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Performance Analysis of IIR & FIR Windowing Techniques in Electroencephalography Signal Processing

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Abstract: ***A very small amplitude (µV) of the electroencephalography (EEG) signal is infected by diverse artifacts. These artifacts have an effect on the distinctiveness of the signal because of which medical psychoanalysis and data retrieval is difficult. Therefore, EEG signals are initially preprocessed to eliminate the artifacts to produce signals that can serve as a base for further processing and analysis. Different filters are implemented to eliminate the artifacts present in the EEG signal. Recent research shows that window technique Finite Impulse Response (FIR) filter is usually used. In this paper, digital Infinite Impulse Response (IIR) filter and different Finite Impulse Response (FIR) window filters (Hanning, Hamming, Kaiser, Blackman) of various orders are implemented to eradicate the random noise added to EEG signals. Their performance analysis has been done in Matlab (R2016a) by calculating the mean square error, mean absolute error, signal to noise ratio, peak signal to noise ratio and cross-correlation. The results show that Kaiser Window based finite impulse response filter outperforms in removing the noise from the electroencephalogram signal. This research focuses on eradicating random noise in electroencephalogram signals but this approach will be extended to a different source of electroencephalogram contamination.***

Keywords: Blackman Window, FIR filter, Hamming Window, Hanning Window, IIR filter, Kaiser Window.

I. INTRODUCTION

Electroencephalography signal is the electric signal of a brain with a distinctiveness features like nonperiodic, small voltage amplitude and non-standardized pattern [1]-[4].

EEG signals are classified on the basis of frequency:

(i) Alpha waves (frequency 8 - 13 Hz)
(ii) Beta waves (frequency > 13 Hz)
(iii) Theta waves (frequency 3.5 - 7.5 Hz)
(iv) Delta waves (frequency 3 Hz or less) [1],[5]-[7].

While recording the EEG signal or during transmission, the EEG signal is infected by artifact [8]-[11].

The removal of noise using signal processing technique is essential for reliable analysis of the EEG signal [12],[13]. In signal processing, a filter is used to eliminate the unnecessary constituent of the signal [14]. Diverse filter designs viz. Infinite Impulse Response (IIR) and Finite Impulse Response (FIR) are used for different purposes [1], [14], [15]. In the finite impulse response (FIR) system, the impulse response is of limited duration while the infinite impulse response system has unlimited duration. While realization, no feedback is needed in a FIR filter [15]. Due to which, the construction of the FIR filter is much easier than the IIR filter [15],[16]. The IIR and FIR filter is chosen according to the requirements and specifications of frequency response. Then a proper method is applied like Fourier series, Frequency sampling or Window, through which the finite impulse response filter can be obtained [15],[17]. Out of these methods, window techniques are usually used.

There are many other advantages of the FIR filter over the IIR filter [17]. FIR filters are stable, easily designed and various techniques are available to design the FIR filter and are free of limit cycle oscillations, no feedback is required.

In the windowing technique, frequency response specification Hd(ω) and their unit sample response $h_d(n)$ is found by the use of inverse Fourier transform.

$$h(n) = h_d(n)w(n) \qquad (1)$$

The windowing function w (n) multiplied with $h_d(n)$ is same as $H_d(\omega)$ convolution with w (ω), where w(ω) is the frequency domain representation of window function. By using an appropriate window functions method, Gibbs oscillations can be reduced. Researchers have proposed many windowing techniques to filter EEG data, out of which few offer excellent solution to eliminate noise from EEG data[17],[18]. In this paper, among all the windowing techniques, Kaiser, Blackman, Hanning and Hamming techniques have been discussed for designing the FIR filter. This paper focuses on comparing four windowing techniques that outperform in EEG signal filtering process and their performance has been analyzed by calculating the following performance parameters [19]:

(i) Mean Square Error (MSE)
(ii) Mean Absolute Error (MAE)
(iii) Signal to Noise Ratio (SNR)
(iv) Peak Signal to Noise Ratio (PSNR)
(v) Cross correlation (CC).

The rest of this paper is structured as follows: Materials & methods to identify competent filter structure is described in Section II. Section III discusses the results obtained. Section IV describes a comprehensive discussion of the obtained results. The last section concludes along with the future scope of this research.

