Empirical Mode Decomposition for Slow Wave Extraction from Electrogastrographical Signals

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Abstract— **The aim of this study was to investigate the effectiveness of Empirical Mode Decomposition (EMD) for slow wave extraction from multichannel electrogastrographical signal (EGG) the cutaneous recording of gastric myoelectrical activity. From the pacemaker region of stomach both spontaneous depolarization and repolarization occur generating the myoelectrical waves that are called the gastric pacesetter potentials, or slow waves. The 3 cycles per minute (3pcm) (0.05Hz) slow wave is fundamental electrical phenomenon in stomach responsible for the propagation and maximum frequency of stomach contractions. Appropriate spread of gastric contractions is a key for the correct stomach emptying whereas delay in this action causes various gastric disorders, such as bloating, vomiting or unexplained nausea. Unfortunately the EGG signal is not a pure one but usually a sort of mixture consisting of respiratory signals, cardiac signals, random noise and possible myoelectrical activity from other organs surrounding the stomach, such as duodenum or small intestine. Identify and removal of contaminations from different artifactual sources from the EGG recording is a major task before EGG analysis and interpretation. The use of EMD method and Hilbert spectrum combination for slow wave extraction from raw EGG signal seems to be a good choice, because this adaptive decomposition technique is unique suitable for both nolinear, no-stationary data analysis.**

I. INTRODUCTION

Likewise in the heart there is myoelectrical activity in the stomach, which can be measured directly from gastrointestinal mucosa or serosa or by cutaneous electrodes placed on the abdominal skin over the stomach. Such cutaneous recording is usually called the electrogastrogram (EGG) [8]. The EGG signal is very attractive mainly because the method is noninvasive i.e. safe without side effects, inexpensive, accessible anywhere the patient is treated and moreover does not disturb on-going processes in the stomach. Gastric myoelectrical activity (GMA) of stomach can be mainly subdivided into two categories: electrical control activity (ECA), which is an omnipresent slow wave with a frequency 3 cpm (0.05 Hz) in healthy humans and electrical response activity (ERA), which is the spike or fast wave superimpose on the ECA. The first one reflects the maximum frequency of contractions of the stomach, the second one is associated with the appearance of contractions.

The tunica muscularis of stomach walls consist of three layers of muscles: longitudinal, circular and oblique, which however are not able to awake electrical excitation. It is known that particular network of cells called the Interstitial Cells of Cajal (ICC) are the source of electrical rhythmicity (slow wave) recorded as the gastric pacesetter potentials [2]. The most important ICC network for generation and propagation slow wave is located between the circular and longitudinal muscle layers of corpus and antrum. Slow wave decay in amplitude and disappear within a few millimeters in the region of gastric muscle devoid of ICC [1]. Slow wave generated within tunica muscularis of the proximal corpus along the greater curvature spreads circumference and down the stomach toward the pylorus. As the velocity of propagation around the stomach is greater than downwards the ring of excitation, which is electrical basis for gastric peristaltic contraction is invoked [1]. The pressure wave resulting from the gastric peristalsis pushes the contents of the stomach toward the pyloric sphincter. The disorder in slow wave propagation usually cause gastroparesis also called delayed gastric emptying and such symptoms as chronic nausea, bloating, abdominal discomfort or vomiting could be observed.

II. METHODS

EGG recording does not contain only the myoelectrical activity of stomach but it is usually contaminated by cardiac and respiratory signals as well as myoelectrical activity from organs nearby the stomach such as duodenum or small intestine [7]. From medical point of view the slow wave extraction from multichannel EGG data is a key for decoding the useful information hidden in the EGG raw signal. In this paper Empirical Mode Decomposition (EMD) combined with the Hilbert-Huang Transform were proposed as an effective tools for slow wave extraction from 4-channel EGG recording.

A. Empirical Mode Decomposition

The Empirical Mode Decomposition (EMD) method invented by N.E.Huang et al.[3] is an adaptive technique derived from assumption that the any signal consist of finite number of Intrinsic Mode Function (IMF) representing an embedded characteristic oscillation on separated time scale [5]. The method presents a good performance in the case

