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A Novel Technique for Extraction of FECG using Multi Stage Adaptive Filtering

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Abstract: In this study, a two stage adaptive filtering along with the denosing technique to extract the FECG from the maternal abdominal signal is proposed. This method leads to enhancement of fetal ECG by canceling maternal ECG. The FECG extraction is from two ECG signals recorded at the thoracic and abdominal areas of the mother's skin. The thoracic ECG (TECG) is assumed to be almost completely maternal while the abdominal ECG (AECG) is considered to be composite as it contains both the mother's and fetus ECG signals. The proposed method is applied to real ECG signals to demonstrate its superior effectiveness and it is found to meet or exceed that of the published results using other techniques. The algorithm performance with sensitivity, positive predictivity and accuracy were calculated and the obtained results indicate high detection ability.

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

INTRODUCTION

The ECG has become the most common diagnostic tool for monitoring the patients believed to suffer from cardiac disease. The fetal electrocardiogram (FECG) is the electrical activity of the fetal heart and first demonstration was carried out in 1906 by Cremer (Deam, 1994). Fetal electrocardiogram provides clinically significant information about the physiological state of a fetus. So, an early diagnosis of fetal ECG before delivery increases the effectiveness of the treatment (Mazzeo, 1994). To record FECG, many experiments were performed using an invasive technique which is the direct method of measurement. Non invasive techniques appeared in seventies which is the indirect method of measurement. The electrical signals generated by the fetal heart is measured from the multi channel electrodes placed on the mother's body surface which doesn't have a direct contact with the fetus is called as non invasive method. These obtained signals are characterized by a great amount of overlapped noise such as base line wander, power line interference, MECG, electromyogram and its variability was increased by factors related to gestational age, position of the electrodes, skin impedance etc (Khamene and Negahdaripour, 2000). The main noise contribution is the maternal electrical activity since its amplitude is much higher than the fetus. The intensity of MECG is 5 to10 times higher than the FECG (Widrow and Stearns, 1985). If one is able to eliminate the maternal ECG component from the composite signal, a reasonable FECG signal can be obtained.

Many signal processing based techniques were used to extract FECG with various degrees of success. These techniques include adaptive filtering (Thakor and Zhu, 1991), correlation techniques (Abboud *et al*., 1992), singular value decomposition (Callaerts *et al*., 1990), wavelet transform (Mochimaru *et al*., 2002) blind source separation via independent component analysis (Zarzoso and Bacharakis, 1997), fractals (Richter *et al*., 1998), FIR neural networks (Camps *et al*., 2001), IIR adaptive filtering combined with genetic algorithms (Kam and Cohen, 1999), fuzzy logic (Azad, 2000), frequency tracking (Barros, 2002) and real-time signal processing (Ibahimy *et al*., 2003). Projective filtering techniques were also used to extract fetal ECG (Kotas, 2007). Some of the proposed techniques mentioned above can be applied to the single channel of the abdominal ECG signals e.g., Singular value decomposition and wavelet. In contrast, some techniques such as adaptive noise cancellation and blind source separation require two or more channels of measurement. The most recent and most successful method of extraction is Blind Source Separation (BSS) via Independent Component Analysis (ICA). In order to study with ICA based BSS it needs multiple leads for collecting several ECG signals. The proposed two lead method is not yielding a satisfactory result of extraction using BSS via ICA technique.

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

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MATERIALS AND METHODS

The development of different algorithms to extract fetal ECG presented in this paper started in the year 2007 and the testing of the algorithms was done by using data from SISTA/DAISY and Physionet. The data from SISTA/DAISY has abdominal data of 5 channels and thoracic data of 3 channels. Physionet has 2 channels of thoracic signals and 4 channels of abdominal signals. 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 to 40 weeks. DAISY data and Physionet data have different sampling frequencies. The algorithm has been tested with both the data.

Extraction method: The proposed method detects fetal ECG by preprocessing and denoising of abdominal ECG (AECG) and subsequent cancellation of maternal ECG (MECG) by multi stage adaptive filtering. The thoracic signal (TECG) which is purely of MECG is used to cancel MECG in abdominal signal and the fetal ECG detector extracts the FECG.

