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BISPECTRAL ANALYSIS OF ECG – LATE POTENTIALS

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ABSTRACT

The bispectrum can suppress Gaussian activity and extracts signals ariasing from non-linear process. It is used bispectral analysis to detect diagnostically important low level signals, that are masked by background electrocardiogram (ECG) activity. The detecting performance is tested by Z-statistical test.

Keywords : Bispectrum, ECG signal processing, Late potentials

EKG-GEÇ POTANSİYELLERİN BİSPEKTRAL ANALİZİ

ÖZET

Bispektrum, Gauss olasılık dağılımlı etkinliği bastırmasının yanısıra, doğrusal olmayan süreçten kaynalanan işaretleri ortaya çıkarmaktadır. Bispektal analiz; arka plan Elektrokardiyogram (EKG) tarafından maskelenen düşük düzeyli ancak tanı açısından önemli işaretlerin sezimlenmesinde kullanılmaktadır. Sezimleme başarımı, z istatistiksel testi ile sınanmıştır.

Anahtar Kelimeler : Bispektrum, EKG Sinyal İşleme, Geç Potansiyeller

1. INTRODUCTION

Sudden cardiac death is one of the greatest problem specifically in modern industrialised countries. This case is usually predicted by detection of very small signal components known as Ventricular Late Potentials (VLPs) usually occurred in the late phase of the QRS complex. From the engineering point of view, VLPs are regarded as a manifestation of delayed electrical conduction or a re-entry mechanism in the heart that is caused by small areas of ischemic or demaged tissue of the myocardium(1). Ventricular late potentials are small of about 5-40 micro volts. Their frequency band starts from 40 Hz or even less up to a few hundred Hertz.They occurred during the whole QRS complex but mainly in the last phase of QRS and during the ST segment. These signals generally are masked by background Gaussian noise (ie. ongoing ECG). There are sevaral methods of signal enhacement and feature selection for detection of VLPs. Typically three orthogonal (XYZ) lead ECG signals from patient's surface electrodes are amplified and digitized. To improve signal to noise ratio(SNR), several (200-300) cardiac cycles are cross corelated with template, aligned and averaged(2). The averaged QRS complex is analysed for VLPs in either time or frequency domain. In the frequency domain, energy in a band of frequencies in the spectrum of a windowed signal or energy ratios of high or low frequencies are examined. Other frequency domain methods employ spectro-temporal analysis over large segment of the cardiac cycle. The time domain analysis employs high-pass filtering (cut-off frequency 40 Hz.) of the XYZ leads and combines them into a vector magnitude waveform. Also, Artificial Neural Network (ANN) approach and Wavelet Transform based methods are used to detect the VLPs. Recently, employing higher order statistics (or cumulant) has be come an efficient approach for detection of deterministic or non Gaussian signals in Gaussian noise. This is motivated by the fact that higher order cumulant have a natural tolerance to Gaussian noise (white or colored). Bispectrum based detector shown a significantly higher reliability than PSD (power spectral density) or time domain based detectors. This improvement can be to decrease the false alarm probability as well as to reduce the amount of data necessary. In the analysis of biosignals practiced so far, a distinction is made, in general , between two alternatives of signal processing: ensemble averaging in the time domain to increased the SNR, and averaging in the frequency domain to obtain good

consistency of the power spectral density. In the time domain, latency fluctuations reduce the obtainable increase of the SNR. The bispectrum combines the advantages of the both approaches: noise is suppressed, which leads to an increase in SNR, and consistency is improved by averaging in the frequency domain. Another essential property of the bispectrum is that the phase shifts resulting from latency fluctuations in the time domain do not be come noticeable. In this study, we applied the bispectrum to beat to beat ECG recordings to extract the VLSs.

