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Interference Cancellation in FECG Using Wavelet-Adaptive Filtering Technique

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Abstract: In this study, we investigate the use of wavelet transform denoising along with two stage adaptive filtering technique for fetal electrocardiogram (FECG) extraction from the two ECG signals recorded at the thoracic and abdominal areas of the mother's skin. The abdominal ECG (AECG) is considered to be composite as it contains both the mother's and fetal ECG signal, whereas the thoracic ECG (TECG) is considered to be almost completely maternal ECG (MECG). By canceling the maternal ECG from the abdominal signal, the fetal ECG is enhanced. The maternal component in the abdominal ECG signal is nonlinearly transformed version of the MECG. We use the wavelet transform to decompose the abdominal signal and FECG component is extracted by adaptive filtering technique. The proposed method is applied to real ECG signals. The proposed technique in extracting the FECG component from abdominal signal of very low maternal to fetal signal-to-noise ratio. The visual results are obtained and show that the technique is capable of extracting FECG even when it is embedded with complex maternal signal.

Key words: Wavelet transform, adaptive filtering, FECG, MECG, TECG, AECG

INTRODUCTION

ECG has become the most common tool for monitoring the patients believed to suffer from cardiac disease. Physiological signals may not be directly measurable and we might have to determine the signal from the complex signals. Fetal electrocardiogram belongs to this category of signal. But it is the interesting and challenging problem that the clinicians face in extraction of FECG. Fetal Electrocardiogram contains information about the health status of the fetus. And also it provides substantial information on fetal well being, fetal positioning, multiple pregnancies and fetal maturity (Matonia *et al*., 2006).

The FECG is obtained by placing the standard ECG electrodes attached to the mother's abdomen (Camps *et al*., 2001). Unfortunately these trans abdominal signal recordings are dominated by strong interference signal such as MECG, base line wander and power line interference (Kam and Cohen, 1998). In trans abdominal signals, the MECG signal has amplitude of 0.5-10 mV and the FECG signal can be as low as 10-100 μV (Datian *et al*., 1998).

So appropriate signal processing techniques are used to extract the FECG from the corrupted recordings. Routine examinations might prove a significant tool for the doctor for pregnancy monitoring. Several approaches have been proposed in the literature addressing FECG extraction with various degrees of success. These techniques include adaptive filters (Ferrara and Widrow, 1982), correlation techniques (Abboud *et al*., 1992), singular value decomposition (Callaerts *et al*., 1990), wavelet transform (Mochimaru *et al*., 2002) and blind sthece separation via independent component analysis (Zarzoso and Bacharakis, 1997) to mention a few. Despite the reported successes of these methods, they are still not used clinically at a large scale.

In this study, we aim to apply an improved method of extracting the fetal ECG from composite abdominal signal. The proposed method uses the wavelet denoising and cancellation of mothers ECG to improve the extracted signal quality. Real abdominal signals were used to test the algorithm.

MATERIALS AND METHODS

The testing of the algorithm was done by using data from SISTA/DAISY and Physionet. The ECG signal in SISTA/DAISY data set were recorded from eight different skin electrodes located on different positions of a pregnant women. The sampling frequency is 500 Hz. The first five simultaneous were recorded from the mothers

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abdominal region and the last three were obtained form the mothers thoracic region. Physionet has 2 channels of thoracic signals and 4 channels of abdominal signals. The sampling frequency is 250 Hz. However, for extraction of the FECG signal any one channel of abdominal and any one channel of thoracic signals are used. The first abdominal recording, which has the highest fmSNR is selected as abdominal signal and any one of the thoracic signal since all the three has the huge maternal signal. The gestation period varies from 21-40 weeks.

Wavelet transform: The wavelet transform is an efficient mathematical tool for local analysis of fast transient signals and non stationary signals. It represents a very suitable method for classification of FECG signals from the abdominal ECG signal.

It allows the use of long time interval analysis and yields more precise low-frequency information and short time interval analysis yields the high frequency information. The wavelet transform is a time scale representation technique. The shape of the wavelet can be selected and it can be matched to the shapes of components embedded in the signal to be analyzed (Daubechies, 1992).

Wavelet denoising: The wavelet denoising method is based on the assumption that the random errors in a signal are present over all the coefficient. But the deterministic changes are getting captured in a small number of large coefficients. The wavelet denoising method consists of applying DWT to the original signal, thersholding the detail and approximation coefficients and inversing the threshold coefficients to obtain the time domain denoised data (Paraschiv-Ionescu *et al*., 2002).

