Enhancing Fetal ECG Using Adaptive Filters by Cancelling the Maternal ECG Signal

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Abstract- *Fetal ECG Extraction is very significant in medical diagnosis to provide valuable information about the heart condition of the Fetal ECG during pregnancy. The extraction of Fetal ECG i.e. enhancing the Fetal ECG is done by suppressing the Maternal ECG Signal with the help of Adaptive filters. In this paper various adaptive filter algorithms such as LMS, NLMS, VSSLMS, VSSNLMS and CSLMS are used. In this paper, we have presented a comparative study of various algorithms in terms of their performance in extracting the Fetal ECG thereby cancelling the maternal signal which is considered to be the noise and their ability to reduce the other noises such as power line interference and baseline wandering. We have found that CSLMS yields the best Signal to noise ratio(SNR) and is the best algorithm among the compared algorithms and eliminated most of the noises present*

Keywords- Adaptive filters, LMS, NLMS, VSSLMS, VSSNLMS, SNR.

I. INTRODUCTION

Filtering is the process of enhancing the Signal to Noise Ratio (SNR) and thereby eliminating a certain type of noise. When the Signal and noise are both stationary and their characteristics are approximately known, anwiener filter can be designed to filter the noise. But, if the Signal characteristics are unknown and there is no priori information about signal and noise a wiener filter just can't satisfy the job.Therefore an Adaptive filter is used that has the ability to adjust their own parameters based on the incoming signal which require no prior knowledge of the signal to noise characteristics. The basic operation of adaptive filters involves two processes.

Filtering: This produces an output signal in response to the input signal.

Adaption Process: In this process the filter coefficients are adjusted.

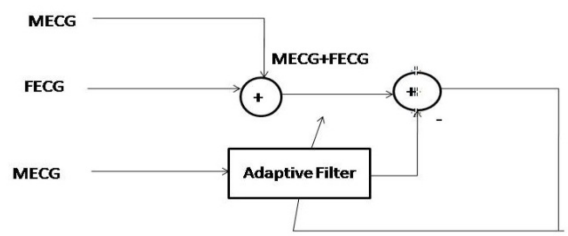


Figure 1: Adaptive Noise Canceller

The primary input of the adaptive filters is provided through a single abdominal lead and it contains both the maternal and fetus ECGs. The reference input is the mother's ECG and is provided through four Chest leads.

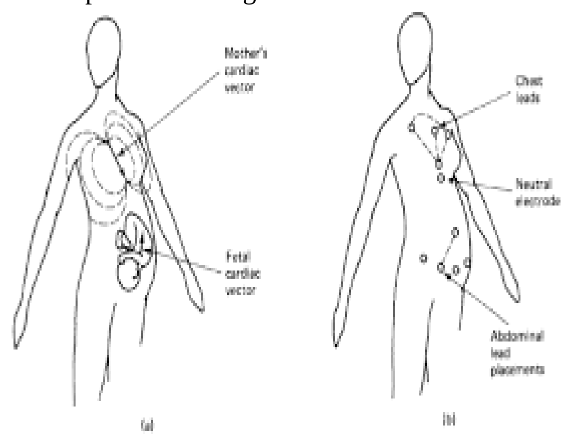


Figure 2**:** Fetal ECG Extraction

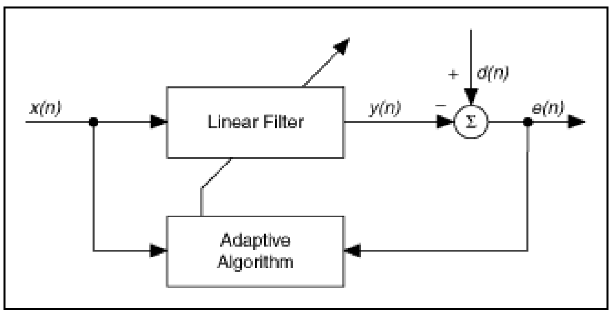
Adaptive filter is the primary method for the noise cancellation and it minimizes the mean squared error between a primary input, which contains both the Maternal ECG and Fetal ECG(i.e. both the noises are correlated with each other) and the reference input which is the Maternal ECG which needs to be eliminated. Since the Primary and Reference Signal characteristics are unknown, an adaptive filter is used which is capable of adjusting its impulse response by minimising the mean square error. The adjusting of the filter weights are governed by the adaptive algorithm used.

