

# EXTRACTION OF FETAL ECG FROM ABDOMINAL SIGNAL

D. V. Prasad and R. Swarnalatha

*Department of Electronics & Instrumentation Engineering, BITS, PILANI, Dubai, U.A.E.*

Keywords: fECG, mECG, TEGG, Adaptive filtering.

Abstract: Fetal ECG monitoring is essential for identification of fetal distress. The assessment of the QRS waveform of fetal ECG is good analysis tool. Extraction of fetal ECG from abdominal signals is difficult. This paper presents a method for extracting fetal ECG (fECG) from composite abdominal signal. This method is applied to composite abdominal signal containing maternal ECG and fetal ECG. Adaptive filtering techniques along with denoising techniques were used to extract fECG. This method leads to enhancement of fetal ECG by cancelling maternal ECG. The results were validated using real signals. The thoracic signal is purely that of mother (mECG) while the abdominal signal contains both mothers and fetus ECG signals (mECG + fECG). The results clearly show the effectiveness of the method in extracting fECG.

## 1 INTRODUCTION

The fetal electrocardiogram (fECG) is the electrical activity of the fetal heart and first demonstration was carried out in 1906 by Cremer (Jenkins, 1986). Fetal electrocardiogram fECG provides clinically significant information about the physiological state of a fetus. Anoxia is known to alter the balance between the electrical polarization and repolarization of the heart. Similarly arrhythmias show the maturity of fetal cardiac activity (Symonds EM, Sahota T, and Chang A, 2001). Many experiments were performed using invasive techniques to record fECG. Non invasive techniques appeared in the seventies. These methods use recorded signals from maternal abdominal wall. These signals contained not only maternal electrocardiogram (mECG) but also fetal ECG (fECG) and other signals. The maternal signal level is much higher than fetal ECG and hence has to be suppressed from the composite signal. With advent of technology and analysis tools many methods of maternal ECG suppression were developed.

Adaptive filtering was used with thoracic signals as the reference inputs, combined to cancel the maternal ECG in the abdominal signals (Widrow et al, 1975). A weighted addition of four or more abdominal signals was calculated to suppress the maternal ECG (Bergveld P and Meijer JH, 1981). Singular value decomposition was used successfully to separate maternal ECG and fetal ECG (Callaerts

D, De Moor B, Vanderwalle J and Sansen W, 1990). Blind source separation algorithms have also been applied to extract fECG (Zarcoso and Nandi A K, 2001).

Fetal ECG contains information about the health status of the fetus. It gives an early diagnosis of any cardiac defects before delivery (Mazzo J R, 1994). Non invasive techniques of fetal monitoring are Doppler ultrasound, fetal electrocardiography and fetal magneto cardiography. Among these methods the most commonly used is Doppler ultrasound. However this method produces an averaged heart rate and therefore cannot give beat to beat variability. This method cannot provide electrophysiological information such as arrhythmias. Fetal electrocardiogram offers the advantage of monitoring beat to beat variability. (Fukushima T, Flores CA, Hon EH, Davidson EC, 1985). There are many technical problems with non invasive extraction of fECG. The fECG signal is corrupted by different sources of interferences such as maternal EMG, 50 Hz power line interference and base line wander. The low amplitude of the signals, the different types of noise and overlapping frequencies of mother and fetal ECG make the extraction of fECG a difficult task (Goddard B A, 1966). Projective filtering techniques were also used to extract fetal ECG (Kotas M, 2007)

The fetal heart rate variations during pregnancy and labour have been used as an indirect indicator of fetal distress. Observation over longer periods may

yield more information about the status of the fetus. The detection of fetal QRS complex on surface records is very difficult task which is mainly due to overlapping of mothers ECG. The mECG and fECG are partly uncorrelated. Also the mECG signal is very much stronger than the fECG signal embedded in it. The noise in which fECG is embedded is also stronger depending on the gestation age.

In this paper an improved method of extracting the P QRS T waves of 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.