Pre processing algorithm: The preprocessing consists of the following steps (Swarnalatha and Prasad, 2007).

- Read the abdominal ECG
- Separate the high resolution components and low resolution components
- Compensate for the phase
- Derive the noise component
- Separate the noise from the original signal
- Reconstruct the signal back
- Repeat the construction process iteratively

In pre processing stage, the high resolution components which are the maternal QRS wave having large amplitude and frequency is separated from the low resolution components of fetal ECG. The separation is done based on band pass digital filter. The band pass filter reduces the influences of muscle noise, 60 Hz power interference, T wave interference and baseline wander (Pan and Willis, 1985). Then the signal is subjected to the Fast Fourier Transform where it decomposes a sequence of values in to components of different frequencies. The compensation for the phase of the signal is done by phase shifting the signal so that the noise signal can be derived. The noise signal obtained, is separated from the original signal followed by the Inverse Fast Fourier Transform to reconstruct the signal back.

The proposed algorithms: The proposed algorithms in this study are:

- FECG extraction method
- Improved FECG extraction method
- A novel method of FECG extraction

FECG extraction method: In the earlier algorithm proposed by us (Swarnalatha and Prasad, 2008) yielded a fECG signal which is not totally free from maternal components. The objective of the improved algorithms presented in this study is to extract the fetal ECG by suppressing any other components present in the extracted signal. The extraction of fetal ECG includes the preprocessing of the abdominal signal using the steps explained earlier. Then the preprocessed signal is used to develop the non linear parameter Ψ = DS (0.02×DS-1) as shown in Fig. 1.

Ψ is derived by adding the negative of the denoiosed signal with the squared and scaled denoised signal. The scaling factor has been determined looking at the amplitude of the squared signal to match with that of the abdominal signal. The thoracic signal has been modified by scaling, squaring and further scaling. The scaling factors have been chosen such that the adaptive filters are fine tuned to extract the desired signal. Also the advantage of this method is that the input to the adaptive filter need not be original thoracic signal and instead can be a closely resembling signal. This method can totally avoid thoracic signal being recorded if a replica of thoracic signal can be generated.

Adaptive filter algorithm: The adaptive filter has two input signals. One signal is the scaled, squared and again scaled thoracic signal and other signal is the non linear

