JFET 24(2) (2017) 57-66

Journal of Faculty of Engineering & Technology

journal homepage: www.pu.edu.pk/journals/index.php/jfet/index

DE-NOISING ECG SIGNALS CONTAMINATED WITH POWER LINE INTERFERENCE USING NOTCH PRE-FILTERED WAVELET

W. Elahi[1], M. Abrar[2], K. Habib[3] and O. M. Butt[4]

[1, 2] Department of Electrical Engineering, Bahauddin Zakariya University, Multan
[3,4] Department of Electrical Engineering, University of the Punjab, Lahore

Abstract:

This paper presents the fusion of Notch filter and Wavelet Transform method for denoising ECG signals contaminated with Power line interference(PLI). The objective results are compared qualitatively as well as quantitatively while the effectiveness of the method is also validated by Comparing the obtained results with traditional notch filters as well as the wavelet denoising method. The simulation results demonstrate that the purposed method is most effective for removal of power line interference in terms of fast time convergence as well as less complexity of the deployed algorithm.

1. Introduction

The electrocardiogram (ECG) is an electrical activity exhibition of heart. An ECG signals gets contaminated by several kinds of noises such as PLI during recording and transmission. According to American heart association an ECG must have 3dB frequency ranging between to 0.067HZ to 150HZ.Which includes the electrical power system's frequency of 50HZ or 60HZ in different regions of world [1-3]. PLI usually do not have a constant amplitude, it usually tends to show variations around the central frequency while masking the finer details of ECG signals leading to improper evaluation by the physicians.

2. Literature review

Traditionally Notch filters have been employed for denoising ECG signals corrupted by PLI. A comparison between FIR and IIR notch filters such as Butterworth, Chebyshev I, Chebyshev II and elliptical was made on the basis of PSD, SNR and MSE in [4]. Kaiser window of order 56 was found most effective in eliminating PLI from ECG signals. Chebyshev window was found most useful for denoising ECG signals. Barlet window was found most efficient for PLI removal as compared to the Kaiser window in [5]. FIR cascaded notch filter scheme using Kaiser window was found effectual in order to remove PLI from ECG signals. [6]. Widrow et al [7] used concept of adaptive filtering to find out the changes in amplitude and phase of PLI for its removal from the ECG signals. An improvement to the above-mentioned technique was made to find out frequency deviations of the PLI by purposing a phase locked loop system. [8]. A novel mechanism based on LMS algorithm for detecting phase and amplitude and phase was purposed in [9]. An adaptive filter not dependent upon reference signal was

* Corresponding Author: jaskani_waleed@yahoo.com

purposed in [10]. A RLS based adaptive filter was found effective for denoising ECG signal as compared to the traditional notch filter in [11]. A performance enhancement of adaptive filters was made possible by using SSRLS (State Space Recursive Least Square) algorithm in [12]. An intelligent adaptive filter using SSRLS algorithm was used for Tracking of 1st, 2nd and 3rd harmonics of PLI was purposed to eliminate high frequency components from High resolution ECG (HRECG) [13]. Empirical mode decomposition (EEMD) method was purposed in [14]. Only noisy segments of ECG signals were processed to denoise ECG signals contaminated by PLI. The non-stationary sinusoids were extracted by using Sliding discrete Fourier transform (SDFT) in [15].

Wavelet denoising method was used to denoise noisy ECG signals in [16]. To denoise ECG signals Dual Tree Complex Wavelet transform (DTCWT) was used in [17]. A performance comparison between different denoising methods such as Adaptive noise canceller, Discrete wavelet method and Savitzky-Golay filtering was made in [18]. Non-Local wavelet transform was applied to remove AWGN (additive white Gaussian noise) by using local as well as non-local redundancy in the signals in [19]. Optimized Wavelet Thresholding (GOWT) method was used in [20] to eliminate noise from ECG signals. Also, the comparison was made by using soft and hard thresholding techniques. An Adaptive Dual Threshold Filter (ADTF) and Discrete Wavelet Transform (DWT) was used to denoise ECG signals in [21].

