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An Improvement of Normogastric Rhythm Extraction from Electrogastrographic (EGG) Signal using Independent Component Analysis

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***Abstract*—Electrogastrographic Signal (EGG) is considered to be one of the less interesting from both registration and interpretation point of view. There are several reasons of that two facts. EGG presents gastric myoelectrical activity measured by several electrodes attached on the abdomen. Unfortunately the registration procedure does not deliver a pure signal as EGG is usually associated with some interferences caused by the other organs localized near stomach. On the other hand however there are no databases available, which could allow both comparison and proper interpretation. One of the parameter, among others, which is analyzed owing to proper registration is so called normogastric rhythm, which should cover around 70% of rhythmic behavior of the signal. Proper extraction of the normogastric rhythm is a subject of this paper. Special signal preprocessing steps should be applied before the main tool i.e. Independent Component Analysis (ICA) is applied for normogastric rhythm extraction. Also, to make this analysis possible a special registration procedure has been applied concerning two phases of registration – one with feeding and the other one without with 5 minutes brake between them.**

I. Introduction

THE source of EGG [1] signal is the stomach, which similarly like other elements of gastrointestinal system is made of parallel positioned, mutually connected muscle layers. From the EGG signal point of view, human stomach is made of special muscle membrane frequently called muscular coat, consisting of three layers: external longitudinal, middle circular and finally internal oblique, which due to mutual close specific connections can commonly work as electric signal network. Longitudinal layer cells create a dominant cluster of cells along both curvatures and does not appear in the front and back walls of stomach. The place where longitudinal layers miocytes are separated is considered to be a pacemaker capable for automatic self excitation. Generally, there are two types of muscle electrical activity inside the stomach: Electrical Control Activity (ECA) or so called slow wave and Electrical Response Activity (ERA) [4]. Slow waves are spread out from one cell to another of longitudinal layer causing electrotonic currents in the circular layer. Slow waves frequency is around 3cycles per minute ([cpm]) and do not produce contractions of the stomach muscles. It is possible to assert that slow waves both integrate and control stomach wall muscularis contractions. Stomach muscularis contraction is produced by ERA, which can only appear at the top of depolarization of the slow wave.

Similarly like in case of cardiac signals there are several reasons causing that EGG signal include apart from normal physiological rhythm 2.4 – 3.7 [cpm] (0.04 – 0.061 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 (0.6 - 2.4 [cpm]) (0.01 – 0.04 Hz), normogastric rhythm (2.4 – 3.6 [cpm]) (0.04 – 0.06 Hz) and finally tachygastric rhythm (3.6 – 9 [cpm]) (0.06 – 0.15 Hz).

II. Procedure of EGG Signal Registration

EGG signal registration has been performed with the standard biosignal amplifier and abdomen electrodes placement [fig.1].

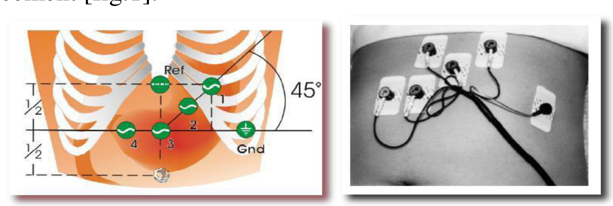

Fig. 1 Electrode placement for 4-channel EGG signal registration

The procedure itself consisted the examination of 6 healthy patients from which two phases namely Phase I and Phase II of signal registration have been performed. Phase I included 33 minutes of registration after feeding with 400 ml of fruit yogurt consisting of 370 Kcal and Phase II concerned next 33 minutes of registration after 5 minutes brake. For each person, each Phase and each channel of registration the percentage of normogastric rhythm has been analyzed before and after adaptive filtering. The mentioned adaptive filtering has been applied as basic preprocessing stage improving quite complicated signal quality. However,

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in normal conditions most researchers consider up 70% of normogastric rhythm to be included in the whole periodicity of EGG signal. Therefore the application of Independent Component Analysis (ICA) has been applied first for EGG decomposition and then results of such decomposition have been applied for improvement of normogastric rhythm extraction as a reference for adaptive filtering. The details of necessary mathematics will be describe in Section III.

