A REVIEW ON PLI MINIMIZATION IN FECG EXTRACTION

Sonalika Bhagat[1], Manjit Singh[2], Butta Singh[3]

ECE Dept., GNDU,RC,Jalandhar

Email: [1]sonali1092sonali@gmail.com, [2]manu_kml@yahoo.co.in, [3]bsl.khanna@gmail.com

Abstract. This paper describes the various processing methods that are available in the literature for the cancellation of the Power Line Interference (PLI) predominant in the bio-potentials. Especially while analyzing the Fetal Electrocardiography(FECG) non-invasively i.e, recording obtained from the maternal abdomen, there is the presence of a noise component and that particular strong noise component is PLI signal which is sometimes 10 times greater than FECG signal. In this review paper, different principles of minimizing PLI have been studied and analyzed.

Keywords: FECG, PLI, Hilbert Huang Transform(HHT), Blind Source Separation (BSS), Fast Independent Component Analysis(FASTICA), Adaptive Comb Filter(ACF)

I.INTRODUCTION

The two most significant emerging tools used nowadays for examining the health of the fetus during pregnancy are Fetal Heart Rate (FHR) and the fetus'morphological analysis. FHR recording is done via standard procedure called as CTG(Cardiotocography)[1] but this technique results in some potential problems of accuracy and reliability. Moreover, CTG traces do not have the presence of beat to beat variability of fetal heart rate. Hence, rapid variations of FHR are unable to detect[2]. Another method named as Invasive Fetal Monitoring is considered when both instantaneous FHR and FECG morphology are necessary to investigate[3]. This method again has a limitation i.e., both mother's as well as fetus' lives are at risk as this method of recording includes a wire electrode which is attached to the fetal scalp after rupturing the membrane. Thus, it can lead to possible infections also.

An alternative method is preferred where above limitations are overcome in which abdominal recording is measured from the maternal abdomen by the placement of electrodes on the abdominal surface. Though the method eliminates the disadvantages of the above techniques but the available recorded FECG signal has very low SNR because of the following two reasons: (a) The signal is generated by a very small source i.e. fetus' heart[4,5] (b) The signal reaches to the maternal belly surface after propagating through different attenuating mediums. Therefore, abdominal signal (ADS) contains FECG signal having very small amplitude of about 10μV [2]. Also in ADS, the only weak component is the FECG signal while the othersignalssuch as Electromyography (EMG) of abdominal muscles, Mother Electrocardiography (MECG), PLI etc. have relatively higher power. Among these, the most disturbing noise sources present in the abdominal signal is the Power Line Interference with fundamental component at 50Hz/60Hz and also its harmonics since it can reach up to those amplitudes that are much greater than the abdominal signal thereby making its analysis almost impossible.

For the reduction of PLI , many practical solutions have been adopted but somehow biopotential measurements are still being affected by PLI. The various different approaches for the PLI reduction have been selected for the review study viz., Notch filters, Adaptive filters, Hilbert Huang Transform, Blind Source Separation, Fast FASTICA and Adaptive comb filter.

II.METHOD

2.1 Notch Filters

Digital fixed notch filters have been designed to remove multiple frequencies. These filters have the advantage to cancel out the fundamental frequency and also its harmonics. But the problem with multiple notch filters in cancelling PLI from fetal ECG signal is the spectral overlapping of both the signals[6].Hamilton investigated the notch filters and the effects of their transient times that increase with the decrease in the bandwidth. The ringing effects near QRS complex and ST segment were observed while using the narrow bandwidth notch filters. But this distortion can be reduced with the increase in transient time. However, the capacity of the filter decreases due to the long transient time[7]. Sander et al. in [8] designed a 50/60 Hz notch filter that removes baseline drift from ECG signal. The filter caused minimum distortions in power spectrum and provided the ECG signal free from any spikes and didn't change the frequency distribution of the original abdominal signal. Bai et al. in their work[9] used adjustable 60Hz notch filter. When digital signal is obtained after transferring from analog ECG signal, digital filter is used to suppress60Hz noise in the digital signal. FIR filter with linear phase property was used for noise reduction without the introduction of phase distortion. Thus, for the suppression of noise, notch filter with pole/zero cancellation and comb notch filter were used and the results were good.

