De-noising of Fetal ECG for Fetal Heart Rate Calculation and Variability Analysis

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***Abstract: - Fetal monitoring* is the way of checking the condition of unborn baby during labor and delivery by continuously *monitoring* his or her heart rate. A normal fetal heart rate (FHR) can reassure safe birth of the baby. Fetal monitoring techniques are broadly classified into invasive and non-invasive techniques. Non-invasive techniques are involves monitoring the fetus through mother's abdominal region. This can be done in all gestation weeks and during the delivery also. Abdominal ECG (AECG) is a composite ECG signal containing both mother's as well as fetal ECG. This paper presents an efficient technique to extract FECG from abdominal ECG. A modified Pan Tompkin's method is employed for the QRS detection. It involves series of filters and methods like band pass filter, derivative filter, squaring, integration and adaptive thresholding. Further heart rate of fetus and mother is calculated and heart rate variability analysis is done using detected R-peaks. The algorithm is tested on 5 different non-invasively recorded abdominal and direct FECG signals taken from MIT PhysioNet database and the results are obtained using MATLAB software. The performance of the QRS detector is evaluated using parameters like Sensitivity and Positive Prediction.**

***Keywords:* Fetal Monitoring, Non-invasive monitoring, ECG, Maternal ECG, Fetal ECG extraction, Fetal Heart Rate, QRS detection, Heart Rate Variability.**

I. INTRODUCTION

Fetal heart rate monitoring is the process of checking the condition of your baby during labor and delivery by monitoring his or her heart rate with special equipment. Fetal heart rate monitoring may help detect changes in the normal heart rate pattern during labor. If certain changes are detected, steps can be taken to help treat the underlying problem [1]. Birth defects can be minor or severe. They may affect appearance, organ function, and physical and mental development. Most birth defects are present within the first three months of pregnancy, when the organs are still forming. Fetal heart rate (FHR) was first introduced in the 17th century. It is an important parameter that can be monitored during pregnancy and/or labor; and in some cases the only available source of information [2].

Techniques to monitor the fetus through pregnancy are broadly classified into invasive and non-invasive methods. An invasive method involves probes or needles being inserted into the uterus which can be done from about 14 weeks gestation, and usually up to about 20 weeks. But which may be slightly more risky to the fetus. Electrocardiogram or called as ECG is one of the simplest and painless non-invasive diagnosis method to estimate the heart condition. Electrocardiography (ECG) provides more useful information about the fetal heart conditions such as the FHR with a better predictive value. Fetus cardiac waveform helps physicians to diagnose fetal heart arrhythmia such as Bradycardia, Tachycardia, Congenital heart disease, Asphyxia and Hypoxia [3]. Non-invasive techniques brings great amount of noise as the electrodes are placed on the mother's abdominal surface. These noises are called artifacts. In the measurement of ECG signals, there are four main types of interference and noise: power-line interference, electromyogram (EMG) noise, baseline drift interference, and electrode contact noise [4].

Numerous attempts have been made to detect the FECG in abdominal recordings. Those methods used either time domain signal processing or frequency domain or both. Different intelligent methods like neural networks, fuzzy logic systems, adaptive Neuro-fuzzy inference systems and genetic algorithms were also applied to extract the FECG signal from the MECG signal [1]. The fundamental objective of the paper is to implement an efficient technique to extract Fetal Electrocardiogram from composite Abdominal Electrocardiogram and develop an algorithm to detect QRS complex, R-peaks to calculate Fetal Heart Rate (FHR) and perform heart rate variability using MATLAB simulation software.

II. MATERIALS AND METHODS

For convenience, overall the system is divided into four stages: I. signal pre-processing of abdominal ECG to remove various artifacts. II. MQRS detection. III. FQRS detection IV. Heart rate calculation and variability analysis.

2.1 Signal Pre-processing

General frame-work of ECG preprocessing has two main parts; noise suppression and baseline estimation and correction. Power line (50/60 Hz) interference is also another source of noise in the ECG. Respiratory signal wanders between 0.15Hz and 0.5Hz frequencies [4]. A high pass filter can be designed to cut of the lower frequency components (the baseline wander). Power line interferences contains 60 Hz pickup (in U.S.) or 50 Hz pickup (in India) because of improper grounding. The typical amplitude of the power line interference can be as high as 50 percent of the peak-to-peak amplitude of the ECG signal. It lies in the ECG signal band

(0.05 Hz to 100 Hz). So, to obtain a reliable ECG signal it is very important to remove PLI [3].

