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A new approach for denoising multichannel electrogastrographic signals

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ABSTRACT

Electrogastrography (EGG) can be considered as a non-invasive method for the measurement of gastric myoelectrical activity. The multichannel signal is non-invasively captured by disposable electrodes placed on the surface of a stomach. The recorded signal can include not only EGG components, but also the interfering signals from other organs, for instance, the disturbances connected with respiratory movements and random noise. In order to correctly calculate the parameters of the EGG examination and improve the patient's diagnosis, the EGG signal requires effective methods for removing disturbances. The aim of this work was to investigate a new approach for denosing the multichannel electrogastrographic signals, performed by means of the Noise-Assisted Empirical Mode Decomposition (NA-MEMD) and adaptive filtering. The proposed method uses NA-MEMD for extracting the reference signal for adaptive filtering in the cosine domain. The suggested technique was validated by comparing the obtained results with the outcomes acquired by the reference method based on the classical bandpass filtering, Independent Component Analysis (ICA) and adaptive filtering. The effectiveness of the proposed algorithm was established by examining the influence of adaptive filtering on the basic diagnostic parameters, calculated from the EGG signal, such as the dominant frequency (DF), the normogastric rhythm index (NI), the frequency instability coefficient (FIC), and the power instability coefficient (PIC). In addition, the effectiveness of the noise attenuation by the proposed method was verified. The paper presents the results of research carried out for the five healthy subjects. Validation of the proposed method was performed using real human EGG signals and real EGG signals with added synthetic noise.

1. Introduction

Electrogastrography is the cutaneous measurement of the myoelectrical activity of the stomach performed by using disposable surface electrodes placed on the abdominal skin of the patient [1]. The one-channel EGG data was obtained for the first time in 1922 by Walter Alvarez [2]. The EGG is a non-invasive test, relatively inexpensive and easy to perform. Due to the fact that the EGG recording does not disturb the myoelectrical activity of the stomach, it can play significant role as an additional evaluation tool in the diagnosis of gastric motility disorders [3]. Electrogastrography is particularly appreciated and increasingly used by pediatricians and neonatologist because of its non-invasiveness and relatively small inconvenience [4–6].

From the pacemaker area of stomach, located on the greater curvature between the fundus and corpus, spontaneous electrical depolarization and repolarization generates the myoelectrical excitation. The main component of the gastric myoelectrical activity, the so-called the gastric slow wave, has a frequency ∼0.05 Hz (3 cycles per minute (cpm)). For appropriate spread of the gastric peristalsis in a form of a mechanical wave, the gastric slow waves must propagate from the pacemaker region circumferentially and distally toward the pylorus. The correct speed and direction of the propagation of the slow wave is the crucial mechanism that controls and integrates the stomach wall motility, which is responsible for the proper emptying of the stomach [7]. Gastric disorders, such as vomiting, dyspepsia and bloating are usually a consequence of the disturbances in the emptying of the stomach contents.

Compared to the other electrophysiological signals, the clinical applications of the EGG are still limited, mainly because the amplitude of the EGG signal is relatively weak ∼40–500 μV and the frequency band is very low (in the range from 0.008 to 0.15 Hz (0.5–9.0 cpm)) [8]. For this reason, there are potential difficulties to extract the EGG components from the surrounding background

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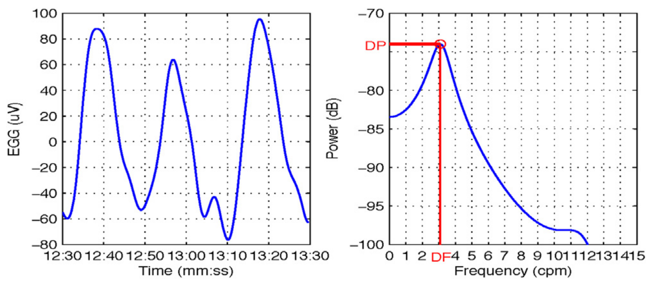

Fig. 1. The fragment of 1-minute EGG data (left), its spectrum (right) with the dominant frequency (DF), and dominant power (DP) indicated.

noise related to the undesirable signals, such as respiratory, heart, duodenal, and colonic electrical activity. Since the EGG is the mixture of the other signals the direct visual analysis of the raw EGG data is difficult or nearly impossible.

Usually, the EGG processing is based on spectral analysis and is performed by computer applications. The typical EGG examination generally takes about 2 h and is divided into three parts: preprandial (fast), meal, and postprandial. According to the conventional method of the EGG analysis [7,9], the recorded signal is usually divided into ~30-minute fragments, one preprandial and two or more postprandial (the meal part is excluded from examination). Each of 30-minute fragments of the EGG examination is divided into 1- to 4-minute (long) segments, then the power spectrum density (PSD), the dominant power (DP), and the dominant frequency (DF) are calculated for each segment. The DF is defined as a value of frequency for the highest peak (dominant power) of the PSD in the range of 0.5–9.0 cpm [7]. A graphical illustration of DF is depicted in Fig. 1. Based on the DF, the normogastric rhythm index (NI) is defined as the ratio of the number of segments with DF in the range of ⟨2.4–3.6⟩ cpm to the total number of segments [3,5,9]. The normogastria range slightly differs, depending on the institution. The EGG recording can also posses some pathological rhythms: bradygastria (0.5–2.4 cpm), and tachygastria (3.6–9.0 cpm). According to the literature, the percentage of normogastria ryhthms for the healthy subject is about 70 [3,10]. The EGG signal recording procedure is described in detail by Kenneth Koch in [7], and Jieyun Yin et al. in [10]. The definitions and descriptions of other parameters that are commonly calculated for EGG signals can be found in the literature [3,7,9,10].