II.ADAPTIVE FILTERS

The word "Adaptive"means self adjusting and "Filter" means to remove the unnecessary particles from its input. Therefore an Adaptive filter self adjusts its transfer function in accordance to the optimizing algorithm used and thereby eliminating the noise present in the primary signal i.e. the input.The adaptive filters are most widely used in eliminating noises in biomedical signals due to low computational complexity, low convergence time and very small residual error. Based on the optimizing algorithm The adaptive filters are of various types and are discussed below.

A. LEAST MEAN SQUARE ALGORITHM

This Algorithm was developed by Widrow and Hoff in 1959 and is widely used due to low computational complexity , high convergence speed and stable behaviour. LMS Algorithm is stochastic based algorithm which utilizes the gradient vector of the filter tap weights to converge on the optimal Weiner solution.



IMPLEMTATION OF LMS ALGORITHM:

Each iteration of LMS algorithm 3 distinct steps need to be executed:

1.The output of the linear filter is given by

$$y(n) = \sum_{i=0}^{N-1} w(n)x(n-1) = w^T(n)x(n)$$

2. The error is estimated as
e(n)=d(n)-y(n)
where d(n) is the desired signal.
3. The Tap weights of the FIR Vector areupdated in preparation for the nextiteration according to the equation

$$w(n+1) = w(n) + 2\mu e(n)x(n)$$

where μ is the step size parameter and is constant throughout the implementation of the algorithm.

B. NORMALISED LEAST MEAN SQUARE.

The main disadvantage of Least Mean Square algorithm is having a fixed step step size throughout the implementation but this requires prior signal statistics. LMS is most suitable when the signal power is constant. But in practical case, the signal power will never be constant which effects the convergence rate and gradient noise amplification takes place. Therefore a little modification has to be done in the implementation to overcome the above problems. The step size is varied in each iteration and is inversely the total expected energy of the instantaneous values of the coefficients of the input vector x(n). This sum of the expected energies of the input samples is also equivalent to the dot product of the input vector with itself.

Step size(μ)=1/dot product (input vector, input vector)

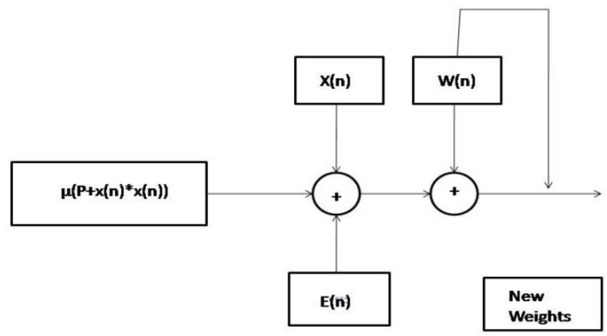


Figure3. NLMS Algorithm

Therefore the weights are updated using the equation

$$w(n+1) = w(n) + \frac{1}{x^T(n)x(n)} e(n)x(n)$$

The convergence rate of NLMS algorithm is within the range of $0<\mu<1$.

C. VARIABLE STEP SIZE LMS(VSSLMS)

When a variable step size is introduced to the LMS algorithms it becomes VSSLMS. In this algorithm, the step size is not constant and is expressed as a vector μ(n). Eachelement of the vector μ(n) is a valuecorresponding to an element of the filter tapweight vector, w(n).

The weight Vector updation is done according to

$$w_i(n+1) = w_i(n) + 2\mu_i g_i(n)$$

Where,
g is a vector comprised of gradient terms.
And $g_i(n) = e(n)x(n-i)$, i=0,1,.......N-1;
And the step is varied in accordance to

$$\mu_i(n) = \mu_i(n-1) + \rho g_i(n) g_i(n-1)$$

And if $\mu_i(n) > \mu_{max,} \mu_i(n) = \mu_{max}$

D.VARIABLE STEP SIZE NORMALISED LMS(VSSNLMS)

The VSSLMS has also the same drawback as that of LMS i.e. Stability is not guaranteed and statistical characteristics of the input signal is required.

We know that the major benefit of NLMS is that it the step size is based on the instantaneous signal strength and therefore VSSLMS together with the NLMS gives us much better results than any other algorithms presented above.