2.2 Adaptive Filters

Adaptive filters are nonlinear filters which can be usedfor the analysis of the ECG signals. Their coefficients change continuously so that they can meet the desired pre-defined conditions[10]. Lee and Lee designed a dynamic structure of adaptive filter(DSAF) and experimental results were positive.Different ECG signals were taken from Kronton Medical's Arrhythmia Simulator 994. DSAF showed better performance than General Adaptive filter (GAF) in minimizing the distortion present in the ECG signal as the Absolute average error (AAE) for GAF came to be 0.056 whereas for DSAF it was 0.014[11].ECG signal enhancement was provided by Syed Ateequr Rehman and R.Ranjith Kumar in their work by using adaptive filters instead of non-adaptive structures. They compared various approaches such as Signed regressor least mean square (SRLMS) which is the computationally simplifies version of LMS, Normalized SRLMS (NSRLMS), Least Mean Square (LMS), Normalized LMS (NLMSis a variant of the LMS algorithm that helps in solving the problem of sensitivity of the LMS to the scaling of the input by normalising with the power of the input), and Differential LMS (DLMS) in terms of SNR improvement. Simulation results showed that NLMS and DLMS have better results than other existing realizations of adaptive filters[11]. The table 1 shows the performance of various adaptive filters and the figure 1 describes the principle of LMS algorithm.

TABLE 1
SNR IMPROVEMENT IN VARIOUS ALGORITHMS OF ADAPTIVE FILTER[12]

ALGORITHM	SNR before filtering	SNR after filtering	SNR improvement
SRLMS	-2.0612	8.8786	6.8174
NSRLMS	-2.0612	8.8915	6.8303
LMS	-2.0612	9.7336	7.7124
NLMS	-2.0612	9.8341	7.7729
DLMS	-2.0612	11.3134	9.2522

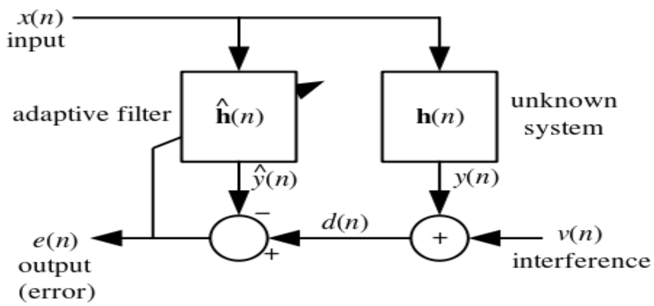

Fig.1 Block diagram of LMS Algorithm

2.3 HHT

The real time signals especially the biopotential signals are non-stationary. Hence, Hilbert Huang Transform (HHT) is suitable for its analysis. This method consists of two steps: a) Intrinsic mode functions(IMF's) are generated through Empirical Mode Decomposition (EMD) and b) Hilbert analysis.IMF's are obtained from the data set by decomposing the time series through EMD[12]. This is known as sifting process in which first IMF's have the decomposition of high frequency components and the low frequency components are prevalent in the higher order IMF's. The basic idea of this method is to discard IMF's containing noise and the reconstruction of the signal from remaining IMF's and is shown below:

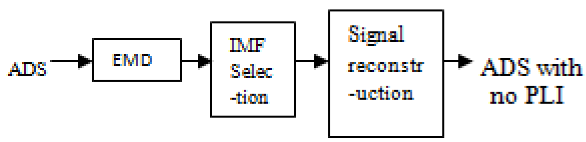

Fig.2 Block diagram of HHT[13]

The problem that occurs in this technique is that it is difficult to identify which IMF's contain just the PLI signal. The conventional EMD process involves the elimination of first IMF since it contains the high frequency component and thus it is considered to have the PLI signal. This is not always true as sifting process may not be perfect everytime. In addition to this, if the PLI signal has the presence of harmonics,the number of IMFs containingPLI components is higher.An algorithm proposed in [13] can identify IMF's containing PLI signal by computing IMFs' cumulative mean and their powers. However, the robustness of the algorithm is not apparent when the PLI signal has very high power as compared totheFECG signal.

2.4Blind Source Separation

From the mixture of signals, each of the signal source is extracted. The basic concept of ICA is given in the block diagram and all the studies report that the extraction of FECG signal from ADS is better by using ICA methods[14].