The performance of the wavelet denoising depends upon the type of wavelet transform, type of the wavelet, thersholding rule and the number of decomposition levels. The wavelets are not only used as a denoising or filtering tool, but the wavelet decomposition projects each data in to a n-dimensional orthogonal basis which consists of scaling function and the wavelet function and n-1 is the number of levels of decomposition. The steps for the noising are:

- Decompose the signal; choose a wavelet, choose a level n. Compute the wavelet decomposition of the signal‘s’ at level n
- After the wavelet decomposition, the wavelet coefficients are modified and then the reconstruction takes place
- Reconstruction of the signal; compute wavelet reconstruction using the original approximation coefficients of level n and the modified coefficients of level from 1-n

Adaptive filters: Adaptive filter is essentially a digital filter with self adjusting characteristics. Moreover, the ECG signals are non stationary in nature. Hence, the best option is to use adaptive filtering. There are different algorithms used for filtering which includes Least Mean Square (LMS) and Recursive Least Squares (RLS) and Normalized Least Mean Square (NLMS). The LMS algorithm is the simple method, whereas the RLS has the increased complexity, computational cost and fidelity. LMS algorithm considers only the current error to minimize, where as RLS considers the total error from the beginning to the current value with the forgetting factor λ (Emmanuel and Jervis, 2002). The algorithm is analyzed with different combinations and the results show significant improvement in quality of extracted FECG.

Design of extraction system: The proposed method detects fetal ECG wave by wavelet decomposition of abdominal ECG and subsequent cancellation of maternal ECG by two stage adaptive filtering. The thoracic signal which is purely of mECG is used to cancel mECG in abdominal signal and the fetal ECG detector extracts the fECG. The design of the extraction system is shown in Fig. 1. The wavelet decomposition and reconstruction were performed by coiflets wavelets, because the wavelet functions belonging to this family have a similar shape of FECG. And the number of level of decomposition was set as 5. The properties of coiflets wavelet are good for this application because it reduces the noise and provides high resolution output. In this method, only the approximation coefficients are retained as a signal carrying the useful information. The different combination of adaptive filters was tested. The different adaptive filter combinations chosen are:

- LMS, LMS
- LMS, NLMS
- LMS, RLS

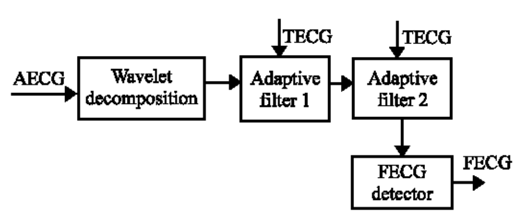

Fig. 1: The design of the extraction system

- NLMS, LMS
- NLMS, NLMS
- NLMS, RLS
- RLS, LMS
- RLS, NLMS
- RLS, RLS

The outputs generated by the combination of adaptive filter 1 as RLS and adaptive filter 2 as LMS combination was able to extract fetal ECG completely and suppress the maternal component. The RLS-LMS combination was selected as a optimum combination for extraction purpose.

Wavelet adaptive filtering technique for FECG extraction: The objective of the algorithm is to extract the fetal ECG by suppressing the maternal ECG and noise from the signal. The preprocessed and denoised signal is represented as DS. The fetal extraction is done using a non linear operator defined by:

$$\Psi = DS\ (K-1) \tag{1}$$

Once the signal is decomposed, the denoised signal is multiplied by factor K. The K value is found to be 2.6 using non linear optimization techniques. The adaptive filter has two input signals. One signal is the scaled, squared as second order and again scaled thoracic signal and other signal is the non linear operator signal, which is the squared and scaled denoised signal as shown in Fig. 2.

The advantage of squaring the signal intensifies the slope of the frequency response curve of the derivative and will help in restricting the false positive T waves, which is higher than the usual spectral energies (Pan and Willis, 1985). If the properties of noise changes in time and if the frequencies of the signal and the noise overlap then the adaptive filtering is selected. The signal extracted by this technique is quite clean and regular signal accounting for fetal heart rate and the effect of the artifacts related spikes were suppressed.

