ISSN(Online): 2320-9801
ISSN (Print): 2320-9798

International Journal of Innovative Research in Computer and Communication Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 10, October 2015

ECG Noise Removal by Selection of Filter from Set of Filters Using Fuzzy Logic

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ABSTRACT: Electrocardiogram (ECG) is an electrical signal used for measuring electrical activity and abnormalities of the heart on the body surface via electrodes (leads). It is the graphical record of measuring change of electrical potential with respect to time. The ECG signal is very sensitive in nature, even a very small noise can affect the ECG signal ie, changes the various features of ECG signal. Therefore, for early diagnosis of heart diseases it is required to reduce the noises. This paper presents the performance of removal of noises like power line interference, baseline wander, white noise and EMG noise by selection of filters with the help of fuzzy logic. The parameters studied are MSE, PSNR, SNR and %PRD. The original ECG signal and noises are generated using MATLAB. For implementation, graphical user interface (GUI) tool is used under MATLAB software.

KEYWORDS: Electrocardiogram (ECG), Peak Signal to noise ratio (PSNR), Mean square error (MSE), Percentage root mean square difference (%PRD), Graphical User Interface, Powerline Interference.

I. INTRODUCTION

Electrocardiogram (ECG) is one of the most commonly used health monitoring and sign sensing method. It provides recordings of hearts electrical potential with respect to time [1]. The ECG signal comprises of P wave followed by QRS complex, T wave and a U wave. The cardiac diseases are detected by ECG signal recordings. The ECG signal is corrupted by different artifacts and causes problem in diagnosis of heart diseases. Therefore, for easy evaluation and interpretation it is required to separate original ECG signal from the artifacts [2]. The various artifacts which corrupts the ECG signal are power line interference , baseline wander, electrode contact noise, motion artifacts, muscle contraction, instrumentation noise etc. ECG signal is a non-stationary signal its frequency range is generally from 0.05Hz to 100Hz [3].

We have used Graphical User Interface (GUI) tool under MATLAB software. The performance parameters for different noises are Mean Square Error (MSE), Peak Signal to Noise Ratio (PSNR), Signal to Noise Ratio (SNR) and Percentage Root Mean Square Difference (%PRD). The proposed method shows better result than LMS and NLMS Filter.

A. *Different Types of ECG Artifacts*

There are different types of artifacts which contaminates the ECG signal are as given below [4].

1) *Power Line Interference*

It comprises of 50/60Hz pickup and harmonics. The range of frequency is 60 Hz (USA) and 50 Hz (INDIA) and the amplitude is 50% peak to peak ECG signal.

2) *Base Line Wander*

Respiration and patients movement causes baseline wander. The amplitude is 15% peak to peak ECG amplitude. The frequency range of ECG signal is 0.15 Hz to 0.3Hz. It is defined as continuous drifting of ECG signal from base line

3) *Electromyography Noise (EMG)*

It is also known as muscle contractions noise. It is produced by the movement of the movement of the patient's body. Its frequency range is from dc to 10kHz and its duration is 50ms. The standard deviation is 10% peak to peak ECG amplitude [7].

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4) *White Gaussian Noise*

It is the special case of Gaussian noise, statistical in nature. Probability density function is equal to that of normal distribution, called as Gaussian distribution. Values of this type of noise are being Gaussian distributed. White noise describes the correlation of noise [8].

II. RELATED WORK

Uzzal Biswas and Md. Maniruzzaman [10] summarized the work by removing the power line interference noise from the ECG signal by using two adaptive filters such as NLMS and RLS, then comparison is made with the notch filter. The 13-bit ECG signal of four patients is taken from the MIT-BIH arrhythmia database. Results are compared using performance matrices such as SNR, PRD and MSE. Conclusion is made based on parameters that NLMS removes noise more effectively and appropriate than RLS and notch filter. S. A. Anapagamini and R. Rajavel [2] proposed their work by removing two noises such as PLI and baseline wander by using empirical mode decomposition (EMD). In EMD algorithm, the ECG signal is decomposed into sum of intrinsic mode functions (IMF) and a final residue. As the first IMF contains the PLI interference therefore, PLI is removed by passing the first IMF through FIR low pass filter. The ECG signal is taken from the MIT-BIH database. For comparison RMSE parameter is used. Rinky Lakhwani et al.[1] implemented by designing of filters such as Rectangular , Kaiser, Gaussian and hamming window with order of 56 and 100 using FDA tool in MATLAB for the base line wander noise removal. Kaiser window with an order of 56 gives the best result. Maryam Butt et al. [11] proposed a SSRLS algorithm in order to remove 50 Hz PLI noise from the ECG signal. Clear ECG signal is obtained by subtracting the PLI reduced by SSRLS from the noisy ECG signal. Comparison is made with the notch filter (A and B) and the result shows that the SSRLS based filter is better than notch filter. Syed Zahurul Islam et al. [12] made a discussion about ECG noise removal using two adaptive algorithms- the LMS and the RLS. The noises that are removed are PLI, motion artifacts, muscle contraction and base line drift. Convergence property, computation time, correlation coefficients are studied and conclusion is made that RLS filter is better than LMS filter unless computation time is of great concern. Uzzal Biswas, Anup Das et al. [6] proposed their work by using LMS and NLMS filter in order to remove different noises. Performance parameters used are SNR, PRD & MSE. Different visual parameters are also shown. The output reveals that NLMS filter is more appropriate and effective than LMS filter for removing various noises.

