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ARTICLE

ISSUES AND CHALLENGES IN FETAL ELECTRO CARDIOGRAM EXTRACTION – REVIEW

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ABSTRACT

Background: *Early diagnosis of cardiac abnormalities paves way to efficient medications and precautions during delivery. The absolute benefit of cardiotocograpic surveillance is very less. Non-invasive electrocardiography reveals itself to be a very interesting method to obtain relevant information about the fetus state, assuring the well being of fetus at the time of pregnancy. The whole PQRST complex of fetal Electro Cardiogram (fECG) is essential to identify fetus distress. FECG and Fetal Heart Rate (FHR) are derived from maternal ECG, gives cardiac condition for the fetus. Location and number of electrodes plays an important role in maternal ECG acquisition and abdomen ECG acquisition. Many filtering methods, algorithms are employed to extract the fECG from abdomen ECG. Various filtering methods used to extract the fetal ECG from the abdomen and various electrode placements are reviewed.*

KEY WORDS
Fetal Electrocardiogram, Fetal Heart Rate, abdomen ECG, Fetal distress

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INTRODUCTION

Heart is developed in the fetus during very early stages of pregnancy. The most critical period of this development is in between three and seven weeks after fertilization. The heart begins to beat by the 22nd day of life and externally monitored using ultrasound imaging from 7th to 9 th week; although only unclear images are recordable. Fetus status during pregnancy is monitored using Echocardiography, Phonocardiography, Cardiotocography & Magnetocardiography. Now a day's routine Ultrasound scan gives prepartum diagnosis of congenital heart disease but Cardiac defects could not be identified with this modality. With this modality prepartum technology improvement is essential to know about additional information of fetal cardiac health. Ultra sound machines with higher than usual levels of ultrasound energy leads potential side effects on the fetus. Fetal movements affect viewing later planes and gives lower quality data and sound shadows can hinder the view if the fetal spine is not at the bottom of the scanned field.

Fetal heart rate identification technology is developed in the 19th century. Mid of 20 th century Fetal Heart Rate monitor (FHR) is developed to observe fetal heart sound. Though this is unreliable, fetal hypoxia is diagnosed by the help of continuous monitoring. Misinterpretation leads to painful and expensive Cesarean, depression and post operative pain to the Pregnant Woman. There is still little evidence that reductions in adverse outcomes are attributable to the use of FHR monitors. The non-invasive fetal ECG (NI-FECG) recorded on the maternal abdomen represents an alternative to Doppler ultrasound recording. NI-FECG provides a accurate estimation of FHR and information related to the electrical activity of the fetal heart from FECG morphology. The cardiac waveforms and beat-to-beat variability of the heart rate are not measurable in ultrasound imaging. Fetal cardiac status is diagnosed as early as eighteenth to twentieth week by the fetal ECG and MCG. However, the FECG is difficult to extract from the abdominal signal.

During delivery the fetus may get resuscitation problem. During resuscitation, fetal distress appears and the problem is identified only by predicting fetal Electrocardiogram signal rather than Ultrasound signal. The detection of the electrical activity of fetus heart helps in the reduction of the rate of fetal still birth by providing confidence measures for estimated cardiac signals. In this review, the fetal cardiac signal extraction methods and its challenging issues are discussed. This study, gives the information in improving the signal processing aspects in order to facilitate the extraction of fetal cardiac signals from abdomen ECG.

The information obtained from the World Health Organization is long-term trend in still birth: implications for developing countries states that late-fetal demise (28 completed weeks of gestation and over) considered as important for both the current and future trends. Even now the child mortality is still remaining as one of the objectives in health programmers', also attention is given to the fetal death. In many developed countries, late fetal death is higher than infant death. Among obstetricians and pediatricians, prenatal deaths are primary subject of concern and causes of ante partum stillbirths and preterm live births, led contribution towards more research initiatives. In developing countries like India and Nigeria during 21st century, late-fetal demise varies from 25 to perhaps 60 per 1000 births, also less than 1 in 250 viable fetuses die before birth, less than 1 in 10,000 mothers die from childbirth related issues and life expectancy at the time of birth is at least 80 years in the most favorable circumstances. A systematic literature review [3] on preterm delivery and small-for-gestational-age births performed from 1985 to 2002 based on maternal age, reviewed that older maternal age is associated with preterm birth. Rather than targeting mothers and newborn, prepare to focus on the unborn.

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In 1906 fetal electrocardiogram monitoring technique is proposed to get information about fetal heart status. Fetal ECG detection plays significant role in fetal abnormality detection during labor rather than heart beat and heart sound. Noninvasively, the fetal status is observed from the abdomen ECG of the pregnant woman. Abdomen ECG is acquired from the pregnant mother by placing electrodes on the abdomen. Abdomen ECG is the mixture of fetal ECG, maternal ECG, maternal muscular noise and power line interference. The accurate information obtained from fECG helps clinicians to make timely decision during labor. Maternal ECG is 10 times stronger than fetal ECG and coincides in time domain and frequency domain. MECG removal from abdomen ECG is the major challenge in extraction of FECG.

