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A NEW APPROACH FOR ELECTROGASTROGRAM CLASSIFICATION : A CASE STUDY

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Abstract :

In this paper, an algorithm has been developed to extract the important features of the electrical activity of the stomach measured non invasively with placing electrodes on the abdomen of the human. The measured signal generated from stomach's muscle contraction, is called the Electrogastrogram (EGG). It is a mixture of action potentials with different amplitudes depending on position of the electrodes, direction of spread over stomach, and firing rate. The proposed algorithm is based on special structure of cascaded filters characterized with high selectivity. Parameters of individual section as well as the number of sections were estimated such that minimum mean squared spectral deviation between the measured and estimated EGG signal is achieved. The amplitudes of individual frequencies extracted by this algorithm are considered as features of EGG signal that can be used for studying stomach's physiological states. An example is given to illustrate the application of this algorithm for evaluating the stomach activity during Hunger or Digestion states. The percentage of success to discriminate between these two states was about 93.8 % for the Hunger state, and 98.9 % for the Digestion.

Keywords:

Stomach, Hunger, Digestion, Electrogastrogram (EGG), Comb Filter, Discrimination analysis

Introduction:

Endoscopy is a well clinical tool to identify the presence of any abnormalities within the human stomach, but it is painful and the patient suffers from it, and needs special sterilization. On the other hand, electrophysiology of stomach is more reliable not only to detect the abnormalities, but also to predict the clinical state. The measured electrical potentials either invasively or non invasively reflect modes of stomach stimulation, contraction, and direction of propagation. Moreover, it shows the rhythmic variations of stomach potentials. Although, the first measurement of the Electrogastrogram (EGG) was started a 70 year ago by placing electrodes on the abdomen [2],[3], the progress in this field was very slow, due to some problems as : 1) difficulty in data acquisition and analysis because of the low Signal-to-Noise Ratio (SNR), 2) difficulty in interpreting EGG and extracting its useful features, and 3) lack of understanding the correlation between the EGG and the gastric motility [4].

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In this paper, a technique based on selective filtering algorithm [1] will be used to extract features from the EGG. These features would be helpful as a diagnostic tool as well as a mirror to reflect the state of stomach under different conditions (Hunger or Digestion). Moreover, it would be used for discrimination between normal and abnormal activity of human's stomach [6].
The proposed approach depends on the assumption that EGG signal is a combination of signals emitted from the stomach pacemakers, and then propagate through smoothed muscles of stomach in different pathways.
Due the influence of other systems of the human body, the measured EGG will be corrupted with sources of interference (noise) which make the analysis process very difficult. There exist many procedures to analyze the EGG signal, but the Fast Fourier Transform (FFT) has been the most commonly used method for extracting the spectral information from the EGG signal.

Formulation of the problem :

Assuming that the EGG signal *s(t)* would be composed of a set of sinusoids having multiple frequencies with different amplitudes and phases defined as follows :

$$s(t) = \sum_{i=1}^{n} a_i \sin(i\omega_0 t + \phi_i) \tag{1}$$

Where

ω_o	The fundamental frequency
a_i	The amplitude of the i^{th} harmonic of the signal
φ_i	The phase of the i^{th} harmonic of the signal
n	Number of multiple harmonics

The interfered signals with EGG would be assumed to be additive white noise *v(t)* having zero mean and variance σ^2 such that the measurements *y(t)* become :

$$y(t) = s(t) + v(t) \tag{2}$$

Due to the need of precise determination of the fundamental harmonic, the structure of the proposed filter becomes a combination of decomposed second order filters similar to Comb Filters [1] to achieve high selectivity. Its transfer function can be represented by :

$$H(z) = \frac{\prod_{k=1}^{n} (1 + \alpha_k Z^{-1} + Z^{-2})}{\prod_{k=1}^{n} (1 + \rho\alpha_k Z^{-1} + \rho^2 Z^{-2})} \tag{3}$$

Where :

$(\alpha_k) = -2*\cos(k\omega_o)$; and

(ρ) is a parameter that controls the selectivity of the filter to pickup certain harmonic. As ρ approaches unity, the selectivity of the filter to a specific frequency increases.

The procedure for estimating signal parameters follows two steps (as shown in Fig.1) :

1-Estimation of fundamental frequency (ω_o) and the minimum number of multiple frequencies (n) such that minimum mean-squared deviation (error) is achieved.

2-Estimation of amplitudes and phases { a_i, φ_i ; i = 1,..,n} for individual harmonics.

