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A Finite Impulse Response (Fir) Adaptive Filtering Technique for the Monitoring Of Foetal Health and Condition

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ABSTRACT :*Foetal heart rate and its in-between beat variability are two vital biomedical recordings for ascertaining the foetal health and condition inside its maternal womb. Naturally, the foetal electrocardiographic signal which is generated by the foetal heart beat is mixed with the maternal electrocardiographic signal and other background noise arising from maternal muscle activity and foetal motion. The morphology of the foetal ECG describes the medical state of the foetus. This ECG must have to be extracted from the contaminating signals before it can be interpreted correctly and clinically. In this paper a design and implementation of an adaptive FIR filter that separates the foetal and maternal ECG signals, and a static FIR low pass filter that removes the high frequency noise from the foetal ECG is proposed. Matlab software is used to design and simulate the results.*

KEYWORDS:*FECG, MECG, ANC, Noise*

I. INTRODUCTION

Foetal electrocardiographic (FECG) signal is a waveform that is generated by foetal heart rate and its beat-to-beat variability. Similarly the maternal electrocardiographic (MECG) signal is a waveform that is generated by maternal heart rate and its beat-to-beat variability. The morphology of the FECG contains much clinical information regarding the health and condition of the foetus. Incidentally, biomedical research has shown that this FECG signal is mixed up with other signals which include MECG signal and background noise resulting from maternal electromyogram (EMG) and foetal motion and these signals degrade the quality of the FECG. For correct clinical FECG measurement and interpretation, the MECG and the background noise associated with the FECG must be reduced to the barest minimum. Different researchers have used different approaches to effect this reduction. In [1] Amin et al used adaptive linear neural network (ADALINE) to separate the FECG from composite ECG, comprising FECG and MECG. This approach is very convenient to the patient during long-term monitoring of the foetus. In [2] Suzanna et al used a method that consists of a sequential analysis approach, in which the “a priori” information about the interferencesignals associated with FECG is used for the detection of the FECG and this method can be used for FECG detection both during pregnancy and labour. The authors evaluated the method on a set of 20 abdominal recordings from pregnant women with different gestational ages and obtained a superior performance when compared with independent component analysis (ICA) method. In [3] Mansoureh et al proposed a multivariate singular spectrum analysis (MSSA) approach for extracting and separating the mother heart signal, foetal heart signal and the noise component from the combined ECG signals. The method is targeted on noisy recordings and the algorithm was validated by using some noisy simulated signals and real life signals. Arias – Ortega and Gaitan – Gonzalez [4] proposed a sequential processing method, in which the detection and cancellation of maternal QRS complexes followed by foetal QRS complex involving hardware suitable processing techniques, for single channel abdominal ECG algorithm for real – time maternal and fetal heart rate monitoring. The authors tested the algorithm on a group of 25 different gestational age pregnant women signals, and performance was very satisfactory. MahaShadaydeh et al [5] extracted foetal ECG from maternal ECG by using adaptive voterra filter. The adaptive voterra filter (AVF) is capable of synthesisingthe non-linear relation between the mother thoracic ECG signal and the abdominal signal which contains a transformed mother ECG, the foetal ECG and other noise elements. An adaptive multi-sensory noise canceller structure was adopted for the extraction purpose and the AVF update algorithm of RLS was proposed. The result showed superior effectiveness over some methods.

