UTERINE CONTRACTIONS EXTRACTION BY SPECTRUM ANALYSIS OF THE EHG

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Abstract: The electrical activity of the uterus can be noninvasively monitored by analyzing the abdominal recordings. This recording technique is referred to as abdominal electrohysterogram (EHG) and allows the physician to examine the evolution of the pregnancy and to identify and classify the uterine contractions, being a useful tool to predict the labour or the preterm labour. The study proposes a new method, based on EHG spectral analysis, computed by parametric and non-parametric methods, and time parameters to detect the uterine contractions.

Introduction

During pregnancy the uterus shows gradually changes, both in mechanical and electrical activity. In the beginning the uterine activity is week and localized in some points but becomes stronger and propagates through the whole uterus with the evolution of the pregnancy. Nowadays both mechanical and electrical activity of the uterus is analyzed in order to get the information regarding the foetal problems or to detect the preterm labour or the onset of delivery. The mechanical activity is monitored either by means of a tocotransducer externally positioned on the abdominal wall with the help of an elastic strap or by a balloon-tipped or open-ended fluid filled catheter which measures the intrauterine pressure.

The electrical activity of the uterus can be noninvasively recorded using abdominal signals. This recording technique is referred to as abdominal electrohysterogram (EHG) and is used to monitor the evolution of the pregnancy, due to the fact that the analysis of the EHG allows the identification of the uterine contractions, being a useful tool to predict the labour or the preterm labour. Even more, some research groups have shown that the EHG can be further processed to detect the foetus movements, the Alvarez waves and the long-duration low-frequency band waves [1].

In order to detect the uterine contractions some researchers have used a two-step processing technique. First, the signal is rectified by applying the nonlinear absolute value operator. Then the resulting signal was filtered using a low-pass filter with the cut off frequency of 0.02 Hz [2].

Other research groups have used the zero-crossing techniques to detect the uterine contractions. According to that processing method, the higher-order zero-crossing counts is performed, by computing the high-order differential operator and counting its sign changes in comparison with the previous order [3].

A new method based on wavelet transform was also implemented known being that it allows the removal of the noise in the physiological data. For this purpose, the coefficients related to noise, i.e. mainly maternal electrocardiogram (MECG), are bounded [4].

This study proposes a new method, based on EHG spectral analysis, computed by parametric and non-parametric methods, and time parameters to detect the uterine contractions.

Recording Technique

The data were recorded during labour using a Portis-32/ASD. For the representation of the digitized values, we used 22 bits, resulting in a resolution of 71.526 nV. The sampling frequency was 400 Hz.

The signals were recorded using the unipolar measurements and 12 electrodes placed on the belly as given in Figure 1.

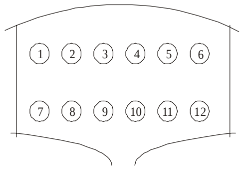

Figure 1: Position of the electrodes

The signals were band filtered between 0.2 Hz and 5 Hz and downsampled to 10 Hz in order to obtain the electrohysterogram (EHG). In order to test the proposed method, data recorded during labour were used, they

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showing very clear uterine contractions. The best signal was recorded along the vertical median uterine axis, where the position of the uterus relative to the abdominal wall is almost invariable during contractions, allowing a better contact of the electrodes and consequently a better signal/noise ratio.

Short Time Fourier Transform (STFT)

When the signal is nonstationary, a single Discrete Fourier Transfor (DFT) is not sufficient to describe its frequency content, the STFT being more suited:

$$X(n,\omega) = \sum_{m=-\infty}^{\infty} x(n+m)w(m)e^{-j\omega m} \tag{1}$$

where $w(n)$ is a window sequence.

The STFT converts a one-dimensional sequence, $x(n)$, a function of a single discrete variable, into a two-dimensional function of the time variable, which is discrete, and the frequency variable, which is continuous [5].