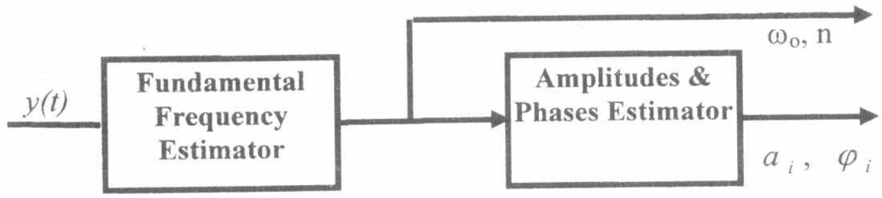

Fig.1. Block Diagram shows the procedure for signal parameters estimation

The procedure for fundamental frequency estimation (Phase 1) is in Table 1, while procedure for harmonics and phases estimation (Phase 2) is in Table 2 :

Table1. Procedure for fundamental frequency estimation

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Initialization:
        Remove DC from input signal, calculate number of segments in the signal
Main loop:
        for segment_number=1 to number_of_segments
          for f=0 to f_sample/2
            for ρ=0.8 to 0.98
              for number_of_section=1 to max._number_of sections
                apply the Filter H(z) on the input
                calculate mean square spectral deviation (MSE)
               end
             end
          end
        end
        get min. of MSE
        identify the corresponding ρ,f,n
Calculate Fundamental harmonic:
        ω_o=2*π*f
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Table 2. Algorithm for harmonics and phases estimation

Initialization:

$\hat{\eta}(0)=0$, $P(0)\cong(100/\sigma_y^2)I_{2n}$

Main loop:

for t=1,2,..., total_number of_samples

$\zeta(t)=[\sin\hat{\omega}_o t \ldots \sin n\hat{\omega}_o t, \cos\hat{\omega}_o t \ldots \cos n\hat{\omega}_o t]$

$e(t)=\hat{x}(t)-\zeta^T(t)\,\hat{\eta}(t-1)$

$$P(t)=\frac{1}{\lambda(t)}\left[P(t-1)-\frac{P(t-1)\zeta(t)\zeta^T(t)P(t-1)}{\lambda(t)+\zeta^T(t)P(t-1)\zeta(t)}\right]$$

$\hat{\eta}(t)=\hat{\eta}(t-1)+P(t)\zeta(t)e(t)$

Calculating Amplitudes and Phases:

$$\hat{C}_k(t)=\sqrt{\hat{\eta}^2_k(t)+\hat{\eta}^2_{n+k}(t)}$$

$$\hat{\phi}_k(t)=tg^{-1}\left\{\frac{\hat{\eta}_k(t)}{\hat{\eta}_{n+k}(t)}\right\}$$

Material and Method :

Eleven Adults (men) with age between 21 and 25 years were selected to be volunteers in our experiment. The main factor of choice was that they are free from any disease related to the digestive system. Moreover, they do not take any pharmacological material to activate the appetite. Silver- Silver-Chloride surface electrodes were used to pick up the biopotential over stomach. The electrodes were placed on a location far 3 cm from the line between the umbilicus and the xiphoid process, with the ground terminal fixed on the bottom of the left leg.

The recording period was made for 18.5 min with sampling rate of 2 Hz for all the volunteers when they were fasting and after an hour of eating a standard meal. A data acquisition Card type DAC-12 with supporting software was used for the acquisition process on 486DX2-66 PC.

Analysis :

The performance of the proposed algorithm was verified first with test signals having multiple frequencies. These test signals are described by :

$$S(t) = \sum_{k=1}^{n} a_k Sin(2\pi qkt + \phi_k) + v(t) \qquad (4)$$

Where :

- n Represents number of harmonics varying from 1 to 5.
- q Value of fundamental harmonic.
- $v(t)$ is WGN with variance σ^2=0.01, 1.

The verification considers the influence of noise level, data segment length from 32 up to 512 samples, number of harmonics n=1 up to 5, and execution time. Details of the analysis are available in [7].

An example of testing the algorithm with a noisy signal having three harmonics n=3 with WGN σ^2=1. These test signals were selected to realize the assumption imposed on the EGG signal. Only 256 samples (segment length) of the test signal were selected and FFT was used to estimate power spectrum. It shows the success of the algorithm to pick up the basic harmonics. Also, the resultant amplitudes compared with the original ones is as in Table 3 :

Table 3. Results of Estimation

Harmonic #	**Original Signal**		**Estimated Signal**	
	Frequency	*Amplitude*	*Frequency*	*Amplitude*
1	0.1523	110.4776	0.1523	108.9162
2	0.3047	113.9591	0.3047	108.9162
3	0.4531	113.9591	0.4531	107.0746