The gradient , Step size and the filter weights are updates as follows.

$$g_i(n) = e(n)x(n-i) \text{ , i=0,1,.......N-1;}$$

$$g(n)=e(n)x(n)$$

$$\mu_i(n) = \mu_i(n-1) + \rho g_i(n) g_i(n-1)$$

$$\mu(n) = \frac{1}{x^T(n)x(n)}$$

$$\mu_i(n) = \mu_i(n-1) + \rho g_i(n) g_i(n-1)$$

If $\mu_i(n) > \mu_{max,} \mu_i(n) = \mu_{max}$

$$\mu_i(n) < \mu_{min,} \mu_i(n) = \mu_{min}$$

E. CONSTRAINED STABILITY LEAST MEAN SQUARE ALGORITHM:

The major drawback of the above mentioned algorithms is that, they are resulting in a large value of mean square error which results in the distortion in the Enhanced Fetal ECG signal. In this Constrained Least Mean Square Algorithm the step size parameter is inversely proportional to the squared norm of the difference between the two consecutive inputs rather than the input vector as in the NLMS.

The weight update relation of the CSLMS is as follows

$$w(n+1) = w(n) + \left[\frac{\delta x(n)\delta e(n)}{||\delta x(n)||^2}\right]$$

The constrained Stability LMS provides faster convergence speed and higher flexibility.

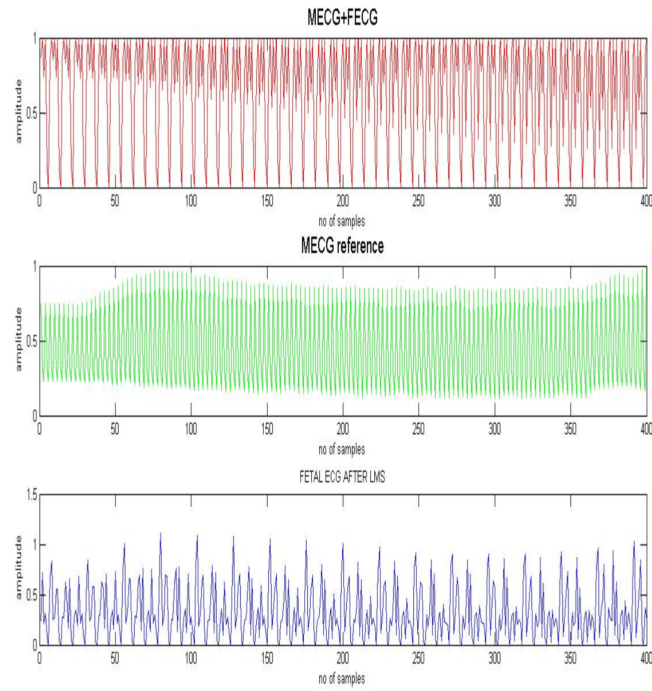
III. METHODOLOGY

Our main objective is to enhance the Fetal ECG thereby eliminating the Maternal ECG when a pregnant women is subjected to ECG i.e. the Pregnant women ECG(Maternal + Fetal) signal becomes the primary signal to the Adaptive filter and the Maternal noise becomes the reference to the Adaptive filter. Both the samples of the Primary and Maternal ECG signals are extracted from MIT-BIH database. They are given to the Adaptive filter input and various Optimization algorithms such as LMS, NLMS, VSSLMS, VSSSNLMS and CSLMS are used to eliminate the Maternal ECG signal. Apart from this, the baseline wander noise i.e. the noise which is effected due to the movement of the patient or poor electrode contact and the power line interference i.e. the interference to the ECG signal which is resulted from the power chords and id usually in the order of 50Hz or 60Hz are also cancelled to an extent.

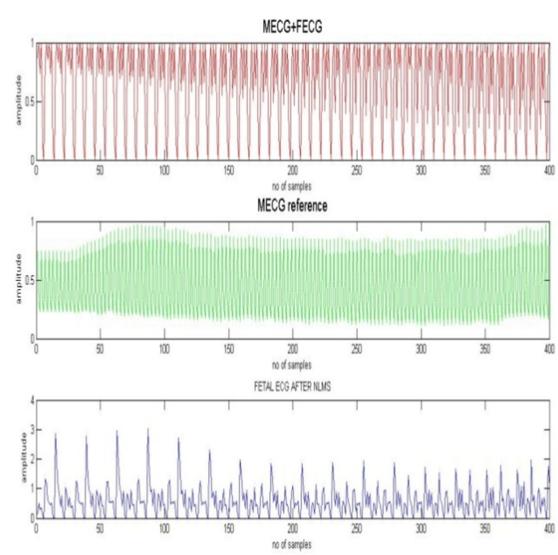
IV. RESULTS

Results from this current study are disclosed herein. Output for each algorithm i.e., LMS, NLMS, VSSLMS and VSSNLMS are studied and the corresponding results were placed in this section.

