The Preliminary Study of the EGG and HR Examinations

Dariusz Komorowski[1] and Stanislaw Pietraszek[2]

[1] Institute of Electronics, Division of Microelectronics and Biotechnology,
Silesian University of Technology, Gliwice, Poland
`dariusz.komorowski@polsl.pl`

[2] Institute of Electronics, Division of Biomedical Electronics,
Silesian University of Technology, Gliwice, Poland
`stanislaw.pietraszek@polsl.pl`

Summary. Electrogastrographic examination (EGG) can be considered as a non-invasive method for an investigation of a stomach slow wave propagation [1] [2]. The EGG signal is non-invasively captured by appropriately placed electrodes on the surface of the stomach. This paper presents the method for synchronously recording and analyzing both the EGG and the heart rate signal (HR). The HR signal is obtained by analyzing the electrocardiographic signal (ECG). The ECG signal is recorded by means of the same electrodes. This paper also presents the method of reconstruction the respiratory signal (RESPIRO). In this way it is possible to examine mutual interaction among ECG, HR and RESPIRO signal respectively. This paper also depicts the preliminary results of a comparison of the EGG and the RESPIRO signals obtained using two different methods, firstly by classical pass-band filtering, secondary by estimation of the baseline drift.

1 Introduction

The standard surface EGG signals were captured by means of disposable electrodes placed on the patient's stomach surface. During the signal registration process standard electrodes were applied configured according to the standard [4], including four signal electrodes (E1..E4), reference electrode (Ref) and ground electrode (Gnd) [1] [2]. An example of the electrodes placement is shown in Fig. 1 [4]. 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. Both useful component of the EGG and RESPIRO signals are localized in the same range of frequency. The example signals recorded from one of the available EGG leads (E1) are shown in the Fig.2. The signals were recorded within the $0.015Hz \div 50Hz$ frequency range. The wide range of the recorded frequency emphasizes the structure of the presented signals.

In popular commercial systems for capturing the EGG, the signals are usually obtained by means of the method based on classical pass-band filtration. The filtration typically is made by using the analog filters placed

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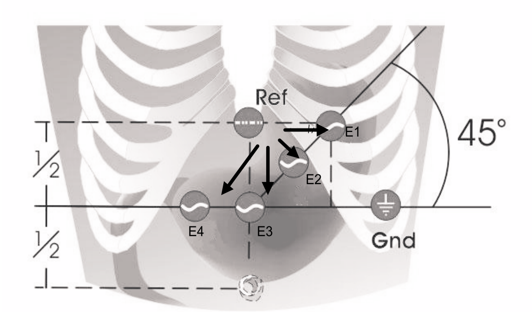

Fig. 1. The standard placement of the EGG electrodes [4]

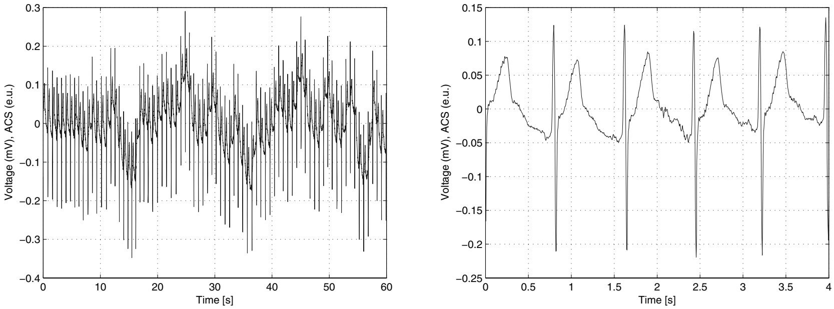

Fig. 2. Measurements of data (E1), time period $60s$ and $4s$

after a preamplifier stage. The typical cutoff frequencies are $0.015Hz$ and $0.15Hz$ [3]. The recording of additional signals requires other devices, so that synchronous signals analyzes becomes difficult. The presented in this paper methods of capturing and analyzing signals obtained from stomach surface, allows to separate the components of the EGG, HR and RESPIRO signals. In this way simultaneous analysis the EGG and the HR obtained from the ECG signals is possible. The HR signal can by obtained from photoelectric pulse sensor, but the precision of RR intervals calculation is insufficient for detail heart rate variability analysis [5]. The RESPIRO signals can be extracted based on the recorded signals. Additionally the accelerometer sensor was placed near the electrodes, to record respiratory movements of abdomen and chest to verify the RESPIRO signals.