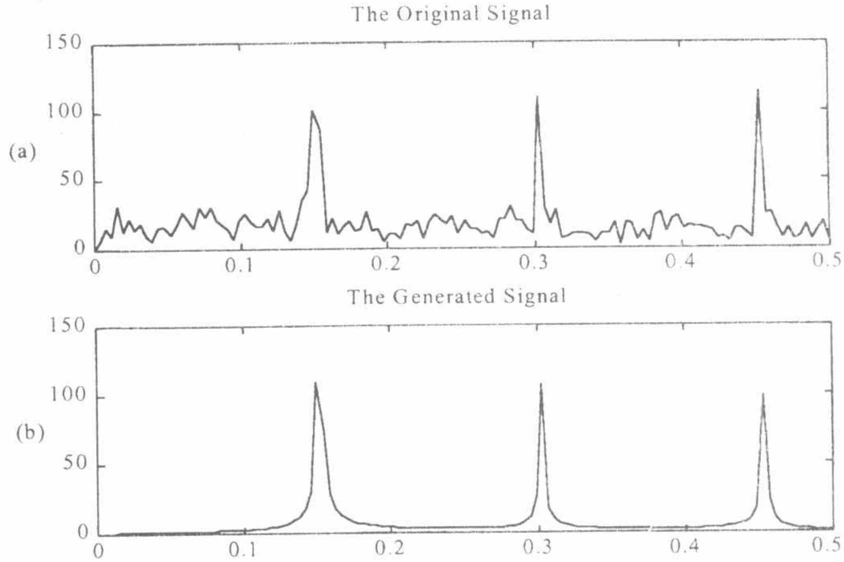

Fig.2 Magnitude Spectrum of 256 samples : a) Test signal having 3 harmonics at (0.15, 0.3, and 0.45 Hz) contaminated with WGN having $\sigma^2=1$, and b) Estimated signal

Results:

Samples of the recorded EGG signals (2048 samples) over 18.5 min. are shown in Fig. 3. Figure 3-a shows EGG for Hunger state, while Fig. 3-b for Digestion state.

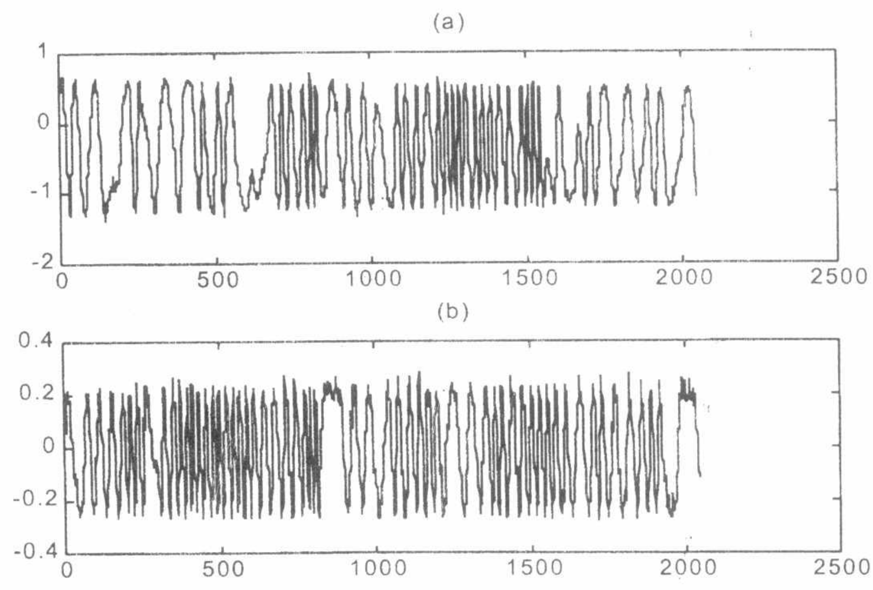

Fig.3 Recorded EGG signals :(a) Fasting, (b) Non fasting

Applying the proposed algorithm on a 256 samples of the measured signals shown in Fig.3, the estimated frequencies by the algorithm show dominant frequencies for both Hunger and Digestion. A comparison between the spectrum of measured signal and estimated one are illustrated in Fig.4.