Dr.Walid A.Zgallai [6] combined an adaptive cubic LmFvoterra filter and artificial neutral network classifier to improve the detection of foetal heart beat, in his bi – spectral contour matching method of non – invasive foetal heart beat. Swarnalatha and Prasad [7] investigated the use of wavelet transform denoising along with two stage adaptive filtering technique for foetal ECG extraction from the abdominal ECG. The authors used wavelet transform to decompose the abdominal signal into its two components of MECG and FECG and the FECG is extracted by adaptive filtering technique. Results showed that the technique is capable of extracting FECG even when it is embedded with complex maternal signal. Mariano Ruffo et al [8] used foetal phonocardiography (FPCG) and foetal electrocardiography (FECG) with passive, fully non-invasive low cost digital recording systems in effectively monitoring of the foetus. The authors presented the use of FECG, FPCG and their combination in order to detect the foetal heart rate (FHR) and potential functional anomalies. They also presented signal processing methodologies, suitable for long-term assessment, to detect heart beat events such as first and second heart sounds and QRS waves, which provide reliable measurement of heart rate, and offer the potential of new information about measurement of the systolic time intervals and foetus circulatory impedance. Jimenez-Gonzalez A. and James C. J. in [9] developed a method of separating foetal heart sounds and maternal activity from single-channel phonograms for effective monitoring offoetal health condition and this method involves:

(1) Using temporal decomposition source Separation (TDSEP), (2) Increasing the number of components to be extracted to higher number of ten and (3)Using K-means to find and group components corresponding to the same sources such as FHS, maternal or line-noise. Results showed a better quality and more objective extraction of foetal heart sounds ($s_{1\text{-}S2}$), maternal activity and line-noise. In [10] Ebrahim et al proposed the use of genetic algorithm (GA)-based adaptive filter method in extracting foetal heart signal via two-channel arrangement. In this two channel approach, an electrode is placed on the mother's thoracic and the other placed on the mother's abdomen. The authors argued that the signal recorded from the mother's thoracic represents the maternal heart signal while the composite signal recorded from the mother's abdomen represents the foetal heart signal, the maternal heart signal, the maternal electromyogram, the 50Hz powerline interference and random electronic noise. According to the authors the GA is employed to avoid convergence into local extremum, that is the GA is recruited whenever the adaptive filter is suspected of reaching a local extremum. The maternal thoracic ECG serves as a reference signal to the LMS based adaptive filter. In [11] Hasan M. A. et al reviewed the various existing methodologies and developed algorithms on FECG signal detection and analysis to provide efficient and effective ways of understanding the FECG signal and its nature for foetal monitoring. The methodologies and algorithms reviewed by the authors include wavelet transform, artificial intelligence, ICA and blind source separation, linear adaptive filter framework, genetic algorithm approach, matching pursuits (MP) approach, SVD method, successive cancellation algorithm and adaptiveneuro-fuzzy logic technique. In [12] KokBengGan et al designed and *developed a low-poweroptical system* for monitoring the foetal heart rate. The signal of interest in this monitoring is the photoplethysmogram (PPG) which is generated when a beam of light is modulated by blood pulsations. In this non-invasive technique light intensity, formed by light emitting diode, is modulated by the maternal as well as foetal blood circulation, producing a combined signal which is detected by a photo detector and separated via digital signal processing. The technique was proved to give a satisfactory performance. Camps G et al [13] used neutral network based on finite impulse response filter to extract foetal ECG from maternal ECG, while Kam A. and Cohen A. in [14] combined IIR adaptive filtering and genetic algorithms in the detection of foetal ECG.

In this paper we consider a non-invasive technique of combination of an adaptive and a static FIR filters for the extraction of FECG from the composite EEG(MECG+FECG) and thehigh frequency random noises. The adaptive LMS-based FIR filter separates the MECG from the composite ECG and high frequency random noise resulting from foetal motion and maternal EMG, while the static FIR filter removes the random noise from the FECG, leaving a clean FECG only. The introduction of the static filter makes this work different from other related works for foetal ECG separation.

II. FOETAL SEPARATION PROCESS

The diagram for the separation process is shown in fig1. Abdominal electrodes placed at the maternal abdomen pick up the abdominal ECG (AECG). This abdominal ECG comprises the MECG, FECG and the higher frequency random noise. The AECG is applied to main input of the adaptive filter via the abdominal leads as shown in fig1. The thoracic electrodes placed at the maternal chest pick up the MECG and this is coupled to the reference input of the adaptive filter via the chest leads to serve as the reference input signal to the adaptive filter. The filter output is an estimated value of the reference input signal, here the MECG. The estimation is done by convolution of the filter coefficients and the reference input signal until an estimated signal that is as close as possible to the reference input is obtained. The estimated signal is subtracted from the AECG, producing an error signal "e". This error signal corresponds to FECG and the high frequency random noise. The error signal is further applied to the low pass static FIR filter to remove the high frequency randomnoise, hence leaving only the FECG to appear at the system output as the output signal.