3. Notch filter:

A traditional notch filter is basically a band stop filter which has a narrow bandwidth. In order to design a notch filter there are three basic parameters which are taken into account (1) Bandwidth (2) Notch frequency (3) Quality factor. All of these parameters are related as

$$Q = f0/\Delta \mathrm{f} \tag{1}$$

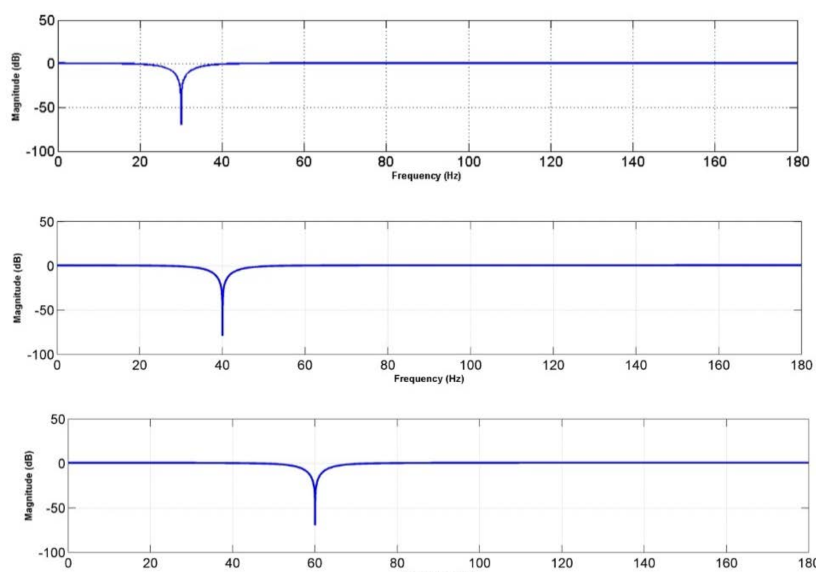

Figure 1: Magnitudes responses of Notch Filters

In order to deal with the PLI of larger amplitude the quality factor of the notch filter must be low whereas the attenuation level should be high for such a case. However, having a high attenuation level will result in the deviation of original characteristics of ECG signal.

In this paper three different type of notch filter with different magnitude and attenuation levels have been applied on the ECG signal to make comparison of their performance based on SNR obtained. Their magnitude responses are shown in the Figure 1. To perform analysis, the ECG signal of sample frequency and bandwidth of 100HZ and 360HZ respectively is taken from the physio bank database. For simplicity of analysis only three peaks of the acquired signal were used as shown in the Figure 2.

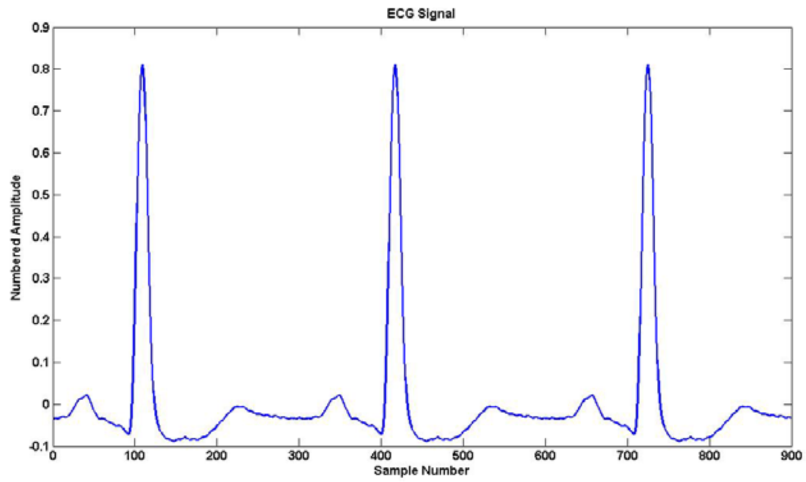

Figure 2: Original ECG signal

A PLI of 50HZ frequency was added to the originally acquired ECG signal from physio bank data database. The subsequent ECG signal is shown in the Figure 3.

