ELECTROGASTROGRAPHIC SIGNALS ANALYZED BY INDEPENDENT COMPONENT ANALYSIS

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Abstract: Electrical activity of the stomach pacemaker structure, the network of interstitial cells of Cajal, can be noninvasively recorded as an electrogastrogram (EGG). Power of the EGG signal is, however, much weaker in comparison with the other biological signals (e.g. ECG, respiratory signal). EGG signal is therefore usually contaminated by other biological signals and artifacts, which are difficult to separate from the EGG signal by conventional filtering methods. In the present study, independent component analysis (ICA), as a method for blind source separation, is used for artifact removal and biological signal separation. EGG signals were recorded using 4-channel custom made recording device controlled by ADμC812 8-bit microcontroller and connected to a notebook computer. All signals were measured relatively to a single reference electrode. The present study shows that ICA application on a set of EGG signals approved potential of this method for artifact removal and signal separation. The algorithm is useful for separation of different types of signals (motion artifact, oscillating transients) from the original EGG recordings. We can conclude that ICA improves further analysis of separated signals and their biological interpretation. It could potentially improve also analysis of relations between signals originating from different biological structures.

Introduction

Electrical activity of the stomach pacemaker structure, the network of interstitial cells of Cajal (ICC), can be noninvasively recorded as an electrogastrogram (EGG) [1,2]. Oscillations of the network of ICC, called slow waves, spread on the neighboring smooth muscle cells and are necessary for their contractions and coordinated motility of the stomach wall. EGG signal therefore represents useful tool for noninvasive functional evaluation of the ICC network, which proper and coordinated activity is necessary (but not sufficient) for proper motility pattern in the stomach [2].

Power of the EGG signal is, however, much weaker in comparison with the other biological signals (e.g. ECG, respiratory signal). EGG signal is therefore usually contaminated by other biological signals and artifacts, which are difficult to separate from the EGG signal by conventional filtering methods.

Recently, a method for blind source separation called independent component analysis (ICA) was introduced [3]. ICA extracts source signals (independent components) contributing to a mixture of signals (recorded signals) without any knowledge about their properties. This extraction is based on the assumption that component signals are statistically independent, meaning that knowing the properties of one component signal provides no information about the properties of the other signals in the mixture. The major constraint of ICA is that it requires at least as many mixture signals as there are component signals in the mixture. Recently, ICA has been successfully applied for analysis of biomedical signals [4]. In the present study we used this method to extract source signals from a set of EGG signals recorded by a custom made EGG device.

Materials and Methods

Multichannel measurement of EGG signals with simultaneous recording of one electrocardiogram for heart rhythm monitoring was implemented in the ProGastro 3 device (Figure 1) [5]. It consists of a measuring box with signal amplifiers and a microcomputer-controlled measuring module. The box is connected to a serial port of a notebook computer. In human subjects, signals are recorded by a set of solid gel disposable electrodes (HP 1394). EGG amplifier with 4 programmable channels, automatic offset compensation, programmable gain 2500 - 20000 and selectable frequency range .015 - .5 Hz or .015 - 3.4 Hz is controlled by ADμC812 8-bit microcontroller. All signals are measured relatively to a single reference electrode, active neutralization electrode ensures common-mode signal rejection ratio higher than 90 dB.

Application software developed in MS Visual C++ and MatLab, is running under Windows 98/2000/XP and allows full control of the measuring box and long term real-time EGG monitoring and recording. Subsequent EGG signal processing includes digital filtering, baseline corrections, interactive amplitude and time interval measurements followed by time-frequency and independent component analysis.

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Figure 1: ProGastro 3 device used for EGG measurement

Measured data in EGG signals can be modeled as a linear combination of source signals that are non-gaussian and mutually statistically independent by the following equation:

$$\mathbf{x} = \mathbf{A} \cdot \mathbf{s}$$

where $\mathbf{x}$ = (x1, x2,...,xn)^T is the vector of observed variables, $\mathbf{s}$ = (s1, s2,...,sn)^T is a vector of variables called independent components or source signals, and A is a mixing matrix. This equation can be inversed and expressed as follows

$$\mathbf{s} = \mathbf{W} \cdot \mathbf{x}$$

where the weighting matrix W equals the inversed mixing matrix A. One independent component can be expressed by the following equation:

$$\mathbf{s} = \mathbf{w}^T \cdot \mathbf{x} = \sum_j w_j \cdot x_j$$

Several algorithms were proposed for computing the independent components and the matrices A and W [6,7]. In the present study, independent components (IC) were estimated using FastICA algorithm implemented in MATLAB (available on the web at http://www.cis.hut.fi/projects/ica/fastica/). This software is based on a fixed-point iteration scheme for maximizing non-gaussianity of $\mathbf{w}^T \cdot \mathbf{x}$ introduced by Hyvärinen and colleagues [8]. In this algorithm, negentropy (or differential entropy) is a parameter quantifying the amount of mutual information shared by the independent components. Negentropy (J) of a random variable **s** (or of independent components) is the difference between the entropy of a gaussian random variable ($H(s_G)$) and entropy of the random variable s ($H(s)$):