2 Methodology

The EGG signals have been 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

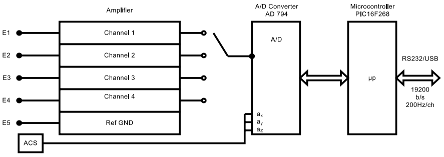

Fig. 3. The block diagram of examination stand

- 12 bits, sampling frequency $200Hz$ per channel and useful signal amplitude range $2mV$. For respiratory motion the special triple-axis acceleration sensor type MMA 7260Q manufactured by Freescale company has been placed near electrodes, with parameters as follows: number of axis 3(XYZ), sensitivity $800mV/g$, measurement range $1.5g$ [8]. Both the acceleration sensor signal (ACS) and the EGG signal have been synchronously recorded. Only one component (AY) has been applied in the examination process due to the fact, that other components in the surfaces perpendicular to the direction of the chest motion did not include visible component correlated with respiratory motions. Signals lasting from 20 to 120 minutes have been recorded during the examination process. The block diagram of the recording system is in the Fig.3. Relatively high sampling frequency (i.e. $200Hz$ per channel) allowed for further analysis of the ECG signal as well. Preliminary filtration of both extraction and visualization of required signals has been applied. The following useful signals have been extracted from the joint recorded signal: the EGG, the ECG and the RESPIRO. These signals have been further extracted using two different methods. The Fig.4 shows the block diagram of the described methods. The first method uses the set of classical filters. The EGG signal extraction is performed by application of the band-pass filter covering the range $0.015Hz \div 0.15Hz$ [9]. The lower cutoff frequency results from the high-pass RC filter applied in the amplifier hardware and digital fourth order high pass Butterworth filter, whereas the upper cutoff frequency results from the application of the digital fourth order Butterworth filter. The RESPIRO signal (i.e. the component of the signal caused by respiratory motions) has been extracted by an application of the Butterworth fourth order band-pass filter $(0.15Hz \div 0.5Hz)$. The mentioned filters are given by the formula (1)

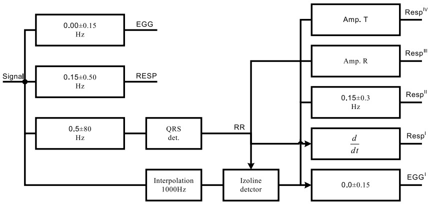

Fig. 4. The block diagram of signals preprocessing

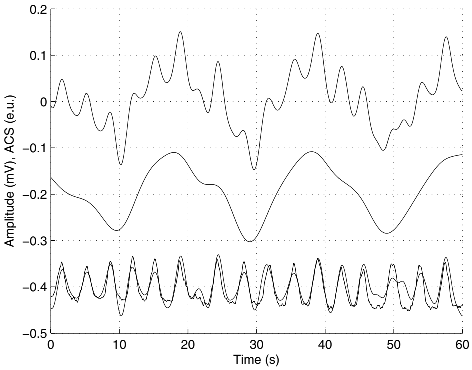

Fig. 5. The comparison of whole EGG, respiratory and ACS signals (from the top: measurement data ($0.015 \div 0.5Hz$), EGG data($0.015 \div 0.15Hz$), respiratory data ($0.15 \div 0.5Hz$), smooth ACS data)

and have been implemented by an application of the appropriate software. The coefficients of the applied filters are in Tab.1.

$$a_0 y(n) = \sum_{i=0}^{4} b_i x(n-1) - \sum_{i=1}^{4} a_i y(n-1), \tag{1}$$

The 60 seconds registration after the filtration process has been illustrated in the Fig.5.