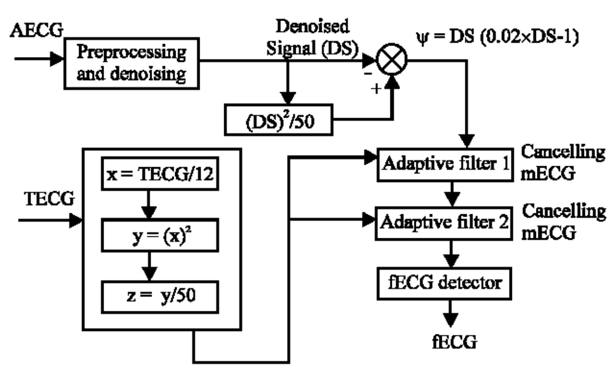

Fig. 1: Block diagram of the FECG extraction method

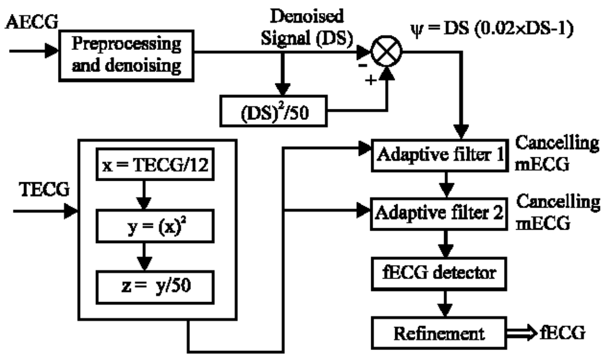

Fig. 2: Block diagram of the FECG extraction with refinement

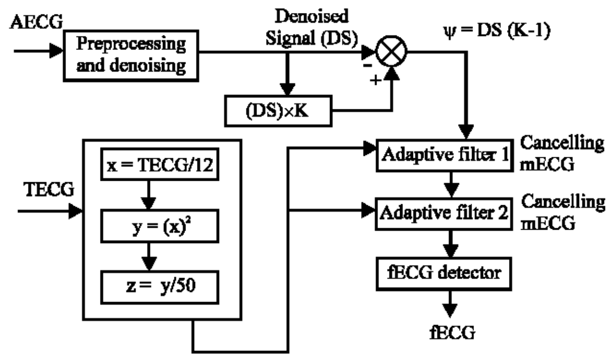

Fig. 3: Block diagram of the novel method of FECG extraction

operator signal which is the squared and scaled denoised signal. 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. Adaptive filter is essentially a digital filter with self adjusting characteristics. More over 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 where as the RLS has the increased complexity, computational cost and fidelity. The 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. The algorithm is analyzed with different combinations and the results show significant improvement in quality of extracted FECG.

Improved FECG extraction method: The refinement is proposed to further enhance the quality of the extracted FECG as shown in Fig. 2. In this proposed algorithm, the steps used to refine the extracted FECG from the FECG detector use the same preprocessing methodology. This was yielding a better result than without the refinement technique. The refinement results are shown in Fig. 8a and b.

Novel method of FECG extraction: This novel method of FECG extraction uses a non linear parameter Ψ = DS (K-1) and avoids the post refinement after FECG detector as shown in Fig. 3. Once the preprocessing steps are done for the input signal the denoised signal is multiplied by factor K. Using non linear optimization method the K value is found to be 2.6. This was yielding a better FECG comparable to other techniques proposed by us. The results are shown in Fig. 9a and b.

RESULTS AND DISCUSSION

There are three algorithms proposed in this study. They are:

- FECG extraction method
- Improved FECG extraction method
- Novel method of FECG extraction

These three algorithms have been analyzed with different combination of adaptive filters. The different adaptive filter combinations chosen are (1) LMS, LMS (2) LMS, NLMS (3) LMS, RLS (4) NLMS, LMS (5) NLMS, NLMS (6) NLMS, RLS (7) RLS, LMS (8) RLS, NLMS (9) RLS, RLS. The outputs generated by the combination of adaptive filter 1 as LMS and adaptive filter 2 as LMS, NLMS and RLS for an input of abdominal signal (Fig. 4a) are shown in the Fig. 4b-d.

The outputs generated by the combination of adaptive filter 1 as NLMS and adaptive filter 2 as LMS, NLMS and RLS for an input of abdominal signal (Fig. 5a) are shown in the Fig. 5b-d. The outputs generated by the combination of adaptive filter 1 as RLS and adaptive filter 2 as LMS, NLMS and RLS for an input of abdominal signal (Fig. 6a) are shown in the Fig. 6b-d.

Out of 9 possible combinations of the filters tested, the combination with NLMS (Fig. 5) was not fully suppressing the maternal ECG component. The LMS, LMS combination (Fig. 4) and RLS, LMS (Fig. 6) combinations were yielding good results. LMS, LMS combination was able to extract fetal ECG completely and suppress the maternal component. However, noisy

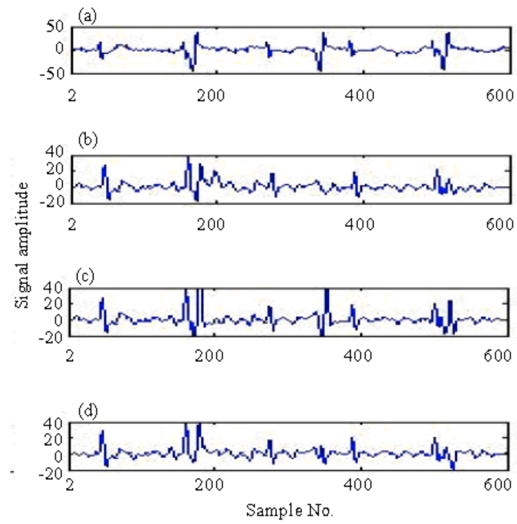

Fig. 4: (a) Abdominal signal (b) LMS, LMS output (c) LMS, NLMS output and (d) LMS, RLS output