Various methods of filtering out the background noise and the automatic analysis of the signal have been developed and widely presented in the literature, for example, bandpass filtering [11], fast Fourier transform [7], running spectral analysis [12], autoregressive modeling [13], neural network [14], continuous wavelet transform (CWT) [15,16], independent component analysis (ICA), and adaptive filtering [13,17,18]. In a classical way of EGG signals processing, the conventional low-pass or bandpass filter are usually applied. Using these methods may result in the waveform distortion of gastric signal [13,18]. In cutaneous EGG recordings [10,13,19,20] the waveform distortion may be due to the fact that frequencies (or its harmonics) of other biological signals: the respiratory disturbance (12–25 cpm), small intestine, distal ileum (~8 cpm), colonic signal or noise may be close to or overlap with gastric signals. Adaptive filtering allows improving the signal-to-noise ratio (SNR) of the EGG, simultaneously keeping the gastric signal component less affected [1,13,17]. Getting a reference signal for adaptive filtering in practical biomedical applications is not an easy task and is frequently mentioned in the literature as the inherent weakness of adaptive technique [21].

The aim of this paper was to present a novel approach to different types of artifact mitigation in the multichannel EGG signal by using the combination of two methods: the NA-MEMD algorithm (for obtaining the reference signal) and adaptive filtering in the cosine domain. The proposed method based on NA-MEMD algorithm can be successfully applied to obtain the reference signal.

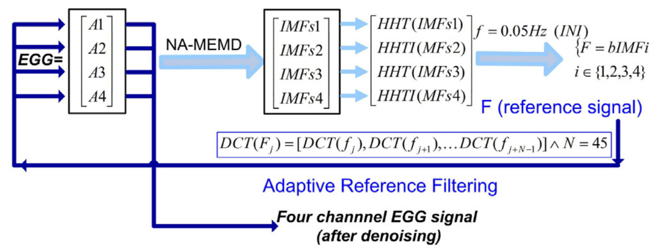

Fig. 2. The block diagram of the adaptive filtering with the reference signal obtained by using the NA-MEMD algorithm (proposed method).

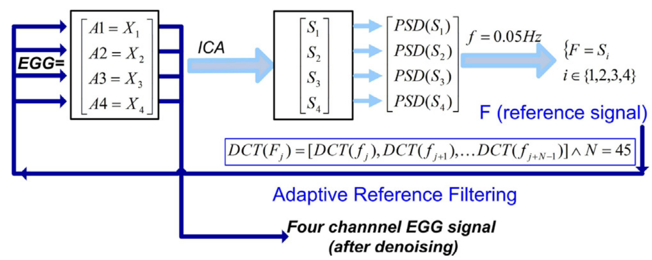

Fig. 3. The block diagram of the adaptive filtering with the reference signal obtained by using the ICA algorithm (reference method).

2. Methods

In this section, the adaptive filtering algorithm for the multichannel EGG signal is presented. The process of adaptive filtering requires a reference signal, which was obtained by the NA-MEMD and ICA methods. This section is organized as follows: first, the process of the acquisition of EGG signals is described, then NA-MEMD, ICA, and the adaptive filter are introduced. Fig. 2 shows the block diagram of the proposed method. The method was validated by using both the traditional bandpass filtering (in the range of 0.5–9.0 cpm) and adaptive filtering with the reference signal obtained by means of the ICA algorithm. Fig. 3 presents the scheme of the second reference (validation) method.

2.1. Procedure of EGG recording

The EGG signals (time series) used in the presented work were recorded using a wireless four-channel biological amplifier [22]. The resolution of the analog-to-digital converter used in the amplifier was 24 bits. The signals were sampled with frequency 250 Hz per channel, and next filtered by anti-aliasing low-pass digital FIR filter with the cut-off frequency set to 2.0 Hz, and next re-sampled to 4 Hz. During the signal recording process, the standard electrode configuration was applied [9]. Fig. 4 presents the position of the electrodes on the abdomen surface during recording process.

The recordings were collected from five healthy subjects (young women), who volunteered to participate in the study. Their average age was equal to 25.75 years (range: 24–31) and average BMI was 19.83 (range: 18.6–21.1). Every volunteer gave a written consent to participate in the study. The research project was approved by the Bioethics Committee of the Silesian Medical University. The time of the examination was from 120 to 180 min. Before the test, all participants fasted for about 12 h. During the EGG recording, the stomach was stimulated by 400 ml of cold water.