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Extraction of FECG from Non-Invasive AECG signal for Fetal Heart Rate Calculation

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Abstract- A Non-Invasive Fetal Electrocardiogram (FECG) is an effective diagnostic tool for determining health status of the fetus. Abdominal Electrocardiogram (AECG) is a composite ECG signal that consist of both fetal as well as maternal ECG (MECG). This paper presents an efficient technique to extract the FECG signal from AECG by means of different Time – Frequency localized transforms and algorithms. A combination of Band Pass Filter , Hilbert Transform and Adaptive Thresholding algorithm has been used for detecting FECG QRS complexes. Further an enhancement of FECG signal is done using Wavelet De-noising and Fetal Heart Rate (FHR) is calculated. This algorithm is performed using MATLAB simulation software and tested on 5 non-invasively recorded abdominal and direct FECG signals taken from MIT Physionet database.

***Keywords*:** ECG, Non-Invasive monitoring, Maternal ECG, Pre-processing, Hilbert Transform, Wavelet De-noising, QRS detection, FECG extraction, FHR.

I. INTRODUCTION

Heart defects are among the most common birth defects and the leading cause of birth defect related deaths. The defect may be so slight that the baby appears healthy for many years after birth, or so severe that its life is in immediate danger. Congenital heart defects originate in early stages of pregnancy when the heart is forming and they can affect any of the parts or functions of the heart.[1] Techniques to monitor the fetus through pregnancy have been developed with the aim of providing sufficient information to enable the clinician to diagnose fetal well-being, characterize development and detect abnormality. This is called antepartum fetal monitoring. On the other hand Intrapartum monitoring is performed during labour and typically this takes place in a hospital environment where monitoring can be continuous and rapid intervention is feasible. These techniques 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. Compared to other procedures used to assess the fetal health including CTG, 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 [2].

Since in non-invasive method the recording electrodes are placed on the abdomen region of the pregnant woman, they record both the maternal electrocardiogram (MECG) and the FECG, also in this case it may contain a relatively large amount of noise [3]. The main sources of noise in the field of extraction of FECG include the maternal electromyogram (EMG) which has a wide frequency range, 50/60Hz power line interference, baseline wander and random electronic noise.

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 [4]. 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) using MATLAB simulation software.

II. ARTIFACTS OF ECG SIGNAL

Electrocardiograph artifacts are defined as ECG abnormalities, which are a measurement of cardiac potentials on the body surface and are not related to electrical activity of the heart. In practical situations, ECG recordings are often contaminated by various sources [5]. The two major artifacts are:

A. Baseline Wander (BW): This is a very common noise in Electrocardiogram recordings. Is caused by variable electrode-skin impedance, patients' movements and breath. Baseline wander have frequency greater than 1Hz.
B. Power Line Interference (PLI): Power line interferences contains 60 Hz pickup (in U.S.) or 50 Hz pickup (in India) because of improper grounding. It is indicated as an impulse or spike at 60 Hz/50 Hz harmonics, and will appear as additional spikes at integral multiples of the fundamental frequency. Its frequency content is 60 Hz/50 Hz and its harmonics, amplitude is up to 50 percent of peak-to-peak ECG signal amplitude. It's high magnitude interference can bury and degrade low voltage (power) signals like the FECG. There are different ways in which the interference enters in the recordings:
C.
   i. Magnetic Induction
   ii. Displacement Currents
   iii. Unbalanced electrodes impedances which give rise to the "potential divider effect", i.e. common mode interference is converted into differential mode interference voltage which is amplified [6,7].

Other non-cardiac sources include the electronic noise introduced by amplifiers, etc., the myoelectric crosstalk from abdominal muscles and, in particular during labor, the uterine contractions [7].

III. METHODOLODY

The implemented scheme is comprised of three main steps. First step is signal pre-processing of abdominal ECG aiming to remove Baseline Wander (BW), Power Line Interference (PLI) and other high frequency noises. Second step incorporates the extraction of FECG from abdominal ECG followed by it's enhancement. The last step is fetal QRS complex detection and heart rate calculation.

Signal Pre-Processing
It is important that the ECG signal used by physicians for identification of physiological and pathological phenomena should have a good quality. In abdominal ECG (AECG) the Maternal ECG (MECG) will be considered as a noise in Fetal ECG (FECG) analysis stage and the fetal will act as a noise during MECG processing. So, in each case an appropriate de-noising algorithms are required to preserve and emphasis one of them and to suppress the other one. This chapter explains removal of the artifacts that are present in the ECG signal.

Removal of Baseline Wander (BW)
Until now various methods have been already proposed for baseline wander correction. Infinite Impulse Response (IIR) filters are used by many of the researchers to remove baseline wander form ECG signal [6]. However IIR filters are easy to implement but they are not suitable for highly nonlinear data in the entire ECG range because of their increased memory and high filtering time constraints. Baseline corresponds to the low frequency components of the signal. Generally baseline correction is estimation of baseline drift and subtraction from the original signal for correction. In this paper the baseline wander has been removed using polynomial fitting which is nothing but a parabolic filter. Polynomial fitting is a method to remove baseline by fitting polynomials to representative points in the ECG signal. The method is used to remove higher frequency baseline noise and preserve low frequency heart information. Fig-1 shows the abdominal ECG signal with and without baseline wander.