III. MATERIALS AND IMPLEMENTATION TECHNIQUES

The original ECG signal is generated by using MATLAB. The EMG noise, baseline wander, power line interference and white noise are also generated by using MATLAB.

A. Filters Used in Design

The various adaptive algorithm filters and digital filter used to remove noise from the ECG signal in the proposed work are LMS, NLMS, RLS, Notch Filter and Lowpass Filter. In adaptive filtering, coefficients of filter changes over time. In order to minimize the error it adapts the changes in the signal characteristics as the name suggests. Various applications include noise cancellation, system identification, frequency tracking and channel equalization [5]. Block diagram for adaptive filtering process is as shown below [3]

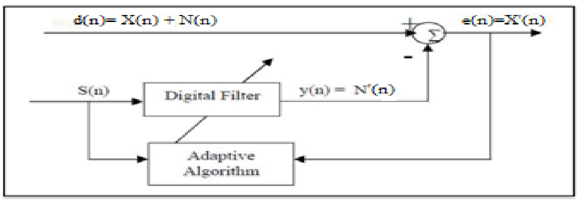

Fig. 1 Adaptive filter

X(n) is the original signal which is obtained by subtracting N(n) from d(n). N′(n) is estimated noise signal obtained from digital filters and noise sources S(n).

If N′(n) is closer to N(n), then the X′(n) is more closer to the original signal X(n).

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e is the output given by
e = X + N – y
Power of e signal is given as
$e^2 = X^2 + (N - y)^2 + 2X(N - y)$
Then,
$E(e^2) = E(X^2) + E(N - y)^2 + 2EX(N - y)$
$E(e^2) = E(X^2) + E(N - y)^2$
Energy with minimum error is given by
$E(e^2)_{min} = E(X^2) + E(N - y)^2{}_{min}$
(e - X) = (N - y) therefore,$(e - X)^2$ is also minimized.
By minimizing the noise energy we can minimize the total output energy [6].

1) LMS

Least-mean-square-algorithm produces least mean square of the error signal. According to LMS algorithm the update weight is given by
$W_{K+1} = W_K + 2\mu e_K X_K$
μ is an appropriate step size between 0 to 0.2. Coefficients fluctuate due to the larger step size.

2) NLMS

The problem of gradient noise Amplification can be simplified by the algorithm called as the NLMS algorithm. This variant of the LMS algorithm with normalization of step size is called normalized-least-mean-square algorithm (NLMS).
According to the NLMS algorithm, the update weight is given as $W_{K+1} = W_K + \beta \frac{X_K^*}{\alpha + \|X_K\|^2}$
β is the normalized step size between 0 to 2 [6].

3) RLS

RLS algorithm is based on the least squares method [9]. The RLS algorithm aims at minimizing the weights least error. The summary of RLS algorithm as follows
$R_{LS=\sum_{l=0}^{n} \lambda^{n-1}|e(n)|^2} = \sum_{l=0}^{n} \lambda^{n-1}|d_n - w_n^T x_n|^2$
where 0< λ ≤1is the exponential forgetting factor. The RLS algorithm operates in three steps at each recursion
$\pi_{n=} \frac{P_{n-1}x_n}{\lambda + x_n^T P_{n-1} x_n}$
$w_n = w_{n-1} + \pi_n(d_n - w_{n-1}^T x_n)$
$P_n = \lambda^{-1} P_{n-1} - \lambda^{-1} \pi_n x_n^T P_{n-1}$
with P0=ρ-1I, where ρ is a small positive constant.

4) NOTCH FILTER

A Notch filter is a filter having deep notches and frequency response characteristic with nulls .Various applications of notch filter are harmonics elimination in instrumentation and recording systems, noise removal etc. The system function for notch filter is given by

$$H(z) = \frac{1 - 2\cos(\theta) z^{-1} + z^{-2}}{1 - 2r\cos(\theta) z^{-1} + r^2 z^{-2}}$$

Where θ denotes angle of pair of complex zeros placed on unit circle in the z plane and *r* denotes the radius of pair of complex poles placed with the same angle as the zeros.

