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The Noise Influence on Determination Dominant Frequencies of EGG Signal

D. Komorowski, S. Pietraszek

Abstract— **Electrogastrographic examination (EGG) can be considered as a noninvasive method for an investigation of a stomach slow wave propagation This paper presents a method for determining dominant frequencies. It also shows details of influence of a noise on dominant frequencies determination. The EGG signal is noninvasively captured by appropriately placed electrodes on the surface of the stomach. The typical range of frequency for EGG signal is from 0.015Hz to 0.15Hz. One of EGG signal analyzing method is based on a determination of dominant harmonic frequencies contained in the chosen segments of EGG signal. The dominant frequencies are used for calculation base parameters of the EGG signal.**

I. Introduction

The EGG examination can be considered as a noninvasive method for an investigation of a stomach slow wave propagation [1][2]. Nowadays EGG signals recording is a standard method for the stomach examination. During the signal registration process the standard protocol is applied according to the EGG Task Force recommendations [3]. The registration process usually includes 30 minutes before the standardized meal (preprandial) and 30-120 minutes after the meal (postprandial).The typical range of frequency for EGG signal is from 0.9cpm to 9.0cpm (cycle per minute). The analysis of EGG signal power spectrum density allows determination of the frequency distribution of EGG segments. The typical EGG examination is divided into three parts: preprandial, meal and postprandial. The preprandial and postprandial parts are divided into 30 minutes long sections (periods). Each period is divided into segments containing 60 seconds of data. The power spectrum density (PSD) is calculated for each segment. The overall power spectrum density (OPSD) is calculated as an average PSD of all segments for each period. Based on the PSD and OPSD the dominant frequencies (DF) are calculated for each segment and for each period (overall dominant frequencies (ODF)). The segments of EGG signal are categorized as according to the dominant frequency: bradygastria (0.5-2.0cpm), normalcy (2.0-4.0cpm) or tachygastria (4.0-9.0cpm) [3][4]. If determination of the dominant frequency by means of standard 2.5dB threshold is not possible, the segment of EGG signal is classified like an arrhythmia [4]. Apart from that, other parameters such as Maximum Dominant Frequency Difference (MDFD) are calculated. The calculation is based on results from the OPSD analysis.

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D. Komorowski is with the Silesian University of Technology, Institute of Electronics, Division of Microelectronics and Biotechnology, Gliwice, Poland (fax: +4832 2372225, e-mail: dariusz.komorowski@polsl.pl).

S. Pietraszek is with the Silesian University of Technology, Institute of Electronics, Division of Biomedical Electronics, Gliwice, Poland (phone: +4832 2371089, e-mail: stanislaw.pietraszek@polsl.pl).

II. Method

The EGG signals were recorded by means of the four-channel amplifier which can be characterized by the set of the following parameters: frequency range from 0.015Hz to 50Hz, gain k=5000, amplitude resolution - 12 bits, sampling frequency 200Hz per channel and signal amplitude range ±2mV. Relatively high sampling frequency allows for synchronous analysis of heart rate variability (HRV). The variability is not the subject of this work.

During the signal registration process standard electrodes have been applied according to the standard [4], including four signal electrodes (A1-A4), the reference electrode and the ground electrode. In this work the several minutes length 4-channel records of the real EGG signal have been used. Apart from that, test signals with known parameters like: frequency, amplitude and noise level have been used.

Preliminary filtering of the recorded signals has been applied. The following useful EGG signals were extracted from the joint recorded signal: the EGG and the electrocardiographic (ECG). The EGG signal extraction has been performed by application of the band-pass filter covering the range 0.015Hz-0.15Hz [3]. An example of recorded and preprocessed EGG signal is shown in Fig. 1.

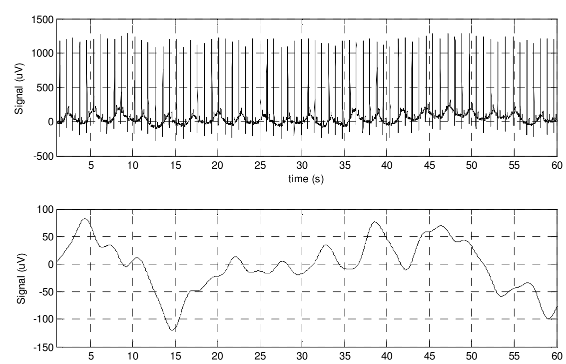

Fig. 1. The example of one-channel recorded (top) and preprocessed EGG (bottom) signal.

