A Survey on Fetal Electrocardiography

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Abstract

Fetal electrocardiogram (FECG) signal is a vital tool used for assessing the cardiac health of the developing fetus during the pregnancy. In this paper, various methods of recording of FECG signals are discussed. These signals, during recording, are contaminated with various types of artifacts. These artifacts and there source of generation is also explored in this paper. Techniques available to extract FECG signals with their advantages and disadvantages are discussed. Finally, the paper gives current issues in this field.

Keywords: Fetal ECG, Maternal ECG, Fetal heart rate, Cardiotocography, Magnetocardiography

1. Introduction

The heart is among the first organs developed in the fetus and its growth is considerable in early stages of pregnancy. The heart of the fetus is believed to begin beating by the 3rd week of the life. The fetal heart can be monitored externally after 7th to 9th week [1][2]. Electrocardiogram (ECG) is graphical representation of electrical activity of heart and it is characterized by a series of wave's viz., P, Q, R, S, T and sometimes U waves [3]. Fetal ECG (FECG) is similar to ECG and contains all the waves and is mainly due to the contraction and relaxation of the atria and ventricles caused by the propagation of the electrical activity through the heart [4]. These signals encounter various types of artifacts and thus prevent accurate diagnosis. Analysis and study of these artifacts is thus the primary requirement in the field of FECG [5]. Fetal heart rate (FHR) monitoring is a routine process to obtain significant information like heart rate, waveform, fetal development, fetal maturity, congenital heart disease etc about the fetal [6].

2. Measurement and Recording of FECG

FECG measurement techniques can be broadly classified in two different ways: direct method and indirect method [7]. In direct method, the electrode is passed through abdomen of mother and enters the womb to touch the fetus's head. This method is considered to provided pure FECG signal (with little interferences) but this may cause problems to both mother and fetus and unfortunately the method is invasive. Popular direct methods are scalp electrode (spiral, clip or suction) method [8][9].

Indirect way (non-invasive) of FECG measurement is extraction of FECG recorded on the mother's abdomen. Abdomen signal includes MECG (Mother ECG), FECG and noise signal.

The MECG signal is 5-20 times bigger in amplitude and always superimposes FECG. Noise signal includes muscular noise, electrodes noise, base lines noise and recording system noise. This method is now becoming more popular and mainly includes abdominal FECG, fetal phonocardiogram and ultra sound techniques [10][11]. The major problem in determining FHR from noninvasive abdominal ECGs is the accurate detection and timing of the fetal heartbeat occurrence. With good discrimination between the presence and absence of the fetal events, the time between beats, the instantaneous FHR can be easily computed.

The well-being of the fetal heart can also be monitored by following techniques:

Echocardiography [12] also known as cardiac echo / sonography of the heart and is based on standard ultrasound techniques. Echocardiography uses standard two-dimensional, three-dimensional, and Doppler ultrasound to create images of the heart.

Phonocardiography [13][14] is a diagnostic technique that creates a graphic registration of the heart sounds and murmurs produced by the contracting heart including its valves and associated great vessels. The phonocardiogram is obtained either with a chest microphone or with a miniature sensor in the tip of a small tubular instrument that is introduced via the blood vessels into one of the heart chambers.

Pulse Oximetry [15] is a noninvasive method for monitoring a person's oxygen saturation (SO2). This technique is safe, convenient, noninvasive, inexpensive and valuable for measuring oxygen saturation in clinical use. The technique is used to measure oxygen saturation of fetal blood as an adjunct to electronic fetal heart monitoring.

Cardiotocography (CTG)[16] is a technical means of recording the FHR and the uterine contractions during pregnancy. The machine used to perform the monitoring is called a cardiotocograph/ electronic fetal monitor (EFM) which simultaneously measures of FHR with an ultrasound transducer, and the uterine contractions with a pressure-sensitive transducer (called a tocodynamometer), for measuring the strength and frequency of uterine contractions [17].

Magnetocardiography (MCG) is a technique to measure the magnetic fields of cardiac signals using extremely sensitive devices such as the Superconducting Quantum Interference Device (SQUID) [18]. Sources of abnormal rhythms or arrhythmia may be located using MCG.

3. Factors Affecting Morphology of FECG Signals

During acquisition, FECG signal gets contaminated with various types of artifacts. These artifacts change the morphology of FECG signals and thus affect accurate diagnosis. The noises that affect the characteristics and shape of FECG are viz., power line interference, muscle contractions, respiration, skin resistance, instrumental noise, electromyography noise and most important mother ECG [19][20].