5) LOWPASS FILTER

A low pass filter passes only lower frequencies and rejects high frequencies. In order to remove high frequency noise low pass filter is used.

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B. Flow Chart

In this proposed algorithm, we have used selection of filters from the set of filters such as Least-mean-square filter (LMS), Normalized-least-mean-square filter (NLMS), Recursive-least-squares filter (RLS), Notch Filter and Lowpass filter etc using fuzzy logic to get clear ECG signal. The decision making tool that is used for the analysis of varying parameters is fuzzy rule based system. It is useful in making decision for the system. In Fuzzy, rule set is added for selection of filters for different noises and decision is made based on the rule set. Instead of using single filter for all the noises, combination of different filters is used for different noises based on selection. Power line interference (PLI), Baseline wander, white Gaussian noise and EMG noise are used in the study.

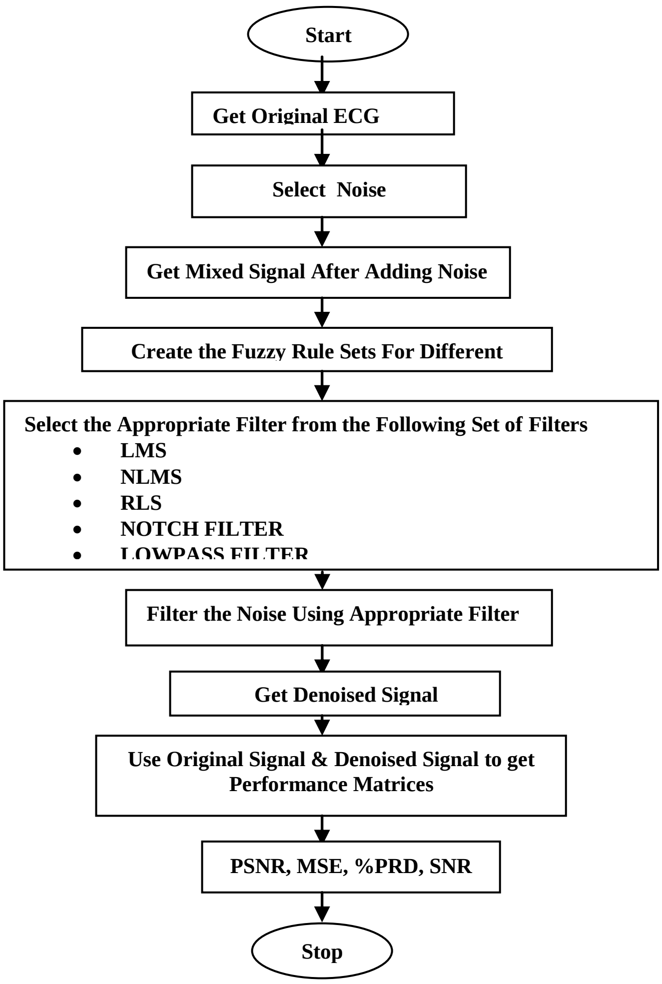

Fig. 2 Flow chart of proposed work

IV. SIMULATION RESULTS AND DISCUSSION

As the noise present in the ECG signal is the major issue in the field of biomedical. PLI noise is added is as shown in the figure 3(a), 3(b), 3(c). Figure 3(a) shows the PLI interference removed using adaptive LMS filter.

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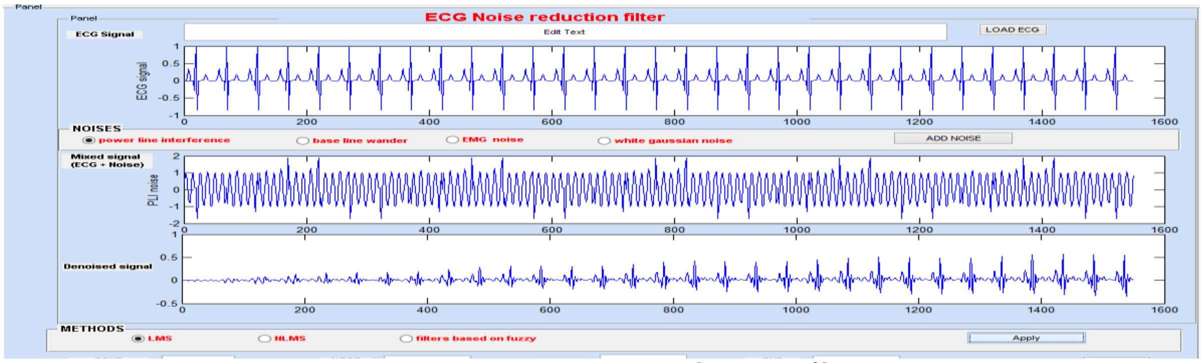

Fig. 3(a) PLI noise removal using LMS filter

The ECG signal of 50Hz and PLI interference of 50 Hz is generated by MATLAB. NLMS filter is used for the PLI noise removal as shown in figure 3(b) below.