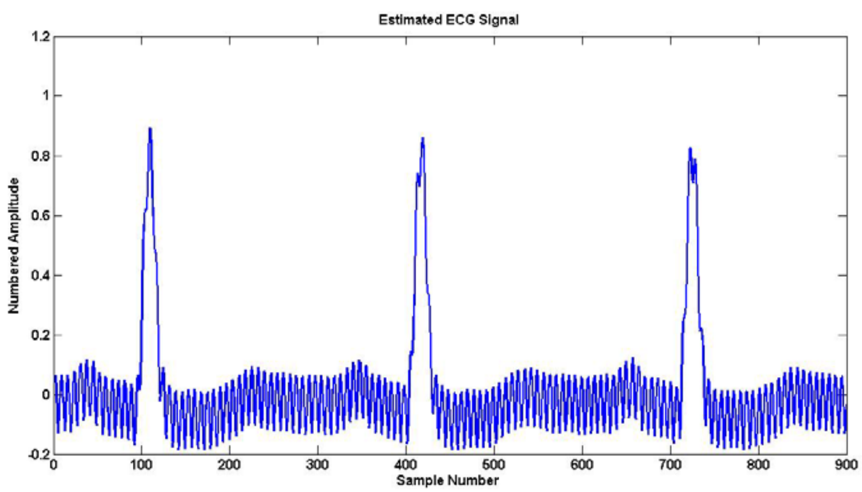

Figure 3: ECG signal contaminated with PLI of 50HZ

Type	Attenuation (dB)	Signal/Noise(dB)
Notch Filter 30dB	33dB	25.6455
Notch Filter 40dB	66dB	25.0002
Notch Filter 60dB	100dB	20.4866

Table 1: SNR Comparison of Notch Filters of different magnitudes

The SNR comparison of different Notch filters shown in the Table 1 indicates that the Notch filter of 30dB and notch width of 0.1 have the highest SNR. The estimated ECG signal and power spectral density of obtained by using the 30 dB Notch filter is shown in the Figure 4 and 5 respectively

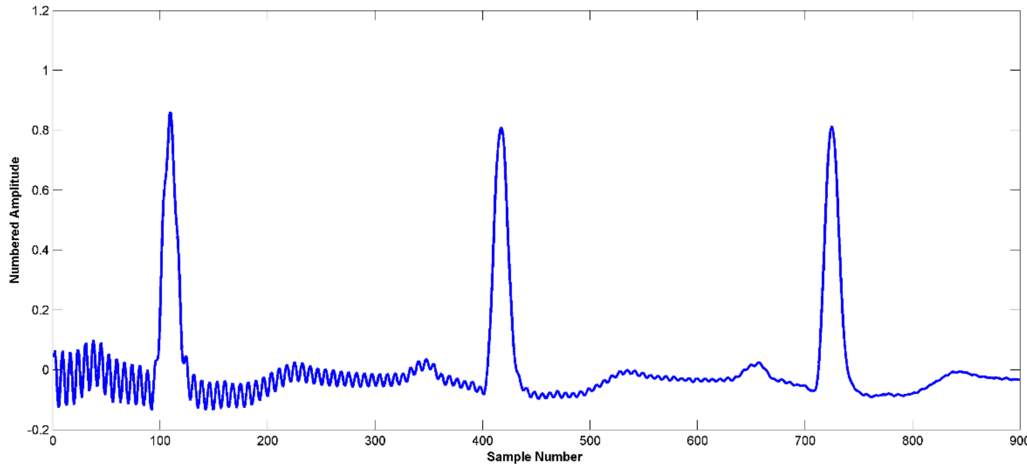

Figure 4: Estimated ECG signal for 30dB Notch Filter

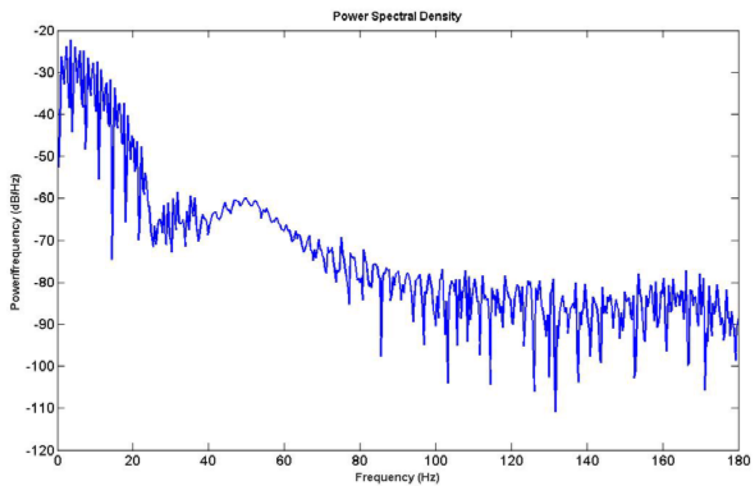

Figure 5: Power Spectral Density of Estimated ECG Signal

Though it does not completely remove the noise but it also does not bring any significant changes to original signal characteristics.