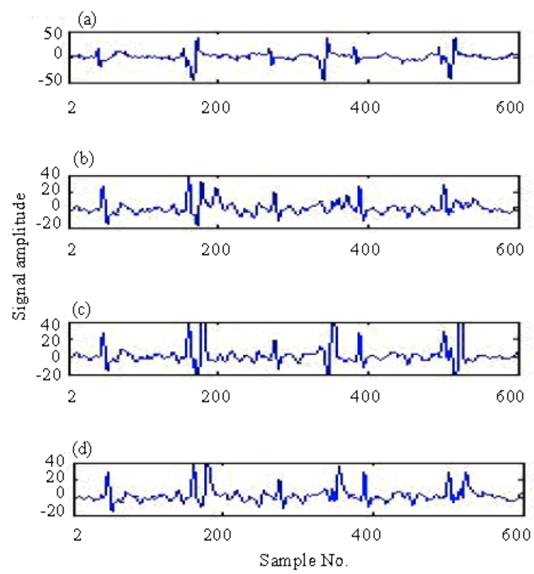

Fig. 5: (a) Abdominal signal (b) NLMS, LMS output (c) NLMS, NLMS output and (d) NLMS, RLS output

components were present in this method. RLS, LMS is yielding comparatively better result. It is seen that the fetal ECG has significant dominance and maternal ECG is totally suppressed. Thus for further analysis purposes the RLS, LMS combination has been used to extract the fetal ECG by the three different proposed algorithms in this study. The algorithms were analyzed for sensitivity, positive predictivity and accuracy mentioned earlier.

Figure 7a is the abdominal signal and Fig. 7b is the extracted FECG with Ψ = DS (0.02×DS-1). The visual quality of extracted FECG is seen to be good.

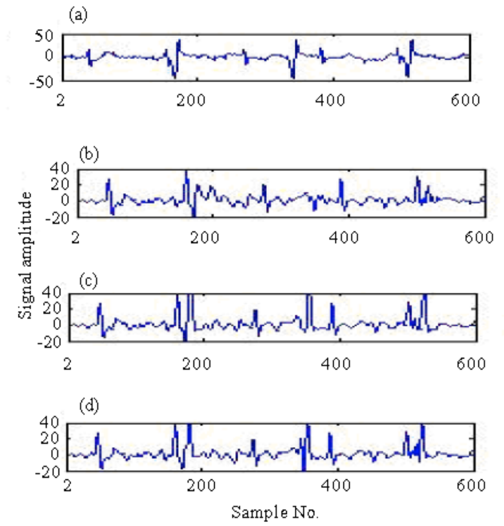

Fig. 6: (a) Abdominal signal (b) RLS, LMS output (c) RLS, NLMS output and (d) RLS, RLS output

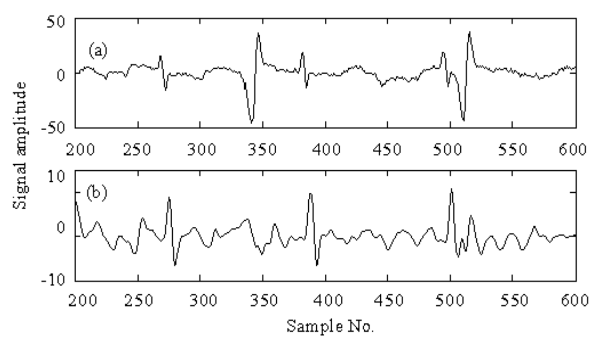

Fig. 7: (a) Original abdominal ECG and (b) extracted FECG (Ψ = DS (0.02×DS-1))