The lower cutoff frequency results from the high-pass RC filter applied in the amplifier hardware and the digital fourth-order high pass Butterworth filter. The upper cutoff frequency results from the application of the digital fourth-order Butterworth filter. Next the obtained signal has been resampled. The new sampling frequency has been set to 4Hz.

A. Calculation of Dominant Frequency for Segments

Except the first segment, each of segments included 10 seconds overlap of the previous segment. The spectrum analysis was made for these segments of the EGG signal. The spectrum analysis of the EGG signal was performed by means of identification parameters of an autoregressive model and an estimation of the power spectrum density.

A time series $x[n]$can be modeled as an AR process. The AR model is given by input-output difference equation

$$x[n] = -\sum_{k=1}^{p} a_k x[n-k] + e[n] , \quad (1)$$

where $x[n]$ is the output of the model, $e[n]$ is the input of the model, a_k are its coefficients, and p is the order of the model. The input $e[n]$ is a zero mean white noise process with unknown variance σ^2. This model is usually abbreviated as an AR(p). The power spectrum density of the AR(p) is given by

$$P_{AR}(f) = \frac{\sigma^2}{\left| 1 + \sum_{k=1}^{p} a_k e^{-j2\pi fk} \right|^2} . \quad (2)$$

If the coefficients a_k and the noise variance σ of the AR(p) model are identified, the power spectrum density $P_{AR}(f)$ can be calculated. After some mathematical manipulation and simplification of Eq. (1), the Eq.(3) for $k \geq 0$ is obtained.

$$E(x[n]x^*[n-k]) = \sum_{l=1}^{p} a_l E(x[n-l]x^*[n-k]) + E(e[n]x^*[n-k]) , \quad (3)$$

where * denotes the complex conjugate and E is the expectation. Eq.(3) is often written by the following expressions and known as the Yule-Walker equations Eq.(4)

$$r[k] = \begin{cases} -\sum_{l=1}^{p} a_l r[k-l], & k > 0 \\ -\sum_{l=1}^{p} a_l r[k-l] + \sigma^2, & k = 0 \end{cases} , \quad (4)$$

where the $r[k]$ is the autocorrelation function of the process realization. The estimation of the p unknown a_k coefficients from Eq.(4) requires at least p equations as well as the estimates of the appropriate autocorrelations. The equations that require the estimation of the minimum number of correlation lags are given by the following formulas

$$\hat{R}a = -\hat{r} , \quad (5)$$

where $\hat{R}$ is the $p \times p$ matrix

$$\hat{R} = \begin{bmatrix} \hat{r}[0] & \hat{r}[-1] & \hat{r}[-2] & \cdots & \hat{r}[-p+1] \\ \hat{r}[1] & \hat{r}[0] & \hat{r}[-1] & \cdots & \hat{r}[-p+2] \\ \vdots & \vdots & \vdots & \cdots & \vdots \\ \hat{r}[p-1] & \hat{r}[p-2] & \hat{r}[p-3] & \cdots & \hat{r}[0] \end{bmatrix} \quad (6)$$

and

$$\hat{r} = [\hat{r}[1]\, \hat{r}[2] \, \cdots \, \hat{r}[p]]^T . \quad (7)$$

The parameters a are estimated by

$$\hat{a} = -\hat{R}^{-1}\hat{r} , \quad (8)$$

and the noise variance $\hat{\sigma}^2$ can be found from

$$\hat{\sigma}^2 = \hat{r}[0] + \sum_{k=1}^{p} a_k \hat{r}^*[k] . \quad (9)$$

The power spectrum density estimate is obtained if $\hat{a}$ and $\hat{\sigma}^2$ are substituted in Eq. (2). This approach for estimating the AR parameters is known in the literature as the autocorrelation method [5].