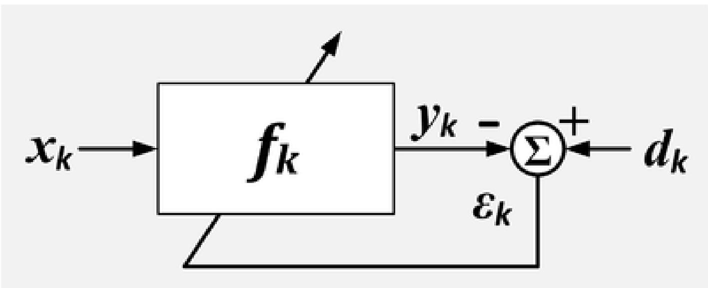
MATERIALS AND METHODS

In signal processing, filters plays vital role in reproducing original signal by removing unwanted signal. Rarely, the filtering technique completely or partially suppresses some features of the acquired signal. The main features of the filter are to remove unwanted frequencies, to suppress the interfering signals and decreases background noise. There are different bases of classification in filters and many filters are used to eliminate the maternal Electro Cardiogram (mECG) from the composite signal.

Adaptive filtering technique

The extrication of fetal ECG from the abdominal ECG is done by various filtering technique. The author reveals that the adaptive filtering and de-noising technique involve in cancelling of maternal ECG [17] from the abdominal ECG leads to enhance fetal ECG.

Adaptive filtering block diagram



k = sample number, x = reference input,
X = set of recent values of x, d = desired
input, ε = error output, f = filter impulse response

Fig. 1: Adaptive filtering block diagram.

The combination of Recursive Least Squares filter (RLS), Least Mean Square (LMS) algorithm results the high detection ability with accurate sensitivity and positive predictivity with one abdominal signal and one thoracic signal. Based on spatial filtering and adaptive rule, the author developed an algorithm [13] to extract fetal ECG (fECG) with the measurement of mean square error of fetal heart rate and root mean square error of fetal RR interval by validating 75 and 100 fECG datasets. The cardiac residues are obtained after maternal ECG (mECG) attenuation and adaptive fetal QRS beat insertion may not be at true QRS location. The windowing technique is also applied to eliminate the maternal ECG based on wavelet transform

Wavelet transform technique

The author states [20] fECG is extracted from the abdomen ECG based on wavelet analysis and LMS adaptive algorithm. Initially, Stationary Wavelet Transform (SWT) is applied to process abdominal signal and thoracic signal then wavelet co-efficient is obtained from the SWT are processed with LMS algorithm. Secondly, abdominal signal co-efficient as original input and co-efficient of thoracic signal as reference input, correlations are computed. Then, Spatially Selective Noise Filtration (SSNF) is employed to remove the noise component. Finally, inverse SWT is applied to obtain the fetal ECG signal and the performance is qualitatively checked for twenty simulated data and twelve clinical data by estimating Signal to Noise Ratio (SNR).

The author described a technique [6] to classify ECG signal into abnormal and normal class by employing Back Propagation Network (BPN), Feed forward network (FFN) and Multi Layered Perceptron (MLP) as neural network classifiers. In this, three classifier performances are measured in terms of sensitivity, positive predictivity and specificity. The performance result shows that MLP produced 100% accuracy than other two classifiers. The Kalman Filtering (KF) is also applied for the extraction of getting fetal ECG from the single channel abdomen ECG.

Kalman filtering technique

A synthetic dynamic ECG model within a KF framework is designed by the author to extract desired fetal ECG from a unique mixture of maternal and fetal ECGs and noise. The model [15] uses a single channel for the extraction of fetal ECG for long term monitoring. Performance of this system is examined with respect to the noise level, heart rate and amplitude ratio. The system is reliable for the detection of R-peak in a single pregnancy than the multiple pregnancies. Since, only a single electrode placed on the mother's abdomen for the acquisition of abdomen ECG is more convenient and portable device at home. The author designed an efficient extended KF method is to extract fECG from an ECG by using multiple electrodes in the robust tensor decomposition algorithm [9]. Here, preprocessing is carried out by low and high pass filter to remove base line wandering and higher frequency components. Various source separation techniques are applied after normalizing the preprocessed signal. Template subtraction, principal/independent component analysis, extended KF and a combination of a subset of these methods called FUSE are also employed to extract fECG signal. Then, Pan and Tompkins QRS detector is applied on all residues to detect fQRS signal and smoothest fetal Heart Rate (FHR) time selection. FUSE algorithm, the Q-T interval measurement requires different extraction condition though it is performed better than all the individual methods on the training set data. On the validation set, error scores obtained from two different events . Identification of fetal status with blind source separation is possible with various algorithms.