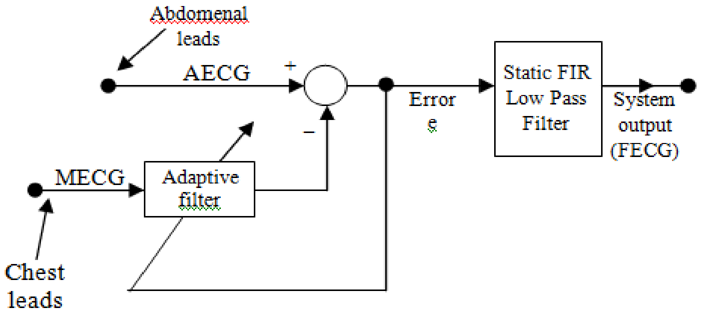

Fig 1: Foetal Monitoring System

III. DESIGN OF THE ADAPTIVE FILTER

With a sampling frequency of 1000HZ, adaptive step-size of 0.00087and filter order of 100, the impulse, magnitude, phase and Z – plane responses of the adaptive filter are shown in figures 2, 3, 4 and 5 respectively.

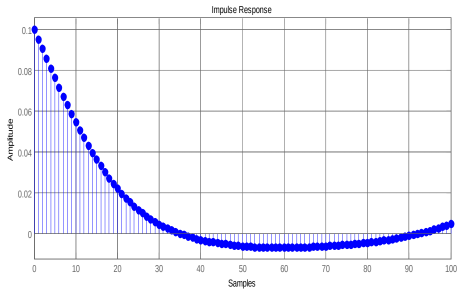

Fig 2: Impulse Response of the Adaptive Filter

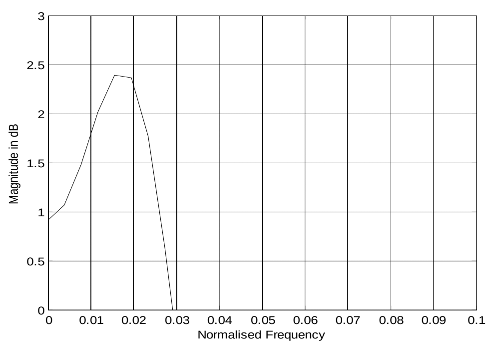

Fig 3: Magnitude Response of the Adaptive Filter

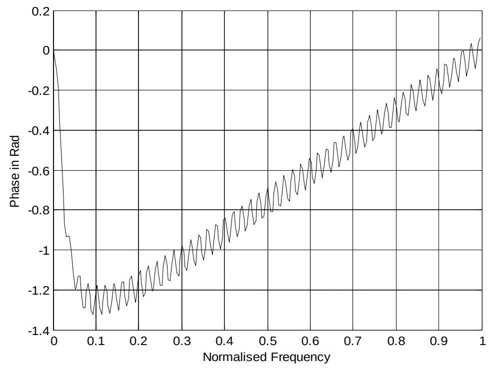

Fig 4: Phase Response of the AdaptiveFilter.

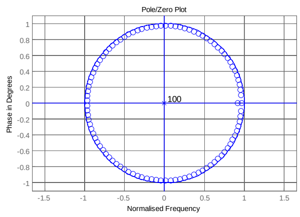

Fig 5: Z-plane Response of the AdaptiveFilter

IV. DESIGN OF FIR LOW PASS FILTER

With a sampling frequency of 1000HZ, cutoff frequency of 100Hz and static filter order of 100, the impulse, magnitude and phase responses of the static low pass filter are depicted as figures 6, 7 and 8 respectively.