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II. MATERIALS AND METHODS

A system has been proposed to identify the efficient filter structure to eliminate noise from EEG signals. A block diagram to identify the efficient filter structure to eliminate the artifacts from the EEG signal is sketched in Fig.1. The proposed system comprises of three steps namely loading of EEG data & preprocessing of acquired EEG signals and identification of the competent filter structure in subsection A and B respectively. Various filter structures are designed in MATLAB (R2016a, 64bit) to find out the competent filter structure to eliminate artifacts from acquired EEG signals.

A. Loading & Preprocessing of EEG data

EEG signals can be loaded from an online dataset of Neuroelectric and Myoelectric database of Physiobank ATM to Matlab workspace with the use of "load" command[22],[23]. This EEG database consists of EEG signals acquired from 11 participators at a frequency of 5, 6, and 10 Hz. The acquired EEG signals are signals when a rapid serial visual presentation (RSVP) task is done. The eight diverse channels of 10-20 EEG signal acquisition system (PO8, PO7, PO3, PO4, P7, P8, O1, and O2) were used to acquire the EEG signal. Channel "O" represents the occipital region and "P" represents the parietal region. The five dissimilar continuous EEG signals of frequency 10Hz with a sampling rate of 2048 Hz, amplitudes of the order of microvolt from the PO7 channel is considered in this proposed work. A random noise is added to the loaded EEG signals and digital filter structures (IIR and FIR) are implemented to identify the best filter structure. Noise is a random signal which occurs naturally. There are many types of random noise like square root noise, pink noise, white noise, proportional noise, blue noise and thermal noise. Random noise occurs in any conducting medium which is due to the random motion of electrons. When signals of random noise are collective with electronic circuits, the resulting noise is the combined power of individual signals. In this work, white noise which consists of distributed random numbers is used. The "randn" MATLAB function is used to generate a 1-by-N vector random numbers with 0.1 standard deviation. A randn function generates a random number with an undefined pattern of numbers. Extremity of signal fluctuation from the mean is calculated by the standard deviation. No precise peak to peak value is there in the random noise, it's nearly 6 to 8 times of the standard deviation so a random noise of 0.6 to 0.8 peak to peak is generated in this work for analysis.In this research, the EEG signals are loaded from the database of Physiobank ATM. The recorded EEG signal is exported to MATLAB (R2016a) workspace which is shown in Fig. 2.

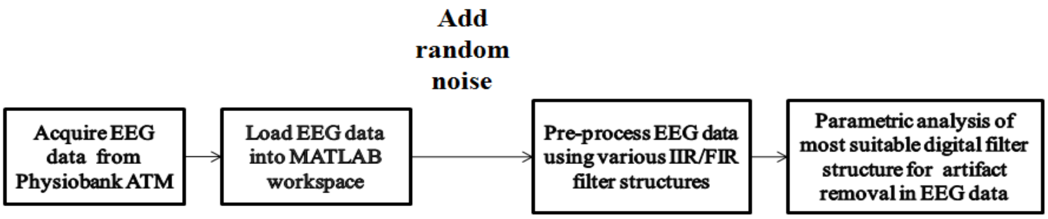

Fig.1. Block Diagram Of The Filter Structure Identification System.

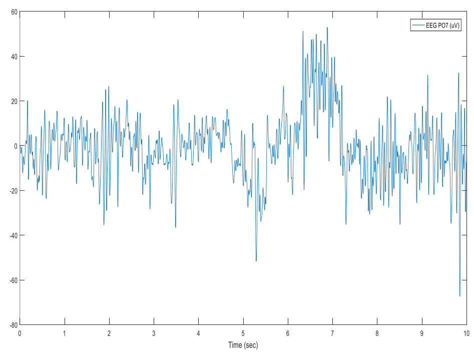

Fig. 2. An EEG signal loaded from the database of Physiobank ATM

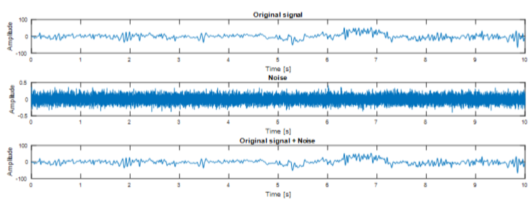

Fig.3. EEG signal with random noise introduced

A random noise is introduced to the records of the loaded EEG signal. The original EEG signal, a random noise signal and resulted noisy EEG signal is shown in Fig.3. It shows a loaded EEG signal, random noise and the EEG signal with random noise. To filter the noise present in the EEG signal, different digital filter structures are proposed. Filtering is required to allow the desired frequencies and restrict undesired frequencies from the input signal. The passband is the range of frequencies of a signal which are allowed to pass and stopband is the range of frequencies which are not allowed to pass from the filter. The following digital filters have been proposed to reject the added noise from EEG signals.

