ICA, EGG, biomedical signal processing

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INDEPENDENT COMPONENT ANALYSIS AND ADAPTIVE FILTERING AS SUCCESSFUL TOOLS FOR AN IMPROVEMENT OF NORMOGASTRIC RHYTHM EXTRACTION IN ELECTROGASTROGRAPHIC SIGNALS

The aim of this study was to investigate the possibility of combining two methods: Independent Component Analysis (ICA) and Adaptive Signal Enhancement for the improvement of normogastric rhythm extraction from multichannel recording of electrogastrographic signals (EGG). Unfortunately the electrogastrogram, is a transcutaneous measurement of gastric electrical activity, does not contain pure signal but usually is a sort of mixture from both electrical activity of stomach as well as other organs surrounding it and random noise. In order to benefit the diagnostic power of multichannel recording of EGG, which can provide deeper understanding of gastric disorders, it is necessity to extract gastric slow wave in each channel. One of the parameters, which are analyzed and require proper registration is so called normogastric rhythm. According to the literature, the normogastric rhythm should cover around 70% of rhythmic behavior of signal for a healthy man. Proper extraction of basic 3-cpm normogastric rhythm in each channel is a subject of this paper. Independent Component Analysis is applied for extracting the reference signal for adaptive filtering what next result in obtaining less contaminated signal in each channel. Analysis has been perform for two postprandial phases with five minutes break between them. In both mention cases proposed procedure gives a promising results.

1. INTRODUCTION

The electrogastrogram (EGG) is a gastric myoelectrical activity noninvasively recorded by the surface electrodes placed on the abdominal skin [1]. The stomach is a sac-shaped organ with two outlet, the upper one called cardia and the bottom named pylorus. From the anatomical point of view it is possible to distinguish three regions in the stomach: fundus, corpus (body) and antrum. As in the heart, from a pacemaker region of stomach, situated on the greater curvature, between the fundus and corpus, spontaneous electrical depolarization and repolarization occurs and generates the myoelectrical excitation. Pacesetter potentials propagate with velocity greater circumferentially than distally causes developed ring excitation which is the electrical basis of gastric peristaltic contraction and the main mechanism of emptying the stomach from its contents [10]. Generally, there are two types of electrical activity in tunica muscularis of stomach: electrical control activity (ECA) and electrical response activity (ERA), the first one is called slow wave the second one spike potential. In 1911, Santiago Ramon y Cajal pointed out and described a special network of cells in gastrointestinal tissues and named them Interstitial Cell of Cajal (ICC). ICC cells are different from both neurons and smooth muscles cells and they are capable of producing spontaneously ion currents for pacemaker function, setting myoelectrical rhythmicity of stomach and the other areas of gastrointestinal trac [17]. As smooth muscle cells lack the ability of slow wave generation, active propagation is performed through the ICC network. Slow wave decay in amplitude and disappear very fast in the regions without ICC [14].

Gastric peristaltic contraction is the basis for emptying solids from stomach because it causes pressure wave which pushes the contents of the stomach toward pyloric sphincter. Delayed gastric emptying causes various gastric disorders, such as an example bloating, vomiting or early satiety. The slow waves do not directly generate contractions of the stomach muscles, these are spike potentials that are responsible for muscularis contraction, but as ERA can only appear at the top of depolarization of the slow wave, the slow wave is the basic mechanism which both integrate and control stomach wall motility. Even though the dominant pacemaker of stomach is situated in the corpus, each region of stomach below has pacemaker activity, too. The corpus pacemaker dominates because it generates a slow wave at the greatest 3 cycle per minute (cpm) frequency i.e. 0.05 Hz and there is a time for generated wave to propagate and initiate slow wave in the more distal sites before they are able to produce they own event. Motility disorders can be an effect of breakdown in the gradient frequency [10]. When one of the waves disappears in distal atrium another one originates in the pacemaker area in the corpus and migrates toward the atrium every 20 seconds. EGG recording reflect the basic 3 cpm rhythm of slow wave [2]. The ERA is also possible to observe but only on serosal or mucosal recording using the electrodes invasively implanted in the suitable layer of tunica muscularis of stomach wall. As far as other biological signals there are several reasons leading that EGG includes apart from normal physiological rhythm 2 - 4 cpm (0.033 - 0.066 Hz) some additional pathological rhythms covering frequencies from 0.5 cpm up to 9 cpm (0.008 - 0.15 Hz). Therefore, due to the leading rhythm in the EGG signal it is possible to distinguish: bradygastric rhythm 0.5 – 2 cpm (0.008 – 0.033 Hz) normogastric rhythm 2 – 4 cpm (0.033 – 0.066 Hz) and finally tachygastric rhythm 4 – 9 cpm (0.066 – 0.15 Hz) [13].