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of signals, which are oscillatory, non-stationary, generated by nonlinear system so it is especially suitable for EGG recording. The main idea of this method is the sifting process leading to decomposition of given signal into its fundamental modes (IMF), which are nonlinear functions extracted directly from the data [3].
The IMF functions should fulfill two assumptions: number of local maxima differs at most by one than number of local minima and the mean of its upper and lower envelopes equals zero [4]. The sifting process for $S(t)$ signal, which means derivation of IMF function is performed into the three steps : firstly the lower $S_{lower}(t)$ and upper $S_{upper}(t)$ envelopes are constructed connecting all the maxima and minima with smooth spline, in this way that they cover all the data between them, secondly the mean of this two envelopes is subtracted so the difference

$$S_1(t) = S(t) - (S_{lower}(t) + S_{upper}(t))/2 \tag{1}$$

is calculated and thirdly the steps 1 and 2 are repeated for $S_1(t)$ as far as the criteria of intrinsic mode are obtained [4], [9]. The first extracted IMF component by the nature of the process has the smallest time scale i.e. the fastest time variation of data, as the sifting process propagating the time scale increases and the frequency of the IMF decreases [4].

B. The Hilbert Transform

Fourier spectral analysis is a general method for examining the global energy-frequency distributions but in the case of nonlinear and non-stationary signal this distribution is misleading, as such type of signals can carry spurious harmonic components that cause energy spreading. The EMD signal decomposition method based on the direct extraction of energy, associated with various intrinsic time scale and the IMF function can be treated as the basis for expansion of the data, which can be linear or nonlinear. The physical time scale, which characterize the oscillation of the phenomena is the rule of basis construction. The local energy and the instantaneous frequency derived from IMFs by the Hilbert transform can display energy-frequency-time distribution of data [3].
Let's $s(t)$ be a time series and $z(t) = s(t) + iH[s(t)] \iff z(t) = A(t)e^{i\varphi}$ the associated analytical signal where the A(t), $\varphi(t)$ are both the instantaneous amplitude and the phase accordingly. The $H[s(t)]$ is the Hilbert transform of $s(t)$, which can be expressed following by the formula:

$$H[s(t)] = \frac{1}{\pi} P \int_{-\infty}^{\infty} \frac{s(u)}{t-u} du \tag{2}$$

where P indicates the Cauchy principal value of the integral [6]. The instantaneous frequency (IF) is defined as a rate of change of phase of analytical signal $z(t)$ by the formula $\omega(t) = \frac{d\varphi(t)}{dt}$ [5]. With the aid of Hilbert transform of each IMFs the data series $s(t)$ can be represented:

$$s(t) = \sum_{j=1}^{n} A_j(t) e^{i \int \omega_j(t) dt} \tag{3}$$

The time-frequency distribution of the amplitude is the Hilbert spectrum $H(\omega, t)$[5].

III. Results

As EGG recording does not reflect only the myoelectrical activity of stomach but it is usually contaminated by cardiac and respiratory signals as well as myoelectrical activity from organs nearby the stomach, the combination of EMD and Hilbert Transform was applied to reduce the artifacts in the 4-channel EGG recording and to extract the slow wave in each channel, which are very important for assessment of coupling and slow wave propagation [10]. Abnormalities in a slow wave propagation are associated with gastric motility disorders. The 4-channel EGG data about 30 minutes duration in preprandial state used in this study was obtain from healthy subjects. The slow wave extraction in each channel was performed in the following steps:

- the EGG signal from each of fourth channel was decomposed for finite number of intrinsic mode function by the EMD method,
- the Hilbert transform was applied for each IMFs functions in each channel to obtain the IMFs instantaneous frequency,
- for each IMFs in each channel the *fit coefficient* was calculated as a measure of matching between the original EGG signal and the IMFs component.

The *fit coefficient* was defined as:

$$fig = 100 \cdot (1 - \frac{norm(X - Y)}{norm(Y - mean(Y))}) \tag{4}$$

where X denote the EGG signal in individual channel and Y denote the IMF component and the *norm(X)* returns the *Euclidian norm* of vector *X*. Fig. 1. present the (10 minutes)

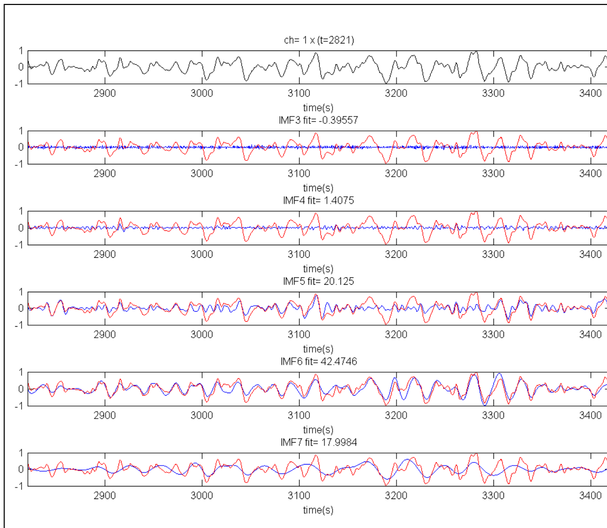

Fig. 1. EMD decomposition for EGG signal from the first channel.The blue marker depict IMF components and the red one an original EGG signal in the first channel. IMF6 present the best fit for the original EGG signal from the first channel.