(i) IIR filter is illustrates by differential equation.

The output signal y(n) is a convolution of the input signal x(n) with the infinite length impulse response h(n) of the filter.

$$\mathrm{y(n)} = \sum_{k=0}^{\infty} h(k)x(n-k) \qquad (2)$$

(ii)FIR filter is also illustrated by a differential equation.

The output signal y(n) is a convolution of the input signal x(n) with the impulse response h(n) of the filter.

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$$y(n) = \sum_{k=0}^{N-1} h(k)x(n-k) \quad (3)$$

The following various windowing techniques have been proposed to implement FIR filters -

(i) Hanning Window: It can be defined as a flat window whose first and last value is zero so there is a fast decay of the side lobes and represented as

$$w(n) = \frac{1}{2}(1-\cos 2\pi \frac{n}{N}) \quad (4)$$

(ii)Hamming Window: This function can be defined as a flat window whose first and last value is not zero so the level of the side lobes is approximately constant.

$$w(n) = 0.54 - 0.46\cos 2\pi \frac{n}{N} \quad (5)$$

(iii)Blackman Window: There is a rapid decay of side lobes and has a wide main lobe with the low frequency selectivity.

$$w(n) = 0.42 - 0.5\cos 2\pi \frac{n}{N} + 0.08\cos 4\pi \frac{n}{N} \quad (6)$$

(iv) Kaiser window: In this, the ratio of the power of the main lobe to the sidelobe is maximized. The sidelobe height is controlled by the parameter β. For a particular β, the height of the sidelobe is fixed with respect to the length of the window. As β increases, the height of the sidelobe decreases and the width of main lobe increase.

$$w(n) = I_o[\beta(1-[(n-\alpha)/\alpha]^2)^{\frac{1}{2}}] \quad (7)$$

where $\alpha = M/2$, $I_o(.)$ is a Bessel function

IIR Bandstop filter of the second order having the sampling rate of 512 Hz, lower cutoff frequency 50 Hz and higher cutoff frequency 60Hz is proposed to eliminate the noise from EEG signal. The bandstop filter is a selective filter with a high rejection which cannot attenuate other frequencies that belongs to the EEG signal. The IIR filters of the second order are typically recognized as biquads. Biquads are cascaded to realize higher order filters. The order of a filter is proportional to how many components are required or the number of calculations involved in designing a filter. Therefore, by designing a low order filter, the computation time can be minimized. A high-order filter provides superior response, but a high order filter has high cost, more space is required and adds to complexity in design. So, an appropriate selection of order is essential for designing a filter. A low pass filter is used to remove noise at higher frequencies than that of EEG signals. A low pass IIR filter having a sampling rate of 512 Hz, cutoff frequency of 50Hz, passband ripple of 0.01 is proposed to eliminate the noise from EEG signal. Further, an FIR low pass filter with the windowing technique of Hanning, Hamming, Blackman and Kaiser window having a sampling rate of 512 Hz, cut off frequency 50Hz is proposed by changing the order of the filter to recognize at which range of the order FIR filter gives a superior response. The phase delays of the FIR filters can be nullified by zero-phase digital filtering by the use of Matlab function filtfilt ( ). In the zero-phase filtering, EEG data is processed in forward as well as reverse directions which result in the zero phase distortion.

B. Identification of competent digital filter structure

The following parameters have been analyzed to proposed to assess the performance of designed filter structures to eliminate noise from EEG signals. The parameters are selected to evaluate the performance of the proposed IIR & FIR filters. The filter which provides lesser mean absolute error and mean square error, higher signal to noise ratio, peak signal to noise ratio and cross-correlation is considered as an efficient filter for removal of artifacts from EEG signals.

