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The Simultaneous Recording and Analysis Both EGG and HRV Signals

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***Abstract*—This paper presents a method for synchronous recording and analyzing both the electrogastrographic signal (EGG) and the heart rate variability signal (HRV). The electrogastrographic examination can be considered as a noninvasive method for an investigation of a stomach slow wave propagation. The four channel signal are non-invasively captured by the appropriately placed electrodes on the surface of the stomach. The EGG and electrocardiographic (ECG) signals, recorded simultaneously by means of the same electrodes and an amplifier, are separated by the proper digital filtration. In our work the EGG and ECG analysis is limited to calculation the most frequently used parameters: the dominant frequency of the EGG (DF), and LF/HF ratio of the HRV power spectrum for the ECG. In this way it is possible to examine mutual interaction among EGG and HRV. This paper also depicts the preliminary results of a comparison of the some EGG and the HRV parameters e.g. dominant power distribution (DPD) and balance of low frequency and high frequency of HRV power spectrum.**

I. Introduction

Nowadays, recording EGG signals is a standard method for the stomach examination. The electrogastrographic examination can be considered as a noninvasive method for an investigation of a stomach slow wave propagation [1][2].

The classic surface EGG signals are captured by means of disposable electrodes placed on the patient's stomach surface. During the signal registration process the standard protocol is applied according to the EGG Task Force recommendations [3]. The signals which are available on the stomach surface include not only the EGG signal but also ECG signals and signals connected with respiratory movements. The registration process usually includes 30-minute part before the standardized meal (preprandial) and 30-120 minute part 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 to determine frequency and power distributions of EGG segments. The typical EGG examination consists of several periods about 30 minutes long. Each period is divided into 60 or 256 second segments. Based on the PSD of EGG the dominant frequencies (DF) are calculated for each segment and for whole periods (overall dominant frequencies (ODF)). These frequencies are calculated for maximum amplitude of power spectrum density (MPSD). Next the distributions of the dominant frequency and dominant power density are obtained.

Analysis of the heart rate variability (HRV) is one of the common used method for long term ECG records (for example from Holter recorders). The analysis bases on RR intervals and required at least one channel ECG signal and detection of QRS complexes. According to the Task Force rapport [4], several types of parameters, based on time or frequency analysis of RR intervals, may be calculated.

Time analysis may include calculation of the mean value (mSD), the standard deviation (SDNN), the standard deviation of averaged values in segments (SDANN), the average of standard deviations in segments (SDNN index). The frequency analysis requires calculation of PSD of RR intervals. Next the signal power in several bands are calculated: ULF(0-0.0033Hz), VLF(0.0033-0.04Hz), LF(0.04-0.15Hz), HF (0.15-0.4Hz) and ratio of power in LF band to power in HF band called LF/HF balance. Segment length for HRV analysis was set to 256 seconds (1024 samples of RR intervals resampled to 4 Hz), and is in agreement with Task Force recommendations for HRV analysis(2-5 min.).

II. Method

The 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. The block diagram of the registration system is illustrated in Fig.1.

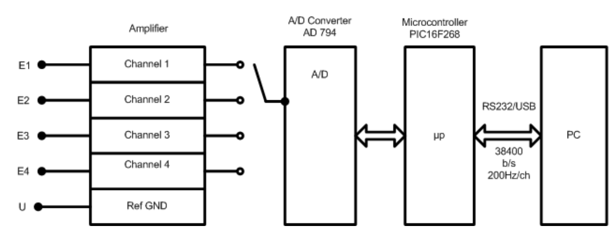

Fig. 1. The block diagram of the registration system.

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During the signal registration process, standard electrodes were applied according to the standard [3][5], including four signal electrodes (A1-A4) the reference electrode (R) and ground electrode (U). Relatively high sampling frequency allows to synchronous recording The EGG and the ECG signal. An example of the electrodes placement is shown in Fig.2.

