Preterm Birth Detection Using EMG Signal Processing

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Abstract: Bioelectric Signals used in different aspect of medicine and biomedicine. In this paper we are going to use these signals to detect preterm birth. In this research we are processing Electro Mayo Gram (EMG) Signals in time domain, frequency domain and time-frequency domain for preterm birth detection. In addition we will compare these methods to achieve the best way for EMG detection by using the difference between uterine contraction frequencies.

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Introduction:

Studying about preterm birth[1] and prediction of the time that pain starts is one of the most important topic in pregnancy consideration. Accomplishing this information help us to save fetus and their mother's life as preterm birth cause serious threat for them. Furthermore it decreases the unnecessary period of staying in hospital that bring about tacking more time and cost [1]. One method that is used to forecast preterm delivery is Cervix measurement using Sonography that is not very reliable. Another method is Doppler Imaging most of the time is used for detecting imperfection of fetus and is so expensive. All these cause to search about a new way to solve this problem which some of them will discuss in this paper.

Considering the differences of uterine contraction frequency between pregnant women and between different stages of pregnancy can help us to foretell about time of birth. Consuming the same stochastic characteristic for all cells it can be considered as a Gaussian distribution that is shown below:

$$x(t) = EMG(t) + \sum_{i=1}^{n} s_i(t) + n(t) \qquad (1)$$

This equation refer to all activity of EMG signals [4].

Uterine contraction caused by electrical activity of polarization and depolarization of billion mayometraum uterine cells. When this polarization happened in mayometraum periodically, produces potential action. We can see this happen by noninvasive and surface recording of pregnant women. That is because the uterus bears a critical condition when it becomes ready for birth. Estimation of electrical signals characteristic carry out at this time. Using these parameters for predicting of birth time is the goal of this research. We can analyze these parameters in time domain using statistic characteristic, or in frequency domain using Power Spectral Density, and considering the fact that in birth, pain transferring to uterus cause an increasing in average amount of peak frequency for Power Spectral Density from lower to upper frequency. More than frequency analysis of peak of Power Spectral Density, other parameters have to be considered for evaluation. Wavelet transform is another method that most of the time is used in EMG activity in time-frequency domain. In following, these methods will describe in details.

Methods

Abdominal electromyography can be of value for pregnancy monitoring, especially if this noninvasive recording can be associated with portable instrument. Up to now, four events have been identified in uterine EMG which can be of value for preterm birth diagnosis: uterine contractions , fetus motions, Alvarez waves and long-duration low frequency band (LDBF) waves [6].

Unlike classical detection problems where every event is well identified in its time and frequency contents, uterine EMG characteristics change from one woman to another and depend on the stage of pregnancy. Therefore no unique database set can be defined for any woman and any given stage of pregnancy. For this reason, it is more reasonable to approach detection of these events with no priori knowledge on the parameters of the hypotheses corresponding to the various process states to be detected. This leads to using an unsupervised method of detection/classification.

In this recording patient need to be motionless and unstressed and be completely relaxed to minimize motion artifact of mother and breath and motion artifact of fetus. Noise of environment need to minimize by turning off cell phones and electrical equipment as well. In addition an especial bed have been used for patient to lie on it.

[1] *preterm birth is the birth of a baby of less than 37 weeks gestational age*

The Electro Hystero Gram (EHG) signals were captured by means of two Ag–AgCl Beckman electrodes, plus one reference electrode located on the patient's hip. After careful preparation of the skin (cleaning with an abrasive paste and degreasing with a mixture of ether, alcohol, and acetone), which lowers the interelectrode impedance to about 10 kΩ , the electrodes are aligned directly above the median axis of the uterine muscle, on the epidermis, spaced of 25 mm, midway between symphysis and uterus fundus. This record has lasted for 15 minutes and breath rate and heartbeat is considered during the record as

well. The best place of electrodes are on the median vertical axis that shows the difference between risk contractions (leading to preterm delivery) and normal contractions (leading to term delivery).It is noticeable that danger of preterm delivery happens in 27–28 weeks of gestation [5].

