A New Method for Attenuation of Respiration Artifacts in Electrogastrographic (EGG) signals.

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***Abstract*— Electrogastrography (EGG) is a test method designed for noninvasive assessment of gastric slow waves propagation. The EGG signal is obtained from the electrodes respectively arranged on the surface of the patient's abdomen. A significant problem during recording of the EGG signal is the elimination of disturbances occurring during registration and unwanted components of other signals such as: components of electrocardiographic (ECG), baseline drift or respiratory disturbances. These components are generally present in the signals registered from the surface of the abdomen of the patient. Since EGG frequency components partly overlap with the frequency components of respiratory artifacts, conventional band-pass digital or analog filtering may cause distortion in electrogastrographic signal. In the paper a method for removing respiratory interference occurring during registration of EGG signal and the effect of filtration on selected parameters of EGG signal analysis is presented. Respiratory artifacts are removed through the use of adaptive filter working in the DCT domain. The applied adaptive filtering method involves the use of the signal including respiratory disturbances. This signal is recorded synchronously with the EGG signal using a thermistor placed near the nose of the patient.**

I. INTRODUCTION

Electrogastrography is a research method designed for noninvasive assessment of gastric slow waves propagation [1, 2]. One or multi-channel EGG signal is obtained from the electrodes respectively arranged on the surface of the abdomen of the patient. It is assumed that the EGG signal frequency range is from 0.015 to 0.15Hz. EGG signal amplitude is about 100-400 μV [3,4]. Typical EGG examination takes about 2 hours and consists of three parts: the first generally lasts no longer than 30 minutes and is referred to as a step prior to a meal (test person should be fasted), the second part takes about 5 to 15 minutes, during that time the examined person eats a standardized meal (standard depends on the audit facility) [3]. The third, postprandial part takes about 90 to 120 minutes. EGG recording basic analysis comes to both determine the frequency of slow waves and rhythm classification of these waves. Determined frequency is referred to dominant frequency (DF) [5,6,7]. Slow wave frequencies are calculated based on spectral EGG signal segments with a length of 60 to 240 seconds. In the case of EGG the most common units to express the frequencies refers to cycles per minute (cpm). On the basis of the slow waves frequencies in the individual sections a normogastria index (NI) expressed as the amount of DF values in the range of <2-4 cpm> (values may be slightly different for different units) to the total amount of the values of DF is determined [8,9]. An example of EGG signal, its spectrum and designated DF frequency is shown in Fig.1.

Because the signal is recorded from the surface of the patient's body it also contains components stemming from other organs or human anatomy systems. These signals, in particular, are the components of ECG, baseline drift and respiratory disturbances. In the classical approach the desired EGG signal is obtained by the use of a traditional analog or digital filtering of recorded signal. Because the EGG signal band overlaps with the bandwidth of respiratory signals, which appear in the range from 0.1 to 0.5Hz [10,11]. EGG and breathing signal separation with the help of classical filtration leads to a distortion in the useful EGG signal and the loss of part of the information contained in the signal. The problem of separation of the desired useful signal interference, which can also be another signal are commonly encountered during registration and analysis of biomedical signals. Such a disruption can be treated as a stochastic process with unknown parameters or characteristics that change over time. One method, which in this case make it possible to separate the useful signal from the interference is adaptive filtration [12]. The main problem of this type of filtration is a "possession" of the reference signal and the selection of appropriate parameters of the adaptive filter. In case of registration of biological signals from the body surface of the patient such signal may be a signal recorded by means of another sensor having no direct contact with the skin surface of the patient.

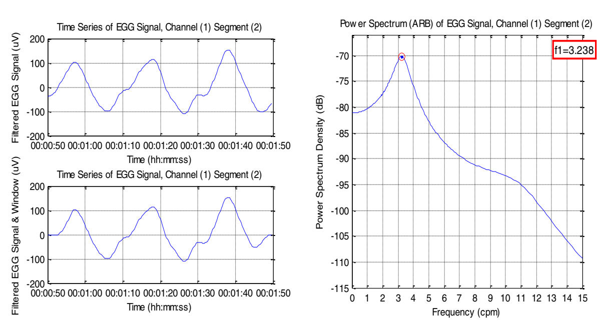

Figure 1. The example of EGG signal and their spectrum with marked DF frequency (red dot) (3.238 cpm).

In the case of respiratory signal it may be an additional sensor for example. a thermistor placed near the nose of the patient.