The following performance parameters have been calculated to evaluate the performance of filters -

(i) Mean absolute error (MAE) is the absolute error between the reconstructed signal & the original signal and is reflective of the performance of filter structure. MAE is used as a gauge to know how much divergence is there in the reconstructed signal from the original signal [20].

$$\text{MAE} = \frac{\text{Original Signal} - \text{Reconstructed Signal}}{\text{length of original signal}} \quad (8)$$

(ii)Mean Square Error (MSE) is the average squared error between the original signal and the reconstructed signal. It is a measure of signal fidelity and provides the altitude of error/distortion among them[21].

$$\text{MSE} = \frac{(\text{Original Signal} - \text{Reconstructed Signal})^2}{\text{length of original signal}} \quad (9)$$

(iii) Signal to Noise Ratio is defined as the ratio of signal power to the noise power.

$$\text{SNR(indb)} = 10\log_{10}\left[\frac{\text{original signal}^2}{(\text{Original Signal} - \text{Reconstructed Signal})^2}\right] \quad (10)$$

(iv) Peak Signal to Noise Ratio is defined as the ratio of maximum possible signal power and corrupting noise power which affects the reliability of its representation.

$$\text{PSNR (db)} = 10\log_{10}\left[\frac{(\text{maximum absolute value of originnal})^2}{\text{MSE}}\right] \quad (11)$$

(v) Cross Correlation is the correlation between the original and the reconstructed signal.

The loading of EEG signals to MATLAB workspace, preprocessing of acquired EEG signals and identification of competent digital filter structure is done using algorithms in MATLAB as per in Fig. 4.

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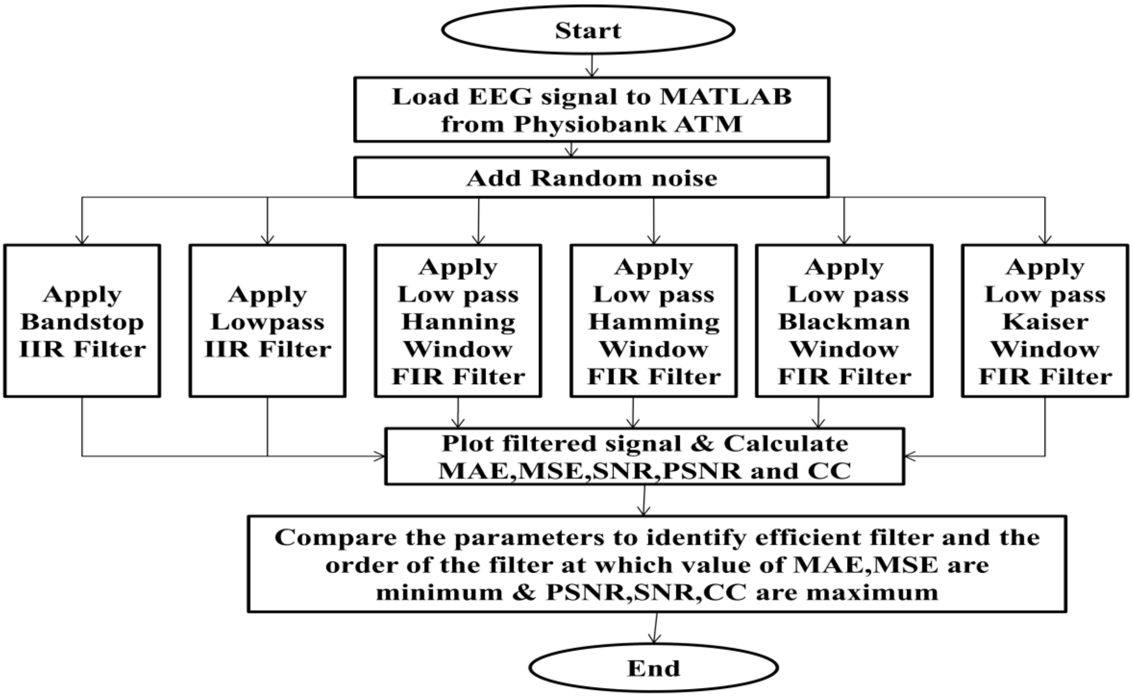


Fig. 4. Detailed Work Flow To Identify A Competent Digital Filter Structure To Eliminate Artifacts From EEG Signals

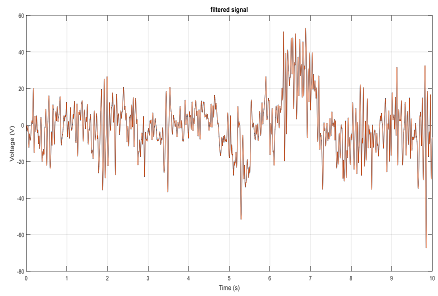
III. RESULTS & DISCUSSION

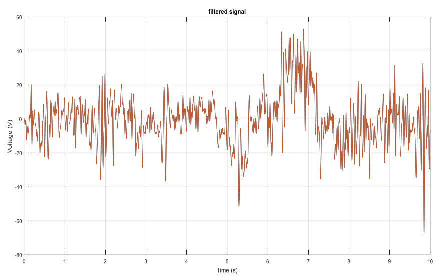
The various results obtained are described and analyzed in this section and the proposed algorithm to identify the competent digital filter structure for elimination of artifacts from EEG signals was developed in MATLAB release (R2016a).

