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ScienceDirect
Expert Systems with Applications 34 (2008) 746–753
Expert Systems with Applications
www.elsevier.com/locate/eswa

Enhancement of time-frequency properties of ECG for detecting micropotentials by wavelet transform based method

Hüseyin Tirtom, Mehmet Engin *, Erkan Zeki Engin

Ege University, Faculty of Engineering, Electrical, Department of Electronics Engineering, Muh. Bölümü, Bornova, 35100 Izmir, Turkey

Abstract

Time-frequency distributions have been widely utilized in the analysis of transients' nature of biomedical signals. In these applications, the time-frequency components with very small amplitude values cannot be displayed clearly. This drawback results from a masking effect on these components by the presence of high-energy slow waves and sharp patterns in the signal that produces large values in the time-frequency distributions. In this paper, we proposed an effective signal preprocessing method-using kurtosis-based denoising of wavelet coefficients.

This method enhances the time-frequency distributions so that the masking effect is greatly reduced, while the original time-frequency signatures of the input signal are preserved. Experimental studies on ECG signal coming from MIT-BIH database, with and without preprocessing methods have shown a clear improvement in observability and sensivity in the time-frequency distributions.

Keywords: Biomedical signal processing; Electrocardiogram; Ventricular late potentials; Time-frequency analysis; Wavelet transform; Higher-order statistics

1. Introduction

A problem often arises where the time-frequency component with small amplitude values cannot display clearly. This problem resulting from a masking effect on these components by the presence of high-energy slow waves and sharp patterns which produce large values in the time-frequency distribution (Sun, Scheuer, & Sclabassi, 2000). These large values often occur in the time-frequency plane as irregular patterns in the low frequency region, and as wideband, impulsive components at certain points in time (due to sharp patterns). This paper is devoted to the enhancement of detection of deterministic class of signals that we call transient signals particularly the cardiac ventricular late potentials (VLPs). These signals have very low amplitude (1–20 μV), high frequency (40–200 Hz) signals within the terminal region of QRS complex extending to ST of electrocardiogram (Engin, 2002). They arise due to the late depolarization of damaged myocardium, which is particularly prevalent in patients susceptible to ventricular tachycardia (VT). These signals are generally masked by additive noise and background ECG. The detection problem of VLPs is very difficult because of the lack of information on signals of interest:

- The temporal signal shape is not exactly known.
- Its brief existence brings reduced information for its characterization.

In contrast to stationary processes, late potentials are a transient or short-time phenomenon, therefore, it would be expected that their statistical properties should change with time hence, VLPs are considered as non-stationary waveforms (Mousa & Yılmaz, 2004). The ECG signal contains linear non-Gaussian (QRS) and non-linear (P and T) waves and are considered to be highly non-stationary (Zgallai, Sabry-Rizk, Hardiman, & O'Riordian, 1997). The non-Gaussianity condition is satisfied in many practical

* Corresponding author. Tel./fax: +90 232 388 60 24.
E-mail address: mehmet.engin@ege.edu.tr (M. Engin).

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doi:10.1016/j.eswa.2006.10.009

applications, since any periodic or quasi-periodic signal can be regarded as a non-Gaussian signal, and self-emitting signals from complicated mechanical or electronic system can also be considered as non-Gaussian signals (Sabry-Rizk, Romare, Zgallai, & Grattan, 1995). From above mentioned descriptions, VLPs can be considered as non-Gaussian and non-stationary signals. Nevertheless, we have studied the properties that distinguish the signals from background noisy effects.

Modern techniques in signal processing had a higher-order statistics (HOS) and wavelet transform techniques (WT) (Ravier & Amblard, 1998) tend to greatly improve the quality of detection. These techniques take advantage of the properties that differentiate the signal from the noise, and are therefore well adapted when these properties are valid assumptions of the signals.