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In this paper the authors propose a new method for the removal of respiratory distortions of EGG signal through adaptive filtering respectively with the use of respiratory signal as the reference signal, recorded using a thermistor sensor. EGG signal adaptive filtering using the adaptive filter has been proposed by [9] or [13]. Their work, however, was not focused on the elimination of respiratory disturbances. The study used four-channel EGG recordings (recorded in accordance with the standard C3) [3] with an additional respiratory signal recorded (TDR). The signals sampling frequency (Fs) was 4 Hz. A fragment of the EGG signal and the respiratory signal is shown in Fig.2.

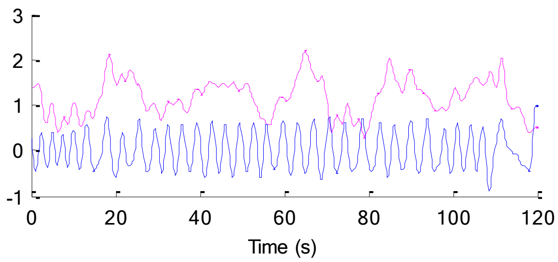

Figure 2. The examples of EGG (magenta) and thermistor derived respiratory signal (TDR (blue)) The signals are normalized to 1 and shifted (to improve visibility).

II. Method

A. Removing the respiratory disturbance of the EGG signal with adaptive filtering method

Suppose that:

$$d(k) = s(k) + n_1(k), \quad x(k) = n_2(k), \tag{1}$$

where: *s(k)* is of interest to us EGG signal at time *k*, $n_1(k)$ and $n_2(k)$ are correlated interference. In our case, $n_1(k)$ and $n_2(k)$ can be treated as an unwanted respiratory signal components. Noise reference signal *x(k)* is subjected to adaptive filtering. The adaptive filter converts the disturbance $n_2(k)$ in a way to make it the most correlated with the signal *d(k)*. Due to the fact that *s(k)* and $n_1(k)$ are uncorrelated, because they are generated by other sources therefore the filter matches $n_2(k)$ to $n_1(k)$, and then at its output an estimate $n_1(k)$ is received:

$$y(k) = H(n_2(k)) = \hat{n}_1(k). \tag{2}$$

As a result, we obtain:

$$e(k) = (d(k) - y(k) = s(k) + (n_1(k) - \hat{n}(k)), \tag{3}$$

which is the desired signal with reduced interference [12]. In this case *e(k)* is the EGG signal deprived of the respiratory signal components. A block diagram of the described method of interference suppression (unwanted signal) with adaptive filter is shown in Fig. 3.

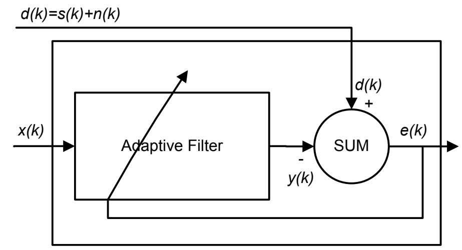

Figure 3. Application of adaptive filtering to remove interference from an unknown system.

In our work as a reference signal for the adaptive filtering we use the breathing signal, which was synchronously recorded with EGG signal. The source of this signal was a thermistor sensor located near the nose of the patient. In the first step the signal is subjected to band-pass filtration in the frequency range corresponding to the respiratory activity (0.10-0.5Hz). The signal in the next step will be the reference signal put on input of adaptive filter. Adaptive filtration was carried out in the field of transformation using Discrete Cosine Transform (DCT). Detailed descriptions of such filters can be found in [13]. To update the weight of the used filter, the least squares algorithm LMS was used. [12, 14]. The applied filter has two parameters which require tuning: L - the length of the filter and μ - factor controlling the rate of adaptation of the filter. In our work, the value of μ and L were chosen experimentally. In our opinion the best filtration results were achieved respectively for μ = 0.008 and L = 14.

Before using adaptive filtering recorded signals, both the signals from the surface of the stomach and breathing signals derived from the additional sensor are with filtered a low-pass-filter with a cutoff frequency of 0.5Hz. After the process of adaptive filtering, which is removing the respiratory signal components from the recorded signal, the resulting signal has been subjected to the classic band-pass filtration process in the frequency characteristic of EGG signal or 0.015-0.15Hz. The study used a zero-phase digital filtration using a digital 4th order Butterworth filter (forward and reverse directions) [15].

III. Validation and Results

In order to verify proper operation of the proposed algorithm, two test procedures were performed: the first was examining the impact of adaptive filtering on the basic diagnostic parameters of electogastrographical tests i.e. the dominant frequency and the index of normogastria (NI), the second was to check the efficiency of respiratory components suppression in registered EGG signals. In both stages of the test the actual EGG signals recorded on the surface of the abdomen of patients were used.