III. APPLICATION OF ICA

In the framework of ICA, introduce in [3], it is possible to observed n EGG signals $X_1(t), X_2(t),...X_n(t)$ recorded by multichannel electrogastrography, which are assumed to be a linear combination of n unknown mutually statistically independent components $S_1(t), S_2(t),..., S_n(t)$.

Let's

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

and

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

then $X = A \cdot S$ where A is unknown non-singular mixing matrix. The algorithm of ICA focuses on obtaining the source signals $S_1(t), S_2(t),...,S_n(t)$ only from their mixed measure, by estimating matrix $W = A^{-1}$ so $S = W \cdot X$ In this study the Matlab implementation of FastICA algorithm proposed by A. Hyvärinen and E.Oja [2] has been successfully applied for simulated EGG data contaminated by respiratory and random noise, leading to extracting physically meaningful signals. FastICA software applied fixed-point iteration scheme for maximizing nongaussianity of $w^T X$. In this algorithm the negentropy (J) called also as differential entropy defined as follow

$$J(Y) = H(Y_G) - H(Y) \qquad (3)$$

where Y_G is a gaussian random variable of the same covariance matrix as Y, has been used as a measure of the amount of mutual information shared by independent components. Because of the fact that gaussian random variables have the largest entropy among all random variables of equal variance, the negentropy is always positive for nongaussian random variables and zero for gaussian random variables. Maximizing negentropy is the same as maximizing nongaussianity of random variable and equivalent of minimizing mutual information. However the estimation of negentropy is difficult and in practice some approximations has been applied. In FastICA algorithm, negentropy is estimated by formula

$$J(Y) \approx [E\{G(Y)\} - E\{G(Y_G)\}] \qquad (4)$$

where both Y and Y_G are standardized random variables i.e. variable with zero mean and unit variance. Function G is considered to be any nonquadratic function.

Simulation EGG multichannel signals were generated in order to verify if ICA method could recover source signals, i.e. independent components. Three channel simulation signals of the same length given by $s_1(t) = \sin(2\pi \cdot 0.05t)$ simulating 3 [cpm] gastric slow wave, $s_2(t) = \sin(2\pi \cdot 0.2t)$ simulating a 12 [cpm] respiratory signal and $s_3(t)$ random noise simulating environmental interference, have been mixed by mixing matrix $A = \begin{pmatrix} 2.1 & 2.2 & 2.8 \\ 1.3 & 0.9 & 2.6 \\ 0.9 & 0.5 & 3.25 \end{pmatrix}$ and three mixing signals X_1, X_2, X_3 simulating EGG data have been obtained.

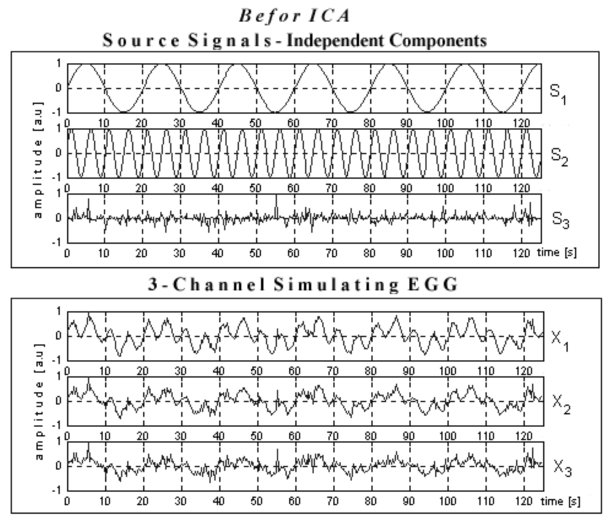

Fig. 2. Before ICA: simulating independent components S_1 3 cpm slow wave i.e. the main gastric component, S_2 12 cpm respiratory signal and S_3 simulating random noise