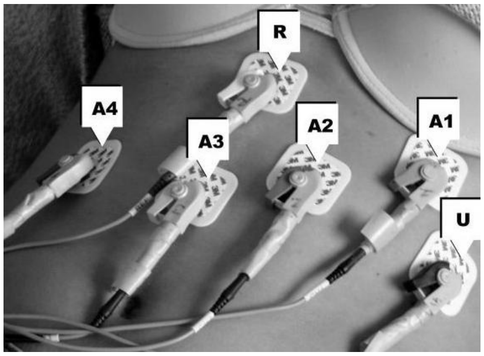

Fig. 2. The standard placement of the EGG electrodes [2].

An example of one-minute of recorded signal (one channel) is shown in Fig. 3. From the recorded data the EGG and the ECG signals were extracted using proper preprocessing.

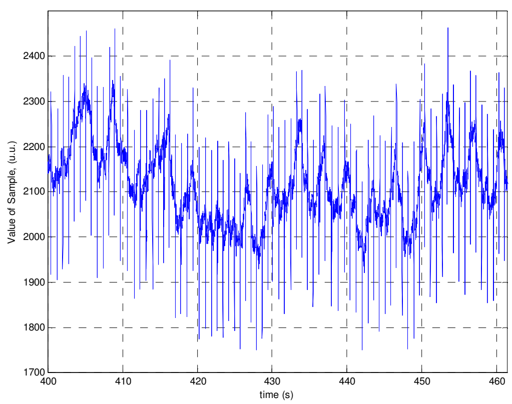

Fig. 3. The example of the recorded signal form A1 electrode.

A. *The EGG preprocessing*

The EGG signal extraction was performed by an application of the band-pass filter covering the range 0.015Hz-0.15Hz [3]. 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 the fourth-order Butterworth filter. Next the obtained signal has been resampled. The new sampling frequency has been set to 4Hz. An example of approximately one minute, the four channel resampled EGG signal is shown in Fig. 4.

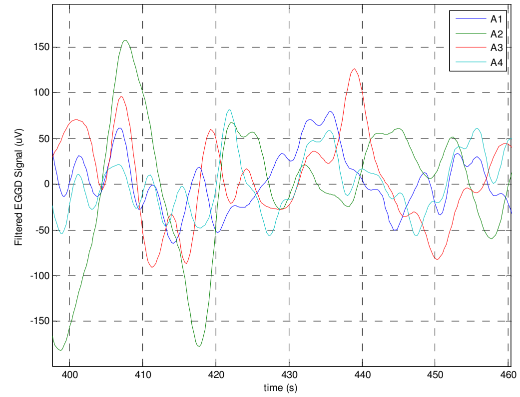

Fig. 4. The example of the four-channel EGG signal.

B. *The ECG preprocessing*

In the Fig. 5. the raw (not filtered) ECG signal from channels A1-A4 is presented.

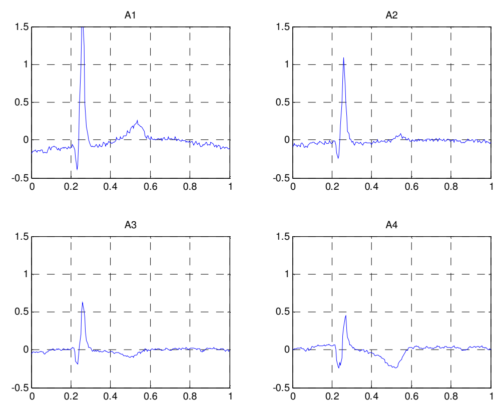

Fig. 5. The example of the four-channel ECG signal, vertical axis is the amplitude in mV, horizontal axis is the time in seconds.