4. Wavelet Transform

Wavelet Transform is a multi-resolution transform which splits signal on time-scale dimension. Wavelet Transform involves convolution of Scaled Version of Mother Wavelet with the signal under analysis to produce co-efficient. The Discrete Wavelet Transform can be mathematically defined represented as

$$\psi(\mathrm{x}) = \sum_{k=-\infty}^{\infty} a_k(sx - y) \quad (2)$$

Here 'S' is regarded as the scaling factor and its value is usually taken as 2. For purpose of analysis several functions have been developed called mother wavelets. These wavelets have been broadly classified into Orthogonal and Bi-Orthogonal Wavelets. In case of orthogonal wavelet transforms scaled mother, wavelets are orthogonal to each other. They give multiresolution analysis at relatively higher computational speed.

A mother wavelet can be represented as

$$CWT(c,a) = \frac{1}{\sqrt{a}} \int h\left(\frac{t-c}{a}\right) s(t)dt \quad (3)$$

$$\psi_{c,a}(t) = \frac{1}{\sqrt{a}} h\left(\frac{t-c}{a}\right) \quad (4)$$

$\psi_{b,a}(t)$ is called scaled mother wavelet function while 'b' is regarded as the translation parameter whose main task is to select a particular portion of a signal to perform analysis. Moreover 'a' is called scaling parameter which is included to keep area constant under the mother wavelet function.

a. Decomposition of signal:
A signal is decomposed by using a particular wavelet. The selection is usually depending on frequency spectrum of the signal used. The other important parameter in the decomposition of signal is the choice of level for decomposing signal up to Nth level.

b. Thresholding:
This step includes the comprehensive thresholding from 1 to Nth level.

c. Reconstruction of signal:
The reconstruction process of signal is based on the coefficient approximation of the noisy signal and denoised signal.

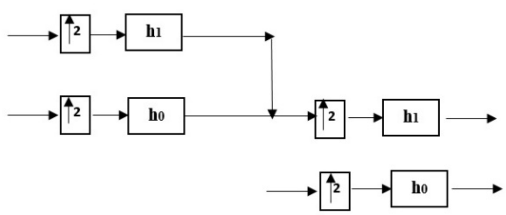

Fig 5: Decomposition of signal using DWT

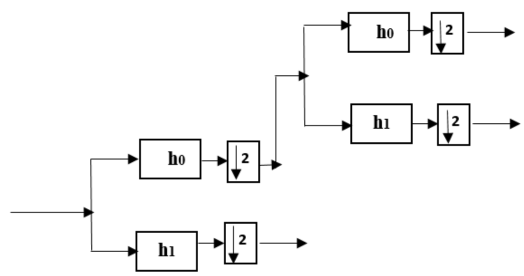

Fig 6: Recondition of Signal using IDWT

Discrete Wavelet transform 1-D denoising scheme is applied on the Corrupted ECG signal by using soft Thresholding method. The SNR Comparison of different mother wavelets is given in the Table 2.

Sr.no	Mother Wavelet	Thresholding	Threshold Level	S/N (dB)
1	HAAR Wavelet	Soft Thresholding	03	11.98906577
2	DAUBECHIES Wavelet	Soft Thresholding	03	22.78797896
3	SYMLET wavelet	Soft Thresholding	03	21.98119656
4	BIORTHOGONAL Wavelet	Soft Thresholding	03	25.91736440
5	COIFLET Wavelet	Soft Thresholding	03	26.84500206