In the second method both signals, i.e. the EGG and the RESPIRO have been extracted using analysis of the baseline obtained from the ECG signal. The ECG signal required for the purpose of the QRS detection has been extracted by means of the band-pass filter tuned in the range $1Hz \div 35Hz$. Finding the fiducial points in this method requires the ECG signal

Table 1. The coefficients of applied filters

	EGG filters		RESPIRO filters		ECG filters	
	LPF	*HPF*	*LPF*	*HPF*	*LPF*	*HPF*
a_0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
a_1	−3.9918	−3.9988	−3.9590	−3.9877	−1.1751	−3.9179
a_2	5.9754	5.9963	5.8777	5.9631	0.9256	5.7571
a_3	−3.9754	−3.9963	−3.8785	−3.9632	−0.3104	−3.7603
a_4	0.9918	0.9988	0.9598	0.9878	0.0477	0.9212
b_0	$^{*}0.0061$	0.9994	$^{**}0.0037$	0.9939	0.0305	0.9598
b_1	$^{*}0.0243$	−3.9975	$^{**}0.0149$	−3.9754	0.1219	−3.8391
b_2	$^{*}0.0364$	5.9963	$^{**}0.0224$	5.9632	0.1829	5.7587
b_3	$^{*}0.0243$	−3.9975	$^{**}0.0149$	−3.9754	0.1219	−3.8391
b_4	$^{*}0.0061$	0.9994	$^{**}0.0037$	0.9939	0.0305	0.9598
	$^{*} * 10^{-9}$		$^{**} * 10^{-6}$			

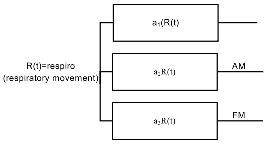

Fig. 6. The model of respiratory signal influence on an ECG signal

resampling after implementation of the interpolation procedure. The new sampling frequency has been set to $1000Hz$ and therefore the accuracy of the procedure has significantly increased. An example of the ECG signal associated with both R and T waves, and the measurement points whole baseline has been recovered are in the Fig. 7. The whole baseline has been recovered based upon estimated fiducial points, sampling the base line (between P and Q waves) and interpolation. Perfect coherence has been observed between the recovered baseline and the line obtained by means of the proper filtration and the first method. The respiratory motions influence not only changes of the baseline as it can be seen in the Fig.5, but also the amplitude of the characteristic waves of the EGG. The motions also influence the changes of the heart rate. The measurements of both R and T waves have been used for baseline estimation. The P wave has not been applied due to very small amplitude. The mathematical model consist of the following equations (2÷4) [7]:

$$izo(t) = a_1R(t), \tag{2}$$

$$am(t) = (1 + a_2R(t))(ECG), \tag{3}$$

$$HR(t) = HR_0 + a_3R(t), \tag{4}$$

where: $izo(t)$ is baseline, $am(t)$ is R wave amplitude, $R(t)$ is RESPIRO signal and $HR(t)$ is an instantaneous heart rate. The block diagram of the presented model has been shown in the Fig. 6. Further analysis requires implementation of the interpolated baseline removing procedure. Such an approach prevents additional disturbances, which always appear when the traditional high-pass filtering is applied. Processing of the ECG signal in such a way leads to elimination of the pure EGG and the RESPIRO. This is crucial when the component extraction is the effect of the amplitude modulation by respiratory motions. The described examinations refer only to the changes of both R and T waves amplitude, which have been interpolated by the cubic spline. As a result of such a procedure an influence of a hypothetic recovery of respiratory motions on the ECG signal is possible according to the model presented above and described by (3). Both interpolated waves, i.e. R and T, have been presented in the Fig.8. This figure presents also signal recordered from the acceleration sensor (ACS) showing respiratory motions. This signal allows for verification of the assumption concerning the influence of respiratory motions on the amplitude of both the ECG characteristic waves (R and T).