2. HIGH ORDER SPECTRUM

The classical power spectrum (based on auto-correlation) only reveals the Gaussian and linear information, while the high-order spectra produces non-Gaussian and non-linear information. Third-order cumulant sequence $R(m,n)$ of the zero-mean discrete sequence $x(n)$ is identical to its third-order moment sequence (3).

$$R(m,n) = E\{x(n)\,x(n+m)\,x(n+n)\} \qquad (1)$$

where $E\{\cdot\}$ denotes the expectation operation. The bispectrum $B(w_1, w_2)$ of $x(n)$ is defined as the two-dimensional Fourier Transform of $R(m,n)$:

$$B(w_1, w_2) = \sum_{k=-\infty}^{\infty}\sum_{l=-\infty}^{\infty} R(m,n)\exp\{-j(w_1 \cdot m, w_2 \cdot n)\} \qquad (2)$$
$$|w_1|, |w_2| \le \pi$$

where w_1, w_2 are the frequency variables. Interaction between two harmonic components of a non-linear process would produce the power of their sum/or difference frequencies. This phenomenon could be due to quadratic non-linearitiy dependence called quadratic phase coupling (QPC). The bispectrum capable of detecting and quantifying phase coupling while the power spectrum suppresses all phase relations. Thus, only the phase coupled components contribute to the third-order cumulant (TOC). The TOC based bispectrum for the Gausian noise will be zero. If the signal of interest does not have a random phase, the qudratic phase coupled components within the signal can be detected. The ECG is a background Gausian signal with respect to the VLPs. The analysis of VLPs can be considered similar to the detection of the non-linear QPC. In order to test the QPC components, let $x(n)$ be a real discrete process.

$$x(n) = \sum_{i=1}^{6} A_i \cdot Cos(\pi f_i \cdot n + \phi) \qquad (3)$$

where $f_1 = 300Hz$, $f_2 = 150Hz$, $f_3 = f_1 + f_2$, $f_4 = 155\ Hz$, $f_5 = 200\ Hz$, $f_6 = f_4 + f_5$ and n denotes number of samples. These frequencies represent the harmonics of VLPs and non-linear intraction between some two harmonic component. Physically, high frequency components of VLPs extend to approximatly 300 Hz. These QPC components is shifted in a randomly fashion within the zero-mean Gaussian sequance $w(n)$. The detection of the QPC components produced by TOC based bispectrum techinique was performed for several SNR values..

3. ECG APPLICATIONS

In contrast to stationray processes, VLPs are a transient or short-time phenomenon. Therefor, it would be expected that their statistical properties should change with time.Hence, VLPs should be considered as a nonstationary waveform(4). In this study, we proposed the TOC based VLPs analysis method.

In order to detect the cardiac late potentials, the normal derivation ECG signals taken from MIT-BIH data base was used for testing our algorithm. MIT-BIH(Massachussetts Institue of Technology- Beth Israel Hospital) recordings were taken between 1975 and 1979 years and consist of more than 4000 long-term Holter recordings. Data base signals are sampled at 360 Hz originally. For the high-resolution VLPs, we doubled the sampling rate by applying linear interpolation on the 720 Hz - samped rate. We processed the 520 samples long segment of the signal starting from the R wave. A randomly shifted sinusoidal packet is inserted to this ST segment to be sure of the late potential activitiy. Before the bispectrum process, the zero-mean $s(n)$ is passed through the Teager energy – operator to enhance the signal-noise ratio. The Teager energy operator is capable of extracting of the discontinitues due to the transient components as like VLPs(5). The Teager operation is given as follows,

$$T_s[n] = s^2(n) - s(n-1)s(n+1) \quad (4)$$

Detection Statistics

Given an N-length observation of the received discrete sequence $s(n)$; null and alternative hypotheses are as follows:

$$H_0 : s(n) = w(n) \text{ noise alone} \quad (5)$$

$$H_1 : s(n) = y(n) + w(n) \text{ signal plus noise} \quad (6)$$

where $w(n)$ is a zero-mean Gaussian process (background ECG) and $y(n)$ is non-Gaussian signal (VLP components). We have performed the 100 TOC based bispectrum operation for each SNR. Randomly shifting of the VLP activity may be a useful techinique for ECG physiology.