Table 2: SNR Comparison of Mother Wavelets

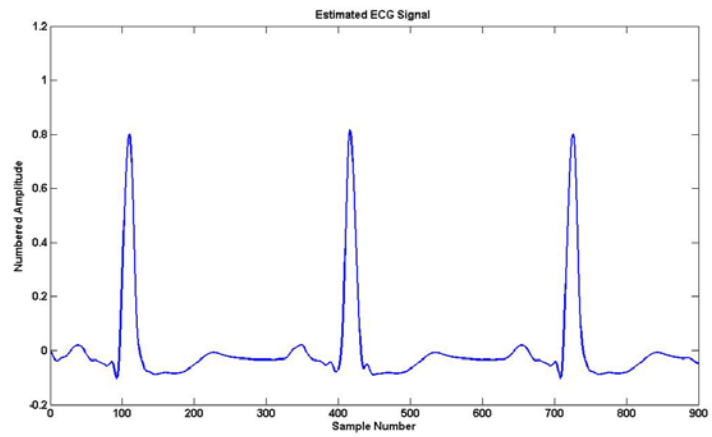

Figure 7: Estimated ECG signal by COIFLET Wavelet

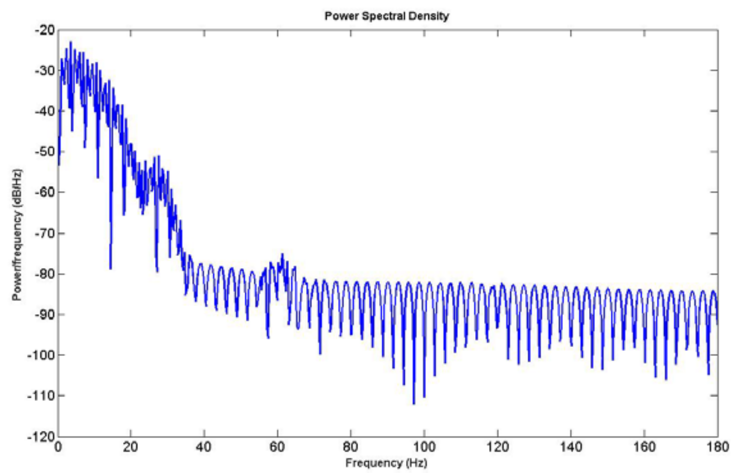

Figure8: PSD of Estimated denoised signal

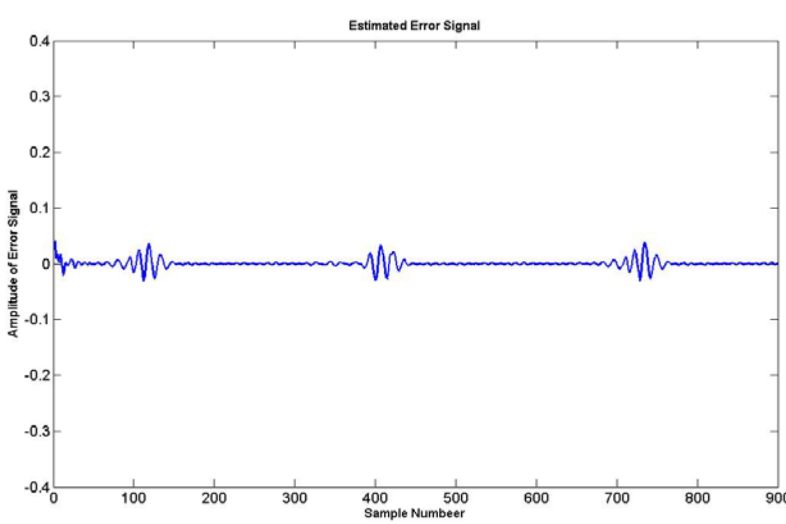

Figure 9: Estimated Error signal for Denoised Signal

The Table 2 shows that the COIFLET 03 mother wavelet has highest SNR among all the mother wavelet used. The resultant signal after applying COIFLET 03 wavelet is shown in the Figure 7. In order to see how successfully COIFLET mother wavelet has removed the noise from the Noisy ECG signal the PSD of the Resultant ECG signal shown in the Figure 8. It is quite evident form the PSD of the resultant signal that 50 HZ noise has been completely removed from the original ECG signal. Error signal plot for estimated denoised ECG signal as shown in the Figure 9.