The records of this research were made from 150 women hospitalized for risk pregnancy in the Ghaem Hospital of Mashad. After recording the signals using time, frequency and time-frequency domain processing the birth time can be predicted accurately. These methods will be compared and expressed in details.

Time Domain: Extracted characteristic in time domain such as period, amplitude and phase proved they are really valuable and effective in distinguishing between disease of muscles and nerves. Different views have been examined for recognizing surface EMG consist of Neural Network, Fuzzy Logic and Hidden Markov model (HMM).

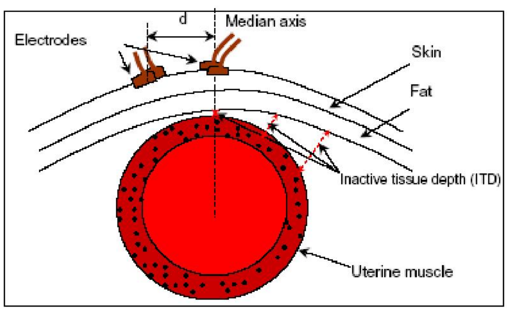

Fig.1:representation of a transverse view of the pregnant abdomen in woman. Dark red crown represents

The uterine muscle. The EHG is obtained with surface electrodes placed on the abdomen permitting the recording of the EMG produced by the uterine muscle. The electrical activity propagates across different layers: a skin layer, a fat layer, and an inactive tissue layer (ITD, which is the inner content of the abdomen pushed apart by the growing uterus). The depth of the ITD layer increases as the distance d between the electrodes and the median vertical axis of the abdomen increases. ITD = 0 when the electrodes are located on the median vertical axis (d = 0).

In linear processing, the signal considered as a stationary and ergodic signal.

If : $m(t) = E(x) = \int_{-\infty}^{\infty} x f(x) dx$ (2)

then the signal is stationary and if :

$$< x(t) > = \lim_{T\to\infty} \frac{1}{T} \int_{-\frac{T}{2}}^{\frac{T}{2}} x(t) dt \quad (3)$$

An important criterion for distinguishing between term and preterm delivery is minimizing the variance inside a class, and maximizing the variance between two classes. The Euclidean distance between two classes have to be maximized. As uterine EMG events expressed by frequency content, the estimated variance produce useful information to know these events.

Uterine EMG signal has a Gaussian distribution with definite mean and standard deviation.

$$N(m, \sigma): f(x) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{1}{2}\left(\frac{x-m}{\sigma}\right)^2} \quad (4)$$

Mean Squared Error (MSE) measures the average of the squares of the errors. The error is the amount by which the value implied by the estimator differs from the quantity to be estimated[7].

$$MSE = \frac{\sum(\hat{y}_t - y_t)^2}{n} \quad (5)$$

Autoregressive (AR) Parameters Estimation: An AR model is a type of random process which is often used to model and predict various types of natural phenomena.

The autoregressive modeling of a discrete process x(n) of order q is defined as the output of a recursive filter whose input is a white noise process:

$$x(n) = \sum_{i=1}^{q} q_i X_{n-i} + \eta_n \quad (6)$$

η_n are the innovations of the AR modeling. Many methods can be considered to estimate the parameters of these filter. Uterine EMG is modeled by an AR model of order 16 (16 coefficients) in some papers [2].It is used to estimate the AR coefficients of the two types of real EMG signals: preterm deliveries (PD) EMGs and deliveries at term (DT) EMGs[2].

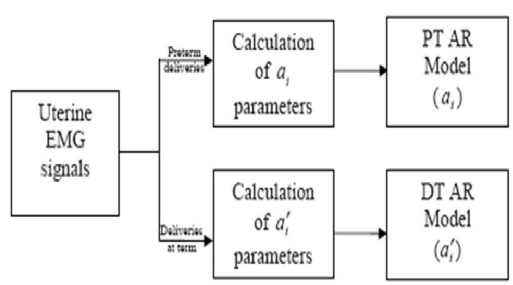

Fig.2: Creation an AR model for the PD and DT

Frequency Domain

In frequency domain before each processing Filter is used to omit unwanted signals, optimizing Signal to Noise Ratio (SNR), prediction, estimation and classification. Noticing to frequency content of signal a low pass filter with 500Hz cut off frequency is needed. In this research a Chebyshev filter with order of 9, 0.05dB ripple and 500Hz passband is used [3](Uterine EMG signals in the range of frequency between 0-500Hz are significant). After that various methods can be used in order to detect preterm birth which will mention below.