A. IIR filter analysis

The second order bandstop IIR filter having a sampling rate of 512 Hz with lower and higher cutoff frequency 50Hz & 60Hz is applied to eradicate the noise from the EEG signal and the obtained filtered signal is shown in Fig 5.

(a)

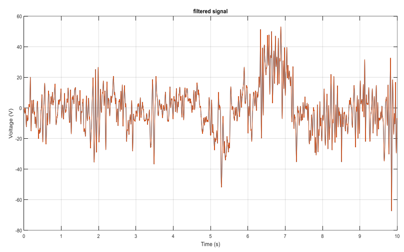




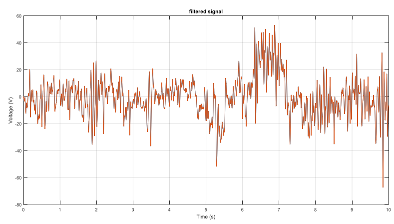
(b)

Fig. 5.Filtered EEG signal using bandstop IIR filter (a) For Subject1 (b) For Subject2

A low pass IIR filter having the sampling rate of 512Hz with the cutoff frequency of 50Hz and the passband ripple of 0.01 is applied to eradicate the noise from the EEG signal. To design digital filters matlab function 'designfilt' is used and the obtained filtered signal is as shown in Fig. 6.



(a)



(b)

Fig. 6. Filtered EEG signal using low pass IIR filter (a) For Subject1 (b) For Subject2

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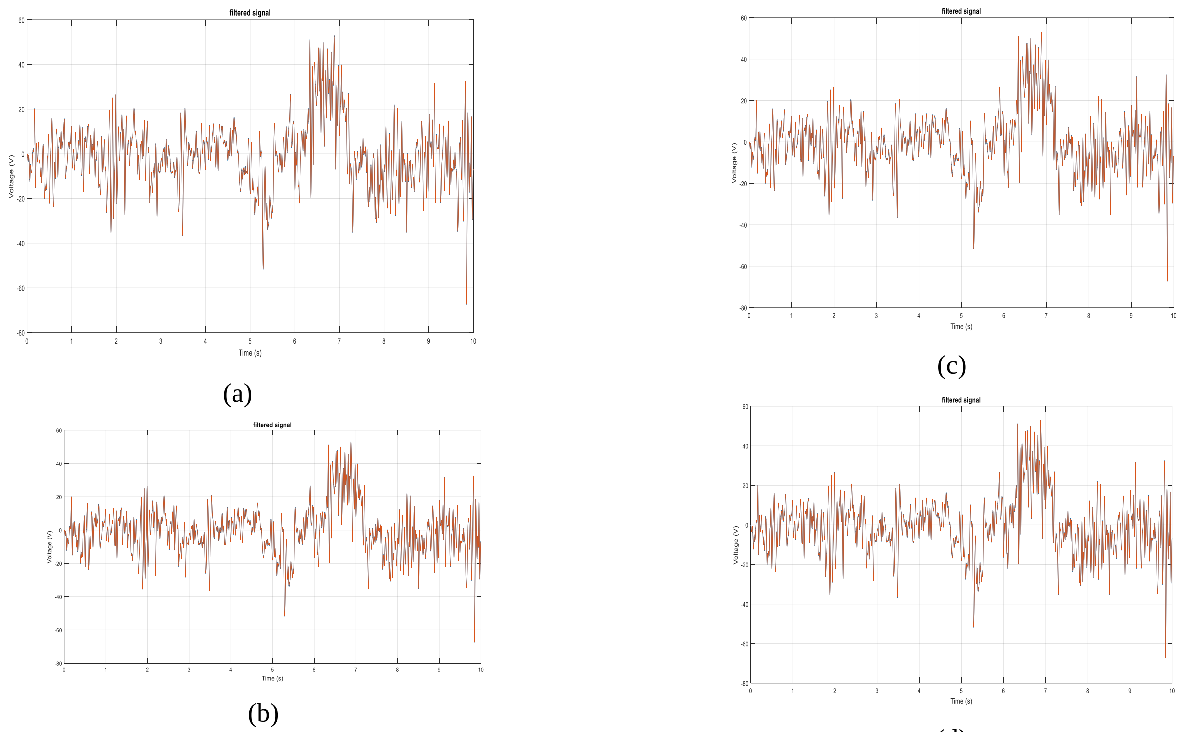
IIR digital filters with different orders were designed. The results illustrate that low pass IIR filter offers the best results at filter order 8. The passband ripple is very less. To assess the performance of the filter, performance parameters are calculated for the noisy signal and filtered signal.Table I illustrates that low pass IIR filter provides a better result than the band stop IIR filter in eliminating the noise from EEG signals. The performance parameter results are shown for two subjects and there is no considerable enhancement in values of parameters even with low pass IIR filter structures which show the necessity of further exploring the filters. So FIR filters were designed.