In AR modeling techniques the most important issue is choosing the proper order of model [6]. In the presented paper the model order was chosen by using the information criterion (AIC) due to Akaike [7]. According to the AIC criterion, the best model is the one that minimizes the function $AIC(k)$ over k defined by

$$AIC(k) = N \log \hat{\sigma}_k^2 + 2k , \quad (10)$$

where k is the order of the model, and $\hat{\sigma}_k^2$ is the estimated noise variance, and N is the number of data samples [5][6][8]. The selected order of the model substantially influences the PSD shape. Details of the analyzed signal may by lost by selecting too low order of the model. Too high order of the model may cause the power spectrum to include additional components that do not exist in the analyzed signal.

In this work the Tukey window was applied to each of the one minute length EGG signal segments. The length of the window was set to 256, and parameter α was equal 0.25 [9]. The model order was calculated for the each segment of signal multiplied by the window. Next the coefficients of the AR model was calculated by the means of Levinson-Durbin algorithm [8].

Because we are mainly interested in the base frequency and lower harmonics of the EGG signal, and we do not want to use high order models, we apply prefiltering of the signal. We selected a 6th order Butterworth filter with cut-off frequency at 0.5Hz. The prefiltered signal was used again to calculate the new coefficients of the AR model. To enhance details of PSD the new model order was increased by adding a constant value to the previous calculated order of the model. This value was set to 6. The PSD for all preprocessed segments was calculated.

The dominant frequency is defined as a value of frequency for the highest peak of the PSD, in the range 0cpm-9cpm. For some shapes of the PSD, maximum of the PSD occurs for zero frequency. In this case the next maximum is analyzed. If the next maximum exists in the range 0.01 to 9.00cpm, and the difference between the first and the second maximum is less then 2.5dB the dominant frequency is established (corrected) for the second maximum. The examples of such a case for real EGG signal is shown in Fig. 2.

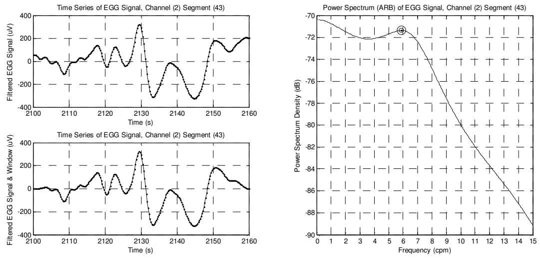

Fig. 2 The example of real EGG signal, the EGG signal after window operation and PSD of signal (correction of DF).

B. CALCULATION OF OVERALL DOMINANT FREQUENCY

The OPSD of periods were calculated by averaging PSD of one or four minutes long segments. For one-minute segments the overlap was set to 10 seconds, while for four-minute segments the overlap was set to 120 seconds. The PSD were calculated using autoregressive modeling (AR1, AR4) and periodogram (PER4) methods. Additionally the pseudospectrum was calculated with the means of MUSIC algorithm (MUS4). The digit in abbreviations means the length of segment in minutes.

III. RESULTS

The test sinusoidal signals with known amplitude, frequency and added noise were generated. The frequencies were chosen to cover whole band the EGG signal (1.0-9.9cpm, Δf=0.25cpm). The amplitudes were set similar to observed EGG signals (up to 400μV). The length of test signals was set to 30 minutes, sampling frequency - 200Hz, resolution-12bits. The noise signal was added to test signals. The noise was generated using the random numbers generator with the uniform distribution. The obtained noise was filtered by the same filters (lowpass and highpass) that were used for the EGG filtering. The filtered noise was normalized due to obtain the assumed noise to signal ratio (n/s). A value of noise to signal ratio equal to zero means pure signal, while a value equal to one means that the standard deviation of noise and the signal are the same in the chosen section. An example of test signal with noise is shown in Fig. 3.

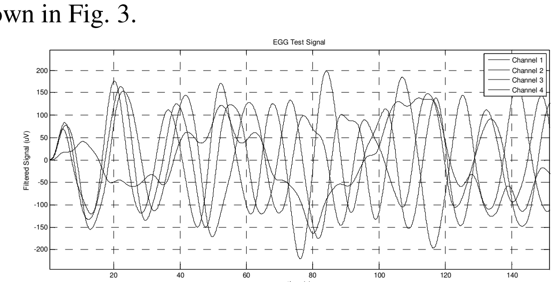

Fig. 3 The example of the four-channel test signal (f=3.00, 3.25, 3.50, 3.75cpm, n/s=0.3).

