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WAVELET ANALYSIS OF ABNORMAL ECGS

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Abstract

Detection of the warning signals by the heart can be diagnosed from ECG. An accurate and reliable diagnosis of ECG is very important however which is cumbersome and at times ambiguous in time domain due to the presence of noise. Study of ECG in wavelet domain using both continuous Wavelet transform (CWT) and discrete Wavelet transform (DWT), with well known wavelet as well as a wavelet proposed by the authors for this investigation is found to be useful and yields fairly reliable results. In this study, Wavelet analysis of ECGs of Normal, Hypertensive, Diabetic and Cardiac are carried out. The salient feature of the study is that detection of P and T phases in wavelet domain is feasible which are otherwise feeble or absent in raw ECGs.

Keywords:

Electrocardiogram, Discrete Wavelet Transform, Continuous Wavelet Transform, P and T Phases

1. INTRODUCTION

The incidence of heart disease has doubled in the past 30 years and it is highly likely that cardiovascular disease (CVD) will soon emerge as the major life threatening factor or become the number one killer. People in the high risk category are those who have a history of heart disease, stroke or diabetes, and/or those who have hypertension.

Diabetes must be considered as a major risk factor causing CVD. CVD accounts for as much as 66% of deaths in diabetic patients [1]. Diabetes mellitus can be considered as a vascular disease because it causes both microvascular and macrovascular complications [2]. In addition, studies suggest that diabetic patients are more prone to ‘silent’ or asymptomatic disease [3], [4] and [5] which could be seen in Electrocardiogram (ECG) however with no symptoms and possibly poorer prognosis.

Hypertension (HT) is a major risk factor for coronary heart disease (CHD). CHD is the first cause of morbidity and mortality in hypertensive patients [6]. Early detection of changes in cardiac performance, before irreversible damage to the heart, can contribute substantially to a further decline in hypertension related death.

Some of the characteristics like exact duration, position, onset and offset of P and T phases in ECG help to identify various problems associated with heart. It may be mentioned here that to discriminate a patient whether he/she is Normal, Diabetic, Hypertensive or Cardiac is a difficult procedure even for physicians/specialists based on only ECG analysis [7].

2. WAVELET ANALYSIS OF ECG

Many mathematical analysis of ECG provide somewhat meaningful interpretation, and there by proper diagnosis. Different methods to analyze ECG established earlier were based on the deterministic or stochastic theory [8]. One of the possibilities is analysis of time frequency spectra of the signals. Time frequency analysis reveals changes in signals with the optimum time and frequency resolution. Over the last a decade and half, the Wavelet transform (WT) has proven to be a valuable tool in many applications of non-stationary signals such as 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.

In the present study ECGs pertaining to the four categories enlisted above were chosen for investigating various aspects of Wavelet transform and thereby to identify the type of ECG. In this direction, application of WT yield information explicitly on P and T wave positions in ECGs of various categories of patients which otherwise cannot be known by routine diagnostic techniques.

3. WAVELET ANALYSIS OF ABNORMAL ECG

A cycle of lead aVL in all the cases of ECGs were digitized at the rate of 500 Hz and then subjected to wavelet analysis. The second cycles in aVL lead of ECGs pertaining to Normal, Diabetic, Hypertensive and Cardiac patients were denoised using the biorthogonal wavelet ‘bior1.1’ (Fig.1) before subjecting them for further analysis.

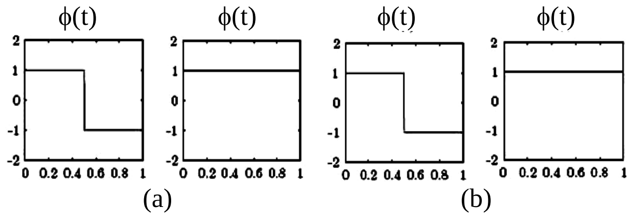


Fig.1(a). Decomposition and (b). Reconstruction filters of ‘bior1.1’

Thus, the process of denoising involves computation of DWT which results approximation and detail coefficients of the ECG signal. Further, these coefficients are passed through a series of high and low pass filters (reconstruction filters) during inverse transformation using inverse Discrete Wavelet transform (IDWT).