result of EMD decomposition for EGG signal from the first channel of 4-channel EGG recording. In the first box there is the original EGG signal from the first channel, below in a blue color there are IMF components and in the red color there is the EGG signal from the first channel. The *fit coefficient* for IMF6 equals *fit*=42.4746 so the gastric signal component in the first channel is represented by the IMF6. The first two IMF components in the Fig.1. were omitted, because as they were associated with the the fastest time variation of data, they were not taken into consideration in the case of slow wave extraction.The slow wave extracted from each channel of 4-channel EGG data are presented in Fig.2. Testing results concerned the best fit coefficient for

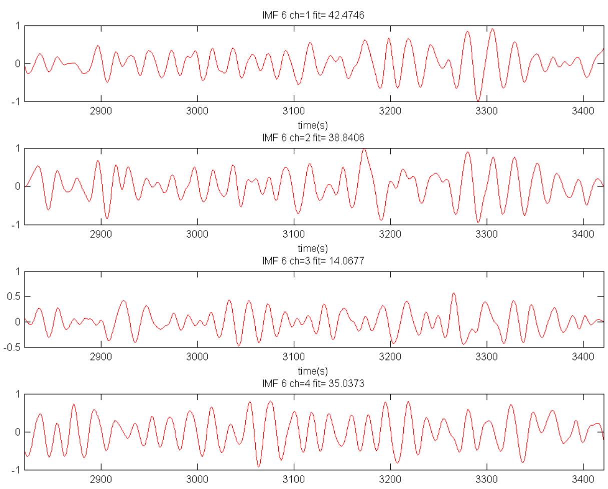

Fig. 2. Slow wave extracted form multichannel EGG data after artifact reduction.

each channel and each of examined volunteers are shown in the Table I. The best fit between EGG signal in each channel and IMF functions in the most cases was received for fifth or sixth IMF component. When the greatest fit coefficient of two IMFs vary less then 10%, then the mean of this two components as a slow wave was proposed. This case would find medical explanation in uncoupled slow wave but such hypothesis needs further studies.

For validation of the procedure of slow wave extraction the Hilbert Transform was perform to each of IMF components in order to obtain their instantaneous frequency and Hilbert spectrum. It can be observed in Fig. 3. that the instantaneous frequency of IMFs in each channel is in the range of physiological slow wave rhythm i.e. 2-4 cpm (0.033-0.066Hz). The results shown in the Fig.4-7, clearly show that the local energy of IMFs components is distributed at the range of the characteristic slow wave frequency.

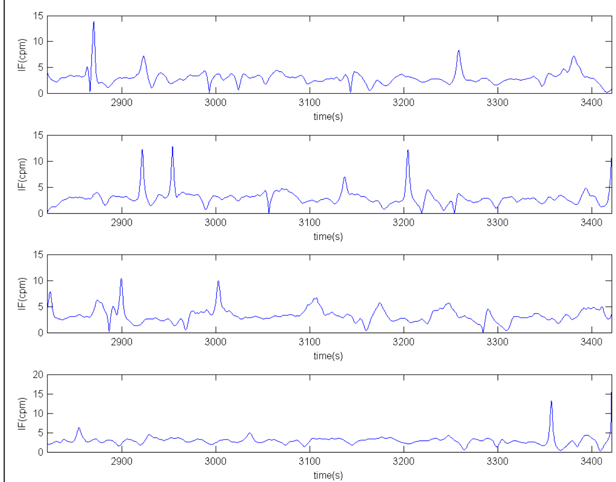

Fig. 3. The instantaneous frequency 3(cpm) (0.05Hz) of extracted slow wave for 4-channel EGG data.