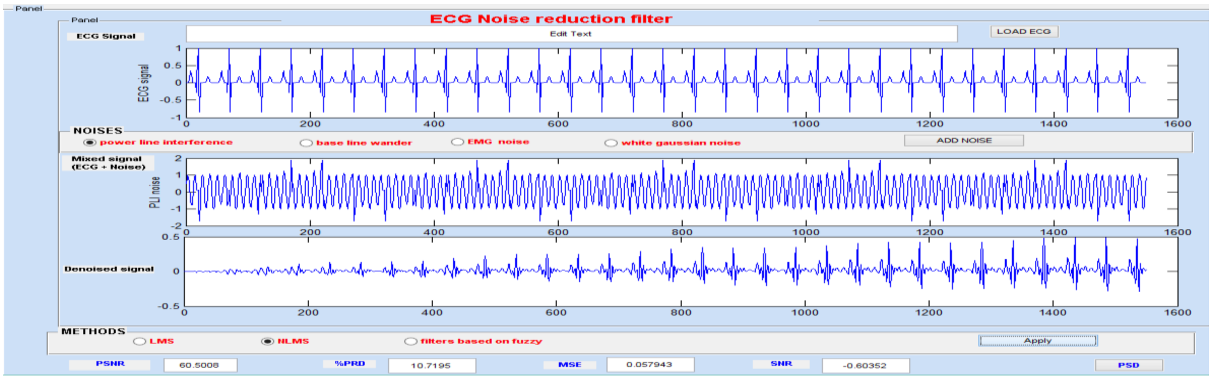

Fig. 3(b) PLI noise removal using NLMS filter

Figure 3(c) shows the use of fuzzy based filter. The combination of filters selected for PLI are LMS and RLS using fuzzy are as shown. The proposed technique shows better result than LMS and NLMS.

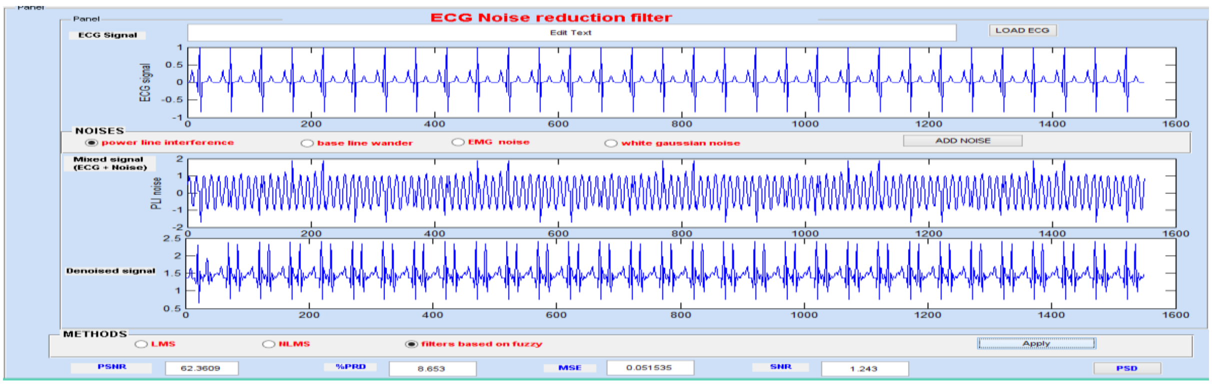

Fig. 3(c) PLI noise removal using filters based on fuzzy

Baseline wander noise is removed in figure 3(d), 3(e) and 3(f). Baseline wander is removed with the help of LMS filter is clearly shown in figure 3(d).

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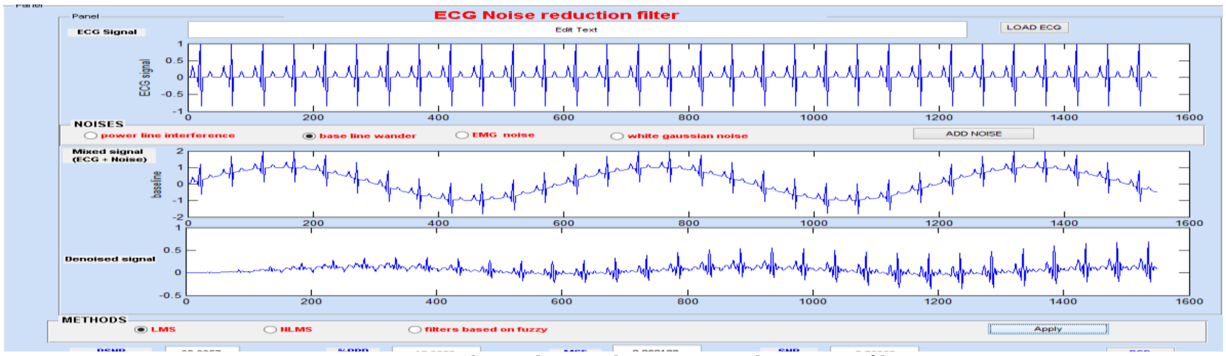

Fig. 3(d) Base line wander noise removal using LMS filter

Adaptive NLMS filter is used to remove baseline wander is shown in figure 3(e).