2. PROCEDURE OF EGG SIGNAL REGISTRATION

EGG signal registration has been performed with standard four channel biosignal amplifier within the range of 0.9 - 9 cpm (0.015 - 0.15 Hz) and abdominal electrodes placement [Fig. 1]. A group of 6 healthy volunteers have been examined in order to estimate the total amount of normogastric rhythm in EGG signal.

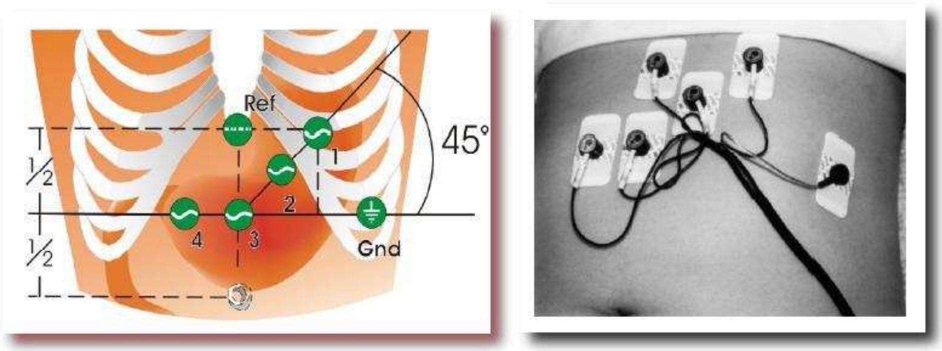

Fig. 1. Electrodes placement for 4-channel EGG registration [12], [3].

Analysis has been performed for 12 registration of 4-channel EGG signals. Two postprandial registrations for each patient has been taken under consideration: phase I and phase II. Phase I included 33 minutes (8008 samples) registration of EGG signal (sampling frequency 4 Hz), directly after feeding with 400 ml of fruit yogurt containing 370 kcal, phase II concerned the next 33 minutes of registration after 5 minutes break. For each person, each phase and each channel of EGG registration the percentage of normogastric rhythm has been analyzed before and after adaptive filtration. It is considered, that for the healthy subjects the normogastric rhythm (2 - 4 cpm) covers over 70% of the whole periodicity of EGG signal [13].

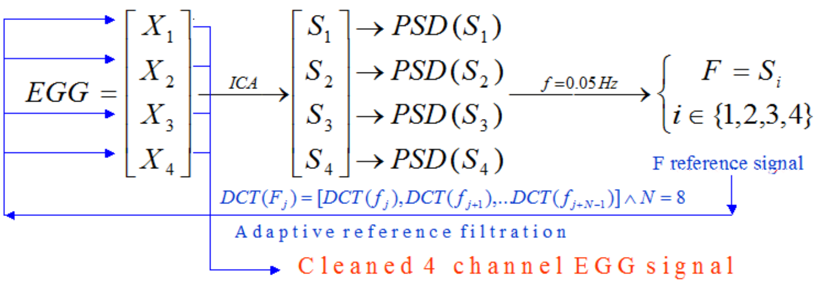

Fig. 2. Scheme of examination procedure for improvement of normogastric rhythm in EGG signal.

In the first step of examination procedure the independent component analysis (ICA) has been applied to 4-channel EGG decomposition, next the integral of power spectral density function (PSD) in the limits concerning frequency of particular earlier defined brady, normo and tachygastric rhythms has been calculated for each obtained source signal. The source signal with the biggest normogastric rhythm contribution has been chosen as the reference signal for adaptive filtration. The adaptive filtering has been performed in the transform domain by means of the discrete cosine transform (DCT) [11] as a basic preprocessing stage improving quite complicated signal quality. Additionally, the percentage of normogastric rhythm in the reference signal has been also analyzed.

3. REVIEW OF APPLIED METHODS FOR EGG ANALYSIS

3.1. INDEPENDENT COMPONENT ANALYSIS (ICA)

The ICA method has been known as an effective technology for blind source separation (BSS) [9], [4], [6], [16]. Multichannel EGG recording is a sort of mixture resulting from the gastric myoelectrical activity of stomach, the electrical activity of other surrounding organs and various kind of noise or artifacts. It is possible to assume that n observed EGG signals $x_1(t), x_2(t), x_3(t),\ldots,x_n(t)$ recorded by multichannel electrogastrography are linear combinations of n statistically independent source components $s_1(t), s_2(t), s_3(t),\ldots,s_n(t)$ such as electrical activity of stomach, heart, respiration or random noise ect.