A. Effect of filtration on the basic diagnostic parameters of the EGG signal

To be sure how the proposed method affects the fundamental values of diagnostic parameters of EGG signal, a comparison of most commonly used parameters that is (DF) and (NI) to (48) records has been made. To evaluate the properties of the proposed method, the calculations of the DF and NI factor for the original signal (Research) have been made (using the classical method of filtration). For the calculations an original program for EGG signals analysis was used, the authors use it in their research for several years [16,17,18]. EGG signals were then subjected to adaptive filtering and the DF and NI were re-calculated. Relative errors (ε) (Fig. 4) and absolute (δ) between NI values obtained as a result of adaptive filtering and NI values of the original signals and the value of the maximum (max), minimum (min) and standard deviation (SD) of individual errors (Table 1) were also counted. Normogastria values obtained were placed on Fig. 5, where the EGG are the original signals, EGG-AF is the original EEG signals after the adaptive filtering.

TABLE I. VALUE OF ERROR RATE OF THE NI FACTOR FOR EGG SIGNALS AFTER ADAPTIVE FILTERING

	max	min	mean	std
(ε)	0.23	-0.05	0.10	0.06
(δ)(%)	42.17	0.00	13.27	9.72

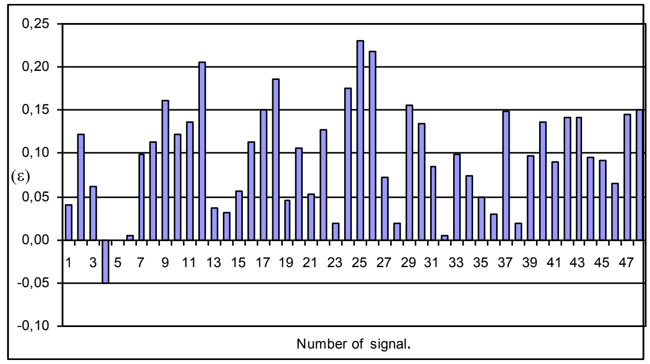

Figure 4. The valuse of absolute error (ε), between NI for classical EGG processsing and NI for EGG after adaptive filtering.

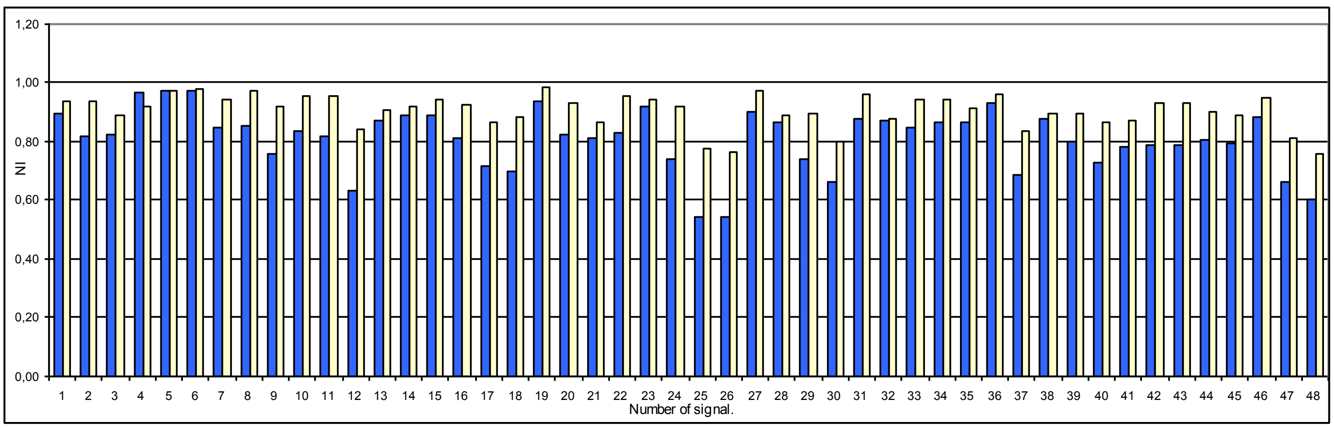

Figure 5. The valuse of normogastria index (NI), NI for classcical EGG processsing (blue), NI for EGG after adaptive filtering (white) (EGG-AF).