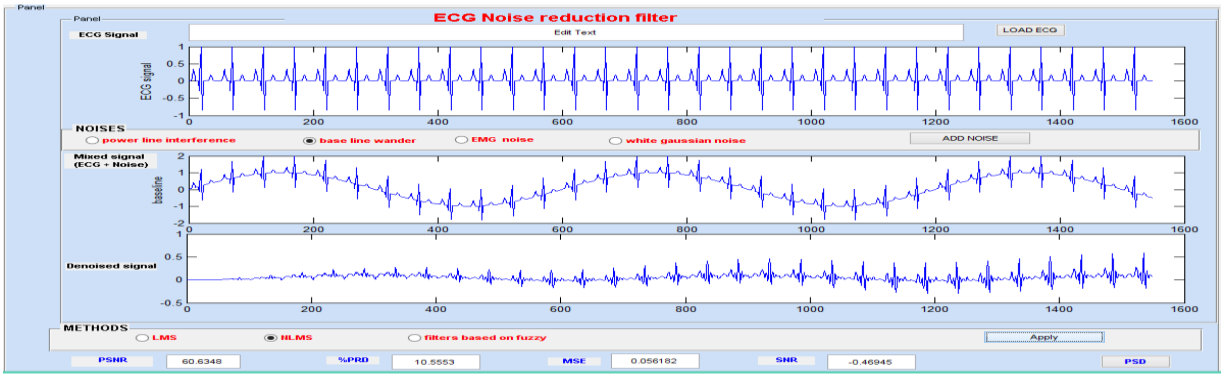

Fig. 3(e) Base line wander noise removal using NLMS filter

Figure 3(f) shows the use of fuzzy based filter. The figure shows the improved ECG signal of proposed technique than LMS and NLMS.

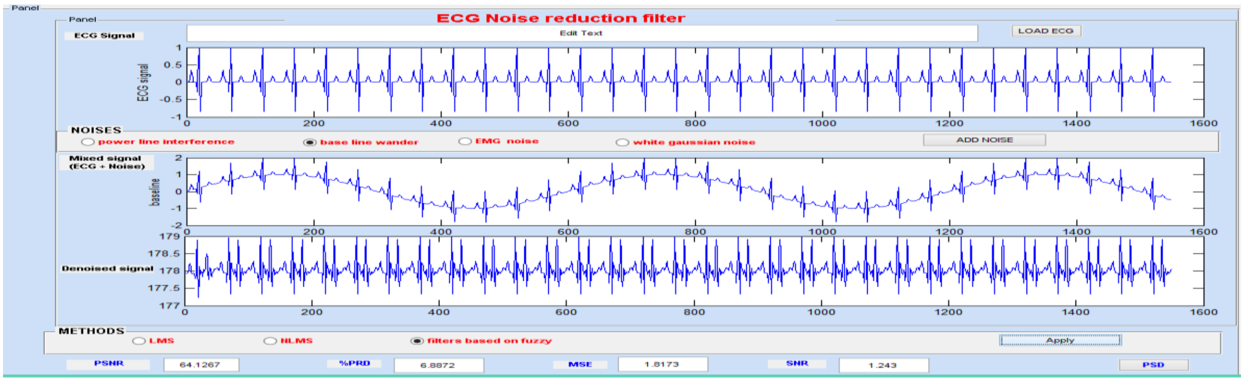

Fig. 3 (f) Base line wander removal using filters based on fuzzy

The noise added to the ECG signal is EMG noise of frequency 300 Hz is shown in figure 3(g), 3(h) and 3(i). The EMG noise is a high frequency noise. LMS filter based output is shown in figure 3(g).