Powerline interference (PLI) consists of 50 Hz sinusoidal harmonics and is 50% of peak to peak of ECG.

Maternal Muscle noise is due to motion of legs and abdominal muscles and is picked from the reference pad on the maternal thigh. Uterus is the source of this kind of noise**.**

Electrode contact noise occurs due to the variation in the position of the heart with respect to the electrodes. Poor conductivity between electrodes also generates electrode contact noise.
Maternal ECG (MECG) is the most predominant abdominal FECG noise which is 5-20 times greater in magnitude than FECG signal. Filtering alone is not sufficient to extract FECG from MECG signals.
Ambient Noise is generated due to electromagnetic radiations.
Motion artifact is due to the movement, vibration or respiration of the subject**.**
Inherent noise is caused by the electronic equipment**.**

4. FECG Extraction Methods

PLI occurs through two mechanisms: capacitive and inductive coupling. Capacitive coupling is responsible for high frequency noise while inductive coupling introduces low frequency noise. It consists of 50- 60 Hz pickup and harmonics, which can be modeled as sinusoids and combination of sinusoids.. For this reason inductive coupling is the dominant mechanism of power line interference in electro cardiology. To limit the amount of power line interference, electrodes should be applied properly, that there are no loose wires, and all components have adequate shielding. Realistic noise models for ECG and FECG were developed by Reza et al. in 2006[21].

Karvaunis et al., employed complex wavelets (CWT), complex valued wavelet modulus maxima to detect the fetal R peaks and a heuristic set of rules based on adaptive threshold to extract FECG. The whole method was divided into four stages viz. Signal averaging, maternal QRS detection, fetal QRS extraction and fetal heart rate detection. The proposed method is able to extract the Maternal Heart Rate (MHR) signal, which can be useful for parallel monitoring of the mothers health [22].

FECG recovery based on adaptive filters is also found in literature. An Adaptive Nonlinear Cancelling (ANC) structure was implemented to extract FECG. In [23], the neural network models extracts maternal
abdominal component from a thoracic reference. The error reference constitutes the recovered fetal signal. The FIR neural network has proven to be a well suited technique for tracing a confident maternal
signal.

The least mean square (LMS) adaptive filter, being unable to track such rapidly varying nonstationarities, would essentially converge to the best least squares time invariant filter. For these signals, an adaptive time sequenced filter with rapidly varying impulse response was proposed and implemented by Ferrara et al. in [24]. The performance of these filters was found to superior to the LMS adaptive filter. The time sequenced approach requires knowledge of the location of the fetal ECG complexes. The time sequenced enhancing of the fetal ECG does not employ simple beat to beat averaging, so that individual variations in pulse shape and beat to beat interval are retained.

A Kalman filter with adaptive noise-covariance estimation has been developed by Vullings et. al. in 2011[25] and evaluated on a variety of ECG signals to assess whether the filter is capable of enhancing these signals, while at the same time preserving clinically relevant morphological variations in the ECG. The filter operates by sequentially estimating the measurement and process noise covariances and uses these covariances to estimate the Kalman gain and update the estimated ECG complexes

The method is based on a combination of singular value decomposition (SVD) and polynomial classifiers are proposed in [26]. Initially, SVD is used to extract an estimate of the maternal component from the composite abdominal signal by exploiting its quasi-periodic nature. The extracted maternal signal is then used along with the abdominal composite signal to isolate the FECG component using polynomial classifiers.

FECG signals extracted by polynomial networks were enhanced by wavelet transforms. Initially, the abdominal signal was suppressed by wavelet denoising algorithm then polynomial networks were used for fetal ECG extraction and again the extracted fetal ECG was denoised using wavelet denoising algorithm [27].

Five different heart rate detection techniques viz. simple threshold, band pass filtering, differentiation of local maxima and minima, autoregressive prediction and matched filters were explored by [27]. They found band pass filtering technique is optimal heart rate detection technique.

Following issues are still with FECG analysis:

- Accurate modeling of FECG signals.
- Robust method of extraction of FECG from MECG signals
- Unavailability of large database FECG signals
- Prediction of fetus growth on the basic of FECG
- Identification of diseases from FECG signals

5. Conclusion

The FECG signal represents the information about the FHR and the fetal condition. These waveforms contain important diagnostic information. Various methods of extraction and recording of these waves are explored in this paper. During acquisition, these waves encountered with various types of artifacts which changes the morphology of the signals, are also discussed. Methods to filter out the FECG from these artifacts are also described. Finally, existing issues with FECG are pointed out.

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