5. Notch pre- Filtered Wavelet Denoising

This method is basically a fusion of two denoising methods used to eliminate the Power line interference from the ECG signals. The whole method can be divided into two stages. The 1st stage consists of a notch filter of 50dB magnitude while the second stage is based on the wavelet denoising method. The block diagram of the purposed system is shown in the Figure 10

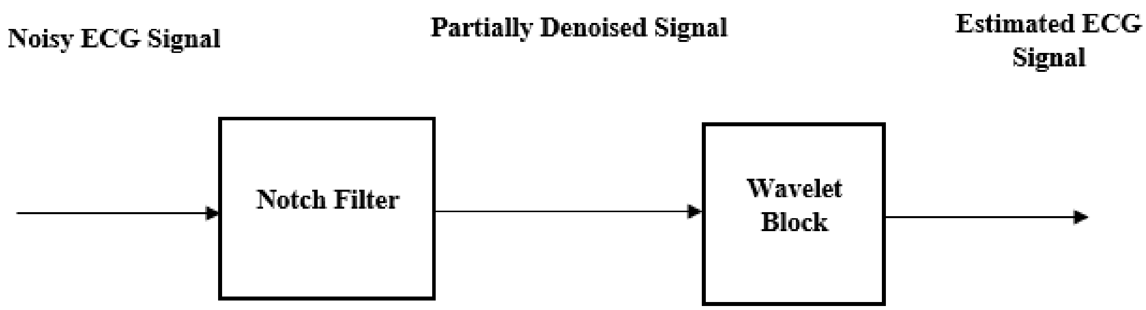

Fig 10: Block Diagram of Notch Pre-Filtered Mechanism

The 1st block here will partially denoise the signal without leaving any change to the original ECG signal characteristics while in the second block the wavelet denoising technique is applied and the process of decomposing and reconstruction are applied on this partially denoised signal to obtain the final denoised signal. We have used the notch filter of 3dB magnitude which we used earlier in this scheme along with COIFLET mother which yielded highest SNR among all the mother wavelets used. The obtained SNR of Purposed scheme is shown in the Table 3.

Notch Filter+	Thresholding	Threshold Level	S/N(dB)
COIFFLET Wavelet	Soft Thresholding	03	30.93461962414165
HAAR Wavelet	Soft Thresholding	03	15.65920360206252
DAUBECHIES Wavelet	Soft Thresholding	03	25.0735879575801
SYMLET wavelet	Soft Thresholding	03	26.0511252065206
BIORTHOGONAL Wavelet	Soft Thresholding	03	28.9200250852024

Table 3: SNR of Notch-Pre- Filtered Mechanism

Using Notch Pre- Filtered Method, a remarkable increase in SNR Value of Wavelet Filters is observed. The SNR obtained for the purposed method is higher as compared to traditional notch filter method as well as wavelet denoising method. The obtained result is shown in the Figure 11.

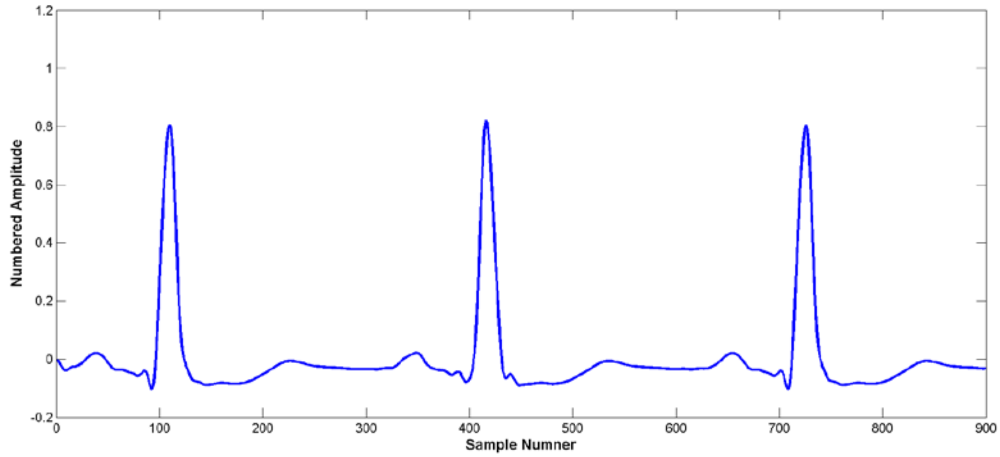

Figure 11: Estimated ECG Signal by COIFLET Wavelet

The obtained result has shown marked improvement in the removal of power line interference from the ECG signal while leaving negligible changes to the original signal. This fact can be validated from the PSD of the estimated denoised signal shown in Figure 12.