Let's

$$X = [X_1(t), X_2(t), X_3(t),..., X_n(t)]^T \quad (1)$$

and

$$S = [S_1(t), S_2(t), S_3(t),..., S_n(t)]^T \quad (2)$$

then

$$X = A * S \quad (3)$$

where A is unknown non-singular mixing matrix.

The ICA algorithm focuses on extracting the source signals $s_1(t), s_2(t), s_3(t),\ldots,s_n(t)$ only from their mixed measure, by estimating matrix $E = A^{-1}$, so $S = E * A$. Each of vector X and S could be treated as a random variables. The ICA method consist of two steps. The first one is a proper construction of so called contrast function or cost function and the second one is an optimization algorithm.

ICA = CONTRAST FUNCTION + OPTIMIZATION ALGORITHM

The contrast function is a quantitative measure of stochastic independence of random variables S_i i.e. extracted source signals. Statistical properties of ICA methods depend on the choice of the contrast function [9], [8]. The key for estimating mixing matrix $E = A^{-1}$ is assumption of –non-Gaussian distribution of source signals. According to the central limit theory the sum of independent random variables tends toward Gaussian distribution, under certain conditions, so the sum of independent random variables has a distribution that is closer to Gaussian distribution than distribution of any element of this sum. Let vector v is a row of estimating matrix E

$$y = v^T * X \text{ and } X = A * S \text{ hance } y = v^T * A * S,\ y = Z^T * S\ . \quad (4)$$

As vector y is a sum of independent random variables s_i,the distribution of vector y is the less like Gaussian distribution when the sum is reduced to the one element i.e. $Y = v_i * s_i$ for some $i \in \{1, 2, \ldots, n\}$, so with the aid of vector y it is possible to find source signal s_i [7]. The aim of ICA method is to find the source signals as vector y and lead the procedure to determine such vector v, which maximize the –non-gaussianity of vector y what reduce the problem to optimization of proper contrast function as a measure of –non-gaussianity of sum $y = v^T * X$.

Artificial multichannel EGG signal has been generated in order to verify the ability of ICA method to recover source signals i.e. independent components. Three source signals of the same length have been taken under consideration: 3 cpm slow *wave* $S_1(t) = sin(2\pi\ 0{,}05t)$, 12 cpm respiration $S_2(t) = sin(2\pi\ 0{,}2t)$ and $S3(t)$ –non-Gaussian random noise as environmental interference. Three channel EGG data ($EGG = X = A * S$) has been generated by using mixing matrix A:

$$\underbrace{\begin{bmatrix} X_1 \\ X_2 \\ X_3 \end{bmatrix}}_{X=EGG} = \underbrace{\begin{pmatrix} 2.1 & 2.2 & 2.8 \\ 1.3 & 0.9 & 2.6 \\ 0.9 & 0.5 & 3.25 \end{pmatrix}}_{A} * \underbrace{\begin{bmatrix} S_1 \\ S_2 \\ S_3 \end{bmatrix}}_{S} \tag{5}$$

Results presented in the Fig. 3 and 4 illustrate good performance of FastICA algorithm. Signals have been clearly separated and a main component of gastric electrical activity of stomach i.e. slow wave has been extracted from mixture of EGG data. Proper choice of function F means better approximation of negentropy, what leads to better recovering of independent components.

3.2. ADAPTIVE FILTERING

The adaptive signal enhancement has been performed in the frequency domain by the mean of filter proposed by H. Liang [11]. The order of adaptive filter used in this work has been $N=8$ and the coefficient controlling the rate of convergence has been experimentally fixed at the value of $\mu=0.00375$. Fig. 5 and Fig. 6 present the results for 3-channel simulated EGG signal $Z = [Z1,Z2,Z3]^T$. PSD function in Fig. 6 does not contain interfering frequency (0.1 Hz), so in each channel cleaned gastric myoelectrical component have been obtained.