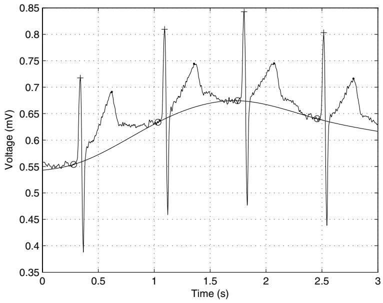

Fig. 7. The interpolation of baseline and measurement points of R and T waves. (top line: ECG data, bottom line: baseline data, sign +:peaks of R wave, sign : peaks of T wave, sign o: points of baseline)

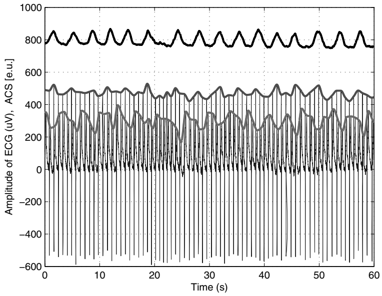

Fig. 8. The reconstructed amplitude modulation data of both R and T peaks detected (from the top: ACS data, modulation data of R peaks, modulation data of T peaks, ECG data without baseline)

Such an influence is more visible in case of R wave than in case of wave T. References [6] [7] conclude that the respiratory motions modulate instantaneous the heart rate. It is possible to extract the heart rate variability based upon the determined position of R wave in the ECG signal. Such changes are not only resulting from the respiration motion but also can be considered as effects of other sophisticated control processes performed by the autonomic nervous system [7]. However, usually it is assumed that respiratory motions influence the most the heart rate.

3 Results

The changes of distance between R peaks as well as the first derivative of RR distances have been calculated in the presented work. The filtered EGG signal and several respiratory dependent components have been obtained as a result of presented data processing. In the Fig.9 the comparison of reconstructed respiratory dependent data has been presented. It seems that the influence of the respiratory movements may be noticed in all presented signals except the EGG. The correlation coefficients between the ACS signal and all other signals have been calculated to verify this influence. The correlation has been calculated in the 60 seconds length window. The window has been moved from the beginning to the end of data. Preliminary examination indicates that the highest correlation exists among respiratory movements and both the filtered respiratory signal and amplitude of R peaks modulation in the ECG signal. The average values of the correlation coefficient have been shown in TAB.2. Special attention should by paid for irregular respiration, when

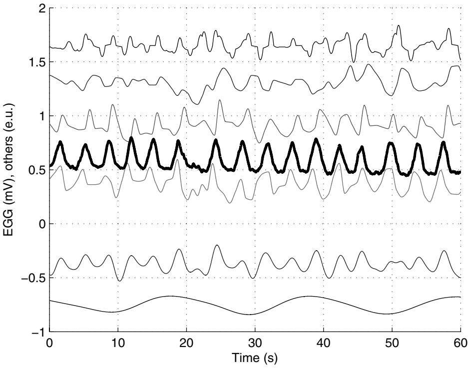

Fig. 9. The comparison of reconstructed respiratory dependent data (from the top: RR derivative data, RR data, amplitude of T data, amplitude of R data, ACS data, respiratory data, EGG data)

Table 2. The average correlation coefficients

ACS-amp.R	ACS-RESP.	ACS-der.RR	ACS-amp.T	ACS-EGG	ACS-RR
0.56	0.52	0.33	0.0058	0.027	−0.4

additional peaks in filtered signals may be observed. This observation may require further investigations.

4 Conclusions

The main agents which caused the EGG signal disturbances are artifacts caused by the respiratory movements. Several methods of reconstruction signals related to respiratory movements have been presented in this paper. The following conclusions may be drawn based on presented analysis. The reconstruction of respiratory related signals based on analysis of the amplitude of R wave in the ECG signal highly correlates with recorded respiratory movements. The obtained results are comparable with signals obtained by means of band pass filtering. In the research process, relatively high influence of baseline interpolation method for changes of the ECG T waves amplitude has been observed. Relatively low values of the correlation coefficient between the ACS signal and the reconstructed amplitude of T waves may be caused by improper selection of a baseline interpolation method. The selection of the baseline interpolation method may require further examinations. Finally simple comparison between respiratory signals obtained by R wave detection as well as by he heart rate variability analysis and the signal from the acceleration sensor allows to conclude that the presented methods recover well the RESPIRO signal.

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