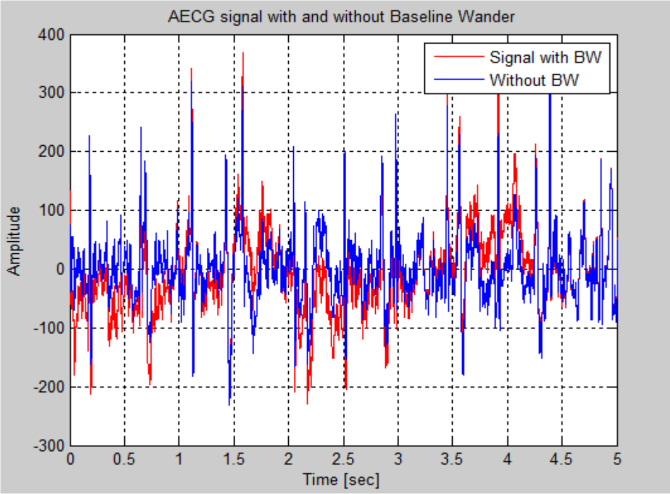

Fig-1: a) AECG signal taken from Physionet Database with and without Baseline Wander

Removal of power Line Interference (PLI)
Power line interferences contains 60 Hz pickup (in U.S.) or 50 Hz pickup (in India) because of improper grounding. 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. Various FIR and IIR filters have already been used for this purpose [9, 10]. But due to non-stationary nature of the ECG signals it is not efficient to apply these filters with fixed coefficients. Adaptive least-mean-square (LMS) and adaptive recursive-least-square filtering techniques are also the well-known techniques that are available for processing and analysis of the non-stationary ECG signal with better performance. But adjustment of step size, computational complexity and stability are the dis-advantages. In this paper we have used Notch filter to remove PLI because of its ability to select a specific frequency and attenuate and eliminate it from the input spectrum without changing the amplitude of other frequencies. An IIR notch filter offers the very best of what IIR filters have to offer; very high attenuation with a low order. Signal after power line interference is shown in Fig-2.

Removal of other high frequency noises
Filters like Butterworth filter and wavelet Transform have been used because of their high signal to noise ratio (SNR) and high accuracy. Butterworth filters are fast and simple

to use. Since they are frequency-based, the effect of filtering can be easily understood and predicted. Wavelet transform is commonly used as an effective signal de-noising tool mainly due to its sparsity, locality and multiresolution nature. The wavelet transform localizes the most important spatial and frequential features of a regular signal in a limited number of wavelet coefficients. Results of these filters on noisy ECG signal are demonstrated in Fig-2.

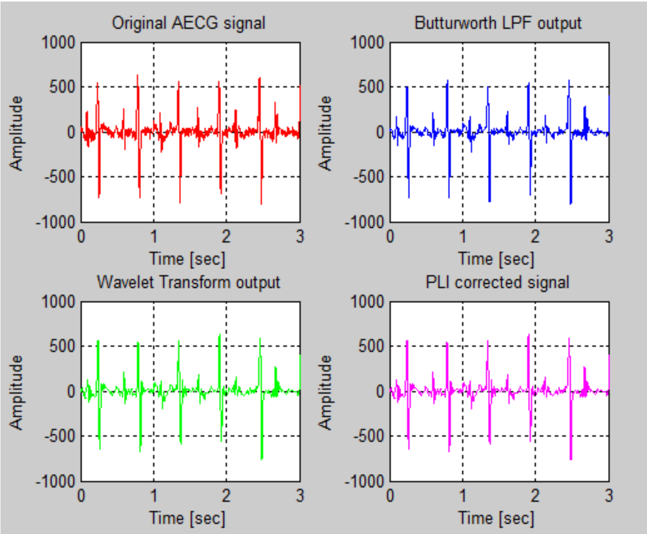

Fig-2: Pre-processing of Abdominal ECG

Fetal Electrocardiogram Extraction

For monitoring fetal heart rate (FHR), it is necessary to extract FECG from composite AECG signal. There are various methods for extraction which are classified with respect to the principle ideas of signal processing as threshold technique, spectral analysis, linear combinations, or weighted sums. So far, research and extensive works have been made in the area, developing better algorithms, upgrading existing methodologies, and improving detection techniques to reduce noise and acquire accurate FECG signals to obtain reliable information about the fetal state thus assuring fetal well-being during pregnancy period.