1. Fast Fourier Transform (FFT): FFT is one of the methods that are used in frequency domain which can be divided the cases into term or preterm delivery using signal amplitude, power and energy.

2. Autocorrelation: Autocorrelation is another method that is used in frequency domain. The related frequency to maximum amount of power spectral density is chosen as desired parameter. If the changes in these parameters as time of birth almost become zero. Power density spectrum peak frequency increased as the measurement-to-delivery interval decreased. Receiver operating characteristic curve analysis gave high positive and negative predictive values for both term and preterm delivery[3]. Considering power spectral density for uterine contraction detection is really effective. The estimation methods that are used mentioned below:

3. Periodogram: In practice, the periodogram is often computed from a finite-length digital sequence using the fast Fourier transform (FFT). The raw periodogram is not a good spectral estimate because of spectral bias and the fact that the variance at a given frequency does not decrease as the number of samples used in the computation increases. The spectral bias problem arises from a sharp truncation of the sequence, and can be reduced by first multiplying the finite sequence by a window function which truncates the sequence gradually rather than abruptly. The variance problem can be reduced by smoothing the periodogram.

4. Welch's method: Welch's method is an improvement on the standard periodogram spectrum estimating method , in that it reduces noise in the estimated power spectra in exchange for reducing the frequency resolution. Due to the noise caused by imperfect and finite data, the noise reduction from Welch's method is often desired.

The signal is split up into overlapping segments: The original data segment is split up into L data segments of length M, overlapping by D points. The overlapping segments are then windowed: After the data is split up into overlapping segments, the individual L data segments have a window applied to them (in the time domain).

$$S_t^{\hat{}}(t) = \frac{\Delta t}{E_w L}\left|\sum_{n=0}^{L-1} X_i(n) W(n) e^{\frac{-i2n\pi k}{L}}\right|^2 \quad i = 0,1,\ldots,I \quad (7)$$

$$\mathrm{Var}(S^{\hat{}}(k)) = \frac{\mathrm{Var}(S_i^{\hat{}}(k))}{I}\left[1 + 2\sum_{i=1}^{I-1}\frac{I-i}{I}p(i)\right] \quad (8)$$

$$P(i) = \mathrm{covar}\frac{(S_i^{\hat{}}(k), S_{i+j}^{\hat{}}(k))}{P(.)} \quad (9)$$

In above equation the variance is calculated in Welch condition, with I windows and length L.

5. Maximum Entropy or Burg Method: Entropy is a criterion of how random a signal is. Entropy is zero For deterministic signals. In this method there is no frequency leakage, frequency resolution is optimized as well and for short length data there is no need to use windows. If a discrete process with j state and probability of P_j foe each state is available, amount of information in each state calculated by:

$$\Delta I = \log_2\frac{1}{P_j} \quad (10)$$

The total information is sum of these states:

$$H = \sum_{j=1}^{i} P_j \,\Delta I = -\sum_{j=1}^{i} P_j \log_2 P_j \quad (11)$$

$$r(n) = \int_{-\infty}^{\infty} S^{\hat{}}(w) e^{j2\pi w\Delta t} dw \,, n = 0,1,\ldots,p \quad (12)$$

$$S^{\hat{}}(w) = \frac{\sigma_p^2 \Delta t}{\left|1+\sum_{i=1}^{p} a_i e^{-j2\pi wi}\right|^2} \quad (13)$$

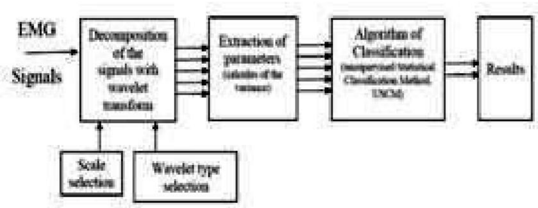

Fig.3:procedure of decomposition, parameter extraction and classification.

$$S^{\hat{}}(w) = |H(jw)|^2 = \left|\frac{1}{A(jw)}\right|^2 = \frac{G^2}{\left|1+\sum_{i=1}^{p} a_i^{\hat{}} e^{-j2\pi wi}\right|^2} \quad (14)$$

Time-Frequency Domain: Time-frequency processing especially Wavelet transform is used a lot in EMG and it has been showed good results.