The dominant frequency was found for each segment. To show the influence of noise on DF, the frequency of test signal was set to 3.00cpm (typical dominant frequency of the EGG for health adult). The distributions of dominant frequencies for the test signal (f_0=3.00cpm), for different n/s ratio (n/s=0.0, 0.2, 0.5, 0.8) are shown in Fig 4.

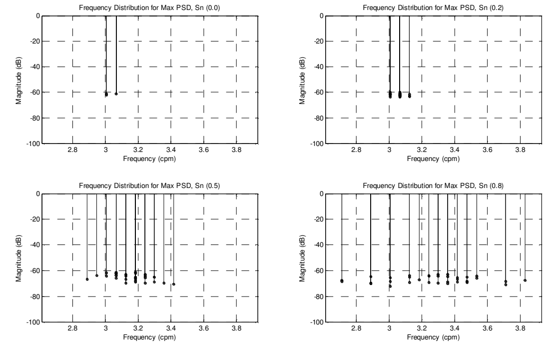

Fig. 4 The distributions of dominant frequencies for test signals (f_0=3cpm, n/s=0.0, 0.2, 0.5, 0.8).

The histograms of dominant frequencies for different n/s ratio are shown in Fig 5.

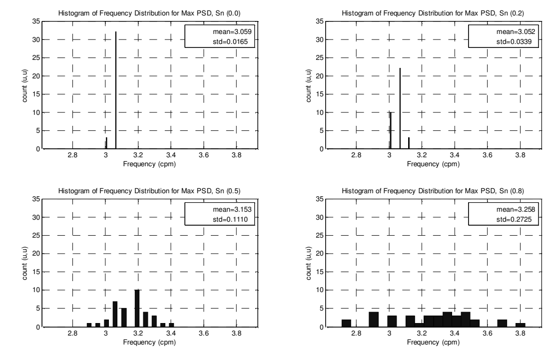

Fig. 5 The histograms of dominant frequencies for test signals (f_0=3cpm, n/s=0.0, 0.2, 0.5, 0.8).

The presented results show a significant influence of the noise level on dominant frequencies and their distributions.

To analyze this influence, the calculations of dominant frequencies were made for test signals with f_0=1.0-9.9cpm, Δf=0.25cpm and n/s =0.0-1.0, Δn/s =0.1. The standard deviation for all combinations of frequencies and different noise to signal ratio values are presented in Fig 6.

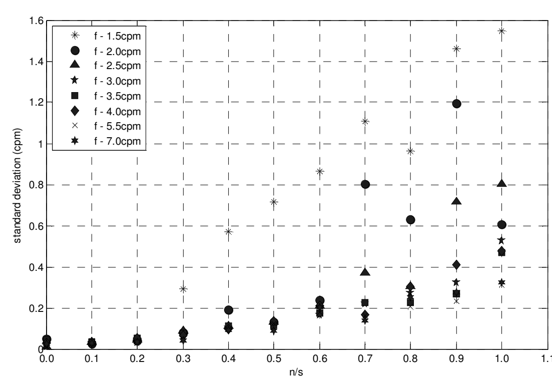

Fig. 6. The standard deviation of dominant frequencies for different values of n/s ratio.

The noise influence on determination the dominant frequency of test signals is much bigger for signals with lower frequency, especially for frequencies below 2cpm. This phenomenon is presented in Fig. 6. The determination of the dominant frequency for lower frequencies may require further investigation.

In case of determination of the ODF, this influence is much lower. The examples of the noise influence on determination of ODF (for f_0=1.5cpm, f_0=3.0cpm and f_0=5.5cpm) are included in Table 1. The f_O are the ODF for different method of OPSD estimation (AR, periodogram, MUSIC).

