Maternal and Fetal ECG Separation using Pitch Synchronous Wavelet Expansion

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Abstract: - This paper proposes a new Maternal and fetal ECG separation method using two pass Pitch Synchronous Wavelet Transform (PSWT). This representation is based on a modeling concept which is able to capture the harmonic behavior the signal by means of basis elements that are comb-like in the frequency domain.
The essence of the two pass approach involves first the estimation of the maternal ECG (MECG) from a corrupted abdominal cutaneaous recording using a pitch synchronous decomposition. Based on this estimation, a second iteration is performed in order to recover the desired Fetal ECG (FECG) components. The performance of the proposed technique is evaluated on a variety of ECG signals. Experimental results show the accuracy of the proposed technique especially in low fetal ECG power circumstance.

Key-Words: - Fetal ECG extraction, Pitch Synchronous Representation, Pitch Synchronous Wavelet transform

1 Introduction

It is proved that the diagnosis of fetal cardiac diseases based on the analysis of the fetal cardiac rhythm is not very reliable. It involves in some cases unnecessary operations and it is unable to detect some diseases, that's why the analysis of the ECG become the basis of the diagnosis. The method of recording directly the FECG is related to an internal electrode fixed on the fetal's scalp during the labor. So, to analyze, earlier during pregnancy, the fetal's health we become interested with noninvasive methods researches: the extraction of the FECG from pregnant women's ECG. The problem lies in the choice of an efficient method to extract the fetal ECG, present with a very low power in the abdominal pregnant women's ECG, with minimum of information's loss.

Different methods have been proposed for the detection and the extraction of FECG. They deal, essentially, with independent component analysis concept and the filtering concept. A method employing the blind source separation principle has been used in [3]. It consists of the constitution of the signal sources by regrouping all the fetal and maternal ECG and considering many parameters related to events occurring during the recording ECG operation as the electrode's position, the noise. A scheme based on a fuzzy decision algorithm is proposed in [1]. The fuzzy detector requires two signals of reference maternal and fetal to enhance the QRS complex to make easier its detection. Some wavelet transform based procedures have been used in the extraction of FECG such as the detection of the QRS maternal complex and the analysis of its characteristics. In [8], the authors used the assumption that the wavelet transform can characterize the local regularity of signals. They proved that the local maxima of the wavelet transform modulus detect the singular points (locations of irregular structures) of both the fetal ECG and the maternal ECG from the composite abdominal signal. After a discrimination stage using a priori information for the extraction procedure, the selected local maxima permit the reconstruction of the fetal ECG contribution.

This paper focuses on maternal and fetal ECG separation using a method based on pitch synchronous wavelet transform [5,6]. The proposed technique is different from the other model based methods, in that it requires only one abdominal signal; neither signals of reference are needed nor many signals are required to constitute a signal base to analyze and extract the fetal ECG. In section 2, we introduce a brief overview on the wavelet transform and the pitch synchronous wavelet decomposition. In section 3, we describe the different steps constituting the proposed method. We propose a technique that relies primarily on the positions of high peaks corresponding to the R wave of the ECG. The principle consists in estimating the periodicity (pitch period) with the autocorrelation function and dividing the original signal into pseudo-periodic segments using the time points obtained from the considered pitch detector algorithm. This segmentation leads to the pitch synchronous representation. By applying the wavelet transform to this representation and synthesis only the approximation component we can obtain the dominating pitched signal's behavior, so the maternal ECG estimation. A second iteration of this technique to the signal resultant from the elimination of the maternal component from the composite one extracts the FECG. In section 4, we demonstrate the effectiveness of the proposed method with the experiment results. Finally the main conclusions of our work are summarized in the last section.

2 Pitch Synchronous Wavelet Transform

Wavelet transform [9] was recently introduced as an alternative technique for analyzing non stationary signal. It provides a new way for representing signal into well-behaved expression that yields useful properties.

The continuous wavelet transform of signal $x(t)$ relative to the basic wavelet is given by:

$$W_{\psi}x(a,b) = \frac{1}{\sqrt{a}} \int_{-\infty}^{+\infty} x(t)\psi^{*}\left(\frac{t-b}{a}\right) \qquad (1)$$

where a, b $(a,b \in IR,\ a \neq 0)$ are respectively the translation and scale parameters.

This transform is essentially employed to derive properties; however, discrete forms are necessary for practical applications. Discrete time implementation of wavelet is based on a tree structure which uses a single basic building block repeatedly until the desired decomposition is accomplished. This basic unit uses techniques of multi-rate signal processing [2] and consists of a low and a high pass filter followed by a down-sampling unit. This results in an octave-band filter bank in which the sampling rate of a subband is proportional to its bandwidth.