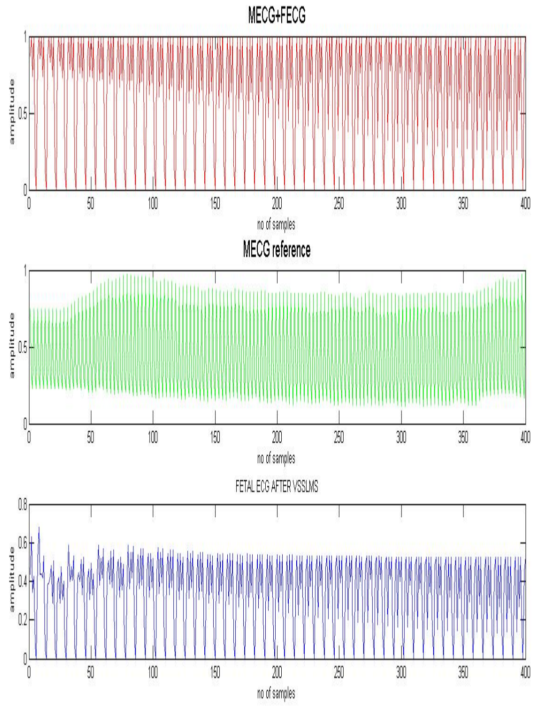
A.USING LMS



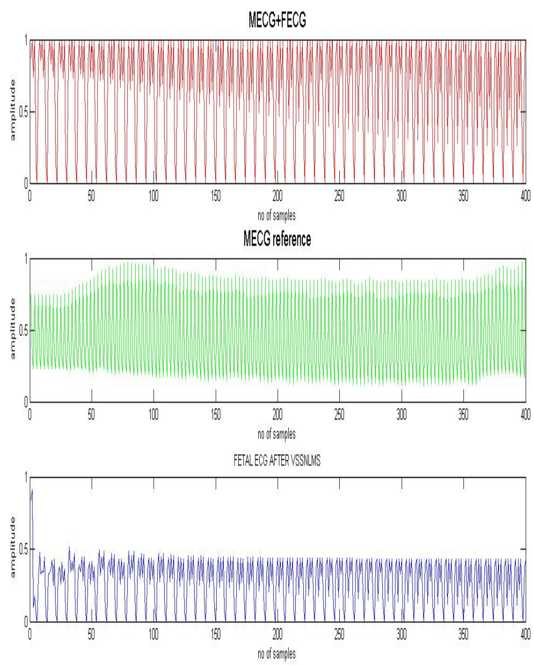
B.USING NLMS:



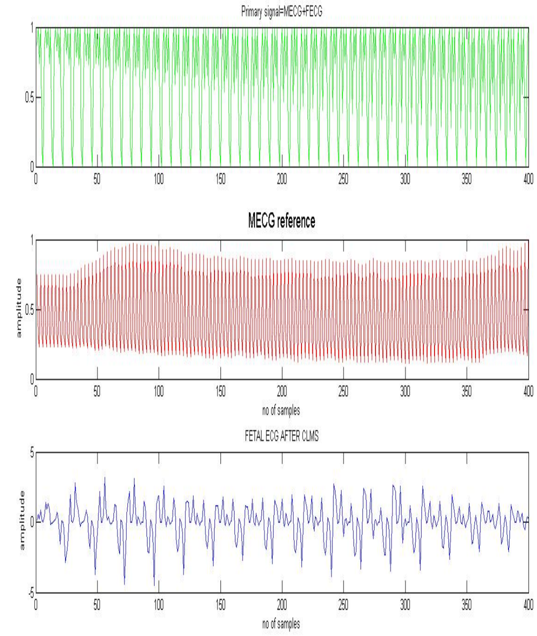
C.USING VSSLMS



D.USING VSSNLMS



E. USING CSLMS

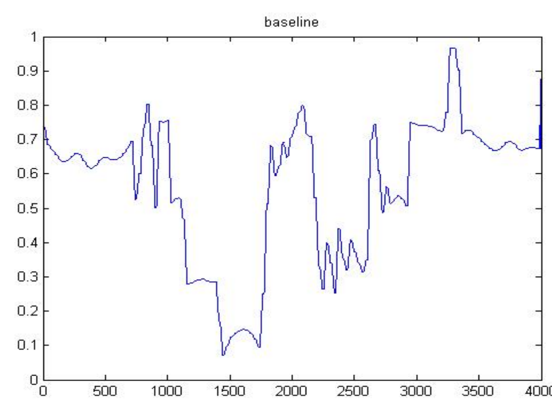


COMPARISION OF VARIOUS ALGORITHS:

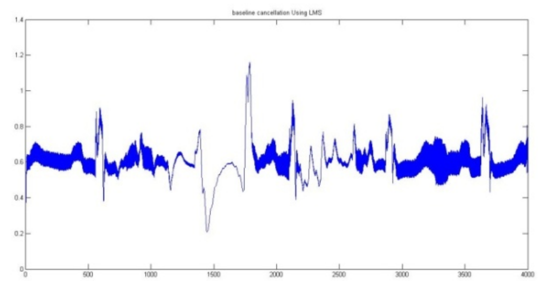
Signal to Noise Ratio in corresponding to Number of samples for various Adaptive filter Algorithms

No of Samples(N)	LMS	NLMS	VSSLMS	VSSNLMS	CSLMS
40	32.5787	34.4661	35.6891	36.4891	38.9915
400	35.8689	36.9192	37.9822	38.1246	40.9894
4000	46.5443	48.9292	49.1218	50.42	54.1965
40000	57.1347	58.1497	59.1683	72.0126	89.0912

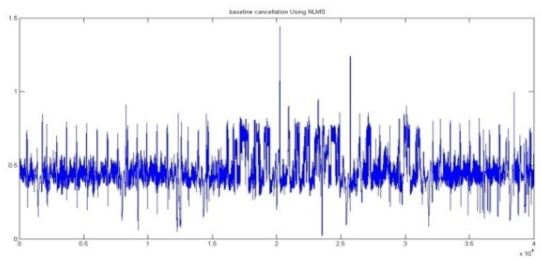
BASELINE WANDERED PRIMARY SIGNAL:



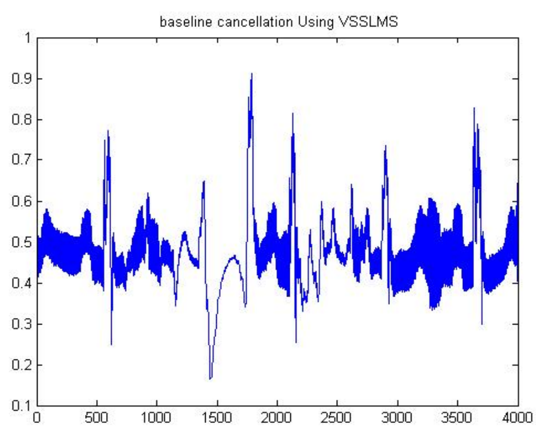
Baseline wander noise removal after LMS:



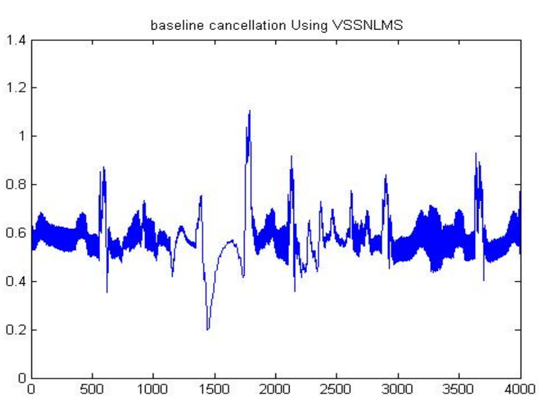
Baseline wander noise removal after NLMS:



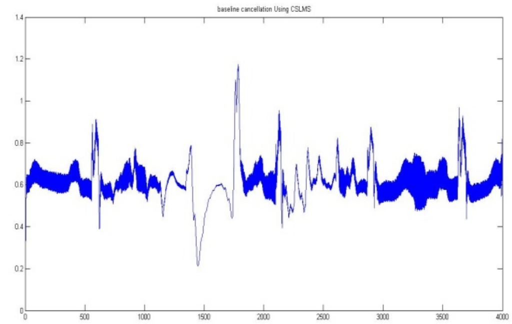
Baseline wander noise removal after VSSLMS:



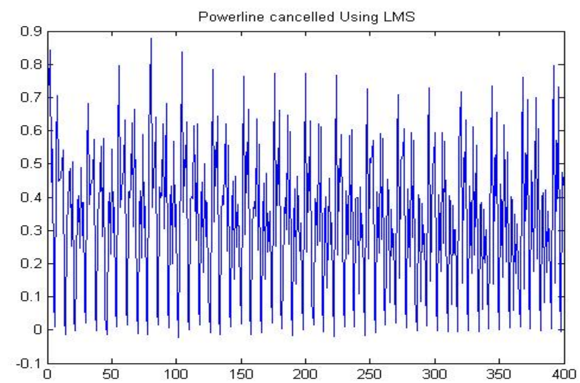
Baseline interference using VSSNLMS:



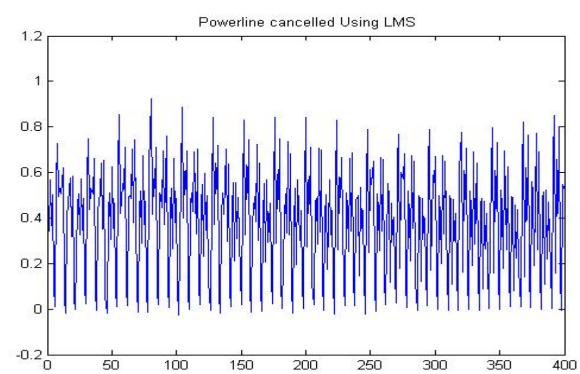
Baseline wander noise removal using CSLMS:



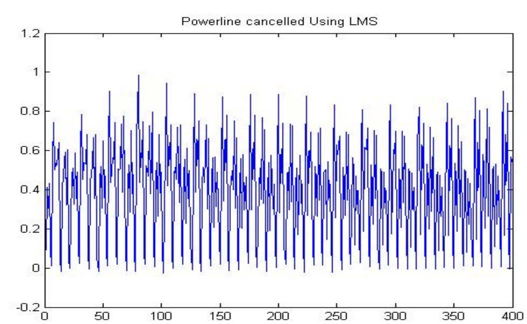
Power line Interference removal using LMS:



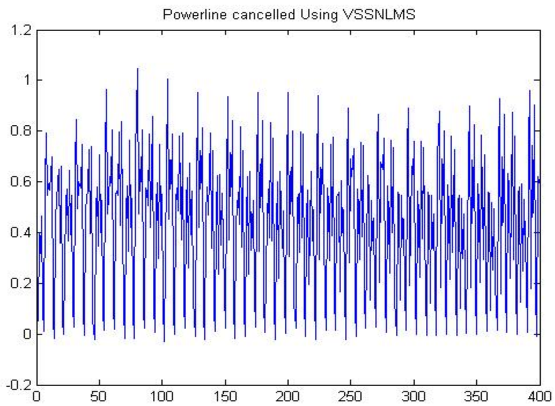
Power line interference removal using NLMS:



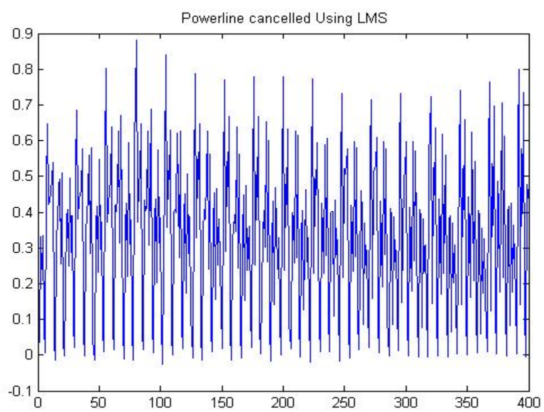
Power line interference removal using VSSLMS:



Power line interference removal using VSSNLMS:



Power line interference removal using CSLMS:



IV.CONCLUSION

The fetal ECG extraction from the Primary ECG signal (Maternal + Fetal) is done using Adaptive filters and we have used various optimization algorithms and have observed that among the Constrained Stability Least Mean Square Algorithm gives us the best results when compared to LMS, NLMS, VSSLMS and VSSNLMS.

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