B. *The effectiveness of breathing interference suppression*

However, in order to assess the effectiveness of the adaptive filtration in removing of the respiratory components, the following procedure was used: recorded EGG signals were divided into fragments with a length of 1024 samples (4 min. 16s) and a spectrum for each fragment of the signal was determined. To determine the spectra the periodogram method with Tukey's window ($\alpha = 0.25$) was used. On the basis of received spectra an averaged spectrum was determined (approximately the method corresponds to the designation of overall spectrum of the standard EGG analysis [5]. This process was repeated for signals that have undergone adaptive filtering. Then the surfaces below the spectra were calculated in the frequency range pf = (0.01 0.40 Hz). Calculations were performed for the original signal (E) and the signals subjected to adaptive filtering (E-AF). Then the surface area ratio was calculated:

$$CofA = \frac{EAF}{E}. \tag{4}$$

Spectra of the original EGG signal and EGG signal after adaptive filtering are shown in Fig. 6. The surface which is included in the ratio calculation was marked in the figures as well. Then the ratio of these surfaces was calculated. The results of this comparison are shown in Fig. 7.

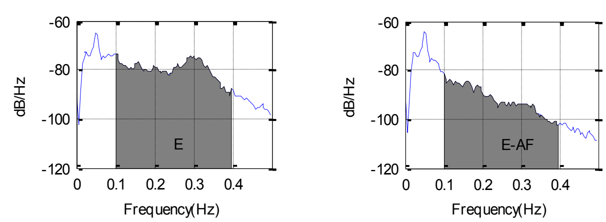

Figure 6. The spectra of original EGG signal and markerd (gray area) range for calculateing area ratios (left) and of EGG signal after adaptive riltering (right) respectively.

Analysis of these results allows to draw the following conclusions: the proposed adaptive filtering method in most cases improves normogastria NI coefficients determination.

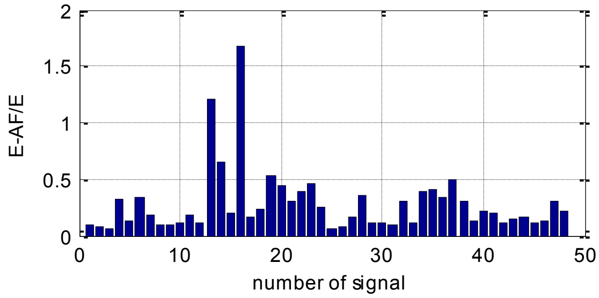

Figure 7. The E-AF/E area ratios in range (0.1 0.40 Hz) for all the registered signals.

In most of the cases respiratory component (if it is visible in the EGG signal) is properly suppressed. Examples of the results in the form of the spectra are presented in Fig. 8, the left part contains the spectra of the original EGG signal with visible breathing components, right contains the same signals but after using adaptive filtering. On these drawings the effect of adaptive filtering on for breathing signal attenuation and improvement of the separation of components typical for EGG signals can be easily observed.

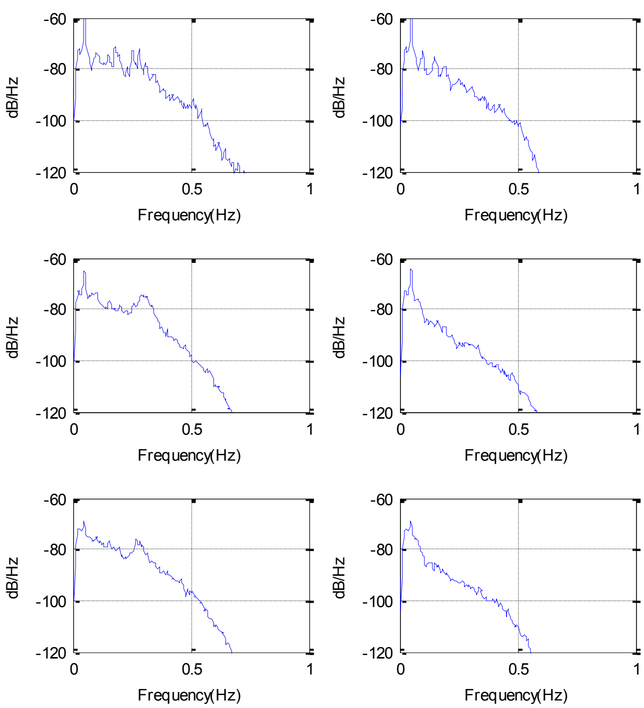

Figure 8. Spectra of the original EGG signal left, and spectra of the EGG signals after adaptive filtration (right).

IV. Conclusion

The presented methods show promising prospective of attenuating the respiratory components. The respiratory signal (TDR) serves well as the reference signal in adaptive filtering for attenuating the respiratory components in signals. An analysis of spectra of reconstructed signals confirms good efficiency of attenuating the respiratory components in EGG signals by means of the proposed adaptive filtering method. The efficiency of attenuating the respiratory components depends on parameters of adaptive filter. Because investigations presented in this paper were made on relatively small number of cases (48), the parameters μ and L may require some corrections and future investigations. This method allow to improve calculating some of EGG diagnosis parameters.

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