This filter bank interpretation shows that the discrete wavelet transform provides a signal model in terms of octave bands plus final low pass band. This low pass plus details model is appropriate for signals, which are primarily, low pass. However, for signals with pseudo periodic structure, the low pass estimate of the wavelet signal model does not accurately represent the signal.

If the wavelets in the filter bank are up-sampled by the periodicity or the pitch of the signal (notion taken from speech signal community [10] and consists of finding the basic repetitive time domain structure within a signal), the result is that the spectral decomposition is adjusted and redistributed. In fact, the low pass band is reallocated in the spectrum to the region around the harmonics and the subband signal of the harmonic band provides a pseudo periodic estimate. This leads to the periodic plus details signal model of the pitch synchronous wavelet transform. In this representation a pseudo-periodic signal $s[n]$ is first converted into a sequence $v[k] = \{v_q[k]\}$ of variable length vector $v_q[k]$, each containing the sample of one period of the signal. The indexes $q = 0,\ldots, P[k]-1$ and k are respectively the inter-period and the period count index and $P[k]$ is a sequence of integer local pitch periods extracted from $s[n]$. Based on this representation the sequences of components are, then, analyzed by means of an array of wavelet transform.

Given a set of decomposition levels $l = 1, 2\ldots, L$, the pitch synchronous wavelet expansion of the signal $s[n]$ is defined by the following sum:

$$s[n] = \sum_{l=1}^{L} w_l[n] + r_L[n] \qquad (2)$$

where the scaling residue (estimation) $r_L[n]$ represents the average behavior of $s[n]$ while the partial (details) $w_l[n]$ represents the fluctuations at scale 2^l local periods. In the transform domain the scaling residue and the partial are represented by the expressions:

$$r_L[n] = \sum_{m,q} \sigma_{L,m,q} \vartheta_{L,m,q}[n]$$

$$w_l[n] = \sum_{m,q} S_{l,m,q} \xi_{l,m,q}[n] \qquad (3)$$

where $\xi_{l,m,q}[n]$, $\vartheta_{L,m,q}[n]$ (m,q integers adapted to the periodicity of the signal $s[n]$), $\sigma_{L,m,q}$ and $S_{l,m,q}$ represent a finite scale pitch synchronous wavelet, L level scaling sequences and the expansion coefficients, respectively.

3 Fetal ECG Extraction Method

The proposed method of extraction of FECG based on the pitch synchronous wavelet transform is shown in the diagram of Fig.1.

It can be described as a three step procedure:

- Denoising the composite signal $s[n] = s_{MECG}[n] + s_{FECG}[n]$ to eliminate the high frequency from it.
- Estimating the maternal ECG $\hat{s}_{MECG}[n]$.
- Extracting the fetal ECG $s_{FECG}[n]$.

In the first step, we eliminate the unwanted high frequency signal components using a soft thresholding in the wavelet domain [7]. These components are caused, essentially, by the random noise due to skin / electrode interface and amplifier.

After this operation, we expand the denoised composite signal according to its dominant harmonic structure

(Maternal ECG). In fact, we consider the autocorrelation function of the signal to obtain one pseudo period of reference. With this pseudo period we divide the signal in sequences to detect the high peak (representing the maternal R wave) in each one. When we obtain two consecutives high peaks we assume that the gap between them is the pseudo period. We divide the signal according to the gaps between two consecutives peaks to constitute a new representation with the pseudo period obtained, that is , the pitch period segmentation. Because of ECG signal characteristics, however, these pseudo period segments do not each have the same duration. It is necessary to remove these local periodicity variations prior to processing. We choose to equalize the period lengths by zero-padding all of the period segments to the maximum period length.