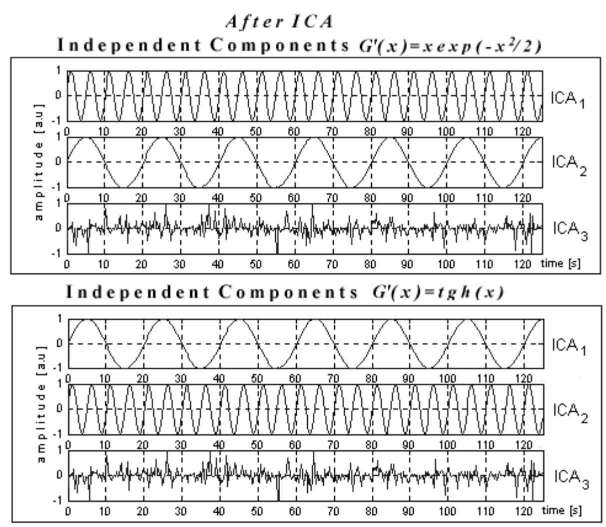

Fig. 3. After ICA: independent component recovered by FastICA algorithm with function $G'(x) = x\exp(-x^2/2)$ and with function $G'(x) = tgh(x)$

Results presented in fig. 2 and fig. 3 illustrate good performance of FastICA algorithm. Signals have been clearly separated and main component of gastric electrical activity of stomach, i.e. slow wave has been extracted from mixture of EGG data. It can be also noticed that choosing properly function G it is possible to obtain better approximation of negentropy, which leads to better recovering of independent components.

IV. Results

This section will give a details of real EGG signal analysis concerning normogastric rhythm extraction with application of earlier described algorithms such as FastICA.

Table I presents results of EGG processing leading to estimation of normogastric rhythm percentage in each channel. Presented results refer to Phase I and have been extracted directly after feeding. The numbers have been obtained as an integral of power spectral density (PSD) in the limits concerning frequency of particular, earlier defined rhythms.

TABLE I
PERCENTAGE OF NORMOGASTRIC RHYTHM BEFORE ADAPTIVE FILTERING IN PHASE I

EGG	bradygastria	normogastria	tachygastria
1.	13.70%	68.71%	17.59%
2.	13.16%	67.05%	19.79%
3.	13.37%	64.97%	21.67%
4.	4.83%	89.27%	5.90%
mean	11.27%	72.50%	16.24%
std	4.30	11.28	7.09

Next, by application of FastICA algorithm a reference signal has been extracted for adaptive filtering purposes.

TABLE II
PERCENTAGE OF NORMOGASTRIC RHYTHM IN REFERENCE SIGNAL OBTAINED BY APPLICATION OF ICA METHODS - PHASE I

EGG	bradygastria	normogastria	tachygastria
ICA	5.07%	89.16%	5.77%

Extracted reference signal has been then applied for adaptive filtering of registered EGG signals in Phase I to estimate of normogastric rhythm percentage. It is believed that in case of healthy subject the normogastric physiological rhythm should oscillate around 70% [5]. Table III presents suitable numbers of described examinations. It can be seen that adaptive filtering of EGG signals with reference extracted using FastICA algorithm improved the recovery of normogastric rhythms in Phase I in comparison to the numbers presented in Table I, where normogastric rhythm has been estimated without adaptive filtering.

Tables IV, V and VI present results for the Phase II of EGG signal registration procedure which have been obtained with the help of the same, described above procedure.