Denoised cycle/lead is then subjected to CWT analysis which results the amplitude and phase for further evaluation of ECGS. 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. Based on a previous extended survey on wavelets suitable to ECG analysis [9], the wavelet namely,

- The second derivative of Gaussian function (also known as Mexican hat wavelet) given by [10] as,

$$\psi(t)=\frac{2}{\sqrt{3}}\pi^{-1/4}\left(1-t^2\right)e^{-t^2/2} \qquad (1)$$

is found to be useful in such a study (Fig.2.).

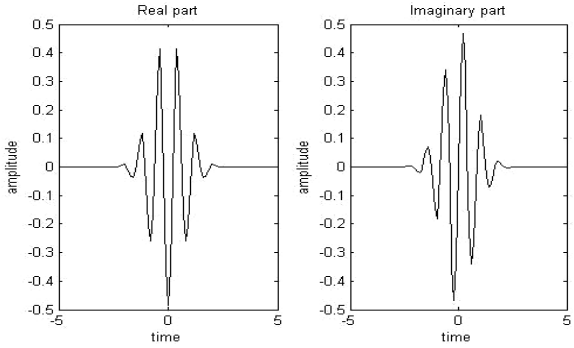


Fig.2. Real and imaginary parts of Gaussian wavelet

On the other hand, a wavelet is proposed exclusively for the present study and thereby the feasibility/utility is investigated. The proposed wavelet namely the ECG wavelet is somewhat similar to well known Morlet and Mexican hat wavelets and is defined as:

- ECG wavelet,

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

The proposed wavelet was established based on trial and error basis and applicable in the study of ECG signal even in noisy environment. This wavelet qualifies to be a standard wavelet as it satisfies the conditions of zero mean $\int_{-\infty}^{\infty}\psi(t)dt = 0$ 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 (Fig.3).

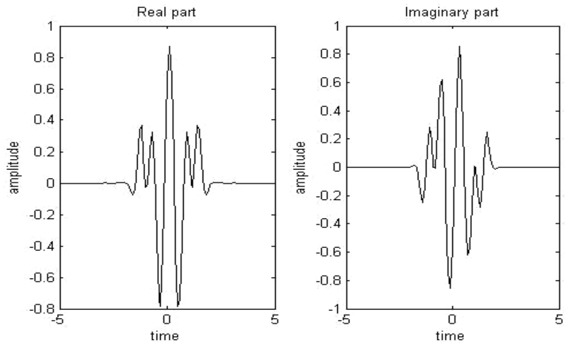


Fig.3. Real and imaginary parts of ECG wavelet

The amplitude of CWT coefficients of the denoised cycles of aVL lead (Fig.4(a) to Fig.7(a)) was computed using the complex Gaussian wavelet (here after referred to as Gaussian wavelet) and shown in the form of 2D contoured images in Fig.4(b) to Fig.7(b) for Normal, Diabetic, Hypertensive and Cardiac cases respectively. The features that are observed in the cycles of different categories of ECGs are highlighted in the corresponding contoured images. Similarly, the amplitude of CWT of all categories of ECGs corresponding to the ECG wavelet are shown in Fig.4(c) to Fig.7(c). The Fig.4(d) and Fig.4(e) to Fig.7(d) and Fig.7(e) denote the phase using Gaussian and ECG wavelets respectively.

4. RESULTS AND DISCUSSIONS

The results of second cycle of aVL lead in all four types of (Normal, Diabetic, Hypertensive and Cardiac) ECGs based on both Gaussian and ECG wavelets were found to yield reliable outcome from the amplitude and phase of CWT.

In Normal ECG, (Fig.4(a)), P and T phases are feeble in time domain however they were brought out very clearly in the amplitude (marked as circles) in both Fig.4(b) and Fig.4(c) in wavelet domain. It is to be noted that the Gaussian and ECG wavelets, although demarcate P and T phases, however in opposite polarity which need to be studied further. Also, the phase of CWT with ECG wavelet (Fig.4(e)) fairly indicates the presence of P and T and in the case of Gaussian wavelet, it is not very explicit.

