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Adaptive power line and baseline wander removal from ECG signal

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Abstract— In this paper a new approach for adaptive power lines noise and baseline wander removal from ECG signal were tested based on array of band pass and band stop (notch) filters with shifted center frequencies to cover the expected variation range of the noise for power lines and an array of band pass and high pass for baseline wander , the band pass filters are used to localize the noise frequency while the corresponding notch and high pass filters for removal . The model was tested using an ECG signal from MIT-BIH database with simulated variable frequency power lines and baseline noise.

Index Terms—**ECG, Baseline wander, MIT-BIH. Notch filter.**

I. INTRODUCTION

Electrocardiogram (ECG) reflect the electrical activity of the hearts and remain the most important tool for heart disease diagnoses .however the ECG signal are corrupted by different types of noises and artifacts such as power- line noise (50/60 Hz),baseline wander, motion artifacts, muscle contraction and other external noises so the removal or reducing the effect of these noise and mainly power-line and baseline wander without effecting the embedded parameters of ECG signal will play a vital role to get clean ECG which in turn help in diagnoses

II. LITERATURE REVIEW

Conventional notch filtering with a narrow frequency band around 50/60 Hz has been a traditional way of eliminating the power line interference [1].but a very narrow notch filter Is not easy to achieve with a possibility of losing some useful information in addition to the degradation in case of frequency variation. Many adaptive techniques was used to track the frequency variation as described in [2] With input signal with noise and noise reference as second input as in Fig 1 One major limitation of the classical adaptive techniques is the necessity of acquiring power-line reference signals; which cannot be achieved without modifying the ECG acquisition hardware and increasing the system Complexity. In addition to performance degradation when there is a non-controlled variation in the reference signal Islam S. Badreldin and Amr A. El-Wakil[3] present a system without the need for power lines noise reference as in Fig.2 with more calculation complexity Wavelet transform are used recently which is based on applying threshold on wavelet coefficients as in [4]-[5][6] Empirical mode decomposition (EMD) based on intrinsic mode functions (IMFs) as in[7] Wavelet transform is used for baseline removal as in[8] based on calculating the energy for both the coarse and detail is calculated for each level and the branch with higher energy is chosen A cubic spline method is used for baseline removal based on estimating the baseline wander and then subtracting from ECG signal as in[9] A cascade adaptive filter working on two stages. The first stage is was an adaptive notch filter at zero frequency and the second was an adaptive impulse correlated filter as in [10] A linear filter with controlled cut-off frequency by low-frequency properties of ECG signal with decimation is used as in[11] A multi-rate architecture with linear low-pass filter working at low sampling rate was used for baseline removal as in [12]

III. THEORY

Poles zeros method is used for notch, band pass filter and high pass filter design [13]

A. Band pass filter

$$r = 1 - \left(\frac{Bw}{F_S}\right)\pi \quad (1)$$

$$\theta = 360 * \left(\frac{F_0}{F_S}\right) \quad (2)$$

$$H(z) = \frac{k(z^2 - 1)}{z^2 - 2r\cos(\theta)z + r^2} \quad (3)$$

$$k = \frac{(1-r)\sqrt{1-2r\cos(2\theta)+r^2}}{2|\sin(\theta)|} \quad (4)$$

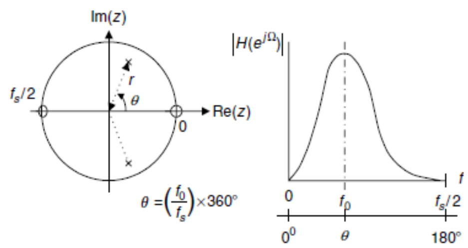

Fig. 1 Pole-zero placements for a second order narrow band pass filter

B. Notch filter

$$H(z) = \frac{k(z^2 - 2z\cos(\theta) + r^2)}{z^2 - 2rz\cos(\theta) + r^2} \quad (5)$$

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$$k = \frac{1 - 2r\cos(\theta) + r^2}{2 - 2\cos(\theta)} \quad (6)$$

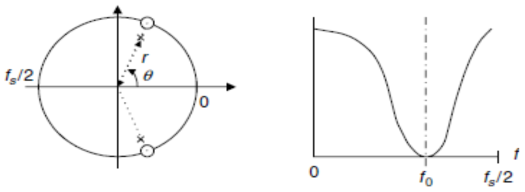

Fig. 2 Pole-zero placements for a second order Notch filter

C. High pass filter

$$H(z) = \frac{k(z-1)}{z-\alpha} \quad (7)$$

$$k = \frac{1+\alpha}{2} \quad (8)$$

$$\alpha = 1 - 2\left(\frac{F_C}{F_S}\right)\pi \quad \text{Good for } 0.9 \le \alpha < 1 \quad (9)$$