## 2 METHOD

The block diagram of the proposed algorithm is shown in Fig 1. The proposed method detects fetal QRS wave by preprocessing and denoising of abdominal ECG (AECG) and subsequent cancellation of maternal ECG in the abdominal ECG. The thoracic signal (TECG) which is mECG is used to cancel mECG and the fetal ECG detector extracts the fECG. This method uses multistage adaptive filtering.

### 2.1 Preprocessing

The preprocessing consists of the following steps (Prasad DV, Swarnalatha R, 2007).

- (a) Read the abdominal ECG
- (b) Separate the high resolution components and low resolution components
- (c) Compensate for the phase
- (d) Derive the noise component
- (e) Separate the noise from the original signal
- (f) Reconstruct the signal back
- (g) Repeat the construction iteratively.

The high resolution components are the components which are well defined in the abdominal signal. These are the maternal QRS wave having large amplitude and the fetal ECG whose amplitudes are much smaller than maternal ECG. The low resolution components are the components which do not directly contribute to the fetal ECG or maternal ECG.

### 2.2 Material

The testing of the algorithm 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 verification of the algorithm only one channel of abdominal signals was used. The gestation period varies from 22 to 40 weeks. DAISY data and Physionet data have different sampling frequencies. The algorithm has been tested with both the data.

### 2.3 Fetal QRS Detection

The aim of the algorithm is to enhance the fetal ECG by suppressing the other components of the signal. The enhanced signal contains mostly fetal ECG and EMG noise. The proposed method detects fetal QRS waves by canceling the maternal ECG. Fetal ECG detection was done by improving signal to noise ratio (SNR) of fetal QRS complex to the other components of the signal using a nonlinear operator defined by equation 1. This reduces the maternal P and T waves. The operator is defined as follows.

$$\Psi = DS (DS-1) \quad (1)$$

where DS is the preprocessed and denoised signal obtained from the original abdominal ECG. Fig 2 (a) shows the abdominal signal to be analyzed and the maternal ECG recorded from thoracic region is shown in Fig 3(a). Fetal ECG can be extracted by direct application of blind source separation (BSS) (De Lathauwer L, De Moor B, and Vanderwalle J, 2000). However such methods fail to give precise extraction. In order to reduce the mothers ECG effects on extraction, mECG was eliminated by using two stage adaptive filtering. The reference signal taken is shown in Fig 3(b) which is the squared signal of the thoracic signal corresponding to mECG Fig 3(a). The advantage of this method is that the reference signal need not closely mimic the signal to be cancelled. If such a reference signal could be generated, than this method can be applied where only the mothers ECG is available. The adaptive filter used behaves as an exponential averager (Laguna P, Jane R, Meste et al, 1992). The output of the adaptive filter 1 is again adaptive filtered with  $(TECG)^2$  to obtain the signal shown in Fig 3(d). To obtain better results the adaptive filter design plays an important role. The selection of the step size of the adaptive filter is very important as the signal to be extracted is highly sensitive to the

step size. The resultant signal depends on the value for the constant of adaptation. The output 3(d) is applied to fECG detector and extracted fECG and mECG are shown in Fig 4(b) and 4(c). The signal quality is high enough to recognize fetal QRS complexes.

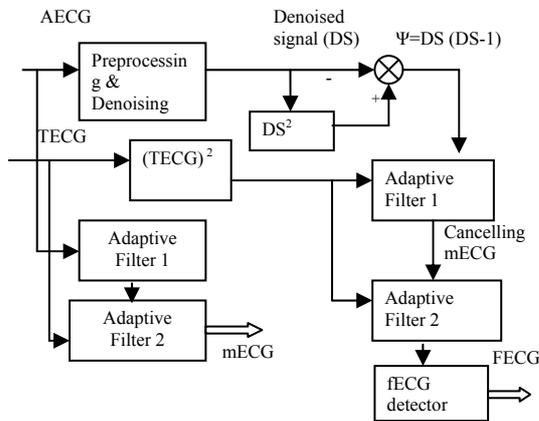


Figure 1: Block Diagram of the proposed algorithm.