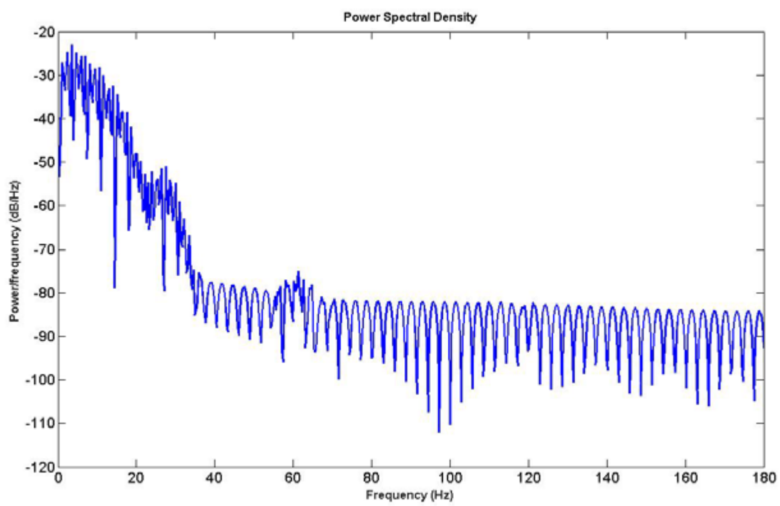

Figure 12: PSD of Estimated denoised signal

Furthermore, the effectiveness of purposed method can be validated by graphical method by plotting error signal for the purposed method as in Figure 13.

From here it can also be concluded that Notch pre- filtered method is more suitable for denoising ECG signals corrupted with the power line interference as compared to the notch filter as well as simple wavelet denoising method. The Signal to noise ratio comparison of all the methods gives the clear indication of the fact that newly purposed Notch-pre- filtered wavelet denoising method is more successful in removing the Power line interference form the ECG signal while leaving not significant changes to original ECG signal.

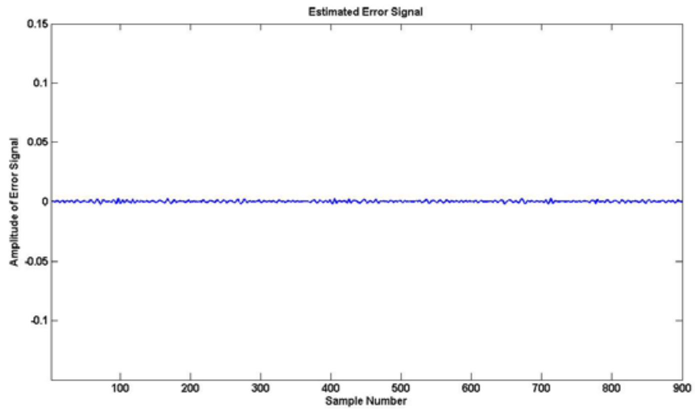

Figure 13: Estimated Error Signal

6. Conclusion and future work:

PLI is the most problematic and most occurring noise among all the noises which can affect the ECG signals. This paper purposed a novel method based on the fusion of two of most commonly used techniques for PLI removal from ECG signals. The purposed method obtained results showed better performance when compared with the two techniques when used individually for denoising purposes. The possible extension of this paper is to compare the purposed method with the other techniques such as different adaptive techniques used for denoising ECG signals.

References:

[1] "Recommendations for Standardization of Instruments in Electrocardiography and Vector cardiography", *IEEE Transactions on Biomedical Engineering*, vol. -14, no. 1, pp. 60-68, 1967

[2] J. Bailey, A. Berson, A. Garson, L. Horan, P. Macfarlane, D. Mortara and C. Zywietz, "Recommendations for standardization and specifications in automated electrocardiography: bandwidth and digital signal processing. A report for health professionals by an ad hoc writing group of the Committee on Electrocardiography and Cardiac Electrophysiology of the Council on Clinical Cardiology, American Heart Association", *Circulation*, vol. 81, no. 2, pp. 730-739, 1990

[3] M. Burke and D. Gleeson, "A micropower dry-electrode ECG preamplifier", *IEEE Transactions on Biomedical Engineering*, vol. 47, no. 2, pp. 155-162, 2000.

[4] K. Kumar, B. Yazdanpanah, P. Kumar," Removal of Noise from Electrocardiogram Using Digital FIR and IIR Filters with Various Methods" *Communications and Signal Processing* (ICCSP), International Conference 2015.