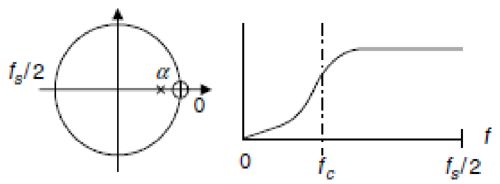

Fig. 3 Pole-zero placements for the first order high pass filter

IV. DESIGN AND IMPLEMENTATION

A. Filter design

For power line noise the following specifications are used. BW=1 Hz ,F_S=360, for F_0=58,58.2------61.8,62 Hz The calculated parameters for Band Pass filter for 60 Hz
K=0.0036

$$H(z) = \frac{z^2 - 1}{265.79z^2 - 263.4705\,z + 261.1713}$$

And for notch filter
K=0.9913

$$H(z) = \frac{z^2 - z + 1}{1.000872\ z^2 - 0.99992\ z + 0.9912}$$

For base wander removal the following specifications
BW=1 ,F_S=360,F_0=0.2,0.4,----2 Hz
The calculated parameters for High Pass Filter F_C=0.2 Hz

$$r = 0.9913$$
$$\alpha = 0.9965$$
$$k = 0.9983$$

$$H(z) = \frac{z-1}{1.0017z - 0.99825}$$

To get sharper cut off and reduced transition zone a cascade of three filters are implemented to get

$$H(z) = \frac{z^3 - 3z^2 + 3z - 1}{1.0542\,z^3 - 3.0523\,z^2 + 2.9458\,z - 0.94765}$$

For notch filter with F_0=0.2 Hz, BW=1 Hz

$$H(z) = \frac{z^2 - 1}{z^2 - 1.9825\,z + 0.982}$$

The frequency responses for the filters as shown in Fig.3,4,5,6

B. Implementation

For power line noise removal an array of band pass filters with shifted center frequencies to cover the range of power lines noise variations (58,58.2,58.4,…………….61.8,62HZ) used to track the power line noise. An array of notch filters with shifted center frequencies as for band pass filters are used for noise removal ,at a given time one notch filter is selected depending on the location of maximum value obtained from band pass filters as shown in Fig 7 For base wander removal an array of band ass filter to localize the noise and an array of high pass filter for removal as shown in Fig 8

V. EXPERIMENTS AND RESULTS

1-An ECG signal from MIT-BIH database is used as shown in Fig. 9 with its spectrum
2- A sinusoidal signals with frequencies 58HZ,58.2HZ,………. 62HZ was generated and added to the ECG signal as follow to simulate power line noise
ECG = ECG + Sin(2*π*58*t)
for number of Samples <3000
ECG = ECG + Sin(2*π*58.2*t)
for number of Samples 3000< number of Samples<6000
ECG = ECG + Sin(2*π*58.4*t)
for number of Samples 6000< number of Samples<9000
ECG = ECG + Sin(2*π*58.6*t)
for number of Samples 9000< number of Samples<12000
ECG = ECG + Sin(2*π*62*t)
for number of Samples 57000< number of Samples<60000
As shown in Fig 10 3-the position of maximums corresponding to noise frequency for all the band pass filters were located which indicate the index for band filters (for samples < 3000 the frequency is 58 Hz ,index =1) as shown in Fig 11 5-using the index calculated in step 3 a given notch filter with center frequency matching the noise frequency to produce filtered ECG signal after removing the power lines noise as shown in Fig 12 for filtered ECG as compared to un filtered ECG 6-for baseline wander simulation a sinusoidal signal with frequencies 0.2,0.4,…2 Hz was added to ECG signal as in step 2 ,as shown in Fig. 13 7-the same procedure is used for removal as shown in Fig. 14

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VI. CONCLUSION

1-the algorithms proposed in this paper for power line and baseline wander removal gives acceptable results based on poles and zero placement method .
2-A better results could be obtained using a higher order Filter
3-The array filters could be implemented based on FPGA Circuit design

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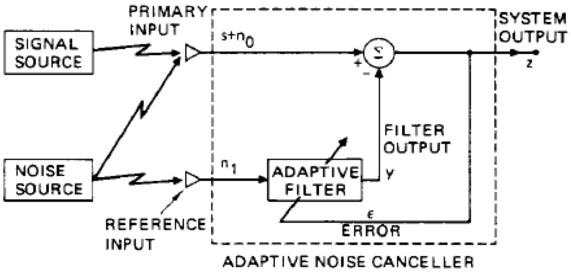