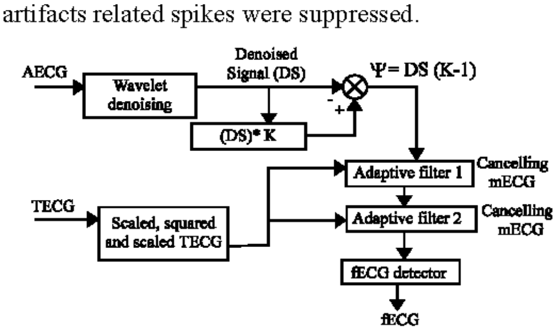

Fig. 2: Wavelet adaptive filtering technique

RESULTS AND DISCUSSION

The wavelength adaptive filter method is tested with the following data and the results are shown in Fig. 3-7.

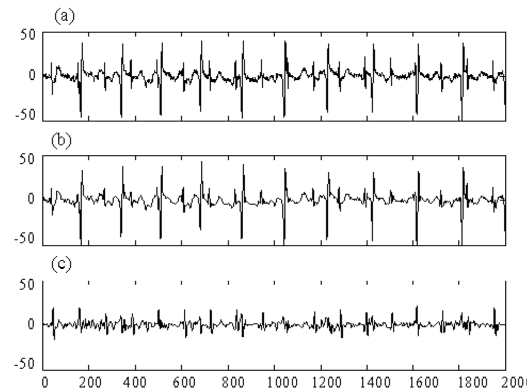

Fig. 3: (a) Abdominal signal; (b) wavelet denoised signal; (c) extracted FCEG for SISTA/DAISY (2, 7)

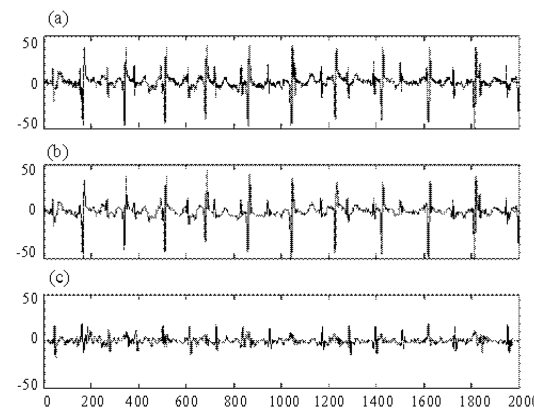

Fig. 4: (a) Abdominal signal; (b) wavelet denoised signal; (c) extracted FCEG for SISTA/DAISY (2, 8)

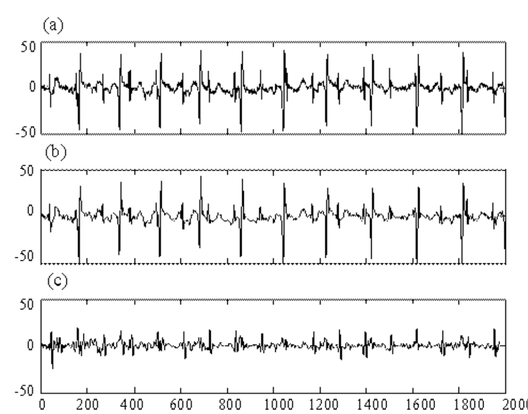

Fig. 5: (a) Abdominal signal; (b) wavelet denoised signal; (c) extracted FCEG for SISTA/DAISY (2, 8)

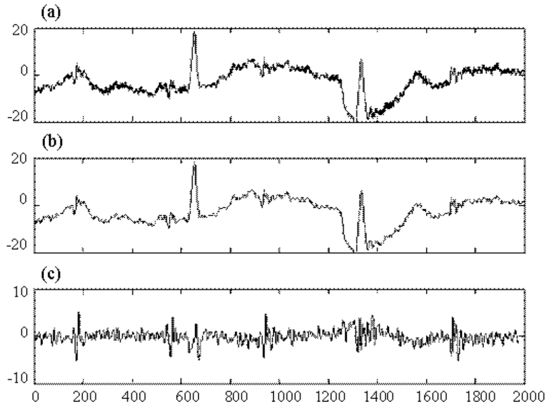

Fig. 6: (a) Abdominal signal; (b) wavelet denoised signal; (c) extracted FCEG for physionet. org (4, 2)