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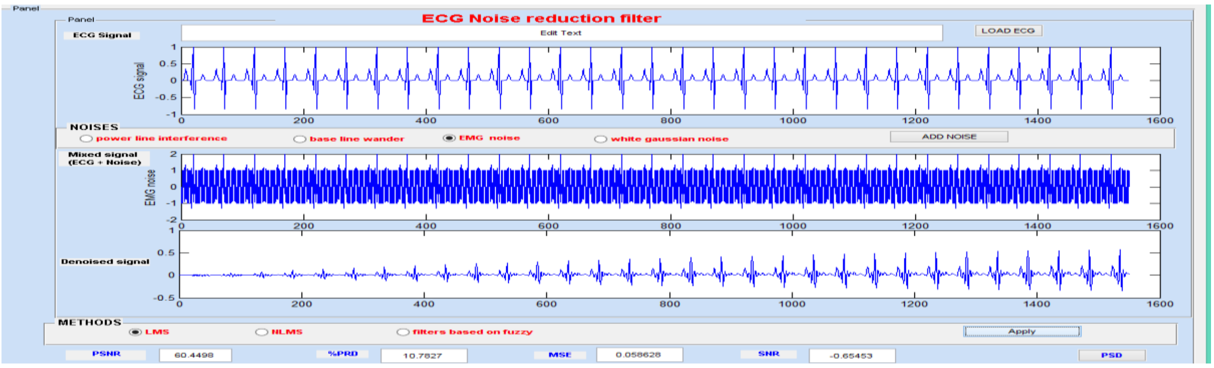

Fig. 3(g) EMG noise removal using LMS filter

Figure 3(h) shows the use of NLMS filter for removing 300Hz EMG noise.

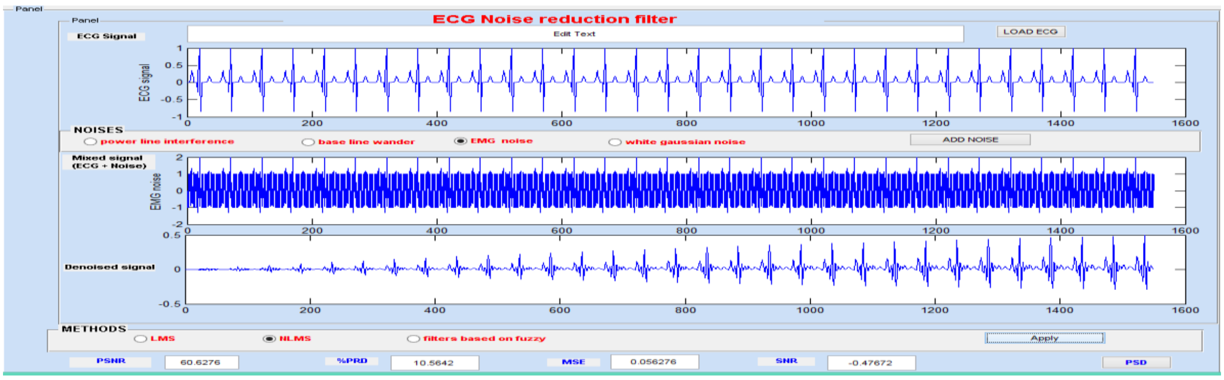

Fig. 3(h) EMG noise removal using NLMS filter

Figure 3(i) shows the output of proposed work which removes noise better by using combination of filters (notch filter and low pass filter) selected by fuzzy logic. Quality of image is improved in the proposed technique than the adaptive filters

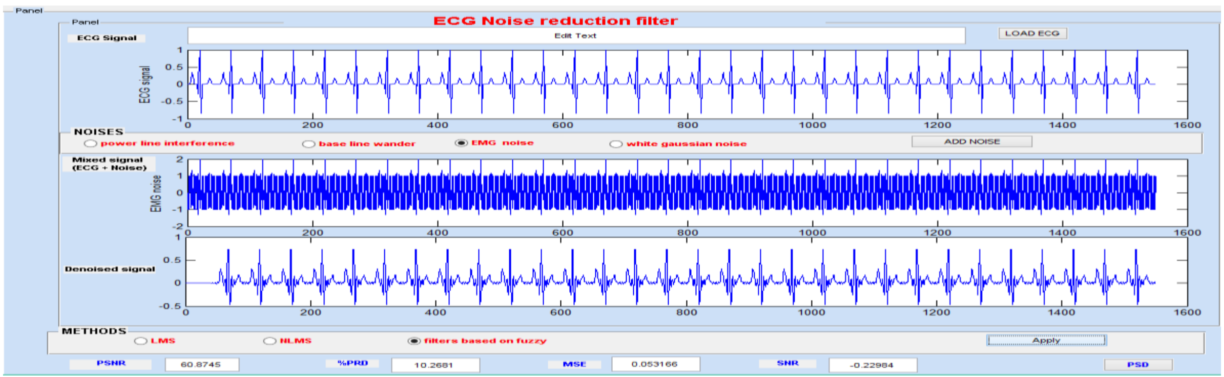

Fig. 3(i) EMG noise removal using filters based on fuzzy

The ECG signal of 50 Hz and the white noise is generated by the MATLAB Software. Mixed signal here is white noise with ECG signal. Figure 3(j) shows the output of the LMS filter.