TABLE 1A.

n/s	0.0	0.2	0.3	0.4	0.5	0.7	0.8	0.9	1.0
f_{OAR1}	1.535	1.594	1.594	1.594	1.594	1.594	1.652	1.535	1.594
f_{OAR4}	1.486	1.545	1.604	1.604	1.589	1.662	1.794	1.765	1.794
f_{OPER4}	1.494	1.494	1.494	1.494	1.494	1.494	1.509	1.494	1.494
f_{OMUS4}	1.523	1.523	1.523	1.523	1.523	1.641	1.758	1.641	1.758

TABLE 1B.

n/s	0.0	0.2	0.3	0.4	0.5	0.7	0.8	0.9	1.0
f_{OAR1}	3.005	3.064	3.064	3.064	3.122	3.240	3.240	3.122	3.240
f_{OAR4}	2.952	3.011	3.011	2.996	2.996	3.025	3.055	2.996	3.025
f_{OPER4}	3.003	3.003	3.003	3.003	3.003	3.003	2.988	3.003	3.003
f_{OMUS4}	2.930	2.930	2.930	2.930	2.930	2.930	2.930	2.813	2.813

TABLE 1C.

n/s	0.0	0.2	0.3	0.4	0.5	0.7	0.8	0.9	1.0
f_{OAR1}	5.474	5.474	5.474	5.474	5.474	5.416	5.416	5.416	5.357
f_{OAR4}	5.444	5.517	5.517	5.502	5.502	5.532	5.532	5.590	5.532
f_{OPER4}	5.493	5.493	5.493	5.493	5.508	5.508	5.508	5.508	5.508
f_{OMUS}	5.508	5.508	5.508	5.508	5.508	5.508	5.508	5.508	5.508

The presented methods were applied to real EGG signals recorded during the standard procedure [2][3]. The examination lasted approximately 180 minutes and was divided into 6 periods of 30 minutes. The average values of dominant frequency and dominant power (DP) for periods were calculated. The results are presented in Fig. 7 and Fig. 8.

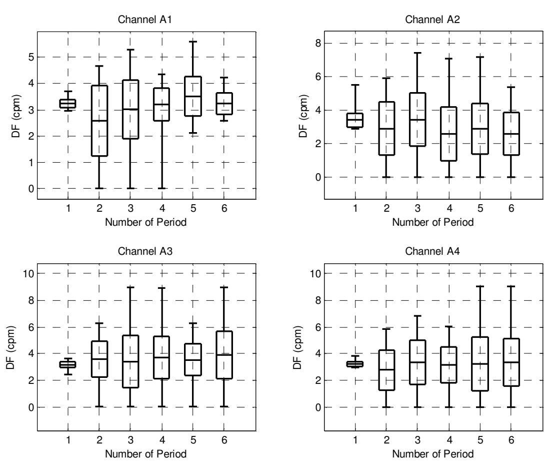

Fig. 7. Averaged values of DF EGG signal (A1-A4 channels).

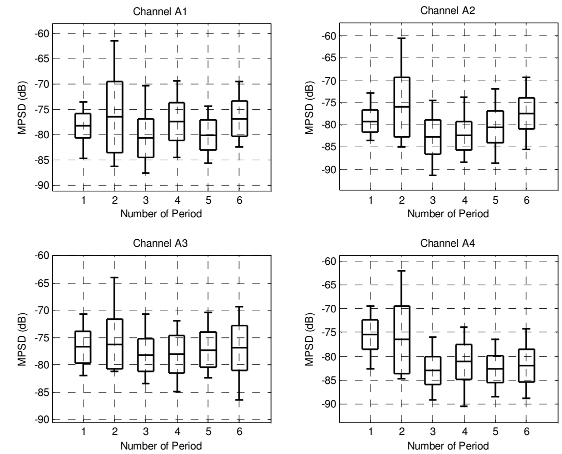

Fig. 8. Averaged values of dominant power of EGG signal (A1-A4 channels).

IV. CONCLUSIONS

The validation shows that the calculation of parameters based on the dominant frequency depend on the noise level. The calculations may cause incorrect classification of the EGG rhythm for some noise to signal ratio values. Parameters based on ODF are much resistant to the noise influence, even for the relatively high noise level (n/s=1). The obtained results show that noise influence is bigger for lower frequencies, i.e. < 2cpm, when calculating the dominant frequency equal to zero is possible.

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