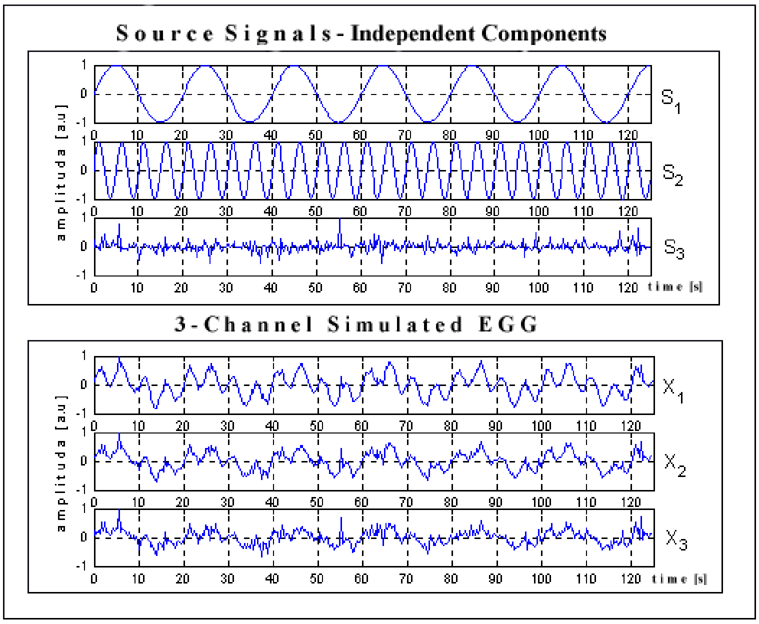

Fig. 3. Before ICA: simulated independent components S_1 - 3 cpm slow wave i.e. the main gastric component, S_2 - 12 cpm respiratory signal and S_3 - random noise.

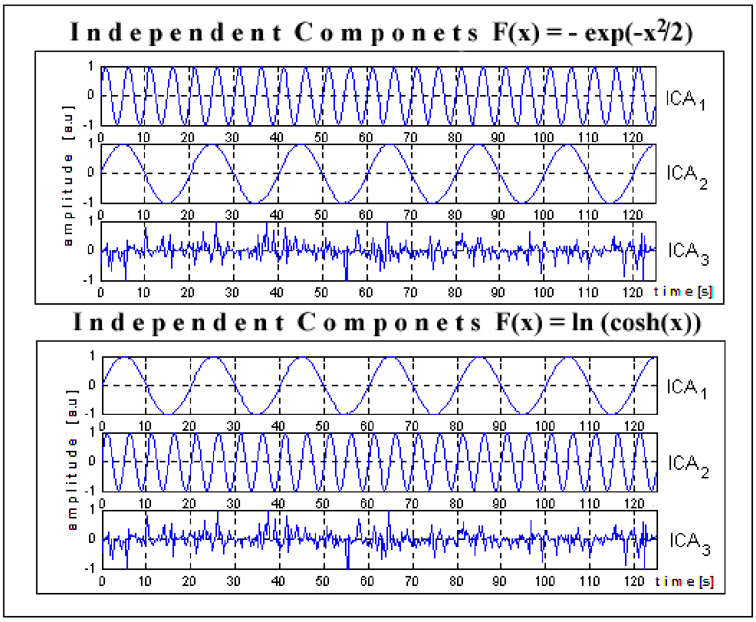

Fig. 4. After ICA: independent components recovered by FastICA algorithm with function $F(x) = -e^{-x2/2}$ and with function $F(x) = ln(cosh(x))$.

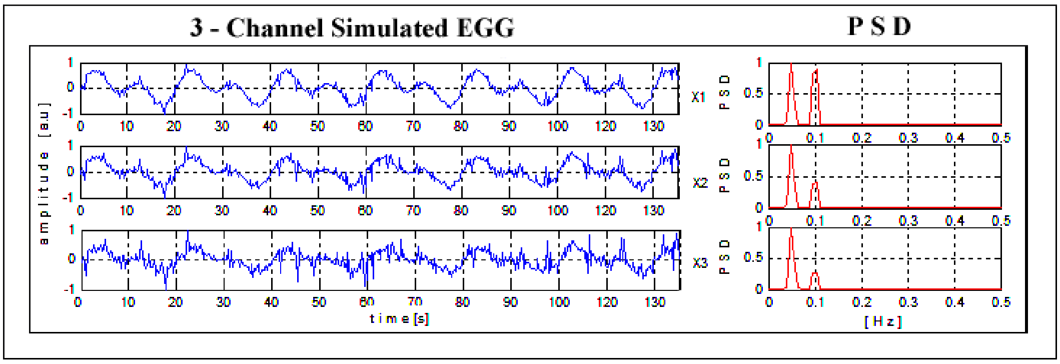

Fig. 5. –3-channel simulated EGG signal.