Vital signals such as EMG are non-stationary, therefore in time-frequency processing that the signal have to be stationary, for optimizing the results high accuracy and speed is needed.

Wavelet transform is a tool that has been frequently used to describe the uterine EMG activity. The wavelet transform (WT) specifically permits to distinguish between non stationary signals with different frequency features. By decomposing signals into elementary building blocks, which are well localized in both time and frequency, the WT is an efficient tool for characterizing local features of the signals.

Authors state that the choice of the wavelet can be determined from the information included in the interesting part of the signal[].

Choosing the best wavelet for providing good result is really important. There are some standard wavelet which are used in the tests, for example, Coif let, Symlet and Dubeclies as right angle wavelet and Spline as a non right angle wavelet however, Harr wavelet decomposition shows the best result in the tests[1].

The multi-resolution analysis consists of decomposing the signal x(n) using the wavelet $\psi(t)$ and its scale function $\phi(t)$:

$$T_x^{\psi}(t,a) = \int_{-\infty}^{\infty} x(s)\psi_{mn}(s)ds \qquad (15)$$

For most purposes, the wavelet model is not required to keep a continuous description. To allow a fast numerical implementation, it is possible to impose a dyadic sequence variation 2^m of the scale:

$$\psi_{mn}(s) = 2^{m/2}\psi(2^m t - n) \qquad (16)$$

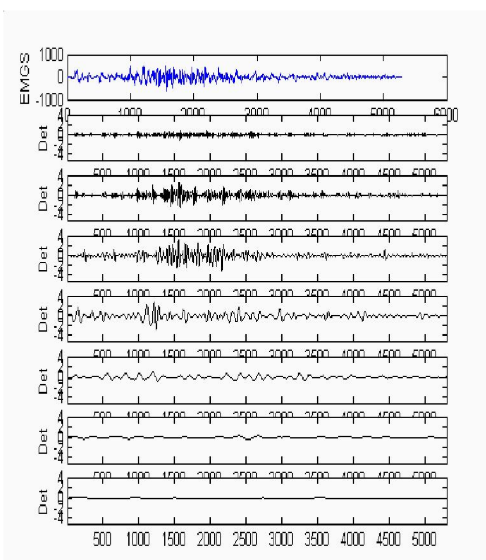

Fig.4. Decomposition of a contraction into 7 details. First trace is the contraction and the seven others are the details.

These equations produce the decomposition of the signal on the different scales, m indicating the scale number and n the time translation.

Using these two functions, any signal can be decomposed in details and approximations. The form of a scaling function is defined by:

$$\phi_{mn}(s) = 2^{m/2}\phi(2^m t - n) \qquad (17)$$

The filter associated with the scale function $\phi(t)$is a lowpass filter and the filter associated to the wavelet is a band pass filter. The following formulas can be used to calculate detail and approximation coefficients:

$$a_x(n,m) = \int_{-\infty}^{\infty} x(t)\emptyset_{nm}(t)dt \qquad (18)$$

$$d_x(n,m) = \int_{-\infty}^{\infty} x(t)\psi_{nm}(t)dt \qquad (19)$$

In this way, the relevant events can be shown as details on specific scale levels. Figure 4 shows the decomposition algorithm [1].

Results

Frequency components are shown in figures below. Figure 5 is related to a preterm delivery. As it is shown number of frequency components and their amplitude is more than figure 6 which is related to a term delivery.

In figure 7 and 8, power spectral estimation is done by Welch method. In figure 8 (term delivery) fluctuation and changes are so less than figure 7 (preterm delivery).