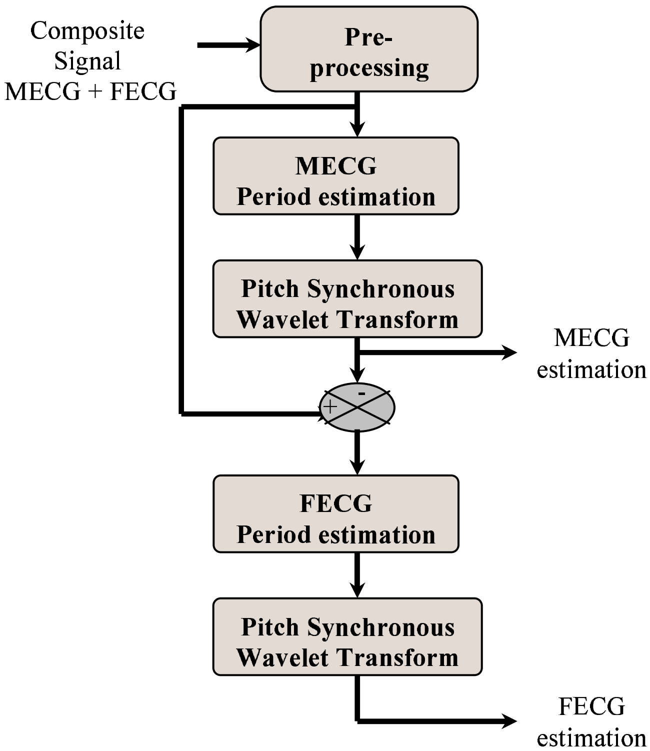

Fig. 1 Fetal ECG extraction diagram using Pitch synchronous wavelet transform.

After structuring the signal in this fashion (pitch synchronous representation) and applying an array of wavelet transform, the dominant periodic behavior (estimation) is tripped in narrowcombs and transients (details) are organized in ensembles of sidebands of the harmonics. By synthesizing, only, the estimation component, we can extract the maternal ECG signal $\hat{s}_{MECG}[n]$. The extracted maternal ECG is eliminated from the original ECG to provide the signal $s[n]-\hat{s}_{MECG}[n]$, which will be treated in the third step.

The last step is similar than the previous one, the difference is the signal concerned. This operation is applied to an ECG constituted essentially by the fetal ECG $s_{FECG}[n]$ and some residual maternal component. The result of this last step is the extracted fetal ECG.

4 Results and Discussion

In Order to evaluate the performance of extracting the FECG by pitch synchronous wavelet decomposition, experiments by computer simulation is carried out. The test set depicted in figure 2 consists of 4-channel recording data of points 2500 sampled at $300Hz$ rate with four electrodes positioned in different parts of the pregnant woman's abdomen. The other details in the experiments are as follows: the decomposition levels are $l=1,2.....,8$ and the mother wavelet is belongs the Daubechies system [9].

Fig. 2 Four-channels recording ECG data from a pregnant woman's abdomen.

Figure 3 indicates some of the results, which are obtained using the above technique. The figures 3-(a), 3-(b), 3-(c) and 3-(d) are composed of three signals: the first one is the abdominal signal which is composed of the maternal and fetal ECG, the second is the maternal ECG estimation obtained after a first application of the pitch synchronous wavelet transform and the last one represents the fetal ECG extracted after a second iteration of the proposed technique. To evaluate the effectiveness of the method we consider a visual criterion; the superposition of the ECG's estimation and the original signal allows us to evaluate the synchronization and the information's loss.

