# Comparison of Algorithms for Fetal ECG Extraction

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***Abstract*— Electrocardiogram (ECG) is a valuable technique that has been in use for over a century. The analysis of fetal ECG signal has always been an interesting topic in the field of signal processing. The presence of noises in the ECG signal causes distortion in the signal morphology. While analyzing the fetal ECG this distortion of the signal is much more severe as the fetal ECG is much weaker than the adult ECG The work compares the method of projective filtering for fetal ECG extraction with a simple FIR filter based genetic algorithm for fetal ECG extraction. The work finds out that the genetic algorithm based FIR filter is more effective when multichannel signals are considered and PFTAB combined with NMF is effective when single channel signals are considered.**

*Keywords*— **Abdominal ECG, Extraction, Enhancement, Fetal ECG, Genetic algorithm**

## I. Introduction

The study of the electrical activity of the heart is known as electrocardiography. The electrocardiogram (ECG) is a graphical technique used to accurately record the cardiac cycle. It is used for recording the functional activity of heart. The method of recording fetal ECG from mother's body without direct contact with the fetus is called the non invasive method. The fetal ECG signal is often corrupted with various noises like Baseline wander, 50 or 60 Hz power line interference, electromyogram etc. Out of this baseline wandering and power line interference are the most significant and it can affect ECG signal analysis strongly. A lot of research are going on in the field for FECG recording and analysis. The non invasive methods are based on the signals from the maternal abdominal walls. These maternal abdominal signals are composed of maternal electrocardiogram trace, fetal electrocardiogram trace and various noises [1]. An efficient algorithm for fetal ECG extraction should effectively suppress all the signals other than the fetal ECG. One commonly used method is the wavelet transforms which involve the decomposition of the signal to wavelets [2,3].The wavelet transform as such decomposes a signal into two sub signals namely detail signal and approximation signal. Detail signal consists of the upper half of the frequency components and approximation signal consists of the lower half. The decomposition is applied on the approximation signal in order to get the second detail and the approximation signal. Another method is the independent component analysis which separates the maternal ECG and the fetal ECG [4,5,6,7]. The independent component analysis (ICA) is a method used for finding out the underlying factors or components multivariate statistical data. The limitation of ICA is that the statistical modeling of the probability density function is very challenging. Neural network approach is also a widely researched method used for extracting fetal ECG effectively [8,9,10]. But they suffer from the problems of bad generalization capability. Some of the other techniques commonly used for fetal ECG extraction are based on adaptive filtering [11,12] and blind source extraction [13,14]. The method of adaptive filtering combined with genetic algorithm is a less researched approach. The work aims in finding an effective algorithm for fetal ECG extraction using the approach and aims in higher accuracy of the fetal ECG extracted.

## II. Methodology

### A. *Projective Filtering of Time Aligned ECG Beats*

The abdominal electrocardiogram (AECG) signals used in this algorithm were obtained from the Physio Net noninvasive fetal ECG database available in the website [15]. The filtering techniques are primarily used for the pre-processing of the signal. The removal of baseline wander is necessary for minimizing changes in beat morphology that do not have cardiac origin. The frequency content of baseline wander is usually in the range below 0.5 Hz. The power line interference occurs at 50Hz frequency. Therefore a filter having the first cut-off frequency at 5Hz will enable in effective suppression of the low frequency base line wander. Also a stop band between 45Hz and 55Hz results in the removal of power line interference. The sampling frequency of the filter is 500Hz and it had multiple notches every 50Hz. The presence of multiple notches located every 50Hz helps in suppression of the low frequency base line wander.

The algorithm used for fetal ECG extraction from composite maternal abdominal signal is Projective filtering of time aligned beats. The output of the pre-processing stage undergoes projective filtering. The initial step of this operation makes use of the following techniques: linear filtering for low frequency noise suppression, QRS complex detection and cross-correlation function based synchronization of the detected complexes. The operation will produce a set of fiducial marks $\{r_k \mid k = 1, 2, \ldots, K + 1\}$ corresponding to the same position within the respective detected QRS complexes. The fiducial marks obtained are applied to projective filtering[16]. This is done in order to enhance the maternal ECG by suppressing the other components of the signal. Subtracting this signal from original signal leads to maternal ECG suppression, and this way to fetal ECG extraction. The enhanced signal contains mostly the maternal ECG and the fetal ECG. The main ideas behind the projective filtering can be summarized as follows:

1. Reconstruction of the state-space representation of the observed noisy signal is achieved by application of the Takens embedding operation. A point in the space constructed is a vector:

$x(n) = [x(n), x(n + \tau), \ldots, x(n + (m - 1)\tau)]T$ (1)

here $x(n)$ is the processed one-dimensional signal, $\tau$ is the time lag (following [16] $\tau = 1$ is applied), m is the embedding dimension.