Fetal QRS detection

The QRS complex is the most prominent waveform within the ECG signal with normal duration from 0.06s to 0.1s representing the ventricular depolarization. It’s shape, duration and time occurrence provide valuable information about the current state of the heart. The possibility of maternal QRS (MQRS) and Fetal QRS (FQRS) overlaps bot in time as well as frequency domain makes the detection a challenging 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. In this paper FQRS detection has been done using combination of band pass filterimg, Hilbert transform and adaptive thresholding.[11]

The frequency components of the QRS complex are different for mother and fetus. The QRS duration cannot excced 120ms for adult and 80ms for the fetus. This leads to the relation between QRS duration as:

QRS (fetal) / QRS(adult) = 80ms/120ms = 0.67

The frequency ratio is therefore 1/0.67 = 1.5 Hz. Hence if the bandpass filter for MQRS has the passband between 18 – 35 Hz. the bandpass filter for FQRS should be designed having the passband between 27 – 53 Hz. This will emphasize the FQRS complex while reducing the MQRS complex.

The Hilbert transform is applied after band pass filter so that at the QRS points positive peaked signals will result. signals with negative amplitude are seen as positive peaks in the Hilbert transform envelope. After that adaptive thresholding is applied with two medical rules: two R-peaks closer than 0.2sec cannot exist in ECG, and time interval greater than 2sec cannot exist in ECG without R-peaks.[11] Fig-3 shows the band pass filtered FECG signal along with its Hilbert transform whereas the fetal QRS detected graph is shown in Fig.4

IV. RESULTS AND DISCUSSION

The aim of this paper was to extract fetal electrocardiogram signal from non-invasively taken composite abdominal ECG. Figure (1) and (2) presents the pre-processing done on the abdominal signal prior to extract FECG signal. Figure(3) shows the extracted and enhanced FECG along with its Hilbert transform. R- peaks detected using adaptive threshold and a search back algorithm are shown in Figure (4).

Heart Rate = Sampling Rate x 60 / R-R interval

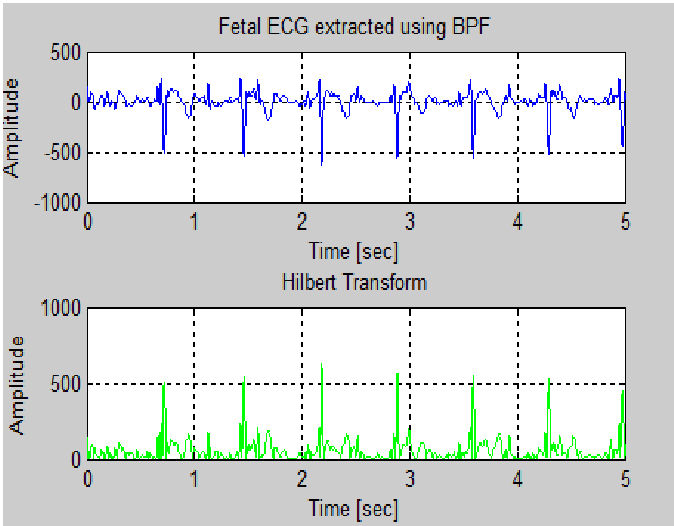

Fig-3. Extracted FECG signal and its Hilbert transform

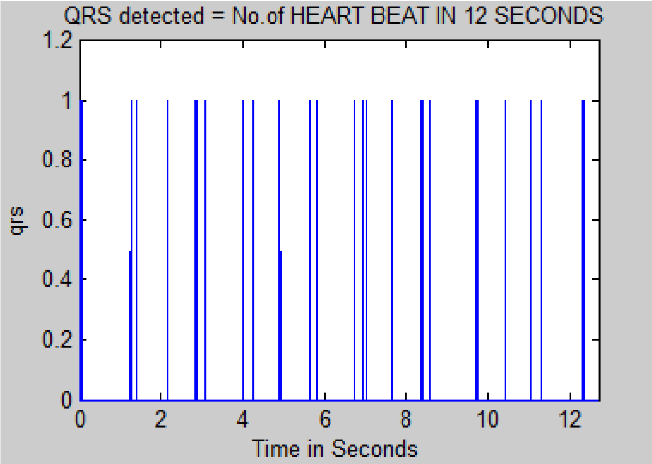

Fig-4. Detected Fetal QRS showing R-peaks

The methods and algorithms explained in chapters 1 to 3 are tested on the real ECG data taken from MIT/physionet database. This method can reasonably estimate the heart rate of the fetus for approximately 80% of the abdominal signal in the database which seems to be giving promising results. Table (1) summarizes the heart rate evaluated for all 5 databases.

TABLE-I

PERFORMANCE ANALYSIS OF PROPOSED METHOD ON PHYSIONET DATABSE

ECG Record	R01	R04	R07	R08	R10
Heart Rate	107.5	137	124.5	118	125.62

V. CONCLUSION AND FUTURE WORK

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 with the wavelet transform and Hilbert transform based approach has resulted in efficient detection of QRS complexes and the R peaks in fetal ECG signal. 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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