Fig. 1 basic adaptive noise cancelation [2]

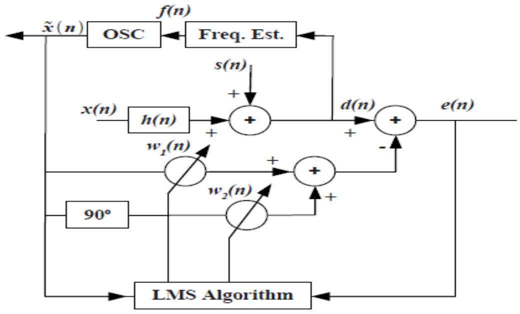

Fig. 2 adaptive noise cancelation without reference signal [3]

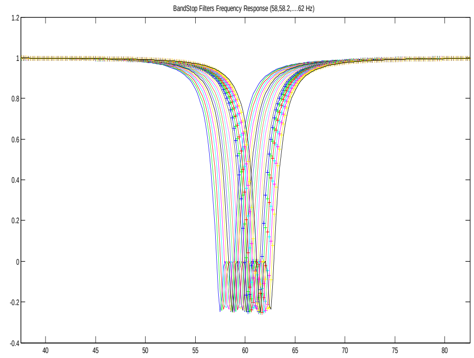

Fig. 3 Notch filter (58, 58.2, ---62 Hz)

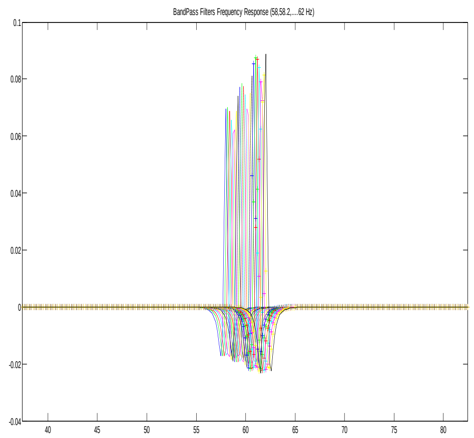

Fig. 4 band pass filter (58, 58.2, ---62 Hz)

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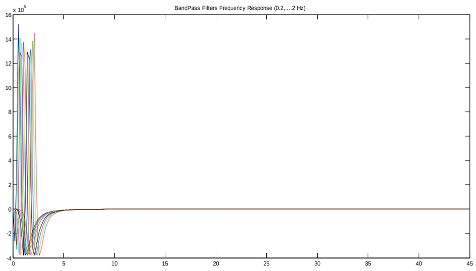

Fig. 5 band pass filter (0.2,0.4,---2 Hz)

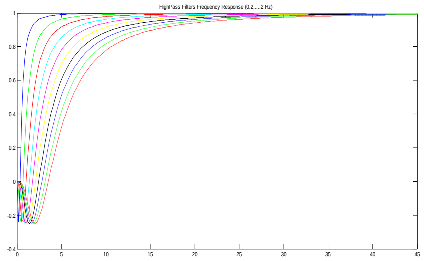

Fig.6 high pass filter (0.2,0.4,---2 Hz)