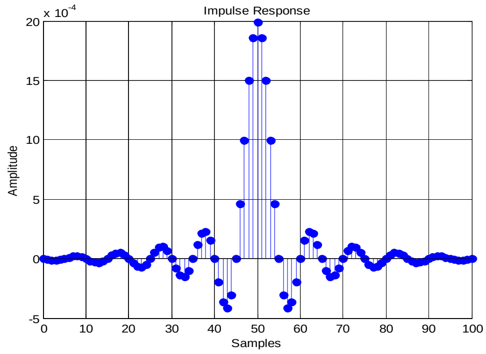

Fig 6: Impulse Response of Low PassFilter

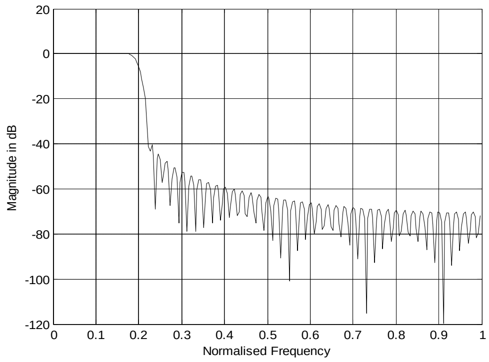

Fig 7: Magnitude Response of Low Pass Filter

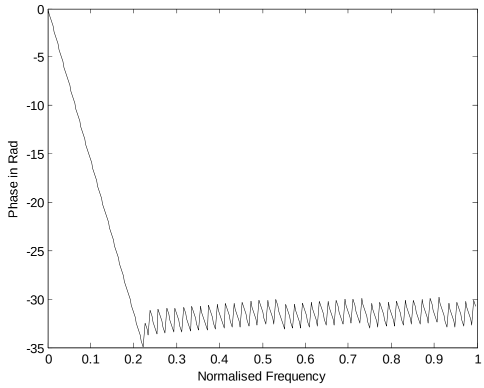

Fig 8: Phase Response of the Low PassFilter

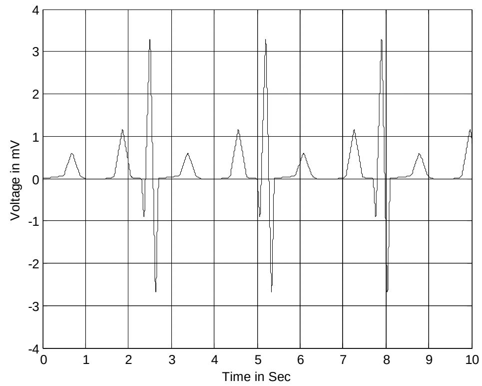

Fig. 9: Maternal ECG FromMatlab

V. RESULTS

A maternal ECG of 3.5 millivolt amplitude resulting from a heart beat of about 89 beats per minute is presented in fig 9 above. Naturally foetal ECG amplitude is less than that of maternal ECG but foetal heart beats faster than the maternal heart. Typically foetal heart beat rate ranges from 120 to 160 beats per minute [3]. Fig 10 represents a typical foetal ECG signal with a heart beat rate of 139 beats per minute and amplitude voltage of 0.25mV. Fig 11 shows the abdominal ECG (AECG) consisting of the 3.5 millivolts MECG, 0.25 millivolt FECG and 0.02 millivolt high frequency random noise. The AECG is applied to the foetal monitoring system of fig 1. The error signal which represents the output of the adaptive section of the system is depicted in fig 12. This error signal is FECG corrupt with high frequency noise. The system output which emulates a clean FECG is provided in fig. 13.