$$J(s) = H(s_G) - H(s)$$

A gaussian random variable has the largest entropy among all random variables of equal variance. Thus, negentropy J(s) is always non-negative and zero if and only if s is gaussian. Maximizing negentropy is therefore equivalent to maximizing nongausianity in a random variable, thus minimizing mutual information. In FastICA algorithm, negentropy is estimated by

$$J(s) \propto [E\{G(s)\} - E\{G(s_G)\}]$$

where s is a random variable assumed to be of zero mean and unit variance, s_G is a gaussian random variable of zero mean and unit variance and G is a nonquadratic function [8]. Detailed information on this algorithm can be found in [8,9]

For frequency transformation, non-stationary method (Wigner distribution) was used in order to obtain spectro-temporal representation of the EGG signal [10,11]. Cross-terms in Wigner distribution were eliminated by smoothing (Choi-Williams filtering was used in our study [12]).

Results

In the present study, usefulness of ICA was examined for removing of sudden discontinuities in the EGG signal (Figure 2) and temporal higher frequency high amplitude signal (Figure 4) in time course of EGG recording.

In Figure 2, high amplitude low frequency artifact at the very beginning of the recording time period is present in EGG signals. ICA separated 3 artifact components (IC 1 – IC 3) and one relevant component (IC 4), which represents gastric slow waves. Expected dominant frequency content of gastric signal (IC 4) was proved to be 3 cycles per minute (cpm) by nonstationary spectrotemporal transform – Wigner distribution with Choi-Williams filtering of cross-terms (Figure 3).

The next example (Figure 4) shows signals contaminated by an artifact at the very beginning of the recorded time period and pronounced in higher frequency signals occurring between the 5th and 6th minute of the recording time period. ICA application on this set of EGG signals approved potential of this method for artifact removal and signal separation. Artifact was separated as a single independent component IC 2 and temporal higher frequency signal occurring in the 6th minute of the EGG recording as component IC 4. The first independent component IC 1 represents the basic signal originated in stomach with a dominant frequency of 3 cpm.

Discussion

Recently, ICA was successfully tested for artifacts removal from EGG signals using the maximal likelihood algorithm [9]. In the present study, usefulness of ICA for artifact removal and signal separation for EGG recordings was tested using fixed-point algorithm proposed by Hyvarinen [8].

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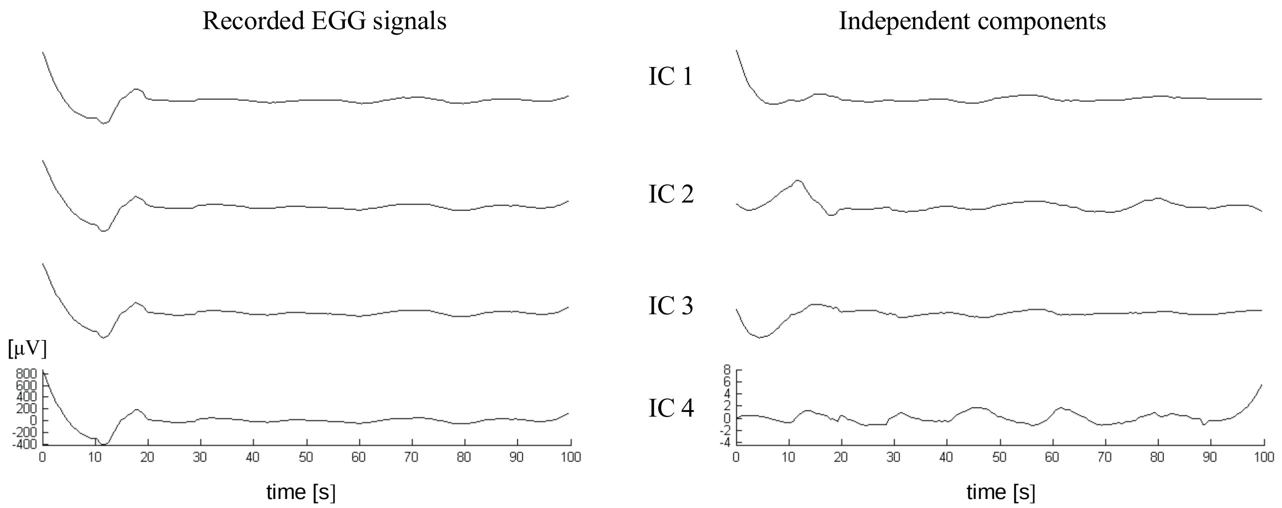

Figure 2: Recorded EGG signals with a sudden discontinuity and independent components IC1 – IC4 as a result of ICA