If we make the substitution $m' = n + m$ in (1) we can write:

$$X(n,\omega) = \sum_{m'=-\infty}^{\infty} x(m')w(-(n-m'))e^{j\omega(n-m')} \tag{2}$$

Equation (2) can be interpreted as the convolution:

$$X(n,\omega) = x(n) * h_\omega(n) \tag{3}$$

where

$$h_\omega(n) = w(-n)e^{j\omega n} \tag{4}$$

From the above equation we see that STFT, as a function of *n* with ω fixed, can be interpreted as the output of a linear time-invariant filter with impulse response $h_\omega(n)$, or with the frequency response:

$$H_\omega\left(e^{j\theta}\right) = W\left(e^{j(\omega-\theta)}\right) \tag{5}$$

The primary purpose of the window in the time-dependent Fourier transform is to limit the extent of the sequence to be transformed so that the spectral characteristics are reasonably stationary over the duration of the window. The more rapidly the signal characteristics changes, the shorter the window should be. As the window becomes shorter, frequency resolution decreases. On the other hand, as the window length decreases, the ability to resolve changes with time increases. Consequently, the choice of window length becomes a tradeoff between frequency resolution and time resolution. If we consider the time-dependent Fourier transform for fixed *n*, then from the properties of the Fourier transforms we get that:

$$X(n,\omega) = \frac{1}{2\pi}\int_{-\pi}^{\pi} e^{j\theta n} X\left(e^{j\theta}\right) W\left(e^{j(\omega-\theta)}\right) d\theta \tag{6}$$

meaning that the STFT is the Fourier transform of the shifted signal convolved with the Fourier transform of the window. In the linear filtering interpretation of equation (4) and (5), $W\left(e^{j\theta}\right)$ typically has a low pass characteristic, and consequently $H_w\left(e^{j\theta}\right)$ is a bandpass filter whose passband is centered at $\theta = \omega$.

The width of the passband of this filter is approximately equal to the width of the main lobe of the Fourier transform of the window, while the degree of leakage of one component into the vecinity of the others depends on the relative sidelobe amplitude.

Parametric Spectrum Estimation

When the signal of interest contains a small number of samples and random noise signal too – the case of the signals studied in analyzing the engine, parametric methods provide better results in computing the power spectrum [6], [7].

Let y be the signal of interest and ai the coefficients of the autoregressive model that approximates the signal autoregressive model that approximates the signal *y*. The spectrum of this signal can be computed by:

$$S_{yy}(\theta) = \frac{\alpha}{\left|\hat{a}\left(e^{j\theta}\right)\right|^2} \tag{7}$$

where

$$\sum_{l=0}^{n} a_l y(k-l) = u(k) \tag{8}$$

is the AR model of order *n* and

$$\hat{a}(z) = 1 + a_1 z^{-1} + ... + a_n z^{-n} \tag{9}$$

α is the power spectrum of $u(k)$:

$$S_{uu}(\theta) = \alpha \tag{10}$$

For computing the power spectrum so that the forward and backward error are minimized using the least squares, the Burg algorithm is used [6]:

Given:

$$L, \mathbf{y}[0, L-1]$$

Initialization:

$$d_0 = 2\sum_{k=0}^{L-1} y^2(k),\ c_0 = 0$$
$$k = \overline{0, L-1} \Rightarrow e_0(k) = y(k), \tilde{e}_0(k) = y(k)$$

Recursive algorithm:

$$m = \overline{1, n}$$
$$\begin{cases} d_m = \left(1 - c_{m-1}^2\right) d_{m-1} - e_{m-1}^2(m-1) - \tilde{e}_{m-1}^2(L-1) \\ f_m = \sum_{k=m}^{L-1} e_{m-1}(k)\tilde{e}_{m-1}(k-1) \\ c_m = -2 f_m / d_m \end{cases}$$
$$k = \overline{m, L-1}$$
$$\begin{cases} e_m(k) = e_{m-1}(k) + c_m \tilde{e}_{m-1}(k-1) \\ \tilde{e}_m(k) = c_m e_{m-1}(k) + \tilde{e}_{m-1}(k-1) \end{cases}$$
$$\alpha = d_n / [2(L-n)]$$

After computing the reflection coefficients c_m, the prediction coefficients are computed using the Levinson-Durbin algorithm [7]:

Initialization:

$$\hat{a}(0, z) = 1$$
$$\tilde{a}(0, z) = 1$$

Recursive algorithm:

$$\begin{bmatrix} \hat{a}(m+1, z) \\ \tilde{a}(m+1, z) \end{bmatrix} = \begin{bmatrix} 1 & z^{-1} c_{m+1} \\ c_{m+1} & z^{-1} \end{bmatrix} \cdot \begin{bmatrix} \hat{a}(m, z) \\ \tilde{a}(m, z) \end{bmatrix}$$