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TABLE III
PERCENTAGE OF NORMOGASTRIC RHYTHM AFTER ADAPTIVE FILTERING IN PHASE I

EGG	bradygastria	normogastria	tachygastria
1.	10.87%	79.52%	9.62%
2.	12.74%	77.18%	10.08%
3.	13.24%	69.57%	17.19%
4.	4.50%	89.29%	6.21%
mean	10.34%	78.89%	10.78%
std	4.02	8.13	6.61

TABLE IV
PERCENTAGE OF NORMOGASTRIC RHYTHM BEFORE ADAPTIVE FILTERING IN PHASE II

EGG	bradygastria	normogastria	tachygastria
1.	17.89%	62.71%	19.40%
2.	12.95%	66.37%	20.68%
3.	12.06%	58.41%	29.53%
4.	9.86%	81.21%	8.93%
mean	13.19%	67.18%	19.64%
std	3.39	9.91	8.44

TABLE V
PERCENTAGE OF NORMOGASTRIC RHYTHM IN REFERENCE SIGNAL OBTAIN ICA METHODS - PHASE II

EGG	bradygastria	normogastria	tachygastria
ICA	7.49%	85.19%	7.22%

TABLE VI
PERCENTAGE OF NORMOGASTRIC RHYTHM AFTER ADAPTIVE FILTERING IN PHASE II

EGG	bradygastria	normogastria	tachygastria
1.	9.11%	78.73%	12.16%
2.	9.06%	80.05%	10.89%
3.	7.42%	74.14%	18.44%
4.	6.53%	83.39%	10.07%
mean	8.03%	79.08%	12.89%
std	1.27	3.83	3.80

It is easy to noticed that is case of Phase II the normogastric rhythm estimation after adaptive filtering is even better.

Graphic representation of the results presented in the tables above can be seen in fig. 4. and fig.5, where ICA2 and ICA4 stand for independent component decomposition channel number respectively, i.e. channel two and channel four. These components have been taken as a reference for adaptive filtering procedure.

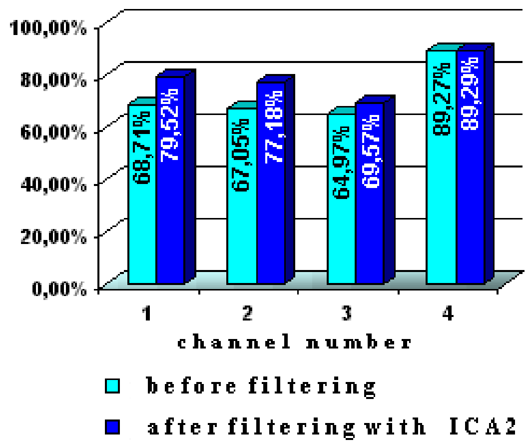

Fig. 4. An improvement of normogastric rhythm estimation in Phase I

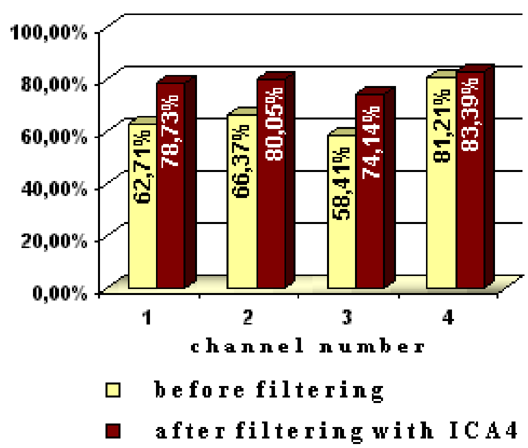

Fig. 5. An improvement of normogastric rhythm estimation in Phase II

V. CONCLUSION

As a conclusion the following aspects of the presented work can be seen: adaptive filtering with the reference signal extracted using FastICA algorithm has improved normogastric rhythm estimation in 22 cases among 24 cases analyzed (91,6%) in Phase I and in 20 cases among 24 cases analyzed (83,3) in Phase II; the reference signal obtained using ICA method being a myoelectric activity of the stomach consists more than 70% of normogastric rhythm, what is with perfect agreement with cited references [5]; 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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