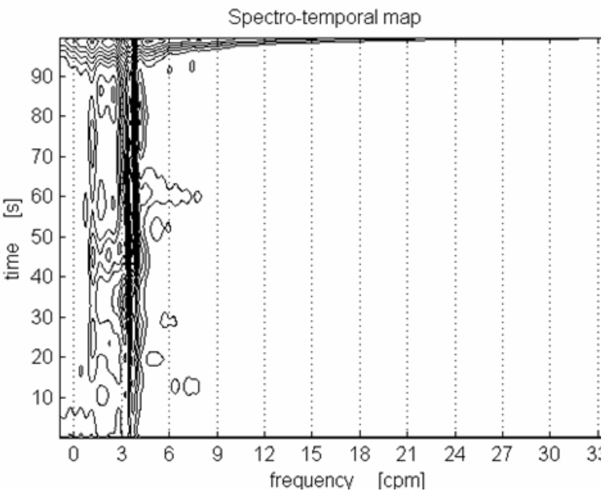

Figure 3: Spectrotemporal representation of the independent component IC 4

ICA is based on the assumption that separated signals are non-gaussian, mutually independent and that the recorded signals are a linear sum of the source signals. It was argued that interesting signals in nature often have non-gaussian distributions (e.g. [13]) and signals with gaussian statistical distribution are thought to be a mixture of non-gaussian ones. It is therefore reasonable to suppose that signals of interest (biological signals and artifacts that should be separated from them) are non-gaussian.

The major constraint of ICA is that it requires at least as many recorded signals as there are source signals in the mixture. EGG recordings contain 4 different signals available for analysis. It is reasonable to suppose that EGG signals are formed by more than only 4 different sources. Iterative optimization is used in fastICA algorithm generated components with a minimum of mutual information. Thus, algorithm generates signals that are not strictly mutually independent but as independent as possible [7].

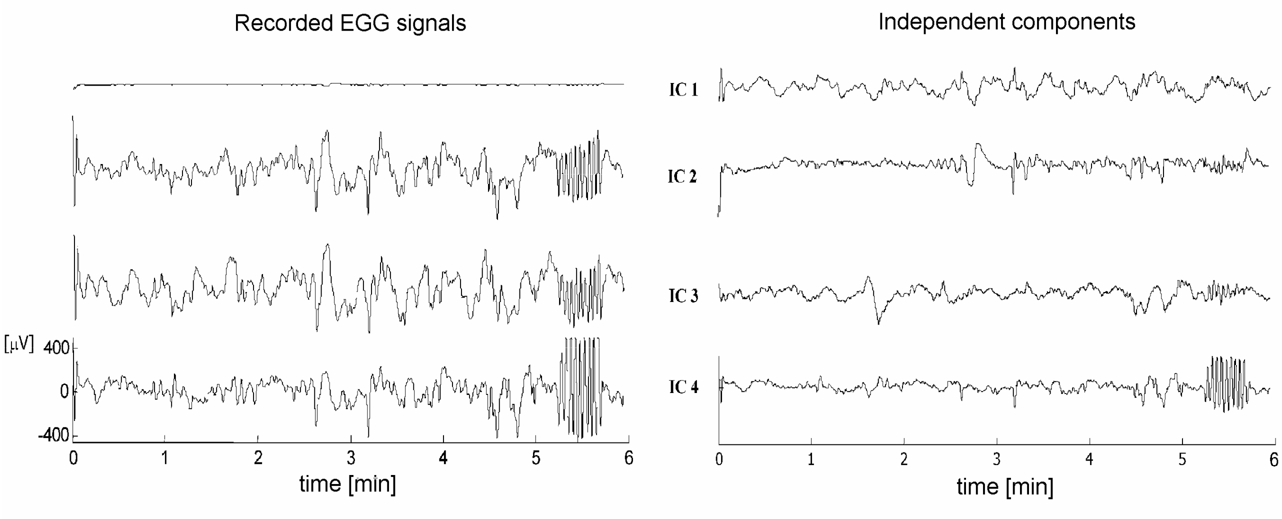

Figure 4: Recorded EGG signals contaminated with temporal higher frequency high amplitude signal and independent components IC1 – IC4 as a result of ICA

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Independent components could be therefore signals that are the most independent signals comprising the recorded ones.

Common problem of EGG analysis is that there is no direct connection between EGG signal parameter and occurrence of contractions of the stomach. ICA could potentially bring a promising tool for separating signal that could indicate contraction incidence from the signal mixture. We can expect that such a signal is very low in amplitude, has overlapping spectra with other signals and is therefore very difficult for detection by conventional signal analysis methods. ICA is a method that could separate such signals and enables further analysis and detection of hidden signals in the mixed EGG recordings.

Conclusions

We can conclude that usefulness of ICA application on EGG signals was approved. The algorithm, used in the study, is suitable for artifacts elimination from the EGG signals. ICA, thus, improves further analysis of separated signals and their biological interpretation. It could potentially improve also analysis of relations between signals originating from different biological structures.

Acknowledgements

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