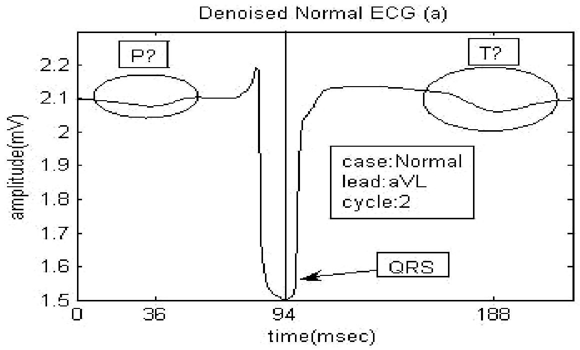
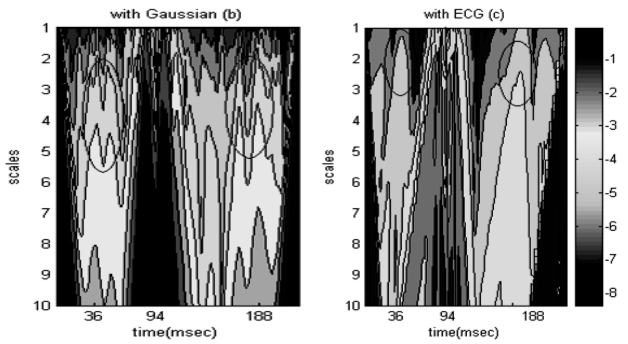
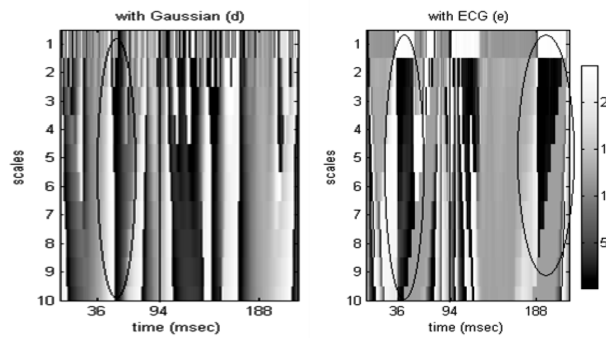


Fig.4(a). The denoised Normal ECG of the second cycle of aVL lead



(b) (c)

Fig.4(b) and 4(c). The amplitude of CWT using Gaussian and ECG wavelets



(d) (e)

Fig.4(d) and 4(e). The phase of CWT using Gaussian and ECG wavelets

In Diabetic ECG, (Fig.5(a)), ambiguous locations of P and T in time domain were clearly brought out in wavelet domain by means of the amplitude of CWT as shown in Fig.5(b) and Fig.5(c). Negative deflection of T wave is clearly evident from ECG where as that of P wave is not clear. The polarity of amplitude of CWT with Gaussian and ECG wavelets indicate negative deflection of P which was not very clear in the original ECG implies Atrial Tachycardia (AT). The phase of CWT with ECG wavelet (Fig.5(e)) indicates the presence of P and T which is obscure in the case of Gaussian wavelet.