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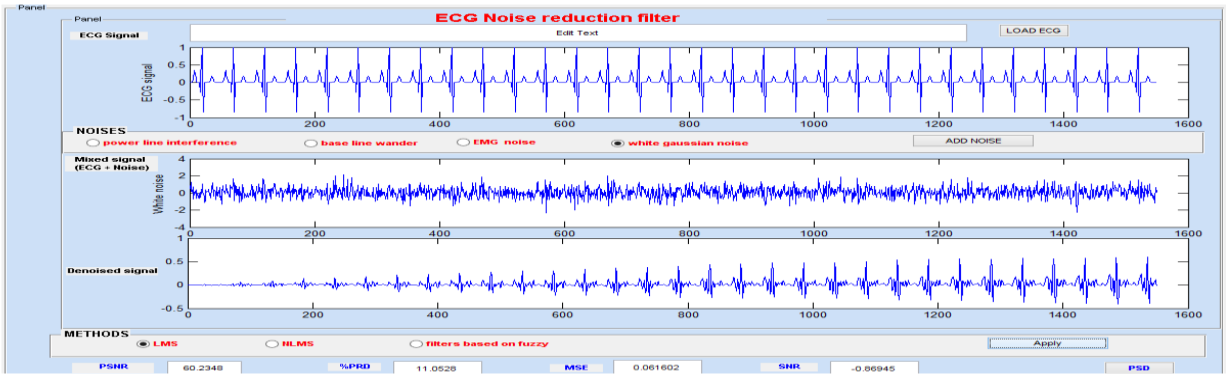

Fig. 3(j) White noise removal using LMS filter

Adaptive NLMS filter is used to remove white noise is shown in figure 3(k). As NLMS filter gives better result than LMS filter.

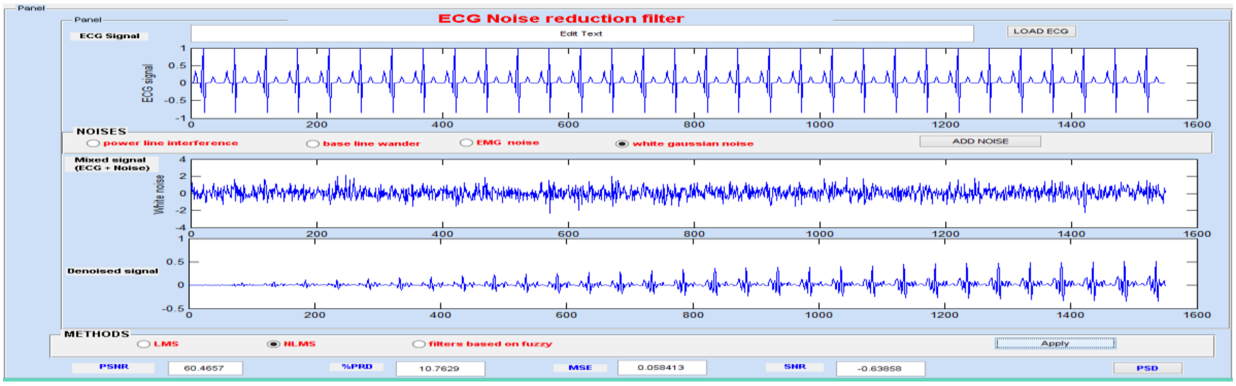

Fig. 3(k) White noise removal using NLMS filter

The output of the proposed technique is as shown in figure 3(l). In the rule set the filters used to remove white noise is NLMS and RLS filter. Better image of ECG signal shows that the proposed technique is more better and efficient than NLMS and LMS filters.

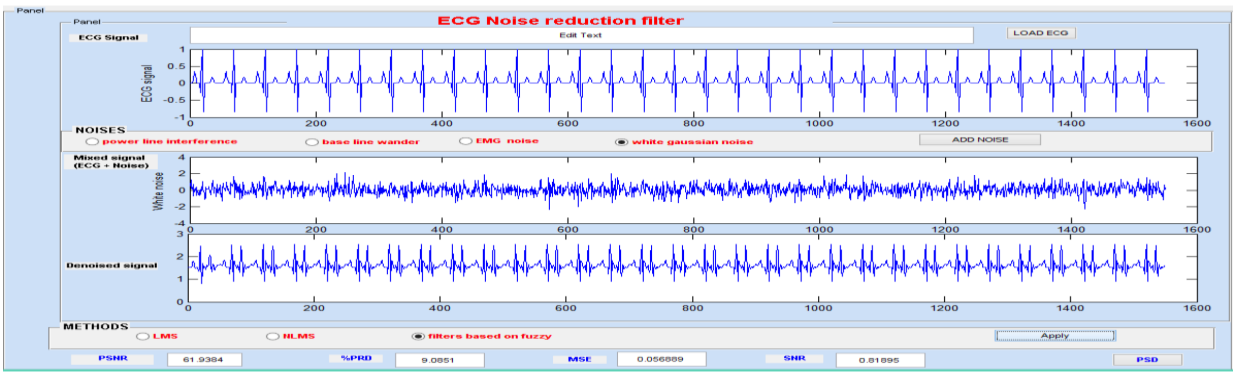

Fig. 3(l) White noise removal using filters based on fuzzy

Table 1 shows the performance comparison of proposed approach with LMS and NLMS filters in terms of PSNR, SNR, %PRD and MSE. The table revels that the proposed technique shows better result than LMS and NLMS for the