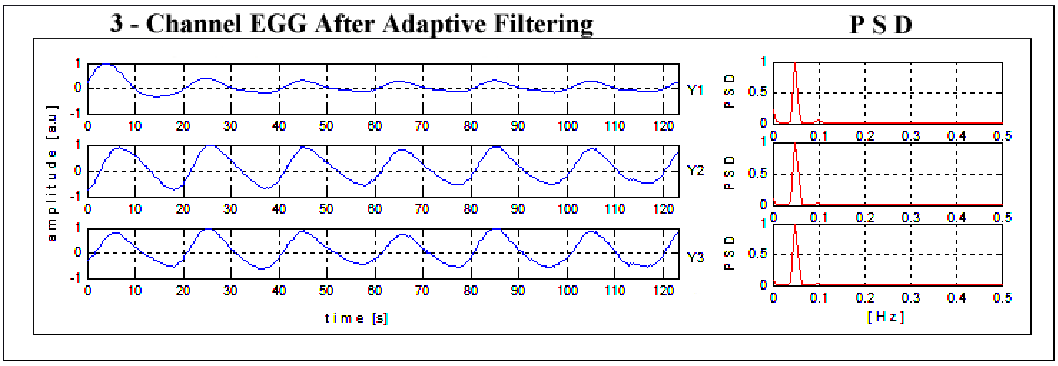

Fig. 6. 3-channel EGG signal after adaptive filtering with the reference signal obtained as an independent component by the aid of ICA method.

4. RESULTS

This section gives the details of real EGG signal analysis concerning normogastric rhythm extraction with application of earlier described methods. As it has been mentioned according to the American Motility Society Clinical GI Motility Testing Force [13] electrogastrogram of the healthy man should contain at least 70% of the basic 3 cpm normogastric rhythm. This empirically obtained threshold value has been confirmed by the results from four independent studying centers for 189 healthy man [13]. The 30% left registration of EGG signal could belong to the range of bradygastric or tachygastric rhythm caused by the damages in the ICC network. Below there are presented results obtained for 6 healthy volunteers (the original signatures have been retained: 070510, 080507, 080509, 080616, 080618 and 080403). Table 1 presents exemplary results of EGG processing for patient 080618 leading to estimation of bradygastric, normogastric and tachygastric rhythm percentage in each channel. Results in Table 1 refer to phase I and have been extracted directly after feeding. The values have been obtained as an integral of power spectral density function (PSD) in the limits concerning frequency of particular, earlier defined rhythms. Afterwards, by application of FastICA algorithm, a reference signal for each phase and each patient has been extracted for adaptive filtering purposes. In four cases i.e. 070510 (phase II), 080509 (phase II), 080618 (phase I) and 080403 (phase II) in order to obtain better quality of reference signal, the dimension of analyzed data has been reduced by principal component analysis method (PCA) [15] before ICA application.

Table 1. Percentage of normogastric rhythm before adaptive filtering for Phase I.

EGG	Brady	Normo	Tachy
Channel 1	13.70 %	68.71 %	17.59 %
Channel 2	13.16 %	67.05 %	19.79 %
Channel 3	13.37 %	64.97 %	21.67 %
Channel 4	4.83 %	89.27 %	5.90 %
$\bar{x}$	11.27%	72.50 %	16.24 %
σ	4.30 %	8.13 %	7.09 %

Extracted reference signal has been then applied for adaptive filtering of registered EGG signal to estimate of normogastric rhythm percentage. Table 2 presents suitable values for described examinations. It has been observed, that extracted normogastric rhythm oscillates around 70%, according to cited literature. Adaptive filtration of EGG signals with reference extracted using FastICA algorithm improved the recovery of normogastric rhythm in Phase I in comparison to the values presented in Table 1, where normogastric rhythm has been estimated without adaptive filtering.

Table 2. Percentage of normogastric rhythm after adaptive filtering for Phase I.

EGG	Brady	Normo	Tachy
Channel 1	10.87 %	79.52 %	9.62 %
Channel 2	12.74 %	77.18 %	10.08 %
Channel 3	13.24 %	69.57 %	17.19 %
Channel 4	4.50 %	89.29 %	6.21 %
$\bar{x}$	10.34%	78.89 %	10.78 %
σ	4.02 %	8.13 %	4.61 %

Tabels III and IV present results for Phase II (study 080518) of EGG signal registration procedure which have been obtained with the help of the same, described above procedure.