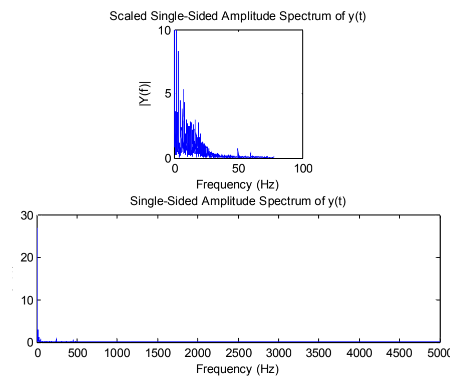

Fig.5. Frequency components related to a preterm delivery.

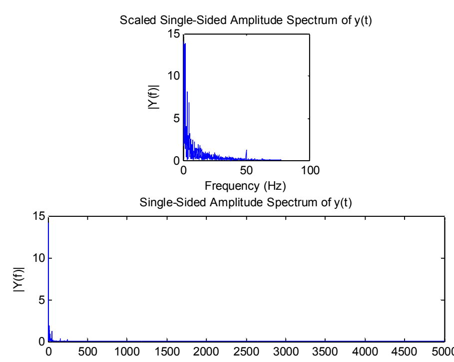

Fig.6. Frequency components related to a term delivery.

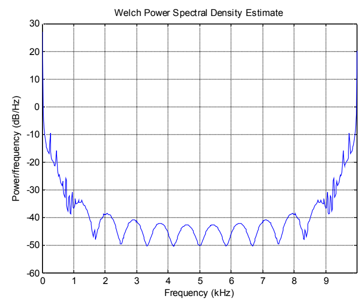

Fig.7. power spectral estimation is done by Welch method related to a preterm delivery.

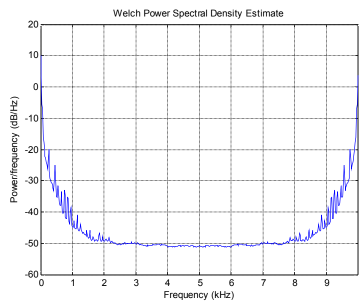

Fig.8. power spectral estimation is done by Welch method related to a term delivery.

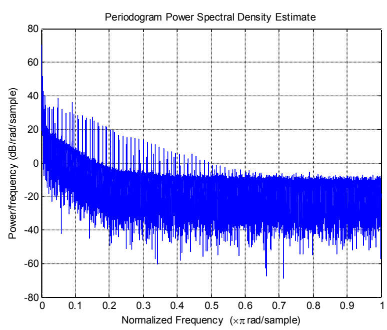

Fig.9. power spectral estimation obtained by Periodogram related to a preterm delivery.

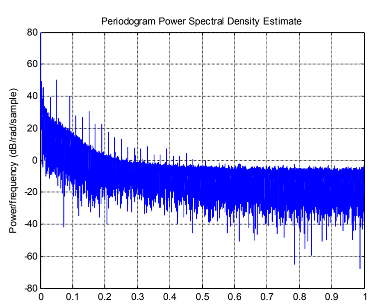

Fig.10. power spectral estimation obtained by Periodogram related to a term delivery.

In power spectral estimation using Burg method because of long length data there is not a noticeable difference between two groups.

Figure 9 (preterm delivery) and figure 10 (term delivery) illustrate power spectral estimation obtained by Periodogram. In this method data that

are gained in preterm delivery shows more changes, and the amplitude is higher as well. Furthermore in this method the estimation is biased.

Surveying frequency content in power spectrum is really useful in detecting uterine contraction. Almost 98 percent of these frequency content are located in low frequency. Comparison between power spectral density in term and preterm delivery indicates more changes in preterm delivery.

Amplitude Histogram is gained by analyzing Harr wavelet with compositions that are shown in figure 11 (preterm delivery) and 13(term delivery).

Figure 14 (term delivery) has a normal distribution that is not seen in figure 12 related to a preterm delivery, in addition in preterm delivery there is a frequency shift to right in distribution. The above result can be seen in Histogram wavelet as well.