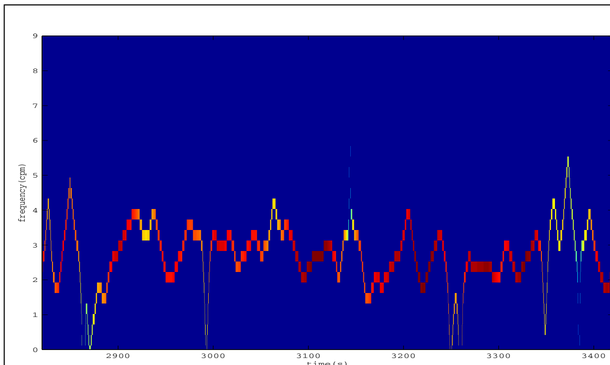

Fig. 4. The Hilbert spectrum for IMF6 representing slow wave in the 1st channel for 10 minutes EGG recording.

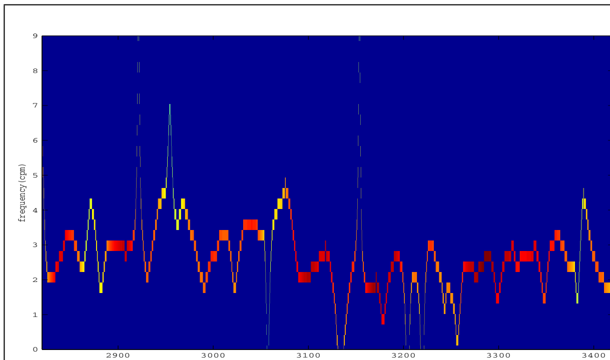

Fig. 5. The Hilbert spectrum for IMF6 representing slow wave in the 2nd channel for 10 minutes EGG recording.

TABLE I

TABLE PRESENTS THE BEST FIT VALUE BETWEEN 4-CHANNEL EGG SIGNAL AND IMF FUNCTIONS

Study	Channel number	IMF number	Best fit (%)
NS01A	ch1	6	42.47
	ch2	6	35.14
	ch3	5	14.36
	ch4	6	35.16
NS02A	ch1	6	42.39
	ch2	6	39.04
	ch3	5	33.13
	ch4	5	30.12
NS03A	ch1	5+1	44.83
	ch2	6	42.70
	ch3	6	31.60
	ch4	5	22.14
NS04A	ch1	5+1	35.30
	ch2	6	32.39
	ch3	6	64.08
	ch4	5	69.68
NS05A	ch1	6	42.47
	ch2	6	38.84
	ch3	6	14.07
	ch4	6	35.04

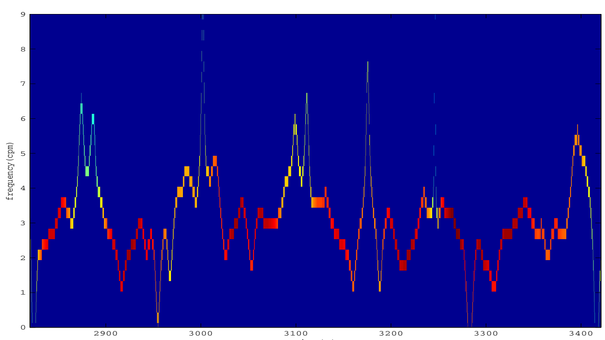

Fig. 6. The Hilbert spectrum for IMF5 representing slow wave in the 3rd channel for 10 minutes EGG recording.

IV. CONCLUSIONS

Both Empirical Mode Decomposition and Hilbert Transform are appealing to be a good technique for adaptively decomposing non-stationary and nonlinear EGG signals for slow wave extraction, as it gives the opportunity for insight into the EGG propagation from antrum to pylorus, present in the source signals but often hidden and difficult to uncover from cuatenous EGG recordings. The proposed method applied for mulitichannel EGG data shows promissing results in detecting of both coupling uncoupling gastric slow waves which is crucial for gastric emptying. The next step of validation requires, additional calculations as well as comparisons between healthy and pathologic patients suffering from stomach disorders.

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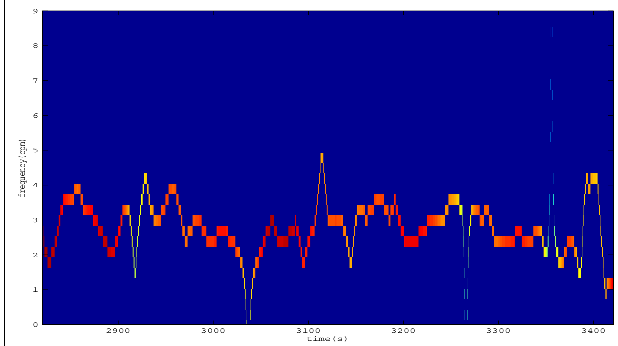

Fig. 7. The Hilbert spectrum for IMF6 representing slow wave in the 4th channel for 10 minutes EGG recording.

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