Table 3. Percentage of normogastric rhythm before adaptive filtering for Phase II.

EGG	Brady	Normo	Tachy
Channel 1	17.89 %	62.71 %	19.40 %
Channel 2	12.95 %	66.37 %	20.68 %
Channel 3	12.06 %	58.41 %	29.53 %
Channel 4	9.86 %	81.21 %	8.93 %
$\bar{x}$	13.19%	67.18 %	19.64 %
σ	3.39 %	9.91 %	8.441 %

It is easy to notice (Table 4) that in the case of Phase II the normogastric rhythm estimation after adaptive filtration is even better. Graphic representation of the results presented in the Tables 1 - 4 can be observed in the Fig. 7.

Table 4. Percentage of normogastric rhythm after adaptive filtering for Phase II.

EGG	Brady	Normo	Tachy
Channel 1	9.11 %	78.73 %	12.16 %
Channel 2	9.06 %	80.05 %	10.89 %
Channel 3	7.42 %	74.14 %	18.44 %
Channel 4	6.53 %	83.39 %	10.07 %
$\overline{x}$	8.03%	79.08 %	12.89 %
σ	1.27 %	3.83 %	3.80 %

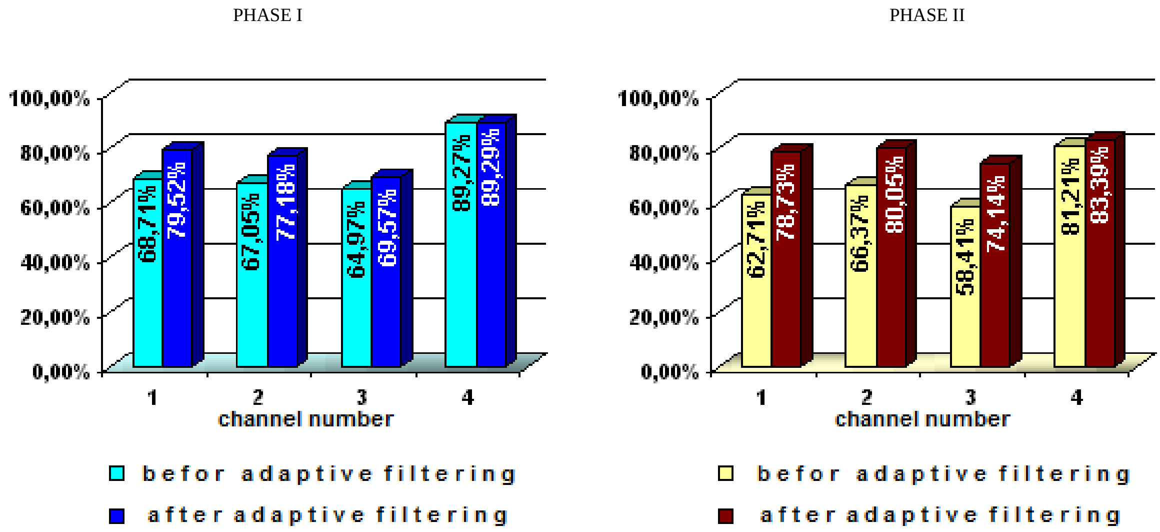

Fig. 7. Percentage of normogastric rhythm in EGG signal before and after adaptive filtering (for patient 080618) in the Phase I and Phase II.

5. CONCLUSIONS

As conclusion, the following aspects of the presented work can be observed: adaptive filtration with the reference signal extracted using FastICA algorithm improves normogastric rhythm estimation in 22 among 24 cases analyzed (91.6%) in phase I and 20 cases among 24 cases analyzed (83.3%) in phase II; the reference signal obtained using ICA method being myoelectrical activity of the stomach covers more than 70% of normogastric rhythm what is perfect agreement with cited reference [13]. In phase I in 17 among 24 analyzed cases (70.8%) normogastric rhythm covered more than 70% of rhythmic behavior of signal but in 7 left cases the level of normogastric rhythm include in the range [66.88%, 69.69%] so only a little bit differ from threshold value. In phase II in 19 among 24 analyzed cases (79.16%) normogastric rhythm cover more than 70% but in 5 left cases the level of normogastric rhythm include in the range [57.46%, 66.63%]. The mean of normogastric rhythm calculated for 4 channels in all the analyzed signals has been improved in 10 of 12 cases i.e. 83%. Presented study needs some further development leading to proper extraction of EGG signal parameters allowing for suitable diagnosis.

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