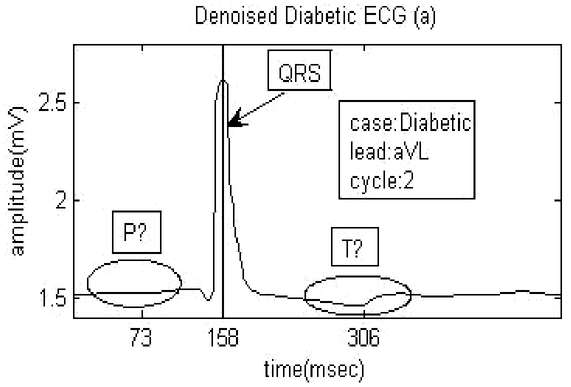
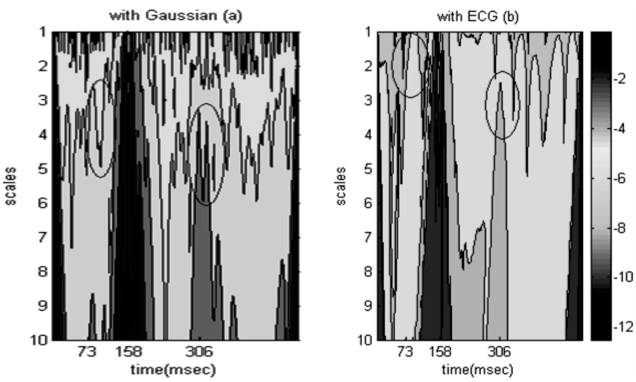


Fig.5(a). The denoised Diabetic ECG of the second cycle of aVL lead



(b) (c)

Fig.5(b) and 5(c). The amplitude of CWT using Gaussian and ECG wavelets

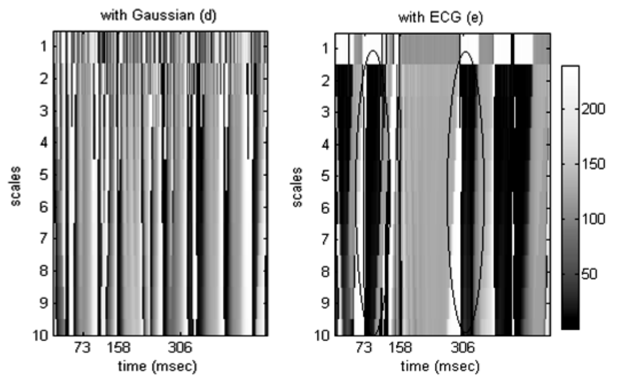


Fig. 5(d) and 5(e). The phase of CWT using Gaussian and ECG wavelets

In Hypertensive ECG (Fig.6(a)), feeble P and T waves were brought out fairly well from the amplitude of CWT in both Fig.6(b) and Fig.6(c). The amplitude of CWT with Gaussian and ECG wavelets confirm negative deflection of T wave, which is an indication of Left Ventricular Hypertrophy (LVH). However, phase of CWT with ECG wavelet (Fig.6(e)) results better localization of P and T than that of Gaussian wavelet.