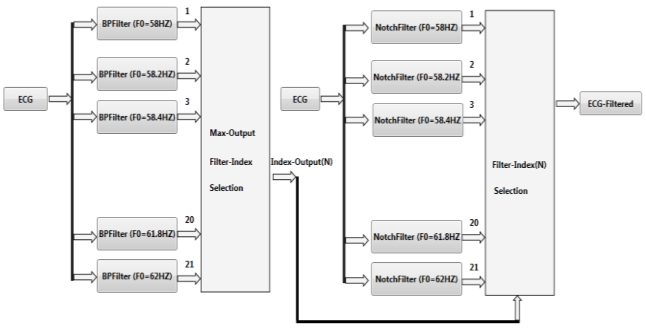

Fig. 7 System block Diagram for power line noise removal

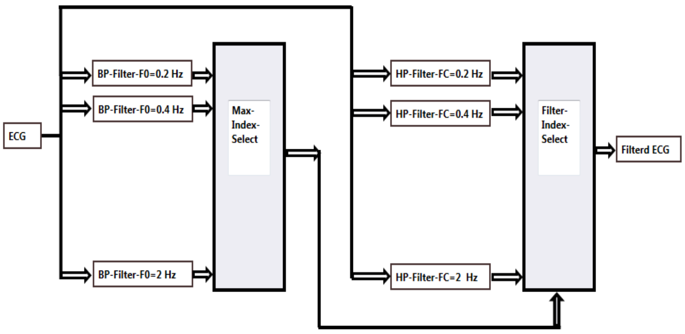

Fig.8 System block Diagram for base line noise removal

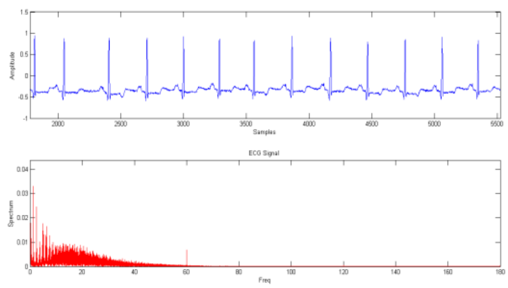

Fig 9 ECG Signal

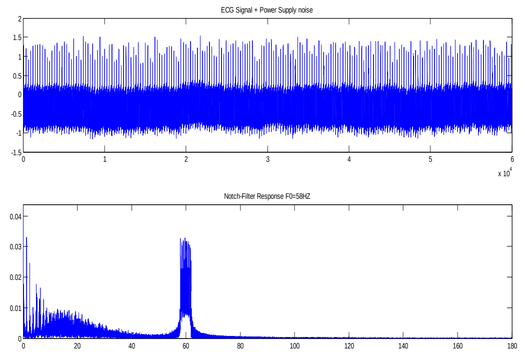

Fig 10 ECG Signals with power lines Noise

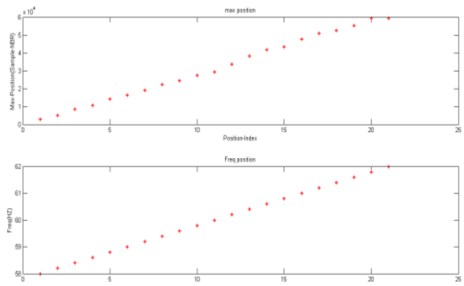

Fig 11 Band Pass Maximum index

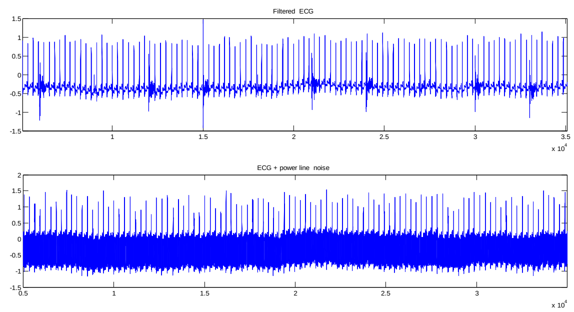

Fig 12 Filtered ECG (power lines noise removal)

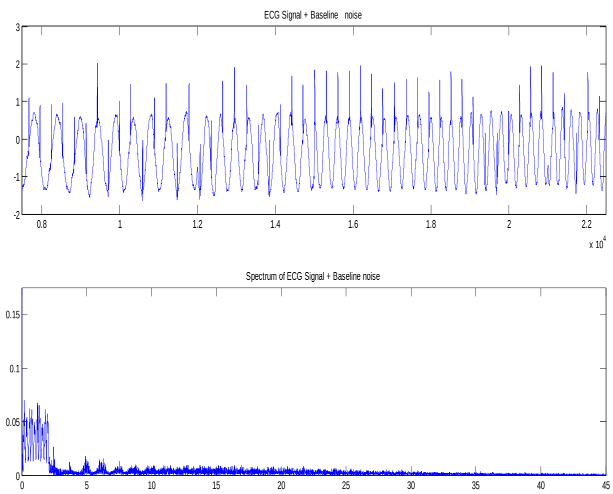

Fig.13 ECG with baseline wanders 0.2—2 Hz

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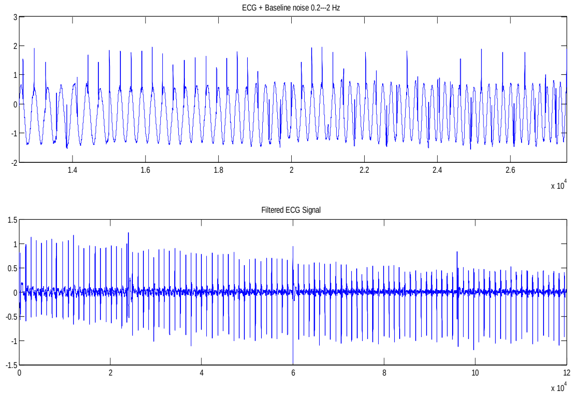

Fig.14 Filtered ECG

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