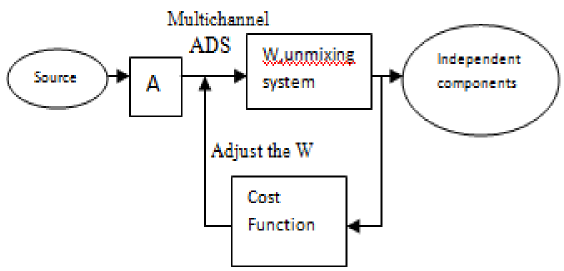

Fig.3 Block diagram showing idea of ICA[15]

The difficulties occuring in separating the original source signals from sensor array which does not have information about channel characteristics of transmission and sources are expressed as blind source separation problems[15].The two basic assumptions are required to be fulfilled for ICA algorithm: a) Linear combinations of the measured signals to the independent source signals. b) Non-gaussianity of the independent source signals. ICA generates mutually statistically independent components[16].ICA methods do not take into consideration the position of electrodes and other physical parameters. Many approaches such as maximization of non gaussianity, maximum likelihood estimation etc. exists for the estimation of the ICA parameters[2].In [17], Wen and Luo adopted two algorithms of ICA namely FASTICA and natural gradient algorithm of ICA and done their comparison. The study resulted in better performance of latter algorithm as the mother ECG obtained was almost close to accurate MECG compared to the former one.

2.5FASTICA

The method proposed in [17] by Immanuelb et al. shows that Lifting wavelet transformation and FASTICA algorithm produce better results and have more SNR values compared to the basic ICA method. The methodology can be described as follows:

1. The signal is loaded and then converted into binary format and finally it is mapped to two-dimensional format.
2. This signal is preprocessed by the use of Wavelet transform in order to remove the noise.
3. The obtained signal is then decomposed to time-frequency domainbyusing Wavelet Lifting decomposition.
4. The noisy FECG signal is then allowed to decomposeto five levels of wavelet transform by using the daubechies wavelet.
5. Now FASTICA is applied for the separation of fetal and maternal signals.
6. Finally, the separated signals are reconstructed using Inverse Wavelet Lifting Transform.

Therefore, FAST ICA is an algorithm that is simple and independent of user-defined parameters.The comparison of different techniques in terms of SNR(FECG) done in [18] is illustrated in table 2:

TABLE 2
SNR FOR FECG USING VARIOUS ALGORITHMS[19]

ALGORITHMS	**SIGNAL 1**	**SIGNAL 2**
ICA	1.8	11.32
FAST ICA	10.10	18.3

Mishra andSingla have proposed a technique of obtaining pure ECG signal using FAST ICA algorithm . It's a promising technique for the extraction of independent sources from the ECG signal which is mixed with the noise. The basic idea of this technique is that the components must be statistically independent[19].However, in the works of Parmar andUnhelkar,[20] different approaches of ICA have been compared and it was investigated that the performance of FAST ICA algorithm degrades as the time duration of the sources increase, though the quality of the separated signals is satisfactory for a very high value of performance index.

2.6Adaptive Comb Filter(ACF)

Another simple and robust algorithm given by Zheng Wei et al. in their paper[21]proves to be very significant in the separation of maternal and fetal ECG signals with minimum interference. The proposed method in[21]can be explained as under:

1.Loading of abdominal signal *a(n)*

2.Removing 50/60 Hz PLI (Preprocessing)

3.Detection of maternal R peaks in *a(n)*

4.The unit sample response $h_m(n)$ is determined for maternal ECG:

$$h_m(n) = \sum_{k=-L}^{L} a_k \delta(n - N_k)$$

5.Now, the maternal ECG estimation is obtained from *a(n)* as:

$mecg(n) = convolution\{a(n), h_m(n)\}$

6.The residual ECG signal is given as:

$$r(n) = a(n) - mecg(n)$$

7.Detection of fetal R peaks in *r(n)*

8.The unit sample response $h_f(n)$ is determined for fetal ECG

9.Finally the fetal ECG estimation is obtained from r(n) as:

$feccg(n) = convolution\{r(n), h_f(n)\}$

The ACF in [21] is compared with ICA and applied to Daisy FECG data and PhysioNet FECG data. In the former data, ICA estimates the source FECG signal that may be taken as coordinates of the fetus' heart dipole. On the contrary, ACF estimates the surface FECG signal. The total execution time taken by ICA algorithm was 0.53s and that of ACF came to be 0.25s.When PhysioNet FECG data was taken , ACF proved to be more robust than the other as its parameters did not change in the presence of very strong background noise.

III. CONCLUSION

In this paper,several methods have been studied which help in the minimization of PLI as well as some other artifacts also. The literature review of the different approaches used for the extraction of fetal ECG shows satisfactory results. HHT method proves to be best amongst the other techniques for the cancellation of PLI. The robustness of the adaptive comb filter is better as compared to the ICA algorithm. The future work focusses on the designing of such a method that provides accurate FECG signal with negligible interference of PLI or mother ECG. Moreover, the time for executing the algorithm must be lesser than the earlier techniques.

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