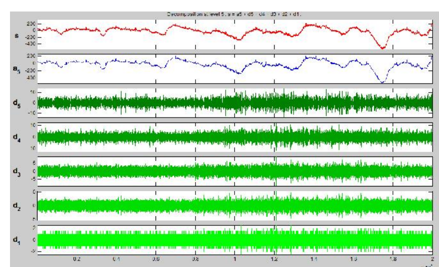

Fig.11. Decomposition of a contraction into 5 details. First two traces are the contraction and the five others are the details related to preterm delivery.

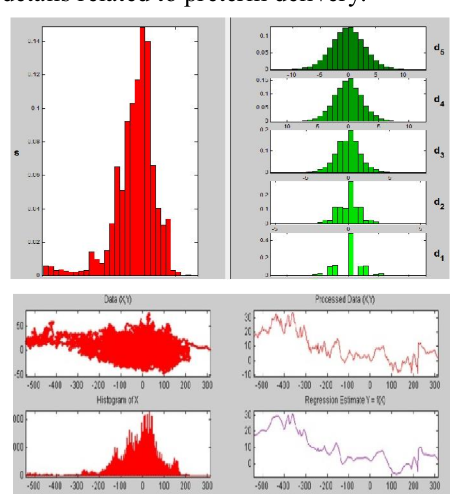

Fig.12. Amplitude Histogram that is gained by analyzing Harr wavelet related to preterm delivery.

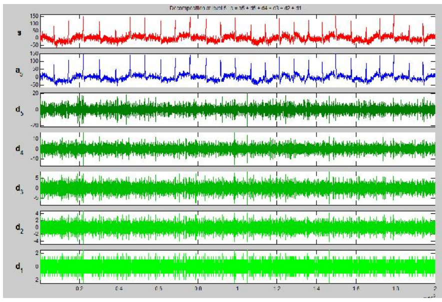

Fig.13. Decomposition of a contraction into 5 details. First two traces are the contraction and the five others are the details related to term delivery.

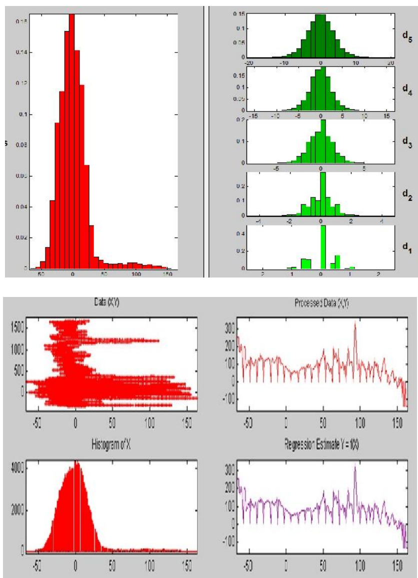

Fig.14. Amplitude Histogram that is gained by analyzing Harr wavelet related to term delivery.

Conclusion:

Different methods of spectrum estimation have been considered in this paper. It has been shown that the result is acceptable by high accuracy.

The figures above show noticeable differences between term and preterm delivery, but more research in different papers indicate Wavelet Transform is one of the most significant and accurate tools in signal processing.

The most important characteristic of Wavelet Transform is that it analyzes signals in both time and frequency domain synthesized variance information and frequency component such that they match with signal properties.

Wavelet Transform is used widely in detecting and determining characteristic of biosignal signals.

Biosignals such as EMG are non stationary, therefore in time and frequency domain processing that signals have to be considered as stationary signals, the results and classifications are not optimized. In such a situation time-frequency processing like Wavelet is recommended because of speed and accuracy.

Among the methods used for power spectrum estimation Periodogram and Welch have shown the best results, and that is due to uterine EMG signal characteristic and length of long recorded data that are appropriate to the needs of these methods.

As body system is nonlinear and the body organs react together, and also because of high temperature of human's body, biologic phenomena are chaos and stochastic therefore if they process as a chaotic signal, they will show better results.

Some methods are proposed to calculating these signals in different aspect for instance: correlation, fractal, Lipanov and etc. In these methods bio-signals are considered as chaotic signals , consequently they might show better distinguishing between two group of term and preterm delivery.

This topic is worthwhile to more research in the future.

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