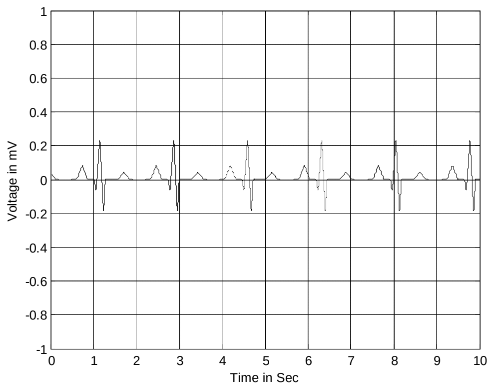

Fig 10: Foetal ECG from Matlab

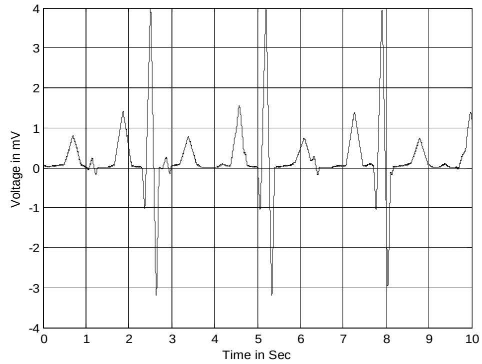

Fig 11: Abdominal ECG from Matlab

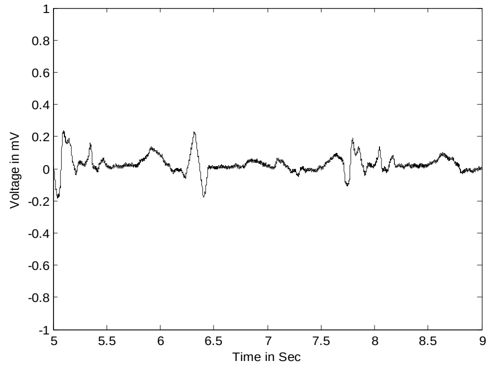

Fig 12:FoetalECGAfter Adaptive filtering Only

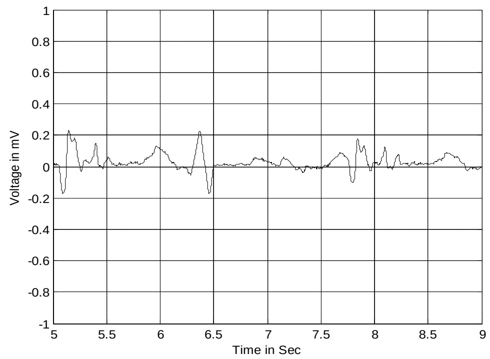

Fig 13:FoetalECG After Adaptive and Low Pass Filtering

VI. DISCUSSION

The impulse and magnitude responses of the adaptive filter as depicted in figures 2 and 3 respectively show that the adaptive filteris stable since the responses do not have sustained oscillations. The z-plane response of fig. 5 shows stability because all the poles and zeros are confined within a unit circle.The phase response of fig. 4 shows a good degree of linearity which implies that the adaptive filter will not distort any applied complex signal. Similarly figures 6 and 7 indicate that the designed low pass filter is stable, while the phase response of fig. 8 is linear within the required frequency range.Fig. 11 shows that the foetal ECG is swallowed up by maternal ECG in the womb. This maternal ECG and the other associated noise signals must be removed before the appearance of the foetal ECG can be determined. Fig. 12 shows the foetal ECG after the maternal ECG is removed. The appearance still indicates presence of noise, and this noise is the random noise arising from foetal motion. Fig. 13 shows a better foetalECG because the low pass filter has reduced the random noise. It can be observed that this ECG of fig. 13 is closer to the uncorrupt foetal ECG of fig. 3, though with small distortion due to presence of overlapping random noise. However, it is good enough for correct clinical interpretations.

VII. CONCLUSION

It has been established in this research that digital filters are very useful in the accurate measurement of foetal ECG. Adaptive filters extract the maternal ECG which swallows up the foetal ECG in the abdomen. Without the adaptive filter the output will appear like a corrupt maternal ECG signal during measurement. The low pass filter plays a vital role in the reduction of the high frequency noise that corrupts the foetal ECG.

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