In this paper, a band pass filter having cut off frequency range of 5-75 Hz is used to remove low frequency baseline wander, 50 Hz power line interference and other high frequency noises.

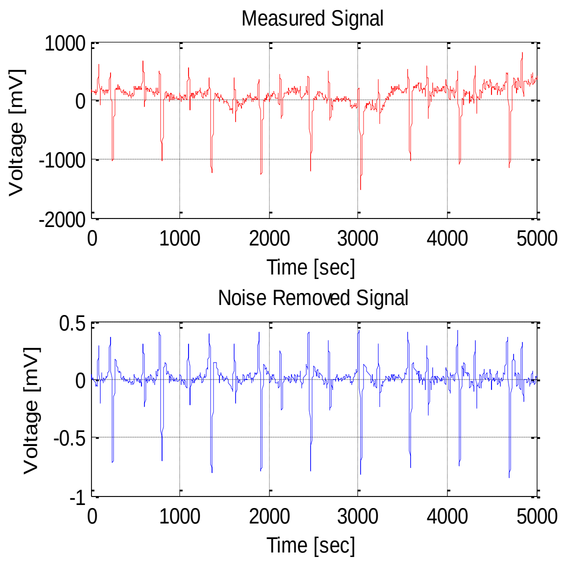

Figure-1 Measured AECG signal before after removing BW, PLI and HF noises

2.2 QRS Detection Strategy

A. MQRS Detection

The QRS complex is the most prominent waveform within the ECG signal with normal duration from 0.06s to 0.1s. It's shape, duration and time occurrence gives valuable information about the state of the heart. The possibility of maternal QRS and Fetal QRS overlaps both in time as well as frequency domain makes the detection a difficult task. Different QRS detection algorithms that are available in the literature are derivative based, template matching, gene based design, and wavelet based algorithms. The methods above may not be efficient in detecting FQRS complex because of the overlapping problem already mentioned [3]. In this paper a modified QRS detection algorithm based on Pan Tompkin's algorithm was optimized to reduce the number of false R-peak detections [5].

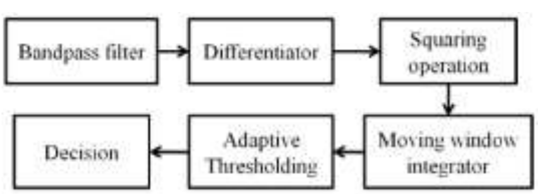

Figure-2 Steps involved in Pan Tompkin QRS detection algorithm[6]

After removing the artifacts from abdominal ECG signal using band pass filter, the next processing step is differentiation. A differentiator is nothing but a high pass filter. In this step, the slow varying P and T waves are attenuated the peak-to-peak R wave signal corresponding to the QRS complex is further enhanced as shown in figure-3

$$H(z) = (1/8\,T)\,(-z^{-2} - 2z^{-1} + 2z' + Z^{2})\ldots\ldots\ldots \quad (1)$$

After differentiation in the previous stage, point by point squaring of the signal is done to obtain all positive values thereby squaring the larger positive frequencies and minimizing the smaller frequencies as shown in Figure-

$$Y(nT) = [x(nT)^{2}] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

After squaring the signal, a moving average filter (MAF) is applied which is nothing but a simple low pass filter commonly used smoothing an array of sampled signal as shown in figure-3 . It takes M samples of input at a time and take the average of those M samples to produce a single output point [5]. At last the signal is subjected to an adpative threshold value to obtain signal and noise peaks [5]. The signal peaks are defined as those of the R waves while the noise peaks are the T waves, muscles noise etc. The average value of the maxima index is taken as the R signal peak. The threshold is automatically adjusted to float over the signal noise peaks as shown in figure-3. The signal peak is adjusted as per the amplitude of each record.