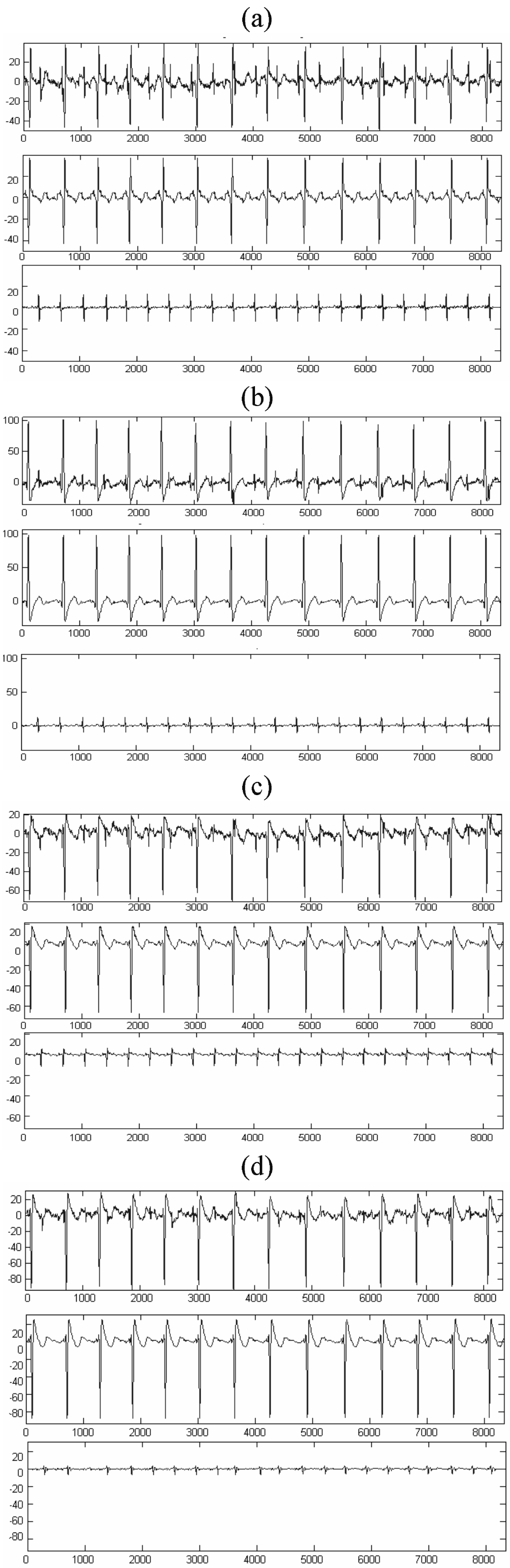

Fig. 3 Fetal ECG extraction of four ECG signal using pitch synchronous wavelet transform

The results with each family vary with the ECG signals. In fact, some families can generate a very little discrepancy between one or two QRS complex of the estimation and the original ECG. The lower resolution values underestimate the maternal ECG and affect the analysis of the fetal ECG, whereas, the upper resolution values deteriorate the signal. In summary, the best results are obtained for the Daubechies 12 and the value 6 for the depth of the decomposition.

These results (figure3) show no missing fetal and no false peaks detection. In addition, the location of the fetal high peaks (resp. maternal high peaks) in the extracted FECG (resp extracted MECG) are aligned with those of the composite abdominal signal.

The robustness of the method is clear. Figure 3-(c) and 3-(d) indicate that the algorithm still gives good results at poor condition: the power of FECG is very small and we have extracted efficiently the Fetal ECG. The pitch synchronous representation makes the procedure of extraction nearly independent of the FECG power level. The robustness is also proved when the technique is applicable to a very big variety of wavelet families with a very little probability of discrepancy for the synchronization and really minimal information's loss even if it varies with the families.

4 Conclusion

In this paper, we have investigated the estimation of maternal ECG and the extraction of the fetal ones by exploiting the pseudo periodic information. The proposed technique is based on a two-pass pitch synchronous wavelet decomposition which permits to extract the Fetal ECG from a composite signal by estimating the signal in term of its spectral content around its harmonic frequency and attenuate the remaining components in the inter-harmonic bands.

This technique is robust: the extraction was successful for the signals represented and we guarantee the minimum of maternal and fetal information's loss and also the synchronization between the estimations and the original signal. Another benefit, which is also the aim of this technique, is the independence from the reference signal: we can extract the fetal ECG from any abdominal ECG without needing any other signal.

References:

[1] K.Azad, *Fetal QRS complex Detection from abdominal ECG: a Fuzzy Approach*, Faculty of Engineering Multimedia University, 2000.

[2] R. Crochiere and L. R. Rabiner, *Multirate Digital Signal Processing*, Prentice Hall, 1983.

[3] L. De Lathauwer, B. De Moor and J. Vandewalle, *Fetal Electrocardiogram Extraction by Blind Source Subspace Separation*", IEEE Trans. On Biomedical Engineering. Vol. 47, No. 5, May 2000.
[4] A. Elloumi, *Extraction de l'ECG Foetal par décomposition atomique*, DEA Automatique et traitement du signal, Ecole Nationale d'Ingénieurs de Tunis, April 2003.
[5] G. Evangelista, *Pitch Synchronous Wavelet Representation of Speech and Music Signals*, IEEE Trans. On Signal Processing, Vol.41, No.12, December 1993.
[6] G. Evangelista, *Comb and Multiplexed Wavelet Transform*, IEEE Trans. On Signal Processing, Vol.42, No.2, February 1994.
[7] A. Jensen, *Noise reduction by wavelet thresholding*, New York, Springer Verlag, 2000.
[8] A. Khamene and S. Negardaripour, *A New Method for the Extraction of Fetal ECG from the Composite Abdominal Signal*, IEEE Trans. On Biomedical Engineering, Vol.47, No.4, April 2000.
[9] S. Mallat, *A Wavelet Tour of Signal Processing*, Academic Press, 1999.
[10] T. F. Quatieri, *Discrete Time Speech Signal Processing*, Prentice Hall, 2002.
[11] M. Vetterli and J. Kovacevié, *Wavelets and Subband Coding*, Prentice Hall, 1995.