Results and Conclusions

In the beginning the spectrum of the abdominal signal, *X*, is computed for segments of 20 s. Considering that the abdominal electromyogram activity shows a low band (from 0.2 to 0.45 Hz) and a high band (from 0.8 to 3 Hz) [8], the mean frequency is computed for both bands. The *n*th moment, M_n, of the power spectrum is defined as given in (1).

$$M_n(X) = \sum \left| \omega_i^n X(\omega_i) \right| \quad (7)$$

Therefore, the mean frequency is $F_m = M_1 / M_0$ [5]. Figure 2 shows the spectrogram of the abdominal signal preprocessed as above. The bands corresponding to the EHG [8] show variations that allow the detection of the uterine contraction segments.

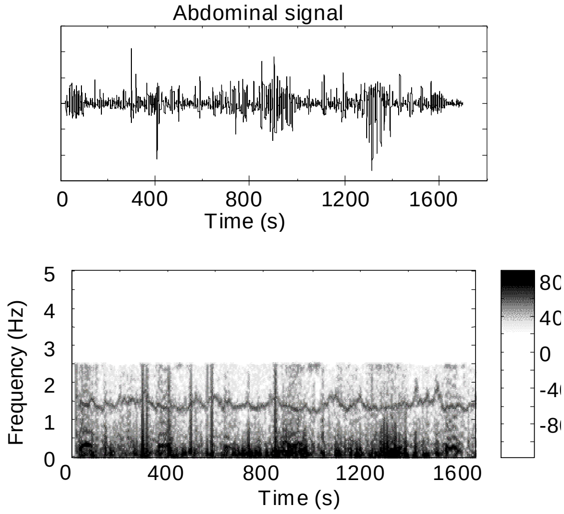


Figure 2: EHG signal and spectrogram

The variance of the EHG signal, showing higher values for the segments where contractions or movements of the fetus appear – Fig. 3, can be used together with the mean frequency of the high frequency range– Fig. 4, to detect the contractions.

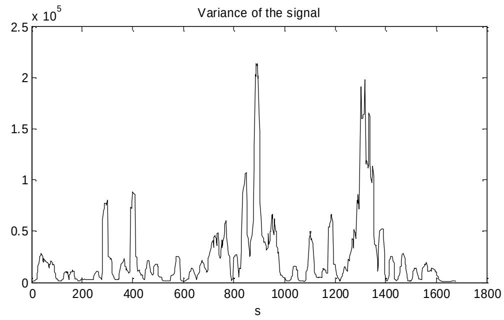
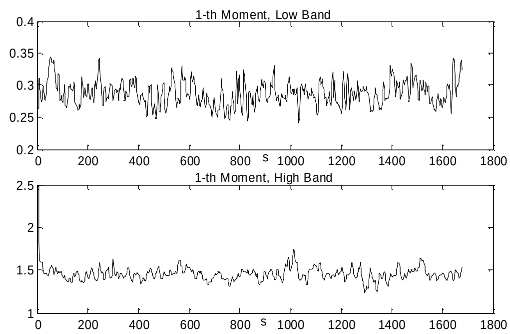


Figure 3: Variance of the EHG signal among the segments considered in the spectrogram



a)

b)

Figure 4: Evolution of the mean frequency for the spectrogram: a) low frequency band; b) high frequency band

The spectrum computed using the parametric methods shows less variation and provides to be a better solution when calculating the mean frequency, as shown in Fig. 5.

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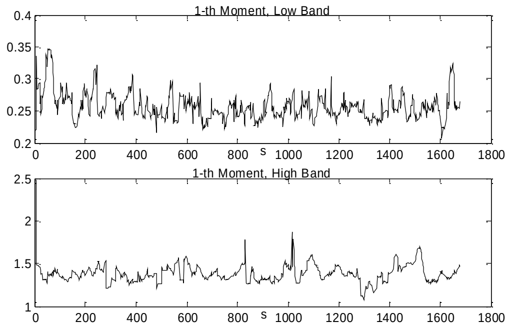

a)

b)

Figure 5: Evolution of the mean frequency when the spectrum is computed using the parametric method: a) low frequency band; b) high frequency band

Conclusions

The EHG can be characterized by the parameters that usually describe the spectrum of an electromyographic signal. The method proposed detect the uterine contractions, allowing their further classifications, but the results need more data investigation.

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