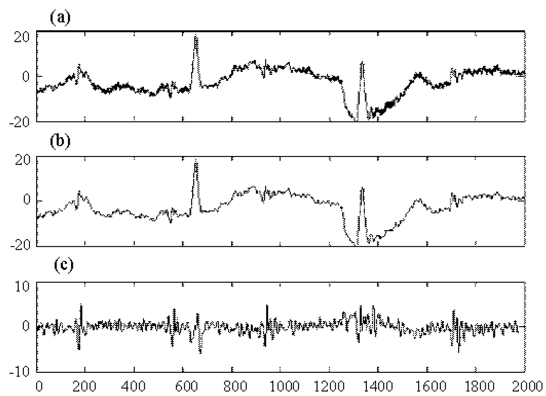

Fig. 7: (a) Abdominal signal; (b) wavelet denoised signal; (c) extracted FCEG for physionet. org (4, 3)

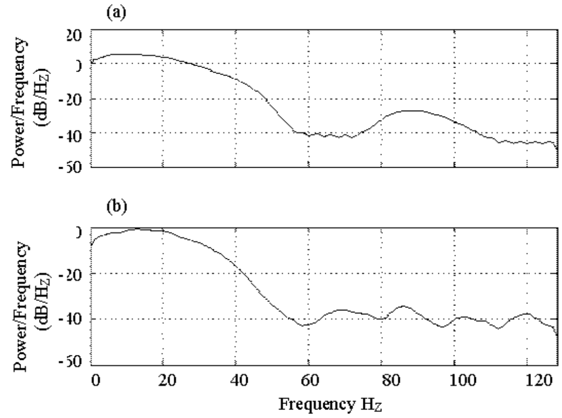

Fig. 8: (a) Power spectrum of abdominal signal; (b) power spectrum of extracted FECG-SISTA/DAISY

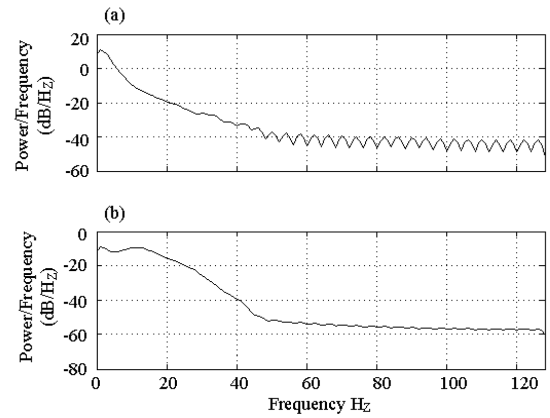

Fig. 9: (a) Power spectrum of abdominal signal; (b) power spectrum of extracted FECG-physionet. org (4, 2)

- Abdominal signal from channel 2 and thoracic signal from channels 7-9 from data taken from SISTA/ DAISY
- Abdominal signal from channel 4 and thoracic signal from channels 2 and 3 from data taken from Physionet. org

FECG extraction with wavelet (adaptive filtering technique): The proposed method uses wavelet the noising and non linear parameter Ψ = DS (K-1). The result clearly shows that the technique is able to extract fetal ECG completely and suppress the maternal component. It is also seen to be noise free (Fig. 3-7).

Power spectrum of extracted FECG: The power spectral analysis was done for the FECG extracted from the data of Sista/Daisy sampled at 500Hz and physionet. org sampled at 250 Hz.

The power spectrum of extracted FECG using the proposed method is shown in Fig. 8 and 9. Their is a significant correlation between the spectrums of FECG obtained. Thus it proves that the proposed methodology is able to extract FECG from the abdominal even though the sampling rate is different.

CONCLUSION

In this study, we have proposed a new method of combining the wavelet decomposition and adaptive filtering to extract fetal ECG from maternal ECG. This method uses wavelet decomposition as an integral part of the extraction system. The limitations of conventional methods led to the design of this extraction system, which uses conventional system to improve the estimate of the fetal ECG and maternal ECG. A two stage adaptive filter system is shown to retrieve fetal ECG from actual patients maternal ECG. It is not easy to see how well the fECG extraction is achieved by looking at a large number of samples. Thus a frame of 2000 samples is taken to illustrate the effectiveness of the algorithm. In this frame there are both overlapping and nonoverlapping between maternal and the fetal components in the abdominal signal. This is a significant challenge to the extraction algorithm.

The results show that the algorithm was able to successfully extract the fECG signal. It can be noted the visual quality of the extracted fECG is comparable to other methods. The advantage of this method is that the reference signal need not closely mimic the signal to be cancelled. This proposed method is seen to provide a clean FECG signal comparable or better than the other existing methods. It is believed that this new method can become a diagnostic tool for treatment of fetal arrhythmias.

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