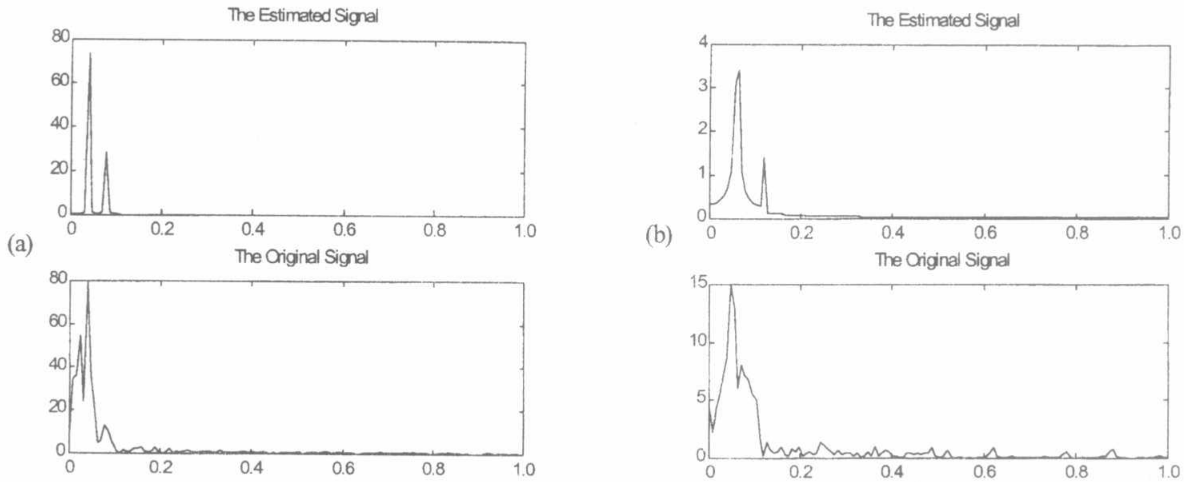

Fig.4 Spectrum of the estimated and original EGG signal : a)Hunger, b)Digestion

The proposed algorithm shows high accuracy for estimation the spectrum of the EGG signal relative to the measured one. Figure 4-a shows the estimation spectral accuracy of the proposed algorithm during the Hunger state. It fully succeeds to estimate both the fundamental, and the second harmonics (0.0469, 0.0859 Hz).

During Digestion state Fig.6-b shows the estimated spectrum where fundamental frequency (0.0703 Hz) deviates from the measured one by (-0.0156 Hz), while the second harmonic (0.0781 Hz) deviates by (-0.0469 Hz)

The distribution of the amplitudes (using the procedure phase II) of first and second frequencies are shown in the normalized scatter diagram illustrated in Fig.5.

This scatter helps us to discriminate between the two states with accuracy of 93.8 % for Hunger, and 98% for Digestion. On the other hand, the phase components don't show an acceptable discrimination.

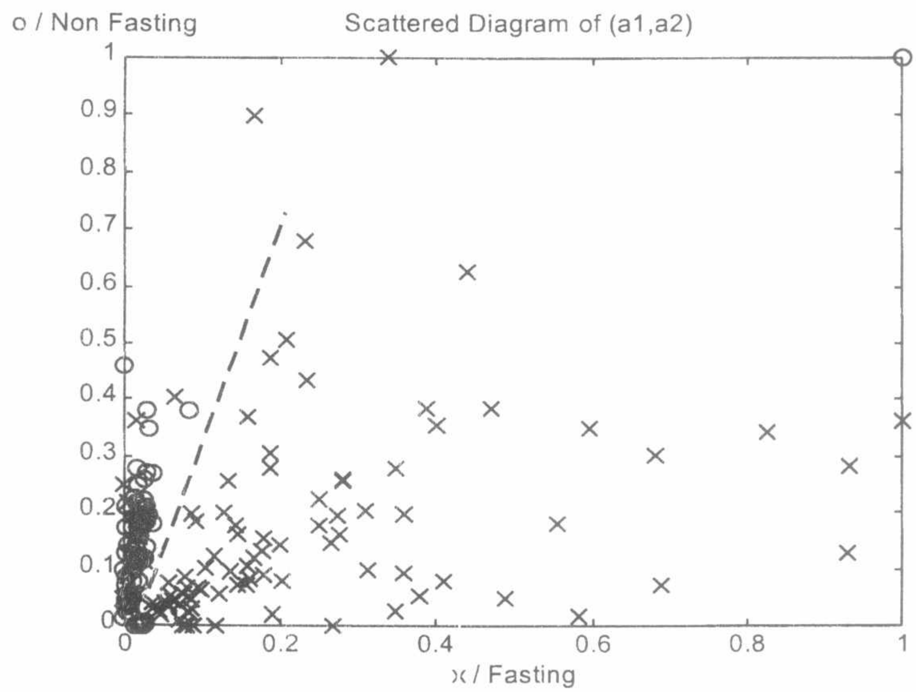

Fig.5 Scattered Diagram between (a1,a2)

Conclusion:

The choice of amplitudes of first and second estimated harmonics resembles high discrimination between different states of stomach activities (Hunger or Digestion).
The estimated phases of this algorithm can not be used efficiently for discrimination between the two states which lead to poor accuracy in discrimination.
Although the accuracy of EGG reconstruction reached 85.74%, it succeeds to determine the basic fundamental harmonic of the signal.

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