For the HRV analysis the signal with the most prominent QRS complex has been chosen. Usually the A1 channel is selected, however in some records the artifacts caused that choosing another channel gives better results of QRS complex detection. The ECG signal required for the purpose of the QRS complex detection was first extracted from the recorded signal by means of the band-pass filter, tuned in the range 1-35Hz. Next the standard cascade of digital filters, tuned to the spectral characteristics of the average QRS complex was applied. The filtered signal was rectified and averaged to obtain single-peak detection function, for each QRS complex. Fiducial points were found in the maximum of detection function [6]. The RR intervals are non-uniform sampled, so for further analysis RR intervals were interpolated and resampled with the frequency of 4Hz. The example of the resampled HRV signal for the whole record (approximately 3 hours) and zoomed 4 minutes segment, is shown in Fig. 6. The gap was introduced on purpose for the time of taking the meal, when great motion artifacts occur.

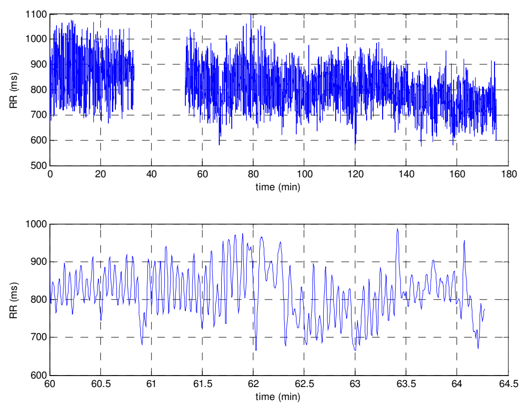

Fig. 6. The example of the HRV signal.

C. *Calculation 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

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

where *x[n]* is the output of the model, *e[n]* is the input of the model, a_k's 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

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

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.

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

where *means 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):

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

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 requires the estimation of the minimum number of correlation lags are given by the following formulas:

$$\hat{R}a = -\hat{r}\,, \tag{5}$$

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

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

and

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

The parameters *a* are estimated by

$$\hat{a} = -\hat{R}^{-1}\hat{r}\,, \tag{8}$$

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

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

The power spectrum density estimate is obtained if $\hat{a}$ and $\hat{\sigma}^2$ are substituted in Eq. (2) [7].

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

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

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 The selected order of the model substantially influences the PSD shape [7][8].

D. *Calculation of Dominant Frequency for Segments*

The running spectra of EGG signal for A1 channel is presented in Fig. 7.

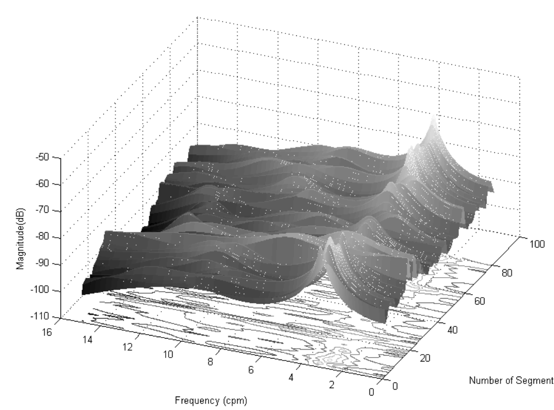

Fig. 7 The running spectra of EGG signal for A1 channel.

The dominant frequency is defined as a value of frequency for the highest peak of the PSD of EGG, in the range 0cpm-9cpm. The spectrum analysis of the EGG signal was performed by the means of identification parameters of autoregressive model and estimation of the power spectrum density. The PSD for all preprocessed segments was calculated and the dominant frequencies were found.

E. *Calculation the LF/HF Balance for Segments*

The signal of resampled RR intervals for entire record was divided into 1024-sample segments, similarly to EGG segments. For all segments the power spectrum density of HRV was calculated by means of the Welch method. The comparison between the PSD of HRV obtained by means of Welch method and periodogram is presented in Fig. 8.