Blind source separation method

The author states that automatic identification of fECG sources performed by the block-on- line tracking algorithm. This algorithm is applied for both synthetic, real signals and it is tested successfully. The on-line-tracking algorithm performance is compatible with an embedded system integrated with OL-JADE (On-Line - Joint Diagonalization of Eigen matrices) based on OMAP L137 processor [4] though the signal quality is poor. The author [21] developed an Adaptive Neuro Fuzzy Inference system (ANFIS) for extricating the fECG from the abdominal ECG. Initially, infinite impulse response (IIR) zero phase filter and notch filters are applied to eliminate noise in the signal. After filtering the fECG the diagnosis of fetal status is performed by detecting fQRS complex then fetal heart rate. The better result is obtained from Sugeno inference method in Matlab tool.

Fetal QRS complex detection

The author reveals that the detection of fQRS is achieved with augmented principal component regression model (PCR) using multi lead template matching technique [8], where as in [10] impulse train, matched filter (energy of fRR), complementary filter (capture noise energy) are involved. The PCR model removes mECG successfully with accurate template identification. In this, the maternal ECG attenuation is performed by PQRST wave template subtraction and principal component analysis. Also, component values are obtained, a single QRS wave is detected by using a modified linear combiner, produces an output signal containing peaks in the respective locations of all FQRS complexes. The best fQRS estimation is achieved by different fQRS detectors [7] and accurate fetal RR is obtained with different abdominal ECGs. Better suppression of Electro Myo Gram (EMG) noise, QT estimation and mECG cancellation are achieved by better Signal to Noise Ratio (SNR) ratio. SNR of fECG is measured by matched filters semi-blind source separation, πCA algorithm and wavelet de-noising [18]. Accurate estimation of cardiac components, fECG subspace preservation is obtained with minimum MSE and RMSE. From this data, single or limit channel signals are not strong, it is highly dependent on matched filter template.

The author [14] describes that the extraction of maternal ECG using tensor decomposition is used . Additionally [9] [1] [12] fetal R-peak detection is performed by extended KF with 25 states in which ECG beat is modeled by 3 state equations (P, QRS and T). This method is useful for the estimation of mECG amplitude for each beat , applicable when mECG and fECG waves fully overlap. It is not applicable to pathological mECG, where mECG morphology varies significantly. The Mean Square Error of fetal Heart Rate, Root Mean Square for fetal RR interval is measured, the detection of QRS complex of the fetal is performed by echo state recurrent neural network [11] from two events. Finally, Performance of the system is improved by sacrificing speed. A robust algorithm is developed with frequency filtering and wavelet de-noising [2]. Maternal QRS time markers are applied to cancel mECG with adaptive cancellation technique. Adaptive cancellation of the mECG is performed using maternal QRS time markers obtained from the principal component containing the largest mECG. The fetal QRS time markers are determined with a local peak detection algorithm from the principal component. The derived fetal HR (event 4) and fetal RR (event 5) time series were compared to the reference values obtained from a scalp electrode signal. This algorithm scored 223.23 for Challenge event 4 and 19.34 for Challenge event 5, outperforming the sample algorithm.

The author [16] proposed a joint filter based and template matching strategy for identifying fQRS complexes from 4-channel non-invasive abdominal recordings at 100 Hz. The low pass zero phase digital filtering is applied in noise interference reduction. Attenuation of P and T waves, emphasizing of QRS complex is performed in two stages with high pass zero phase digital filters. Initially the detection and subtraction of the maternal QRS complexes is performed then fQRS complex is identified. The MSE of fHR and RMSE values of fetal R- R is observed for two different dataset. A method is developed to locate fQRS complex from the Physionet challenge [19]. In the preprocessing base line wandering and artifacts are eliminated using median filter, Notch filter and low pass filter. The maternal QRS complex is removed from the abdominal ECG with an adaptive linear filter. The location of fQRS complexes in the channel is done with the peak detector. The MSE and RMSE value of fetal R-R interval from two different sets are obtained and compared. In future the elimination of steep mother P and T waves is essential and other method is used to reconstruct the maternal QRS complex.

CONCLUSION

The features and limitations of various filtering techniques involved in extraction of fECG from the abdomen ECG are discussed . Signal to Noise Ratio, Mean Square Error, Root Mean Square Error, Sensitivity, Positive Predictivity and Specificity are the quantitative and qualitative parameter for analysis of identifying efficient filtering method used to diagnose fetal status of the pregnant women. Further investigation in these methodologies would be helpful to better understand the fetal status to avoid fetal still birth during pregnancy, the efficient method can be identified and applied in biomedical research & clinical diagnosis. In future, filtering technique limitations will be overcome in the design of Bio-signal Equipment especially for fECG extraction.

CONFLICT OF INTEREST
There is no conflict of interest.

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