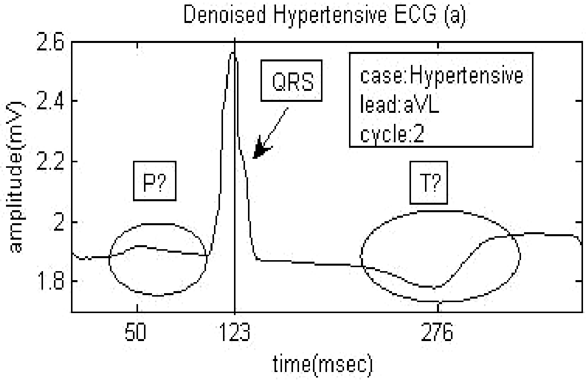


Fig. 6(a). The denoised Hypertensive ECG of the second cycle of aVL lead

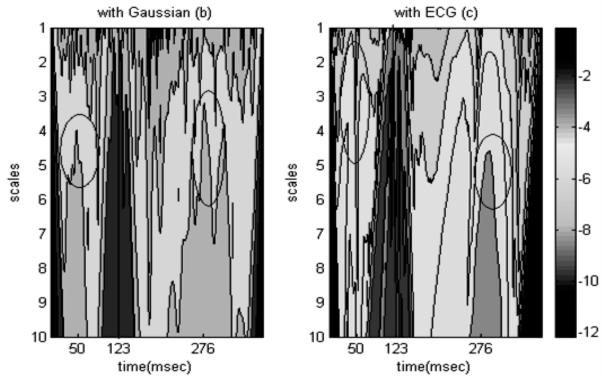


Fig. 6(b) and 6(c). The amplitude of CWT using Gaussian and ECG wavelets

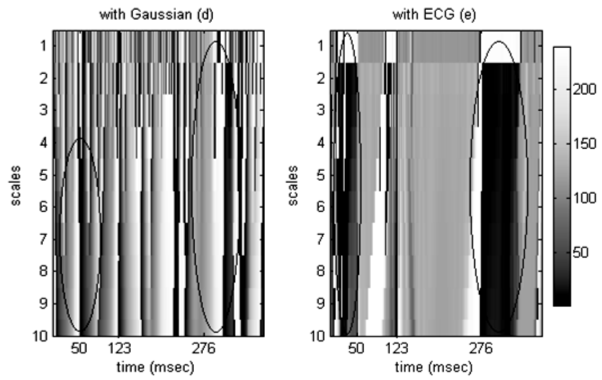


Fig. 6(d) and 6(e). The phase of CWT using Gaussian and ECG wavelets

The P wave in Cardiac ECG (Fig.7(a)), which was not at all visible (usually happens during Bundle Branch Blocks (BBB)) was clearly seen in wavelet domain (Fig.7(b) and Fig.7(c)). That is the amplitude of CWT with Gaussian and ECG indicate clearly the amplitude presence of P wave and the phase of CWT with ECG wavelet (Fig.7(e)) further confirms it.

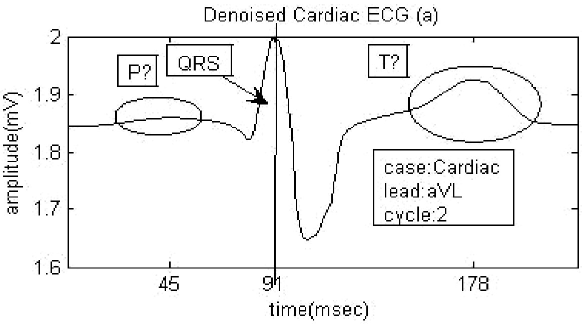


Fig. 7(a). The denoised Cardiac ECG of the second cycle of aVL lead

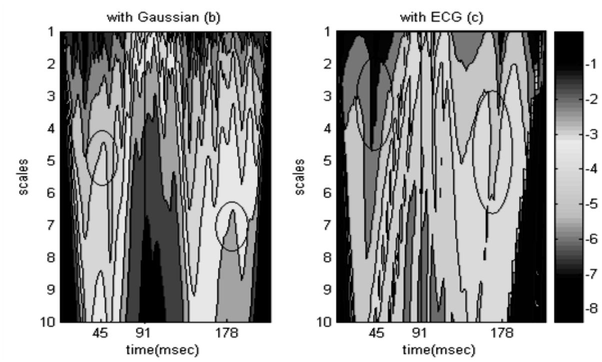


Fig. 7(b) and 7(c). The amplitude of CWT using Gaussian and ECG wavelets

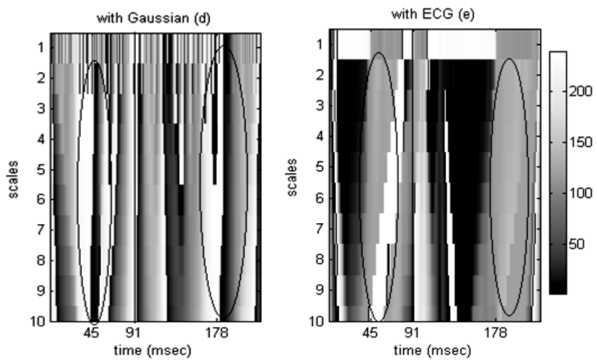


Fig. 7(d) and 7(e). The phase of CWT using Gaussian and ECG wavelets

5. CONCLUSION

The P and T phases which are either conspicuous by their absence or very feeble to be identified/located in raw/original ECG in time domain, are clearly brought out by the amplitude and phase of CWT using Gaussian and ECG wavelets. The proposed mother wavelet namely ECG wavelet exclusively for this study is found to be highly reliable in the detection of feeble P and T waves.

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