A number of higher-order correlation-based methods have been carried out to characterize and detect band limited deterministic transients signals such as VLPs (Pflug, Ioup, & Ioup, 1992). For an unknown narrow pulse source signal, the bicorrelation and tricorrelation detectors perform significantly better than the cross-correlation detectors (Ravier & Amblard, 1998). In this work, we present an effective signal preprocessing method using a kurtosis-based operation on discrete wavelet coefficients of ST segment of ECG. This method equalizes the energy of different time-frequency components in the data so that the masking effect is greatly reduced, while the original time-frequency features of the signal are preserved.

In order to detect VLPs, we used ECG records coming from MIT-BIH Arrhytmia database (Physiobank Archieve Index) from normal and pathological ECG records. First, ECG signals are filtered by a bandpass filter for 50–250 Hz. Then, the ST segments are extracted for beat-to-beat analysis. Artificial late potentials (AVLPs) are formed by a sinusoidal packet. For the denoising of the signal segment, discrete-time wavelet transformation is computed by eight levels. The detail coefficients of each subband are hard thresholded by kurtosis-based estimator. After computing inverse wavelet transforms, Pseudo Wigner–Ville Distribution (PWVD) is computed. Then, we have thresholded the PWVD matrix to enhance high frequency components and reduce dynamic range display. After that, we also used grey-scale transformation ($m = 2$) to reduce masking effect of large amplitude components within the ST segment. In addition, the same numerical experiments are performed for real ECG records coming from same database.

2. Background

2.1. Problem definition

There are two types of components in biomedical signals, which often cause problems in time-frequency analysis (Sun et al., 2000). The first type consists of large amplitude, slowly changing waves such as P, T, QRS waves of ECG. Due to the presence of these large values, other components in the data are masked, i.e. they cannot be displayed effectively with sufficient resolution. The second type of problem is the presence of large amplitude, spiky waves that arise abruptly from the baseline waveform. These multiple spiky waves often produce powerful cross terms spreading broadly in the time-frequency plane.

Currently, there exist several methods to attack the weak signal sensivity problem in the time-frequency analysis. The first approach is to use a logarithm-like function in the time-frequency distribution display. The second approach relies on high-pass filtering of the raw data to remove slow varying waves. However, the cut-off frequency of the filter is difficult to determine without knowing the signal's property, and the time-frequency features of the original signal are modified significantly after filtering. The third approach is to threshold the computed time-frequency distributions prior to the display. Obviously this approach again suffers from a loss of useful information and produces no positive effect on the reduction of cross-terms. Many authors have used wavelet transforms or higher-order statistics with application to improve detection process, but always independently. Our criterion is built on a feature of VLPs that distinguishes them from the background noisy effect, which is assumed that has Gaussian distribution. On the otherhand, segmentation of those portions with VLPs from the rest of the ECG or differentiation between different segments within the ECG is an important problem. In order to solve this problem, some researchers (Meste & Rix, 1994) use averaged QRS complex (i.e., 100 beats). As same fashion, we have used the averaged ST segments in real ECG applications. The detection is therefore good when the noise coefficients are Gaussian and the signal coeffients are not.

The non-Gaussianity property is especially true in the spectral domain (Ravier & Amblard, 1998). Actually, many classes of transients such as VLPs are intuitively oscillating. The oscillation produces a few pulses in the spectral domain. When applying a wavelet transform on the signal, these peaks will similarly result in few wavelet coefficients of high energy. The strong coefficients mentioned yield high values of kurtosis of fourth-order cumulant. These fourth-order statistics are traditionally used for measuring a distance to the Gaussian distribution (Kendall & Stuart, 1963). Gaussian signals have fourth-order statistics theoretically equal to zero. Therefore, wavelet coefficients producing large fourth-order cumulant values are highly non-Gaussian. In summary, oscillating characterizing VLPs appearing in noisy observations will induce a great deviation from Gaussianity in the wavelet coefficients domain.

2.2. Wavelet transform and higher-order statistics

The wavelet transform is capable of representing signals in different resolutions by dilating and compressing its basis functions. While the dilated functions adapt to slow