontinuity at t=16msec and at t= 40msec

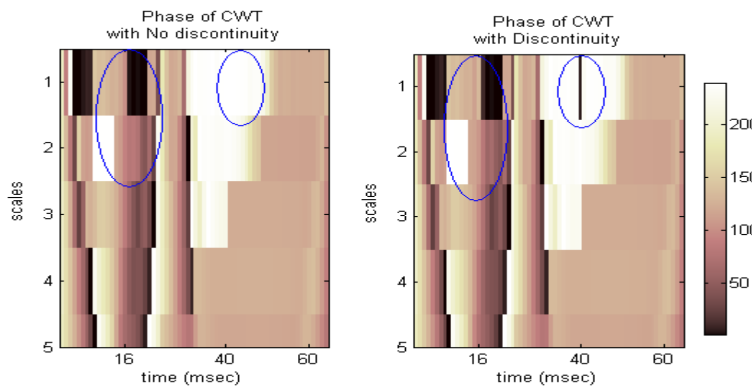

Figure 5: The phase of CWT of denoised ECG using the complex Morlet wavelet
(a) With no discontinuity and
(b) With discontinuity at t=16msec and at t= 40msec

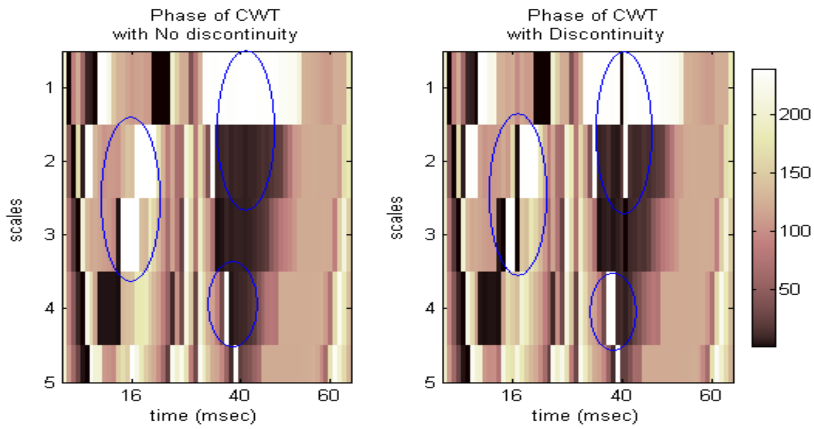

Figure 6: The phase of CWT of denoised ECG using the complex ECG wavelet
(a) With no discontinuity and
(b) With discontinuity at t=16msec and at t= 40msec

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