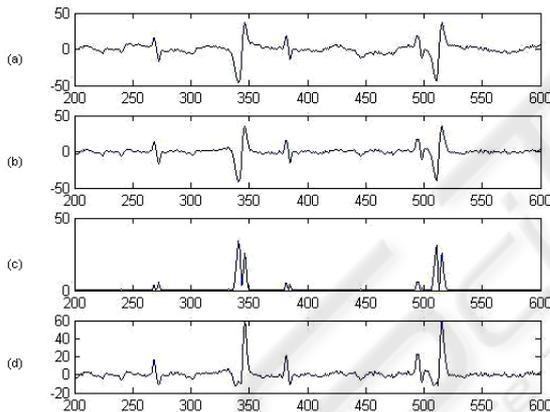


Figure 2: (a)Original abdominal ECG (b) Preprocessed signal (c) Square of preprocessed signal (d) signal obtained after adding b and c.

### 3 RESULTS

The proposed algorithm was assessed by using real composite signal comprising of mECG and fECG. The noise is due to mother's electromyogram activity. The performance of the method is seen from the extracted waveforms centering on R wave peak. The P and T waves can also be seen. Fig 4 gives the extracted fECG and mECG. Fig 6 shows the power spectrum of the original signal and the extracted fECG and mECG. The results show that the P, R and T waves are clearly visible in the

extracted signals. Two cases have been studied. Case 1 has a sampling rate of 250 samples/sec and case 2 has a sampling rate of 1000 samples/sec. Fig 4a shows the results for case 1 and Fig 5b shows the results for case 2.

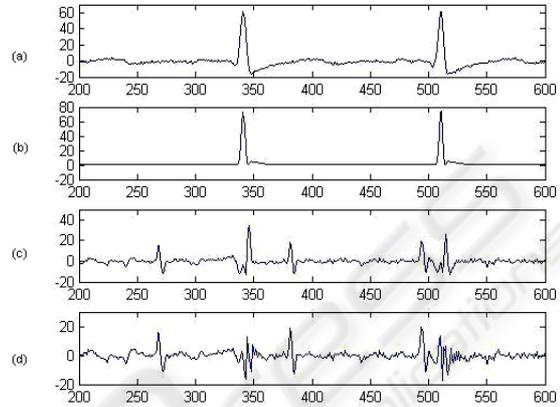


Figure 3: (a) Thoracic ECG (b) square of Thoracic ECG (c) Output of Adaptive filter 1 (d) Output of Adaptive filter 2.

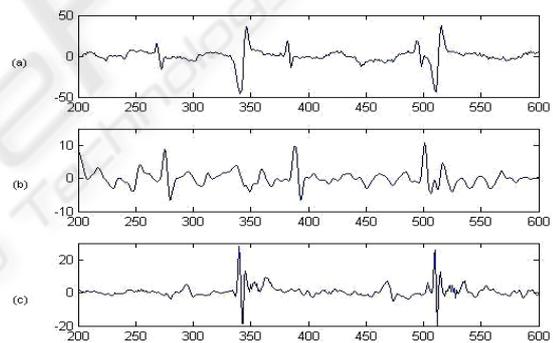


Figure 4: (a) Original abdominal ECG of patient 1 (b) Extracted fECG (c) Extracted mECG.

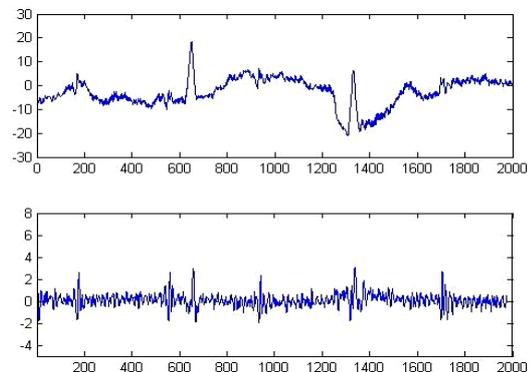


Figure 5: (a) Original abdominal ECG of patient 2 (b) Extracted fECG.