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following four noises. Low MSE and %PRD, high SNR and PSNR shows that the proposed approach is more effective and optimum technique than LMS and NLMS.

NOISES	FILTERS	PSNR	%PRD	MSE	SNR
Power line interference	LMS	60.2991	10.9714	0.060698	-0.80523
	NLMS	60.5008	10.7195	0.057943	-0.60352
	Filters using fuzzy	62.3609	8.653	0.051535	1.243
Baseline wander	LMS	60.3357	10.9252	0.060188	-0.76863
	NLMS	60.6348	10.5553	0.056182	-0.46945
	Filters using fuzzy	64.1267	6.8872	1.8173	1.243
EMG Noise	LMS	60.4498	10.7827	0.058628	-0.65453
	NLMS	60.6276	10.5642	0.056276	-0.47672
	Filters using fuzzy	60.8745	10.2681	0.053166	-0.22984
White Noise	LMS	60.2348	11.0528	0.061602	-0.86945
	NLMS	60.4657	10.7629	0.058413	-0.63858
	Filters using fuzzy	61.9384	9.0851	0.056889	0.81895

Table 1 Performance Parameters in terms of PSNR, %PRD, MSE, SNR

PSD is a visual parameter used to evaluate the performance of the techniques applied for reducing noise from the mixed noisy ECG signal. The PSD of noisy ECG, LMS, NLMS and filters based on fuzzy is as shown in figure 4(a), 4(b), 4(c) and 4(d) respectively.

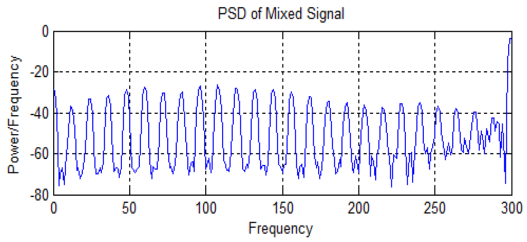

Fig. 4 (a) PSD of mixed EMG signal (300 Hz)

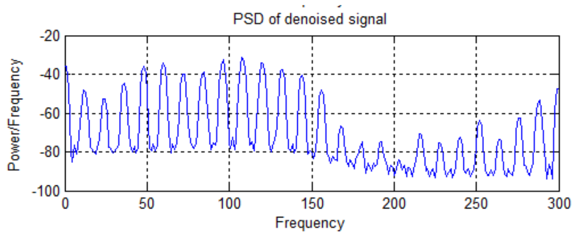

Fig. 4 (b) PSD of LMS filtered signal

By observing the figures it is shown that the 300 Hz EMG noise is more effectively removed by the filtered signal based on fuzzy than LMS and NLMS filter. Reduction of peak at 300 Hz shows that the proposed technique removes noise more effectively.

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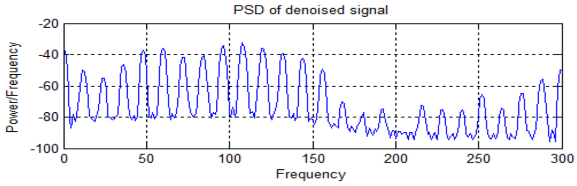

Fig. 4 (c) PSD of NLMS filtered signal

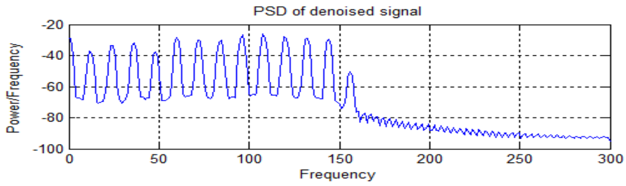

Fig.4 (d) PSD of filtered signal based on fuzzy

V. CONCLUSION

All the three filtering techniques, LMS, NLMS and selective filter using fuzzy reduces the noises ie, PLI, baseline wander, EMG noise and white noise from the ECG signal. The different parameter like low MSE and %PRD, high SNR and PSNR shows that the proposed approach is more effective and optimum technique than LMS and NLMS. The PSD graph shows better result for the proposed approach than LMS and NLMS.

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BIOGRAPHY

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