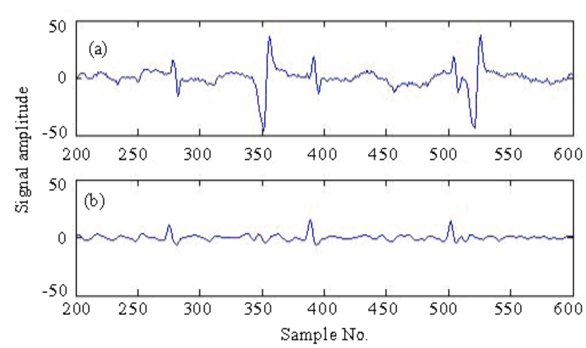

Fig. 8: (a) Original abdominal ECG and (b) extracted FECG (Ψ = DS (0.02×DS-1) with refinement)

Figure 8a is the abdominal signal and Fig. 8b is the extracted FECG with Ψ = DS (0.02×DS-1) with refinement. The extracted FECG shows the QRS complex of the fetal ECG very clearly. Figure 9a is the abdominal signal and

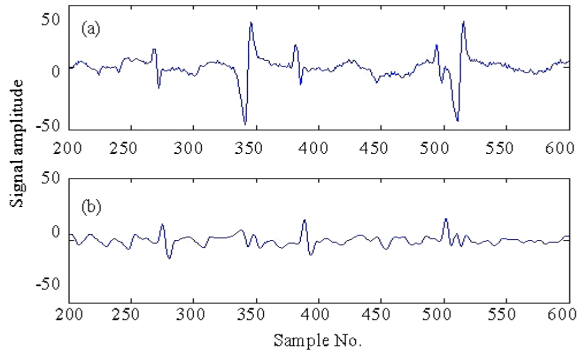

Fig. 9: (a) Original abdominal ECG and (b) extracted FECG (Ψ = DS (K-1))

Table 1: Average performance of FECG extraction

Methods	Sensitivity	Positive predictivity	Accuracy
		(%)	
FECG extraction method	83.28	76.53	72.68
Improved FECG extraction method	91.76	80.37	75.35
Novel method of FECG extraction	96.18	84.94	80.63

Fig. 9b is the extracted FECG by novel method of FECG extraction technique by Ψ = DS (K-1). The result clearly shows that the extracted fetal ECG is better than earlier methods suggested by us. It is also seen to be noise free.

Evaluation of the algorithm: The performance of the algorithms was evaluated based on their sensitivities, positive predictivities and accuracies (Azevedo and Longini, 1980).

- Sensitivity = TP/TP+FN
- Positive predictivity = TP/TP+FP
- Accuracy = TP/TP+FP+FN

The TP (True Positive) is the number of matched FECG i.e., correctly detected FECG, FN (False Negative) is the missed detections i.e., number of events that were not detected by the approach and FP (False Positive) is the extra detection i.e., number of events detected by the approach and not matched to the manual labels. The evaluation was done for different combinations of abdominal signals and thoracic channels. Table 1 shows the comparison of the methods proposed by us.

The average of sensitivity, positive predictivity and accuracy are larger in the case of novel method of FECG extraction. All the three parameters are seen to change with the electrode positions.

CONCLUSIONS

The three methods for fetal extraction from a composite abdominal ECG signal are proposed in this study. The adaptive filter combination has been optimized by testing the different combinations of the filters using LMS, NLMS and RLS. Among these, the RLS, LMS combination has been found to be the most suitable for extraction. With this combination of filters and a different non linear parameters (Ψ) have been used for FECG extraction. The novel FECG extraction technique with Ψ = DS (K-1) was yielding the best extraction out of the three algorithms proposed in this study. The extracted FECG signal very closely resembles the FECG signal pattern. From the extracted FECG doctors are able to diagnose the heart diseases of fetus. The advantage of this technique is that it requires only one abdominal signal and one thoracic signal. And another advantage is that the reference signal need not closely mimic the signal to be canceled. This feature of algorithm can be used in early stages of pregnancy to understand the fetal condition.

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