2. The learning phase of the method consists in application of the principal component analysis to the construction of the local signal subspaces (LSS) for each position *j* within a beat.

3. The processing phase is defined by projecting individual trajectory points into the corresponding signal subspaces. Later these projected points are converted back to the one dimensional signal. Projective filtering operate in a block wise manner, on the signal segments of assumed length, and it should be sufficiently high in order to enable effective accomplishment of the first, learning phase of the method. The parameter K is equal to the number of ECG beats in a segment. An alternative one is based on specifying the required number K. In both of the cases, when longer ECG records are to be processed, it should be divided to successive segments according to the approach chosen. For the construction of local signal subspace the beats are stored in a matrix. The time alignment of beats helps in easy determination of the local signal subspace. The algorithm is effective for extracting the low amplitude fetal ECG traces from the maternal abdominal signal.

After successful extraction of the fetal ECG, we obtain the fetal ECG signal which is corrupted by wide-band EMG and some low frequency contaminations. The application of normalised matched filtering (NMF) allows for effective suppression of the EMG contaminations. Therefore, we process the extracted FECG signal to enhance the QRS complexes. A method called normalized matched filtering is used in this stage. Here the pre filtered input signal is fed to a matched filter and normalization of the output of the matched filter is done [17,18]. A template is required for doing the matched filtering. After selecting the suitable template, filtering of the template is done and for this the filter used in the first stage is itself used. After such an enhancement of the signal, the typical ECG waves are better visible. This is done in order for better R peak detection in the fetal electrocardiogram.

### B. *GA Based Adaptive Filter*

The input signal is taken from the MIT/BIH Database. The algorithm has two inputs. The thoracic signal consisting of the maternal signal alone is the original input and the abdominal signal consisting of the deformed version of the maternal signal, the fetal signal and the noises is the reference signal. Therefore, the abdominal signal can be expressed as the sum of a deformed version of the maternal ECG, and the noisy version of the fetal ECG. A combination of least mean square algorithm, adaptive filtering techniques and genetic algorithm is used in the work. In the LMS algorithm the thoracic signal is used as the reference signal. The adaptive FIR filter estimate the desired abdominal maternal ECG signal. By using the genetic algorithm, the best set of adaptive filter coefficients are found, therefore adaptive filter response converges into global extremum [19].The initial population is made up of binary chromosomes with the size of 1*20 and the number of initial population is 50 members. The chromosomes produced identify the number and type of $W$'s extraction of fetal ECG using Adaptive Filters and this will be done for each $W$, and the mean square error is calculated. In the evaluation stage the equivalent $W$'s with least MSE will be saved for the next iteration, and this process is continued until iteration=50. Thus the best $W$'s are selected[19]. A genetic algorithm is a programming technique that mimics biological evolution as a problem-solving strategy [20]. The evolution will start from a population of randomly generated individuals, with the population of each iteration called a generation. In each of the generation, the fitness of every individual in the population is evaluated and the fitness is usually the value of the objective function in the optimization problem being solved. The more fit individuals are selected from the current population, and each of the individual's genome is modified to form a new generation. The new generations of the candidate solution are then used in the next iteration of the algorithm. The algorithm will get terminated when either a maximum number of generations has been produced, or when a satisfactory fitness level has been reached for the population.

## III. RESULTS AND DISCUSSIONS

The abdominal recording is an input signal taken from the mother's abdomen using the electrodes. Fig. 1 shows the abdominal signal from the maternal abdominal region. The MIT-BIH database is used for the input signal. It is a combination of different biological signals such as Maternal Electrocardiogram (MECG), Fetal Electrocardiogram (FECG), various interferences such as baseline wandering and power line interference and these signals overlaps with FECG making it invisible. For reducing the unwanted noisy signals the pre-processing stage is used.