[5] A. Mittal and A. Rege, "Design of digital FIR filter implemented with window techniques for reduction of power line interference from ECG signal", *2015 International Conference on Computer, Communication and Control (IC4),* 2015

[6] K. Patro and P. Kumar, "De-noising of ECG raw signal by cascaded window based digital filters configuration", *2015 IEEE Power, Communication and Information Technology Conference (PCITC*), 2015.

[7] B. Widrow, J. Glover, J. McCool, J. Kaunitz, C. Williams, R. Hearn, J. Zeidler, J. Eugene Dong and R. Goodlin, "Adaptive noise cancelling: Principles and applications", *Proceedings of the IEEE*, vol. 63, no. 12, pp. 1692-1716, 1975.

[8] J. Glover, "Adaptive noise canceling applied to sinusoidal interferences", *IEEE Transactions on Acoustics, Speech, and Signal Processing*, vol. 25, no. 6, pp. 484-491, 1977.

[9] T. Kanachareon, J. Koseeyaporn, R. Punchalard, and P. Wardkein, "New Adaptive Filter Algorithm for Noise Cancellation in ECG Signals," *The 31th Electrical Engineering Conference*, Thailand, Oct. 2008.

[10] A. Ziarani and A. Konrad, "A nonlinear adaptive method of elimination of power line interference in ECG signals", *IEEE Transactions on Biomedical Engineering*, vol. 49, no. 6, pp. 540-547, 2002

[11] U.Biswas, M. Maniruzzaman ," Removing Power Line Interference from ECG Signal Using Adaptive Filter and Notch Filter ", *International Conference on Electrical Engineering and Information & Communication Technology (ICEEICT),* 2014

[12] M. Butt, N. Razzaq, I. Sadiq, M. Salman and T. Zaidi, "Power Line Interference removal from ECG signal using SSRLS algorithm", *2013 IEEE 9th International Colloquium on Signal Processing and its Applications*, 2013.

[13] N. Razzaq, S. Sheikh, M. Salman and T. Zaidi, "An Intelligent Adaptive Filter for Elimination of Power Line Interference from High Resolution Electrocardiogram", *IEEE Access*, vol. 4, pp. 1676-1688, 2016.

[14] J. Jebaraj and R. Arumugam, "Ensemble empirical mode decomposition-based optimised power line interference removal algorithm for electrocardiogram signal", *IET Signal Processing*, vol. 10, no. 6, pp. 583-591, 2016

[15] V. Pandey and V. Giri, "High frequency noise removal from ECG using moving average filters", *2016 International Conference on Emerging Trends in Electrical Electronics & Sustainable Energy Systems (ICETEESES),* 2016.

[16] G.S. Kumari, S. Kuswanth Kumar, J. Anusha and M.P. Rao, "Electrocardiographic Signal Analysis Using Wavelet Transforms", *International Conference on Electrical, Electronics, Signals, Communication and Optimization (EESCO),* pp. 1-6, January 24-25, 2015.

[17] Md. Motahar Hossain Mishu, A.B. M. Aowlad Hossain and Md. Ehsan Ahmed Emon, "Denoising of ECG Signals Using Dual Tree Complex Wavelet Transform", *17th International Conference on Computer and Information Technology (ICCIT)*, pp. 379-382, December 22-23, 2014.

[18] M. Al Mahamdya and H. Bryan Riley, "Performance Study of Different Denoising Methods for ECG Signals", *Elsevier Procedia Computer Science*, vol. 37, pp. 325-332, 2014.

[19] S. Kumar, R. Sinha and P. Kumar, "Electrocardiogram signal denoising using non-local wavelet transform domain filtering", *IET Signal Processing*, vol. 9, no. 1, March 2, 2015.

[20] H. He, Z. Wang and Y. Tan, "Noise Reduction of ECG Signals through Genetic Optimized Wavelet Threshold Filtering", *IEEE International Conference on Computational Intelligence and Virtual Environments for Measurement Systems and Applications(CIVEMSA)*, pp. 1-6, June 12-14, 2015.

[21] W. Jenkel, R. Latif, A. Toumanari, A. Dliou, O. El B'charri and F. M. R. Maoulainine, "An efficient algorithm of ECG signal denoising using the adaptive dual threshold filter and the discrete wavelet transform", *Elsevier Biocybernetics and Biomedical Engineering*, vol. 36, no. 3, pp. 499-508, 2016.