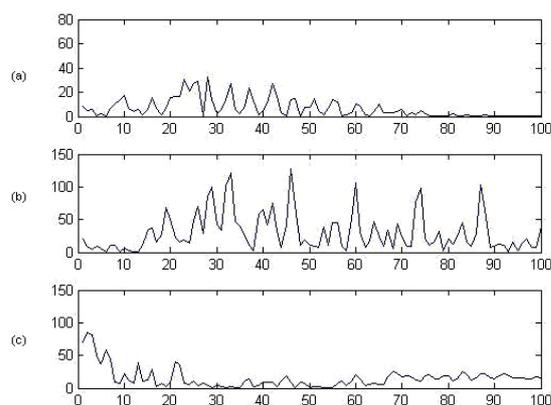


Figure 6: Power spectrum of (a) Original Abdominal ECG (b) Extracted fECG (c) Extracted mECG.

## 4 CONCLUSIONS

Fetal ECG extraction without disturbing the morphology is a difficult task. The limitations of conventional methods led to the design of this extraction system which improves 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 400 samples is taken for patient 1 and 2000 samples for patient 2, to illustrate the effectiveness of the algorithm. In this frame, there are both overlapping and non-overlapping between maternal and 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 that the visual quality of the extracted fECG is much better. The advantage of this method is that the reference signal need not closely mimic the signal to be cancelled. The algorithm was able to reveal complete fetal ECG such as QRS complex, its shape and duration. This also allows for beat-to-beat detection of the fetal R waves. This feature allows us to investigate fetal heart rate fluctuations. This feature of the algorithm can be used in early stages of pregnancy. Consequently, it is possible to understand the fetal heart rate fluctuations as a function of gestational time. The algorithm was able to overcome noise due to sources such as maternal muscle activity, uterine contractions, and external electrical interference.

## ACKNOWLEDGEMENTS

The authors would like to thank Prof. M. Ramachandran, Director, BITS, Pilani-Dubai for his constant encouragement and support. We would also like to thank Physionet.org and SISTA/DAISY for the fetal ECG data.

## REFERENCES

- Bergveld P. and Meijer J. H., 1981, "A new technique for the suppression of the MECG", *IEEE Trans. Biomed. Eng.*, 28, 348-354
- Callaerts D., De Moor B., Vanderwalle J. and Sansen W., 1990, "Comparison of SVD methods to extract the foetal electrocardiogram from cutaneous electrode signals", *Med. Biol. Eng. & Comput.*, 28, 217-224
- De Lathauwer L., De Moor D. and Vanderwalle J., 2000, "Fetal electrocardiogram extraction by blind source subspace separation", *IEEE Trans. Biomed. Eng.*, vol 47, No 5, pp. 567-572
- Fukushima T., Flores C. A., Hon E.H., Davidson E.C., Jr., 1985, "Limitations of autocorrelation in fetal heart rate monitoring", *Am J Obstet. Gynecol.*; 153(6):685-92
- Goddard B. A., 1996, "A clinical fetal electrocardiograph", *Med. Biol. Eng.*, vol 4, pp 159-167
- Jenkins H. M. L., 1986, "Technical progress in fetal electrocardiography – a review", *J Perinatal. Med.*, 14, 365-370
- Kotas M., 2007, "Projective filtering of time aligned beats for foetal ECG extraction", *Bulletin of Polish Academy of Sciences*, vol 55, No 4
- Laguna P., Jane R., Meste O et al, 1992, "Adaptive filter for event related bioelectric signals using an impulse correlated reference input: comparison with signal averaging techniques", *IEEE Trans. Biomed. Eng.*, 39(10):1032-44
- Mazzeo J. R., 1994, "Non invasive fetal electrocardiography", *Med. Prog. Technol.*, 20
- Prasad D. V., Swarnalatha R., 2007, "A new method to detect subtle changes in ECG", *WACBE World Congress on Bioengineering, Bangkok, Thailand.*
- Symonds E. M., Sahota D. and Chang A., 2001, "Fetal electrocardiography", London, Imperial College press.
- Widrow B. et al, 1975, "Adaptive noise canceling: principles and the applications", *Proc. IEEE*, 63:1692-1716