The bispectrum estimation of the signal of interest, $\hat{B}(w_1, w_2)$ is asymptotically complex normal, with unit variance and independent real and imaginary parts (6). The averaged Singular-values (SV) of the imaginary parts of the TOC based bispectrum are considered as a new random variables (n) with the same variance. If the null hypotheses, Ho is accepted then It is assume that only background ECG exists. We estimated a parameter , θ which represents VLP effect of coming from repeated 100 trials for each SNR by Z-hypotheses test. The statistics is given as follows,

$$\theta(n) = \frac{\mu_\theta - \mu_0}{\sigma_\theta / \sqrt{n}} \quad (7)$$

where μ_θ denotes the mean of the new random variables for $s(n)$ and μ_0 is the threshold which corresponds to the mean of the new random variables for the $w(n)$ and σ_θ denotes standart deviation and n is the number of samples. We defined signal to noise ratio as follow , SNR=$10\log_{10}\sigma_y^{\,2}/\sigma_w^{\,2}$.

4. RESULTS AND DISCUSSION

In order to verify the detection of VLPs by TOC based bispectrum, we made so some simulations at different SNR level. For every trial, VLP effect is represented by a sinusoidal packet with random phase. We introduce a new variable μ_θ which represents the averaged over hundred singular values of the imaginary part of the bispectrum that includes the VLP componenets. This averaging process is repeated for every ten trial to determine the optimum detection condition. In order prove that there is an optimum detection we made visual investigation of bispectrum as well. Once that is achieved, μ_θ parameter can be determined at the end of the process. Background ECG's μ_o parameter is around the value of 0.69. We selected , $\sigma_\theta^{\,2}$ as the variance of μ_θ and the significance level of the hypothesis test as α =0.01. The significance level also represents the rejection risk of the null hypothesis Ho. Using the above mentioned variables as input to the " z-test " function we found the followings variables as results; binary based detection criteria (h), probability (pvalues), and confidence interval (ci). All of these are shown in Table 1. Depending on the values of h, the null hypotheis Ho can either be accepted (h=0), or rejected (h=1). In case Ho is accepted then we assume that only background ECG exists. As a result, taking into account the probabilities of different SNR values we produce the graphic shown in Figure 1. The method above allows us to determine the effect of VLPs in ECG.

5. CONCLUSIONS

This study presents a method for detecting non-Gaussian stationary signals (VLPs) in Gaussian noise (background ECG) using a bispectrum. The results of experiments show that the proposed detector has been successful.

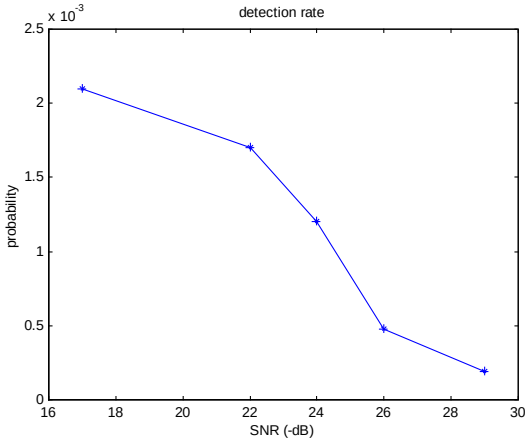

Figure 1. Probability Rate

Table 1. Statistical Test Results

SNR (-Db)	μ_θ	μ_o	σ_θ	α		h	pvalue	ci (confidence interval)
-17	118,7	0,69	38,42	0,01		1	0,0021	19,7-217,6
-22,25	17,1	"	5,23	"		1	0,0017	3,62-30,57
-24,75	10,13	"	3,632	"		1	0,0012	0,77-19,48
-26,69	5,351	"	1,336	"		1	4,8.e-004	1,90087-8,79
-29,19	1,923	"	0,33	"		1	1,93e-004	1,07-2,77

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