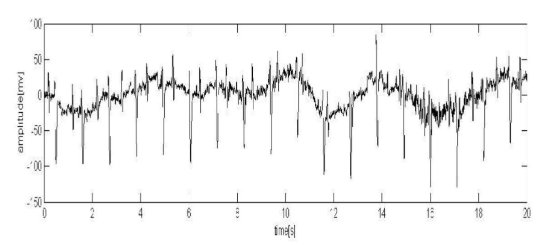


Fig. 1 The Maternal Abdominal signal

The abdominal signal is further processed and the noises are removed using notch filter. The pre-processing is done for extracting the maternal abdominal signal with fewer noises. It is a stable filter which require no feedback and whose response is of finite duration, as it settle to zero in finite time. This is the first step towards improving the signal and reducing the noises such as power line interference and baseline wandering. The IIR notch filter results in infinite duration, it is unstable because it has a feedback.

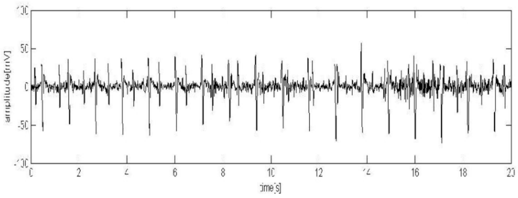

Fig. 2 The Pre-processed signal

For proper extraction of fetal ECG it is important that both power line interference and base line wandering is completely removed. Therefore in order to remove the baseline wandering of the ECG signal correctly a filter having multiple notches every 50Hz is suitable. The filter is having multiple notches every 50 Hz and such a filter is more effective than that which is having a single notch. The Fig. 2 shows the pre-processed signal, after pre-processing the FECG signal is found to be overlapping with the MECG and the unwanted noises and they can be eliminated by suppressing the MECG. The filtered signal is applied to the step of maternal ECG suppression using projective filtering. In this stage initially the maternal QRS complexes are detected and the synchronisations of the beats are done. This step is followed by applying the signal for projective filtering. The fetal ECG extracted using the method of PFTAB is shown in the Fig. 3.

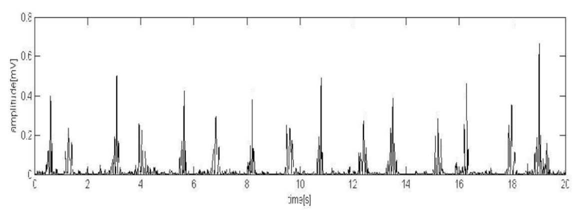

Fig. 3 The Fetal ECG traces

After extraction of the FECG signal, for proper detection of the QRS complexes and the removal of any other remaining noise residues it is necessary that the QRS complexes are enhanced. This process of QRS complex enhancement is done by the method of normalized matched filtering. The enhanced fetal ECG obtained using NMF is shown in the Fig. 4 below.

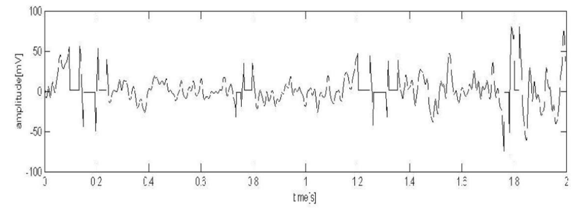

Fig. 4 Fetal ECG after enhancement

The input signal considered is the abdominal signal and thoracic signal. The abdominal signal consists of the maternal ECG, Fetal ECG and noises and the thoracic signal consists of the maternal ECG signal. The GA based Adaptive filter is found to obtain the Fetal ECG trace with good accuracy. The figure 5 shows the fetal ECG trace obtained using the genetic algorithm based FIR filter.

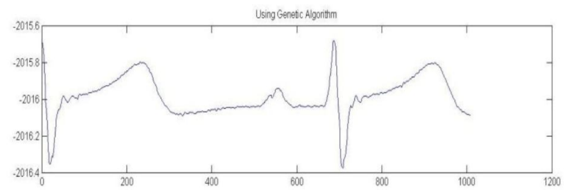


Fig. 5 Fetal ECG traces obtained using GA based adaptive filter

## IV. Conclusions

The Extraction of the fetal electrocardiogram from single channel signals and multi channel signals without disturbing its morphology is a compelling task. The method of projective filtering of time-aligned ECG beats appears to address this problem for single channel signal successfully. The method of GA based adaptive filter allow for effective extraction of signal from multichannel signals. Both the methods preserve the morphological content of the extracted signals not disturbed.

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