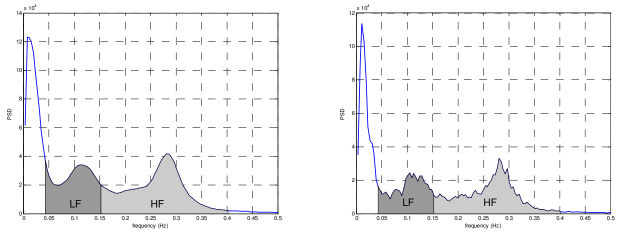

Fig. 8 The PSD of HRV-Welch method (left), the PSD of HRV – periodogram method (right).

Next the values of ratio LF/HF were calculated for each of segments [4]. The boundaries of LF and HF bands are also marked in Fig. 8.

III. RESULTS

For all segments values of DF, MPSD and LF/HF were calculated. Next the percentile values of DF, MPSD and LF/HF for all 30-minute periods were calculated as well. The summarized results of DF, MPSD and LF/HF are presented in Fig. 9, Fig. 10 and Fig. 11.

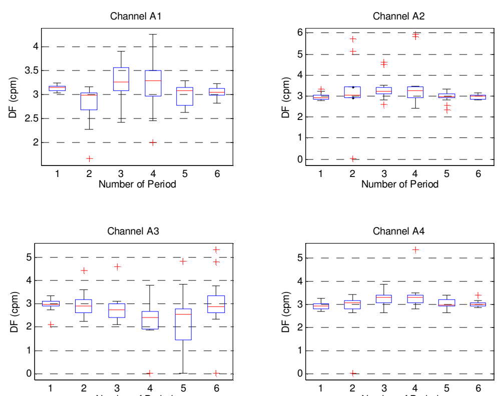

Fig. 9 Percentiles of DF(A1-A4 channel).

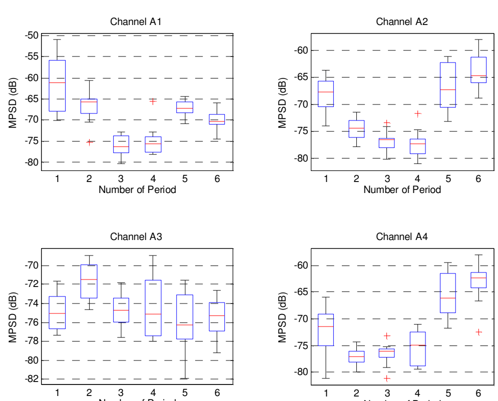

Fig. 10 Percentiles of MPSD (A1-A4 channel).

The observed in Fig. 10 and Fig. 11. results draw a parallel comparison between the percentile values of dominant power of the EGG (A2, A4 channel) and the values of LF/HF ratio.

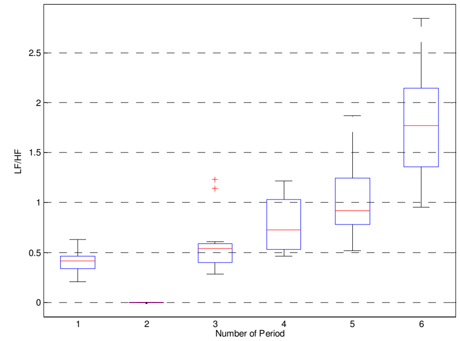

Fig. 11 Percentiles of LF/HF.

IV. CONCLUSIONS

This work explains that more physiological signals may be extracted from standard EGG recording if the sampling frequency of signal increases slightly. The present work shows preliminary analysis of simultaneous recorded EGG and HRV signals. The obtained results suggest some degree of similarity between the percentile values of dominant power of the EGG (for some channels) and the LF/HF ratio of the HRV. Our preliminary investigations do not show similar dependence between dominant frequency and LF/HF ratio. The present method do not require using any additional equipment for simultaneously recording of the EGG and the ECG signals, and is fully implemented in software. Because of relatively small group of EGG records some conclusions and analysis of mutual connections between EGG and HRV may required further investigations.

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