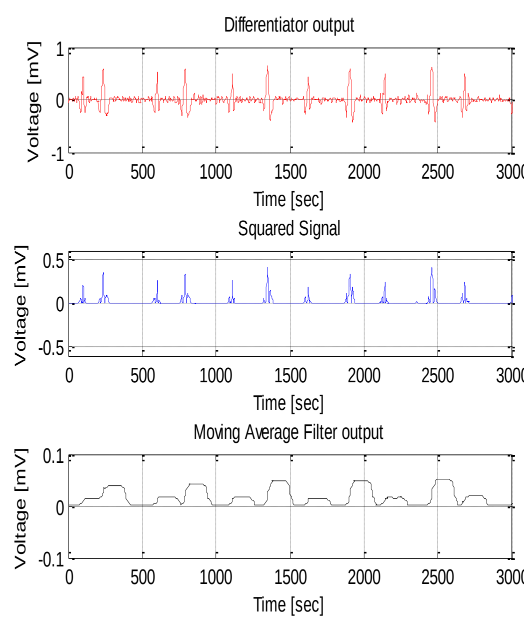

Figure-3 Output after Differentiation, Squaring and moving average filter

Noise_peak =0.1*Signal_peak; ……………………….(3)

Signal_peak = 0.6*Peak_value+0.4*Signal_peak; …..(4)

Noise_peak= 0.4*Peak_value + 0.6*Noise_peak; ……(5)

ATHD=Noise_peak+0.43*(Signal_peak-Noise_peak);.(6)

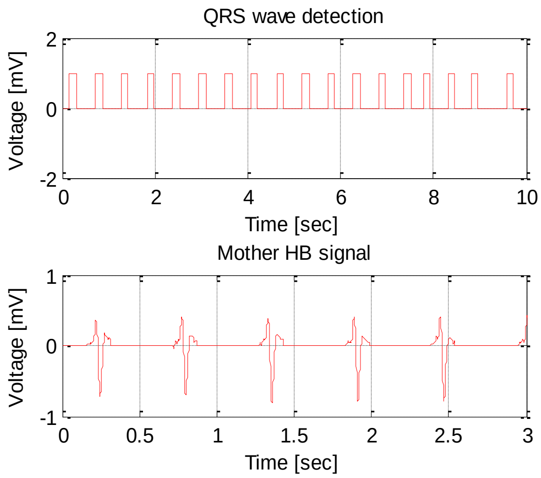

Figure 4- QRS complex detected after adaptive thresholding and extracted mother's heartbeat signal

B. FQRS Detection

Fetal ECG signal is obtained by subtracting mother ECG signal from abdominal ECG signal. Once the FECG signal is obtained, same steps as MQRS detection are applied to obtain Fetal QRS complex. The outputs of differentiator, squaring, moving average filter and adaptive threshold are shown in figure-5.

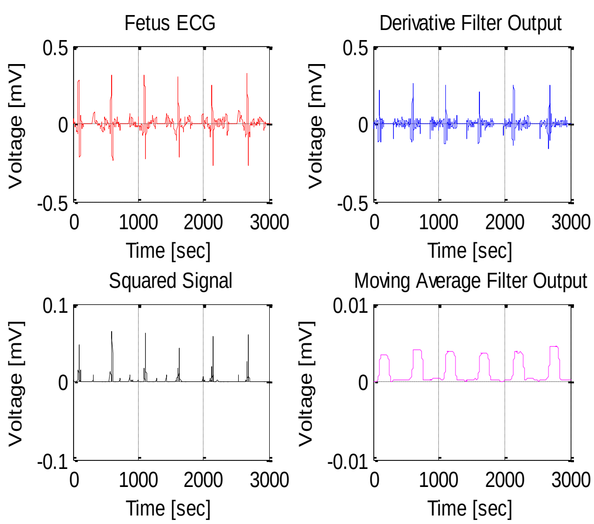

Figure 5- Fetal ECG extracted from composite abdominal ECG, Output after Differentiation, Squaring and moving average filter

2.3 FHR Calculation and FHRV Analysis

Generally the fetal heart rate falls within the range of 120 to 160 bpm during normal condition [3]. Adaptive thresholding will detect the dominant QRS peaks in Fetal ECG signal. These dominant peaks correspond to the heart beats.

$$FHR = \frac{Number\ of\ beats\ counted}{Duration\ of\ signal\ in\ minute} BPM \ .... (7)$$

Heart Rate Variability, has been an important screening tool for diagnostic purposes, is the physiological phenomenon that reveals the state cases of having non-consistent R-R durations/intervals over a number of cardiac cycles per unit time. First the intervals between successive R-peaks are determined. If the peak detected is the first peak, the R-R interval is made zero to remove first peak duration count and for the rest peak points the distance between two peaks will be equal to the new index of peak detection point minus the old index of peak detection point measured in time until all the peak detection is over [3].

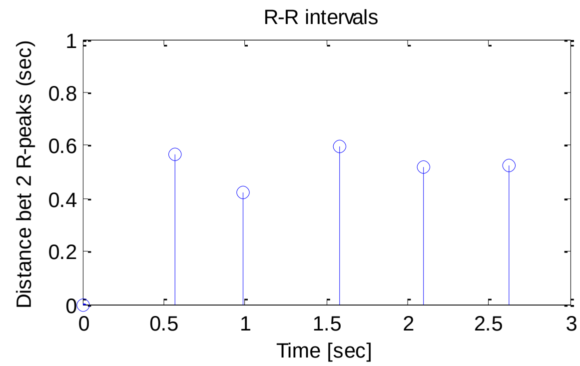

Figure-6 Heart Rate Variability Results (R-R interval)

III. RESULTS AND DISCUSSIONS

The aim of this paper was to extract fetal electrocardiogram signal from non-invasively taken composite abdominal, calculate fetal heart rate and heart rate variability analysis. Time domain parameters like mean RR interval, the mean HR, and the instantaneous low and high heart rates are calculated. Table-1 shows the MHR, FHR, min HR, max HR and mean HR for 5 different non-invasive ECG databases.

$$Max\ HR = \frac{60}{Shortest\ R - R\ length(sec)} \ ... ... (8)$$

$$Min\ HR = \frac{60}{Longest\ R - R\ length(sec)} \ ... ... (9)$$

Table-1 FHR, MHR calculation and Heart Rate Variability Analysis

ECG	MHR (BPM)	FHR (BPM)	HRV Analysis	
			Max HR	Min HR
1.	83.78	136.65	197.36	109.48
2.	78.79	143.63	172.91	80.97
3.	72.81	128.67	191.69	106.00
4.	86.77	130.66	196.07	75.66
5.	101.74	112.71	141.17	101.18

3.1 Performance Analysis of the QRS Detector

Performance analysis of the QRS detector is done using parameters like sensitivity (SE) and positive prediction (PP) which are defined as,

$$SE\ (\%) = \frac{TP}{TP+FN} * 100 \ .... (10)$$

$$PP(\%) = \frac{TP}{TP + FP} * 100 \ldots\ldots\ldots\ldots\ldots (11)$$

Where, FP (False Positive) are peaks detected by the algorithm when the doctor has not scored one. FN (False negative) are peaks missed by the algorithm when the doctor has scored one. TP (True Positive) is when both annotations match with each other.

Table-2 performance analysis of the QRS detector using the above mentioned parameters showing an average sensitivity of 85.72 and positive prediction rate of 90.65 for the 5 abdominal signals from PhysioNet Abdominal and Direct Fetal ECG used in this paper.

Table-2 Performance Analysis Results

ECG	TP	FP	FN	SE (%)	PP (%)
1.	6	1	1	85.72	85.72
2.	5	0	2	71.42	100
3.	5	0	2	71.42	100
4.	9	0	2	81.81	81.81
5.	6	1	1	85.72	85.72

IV. CONCLUSION AND FUTURE SCOPE

In this study, simple and effective scheme is developed using signal processing of non-invasive ECG waveforms for the heart rate monitoring of unborn baby. The appropriate filtering schemes along modified Pan Tompkins QRS detection based approach has resulted in efficient detection of QRS complexes and the R peaks in fetal ECG signal. Performance analysis is carried out using parameters like Sensitivity and Positive Prediction. Application of this method on different datasets may be useful for further validation and also investigate potential clinical implications. This method is applicable only for the single fetus signal from mother's abdomen. In future algorithms can be modified in some way to extract twin's fetal signal as well. Also heart rate variability analysis can be done to monitor fetal autonomic nervous system.

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