Table-I: Performance Parameters Of Noisy And Filtered EEG Signal Using Bandstop IIR Filter & Low Pass IIR Filter For Subject1 And Subject2

	Subject1			Subject2		
Parameters	*Parameters of noisy signal*	*Filtered signal using Bandstop IIR Filter*	*Filtered signal using Low Pass IIR Filter*	*Parameters of noisy signal*	*Filtered signal using Bandstop IIR Filter*	*Filtered signal using Low Pass IIR Filter*
Mean Squared Error	0.009851	0.009853	0.009525	0.009859	0.009496	0.009013
Mean Absolute Error	0.079341	0.079348	0.077786	0.079114	0.077623	0.076006
Signal to noise ratio(in db)	43.180489	43.189671	43.326977	44.764883	44.827634	44.986977
Peak signal to noise ratio(in db)	54.535269	54.552818	54.681757	53.004605	53.167356	53.482597
Cross Correlation	0.999976	0.999976	0.999977	0.999983	0.999983	0.999984

B. FIR filter analysis

A low pass Hanning, Hamming, Blackman and Kaiser window FIR filter having the sampling rate of 512 Hz and cut off frequency 50Hz is applied by changing the order of the filter. The FIR filter introduced a delay in phase which is nullified by applying zero-phase digital filtering by the use of Matlab function filtfilt ( ). Various windowing techniques are used to realize the digital filter and the obtained filtered signal is shown in Fig. 7.



(a) (b) (c) (d)

Fig.7. Filtered EEG Signal Using Low Pass FIR Filter

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Table-II: Performance Parameters Of Noisy Signal And Filtered Signal Filtered Using Hanning Window Low Pass FIR Filter

Hanning Window	Subject1				
	MSE	*MAE*	*SNR(in db)*	*PSNR(in db)*	*CC*
No filter	.0101	.0802	43.0577	54.4124	.999975
Order1	.0038	.0496	47.2647	58.6194	.999991
Order3	.0036	.0482	47.5465	58.8013	.999992
Order4	**.0035**	**.0469**	**47.7004**	**59.0552**	**.999992**
Order5	.0036	.0478	47.5382	58.8929	.999991
Order6	.0039	.0501	47.1684	58.5227	.999990
Order8	.0044	.0531	46.6847	58.0394	.999989
	Subject2				
	MSE	*MAE*	*SNR(in db)*	*PSNR(in db)*	*CC*
No filter	.0099	.0797	44.7118	52.9510	.999983
Order1	.0040	.0500	48.5190	56.9688	.999993
Order3	**.0037**	**.0499**	**48.6323**	**57.1453**	**.999993**
Order4	.0038	.0499	48.3247	57.0652	.999993
Order5	.0044	.0519	47.0668	54.9214	.999992
Order6	.0069	.0747	46.2453	54.1458	.999990
Order8	.0091	.0786	45.0019	53.0153	.999982
	Subject3				
	MSE	*MAE*	*SNR(in db)*	*PSNR(in db)*	*CC*
No filter	.0101	.0801	43.6896	55.3057	.999978
Order1	.0038	.0494	47.9265	59.5427	.999992
Order3	.0037	.0489	48.0354	59.6217	.999993
Order4	**.0034**	**.0468**	**48.3778**	**59.9940**	**.999993**
Order5	.0036	.0483	48.1265	59.7426	.999992
Order6	.0040	.0503	47.7469	59.3630	.999992
Order8	.0044	.0531	47.2754	58.8915	.999991
	Subject4				
	MSE	*MAE*	*SNR(in db)*	*PSNR(in db)*	*CC*
No filter	*.0100*	.0798	49.6251	61.2756	.999995
Order1	*.0037*	.0484	53.9883	65.6388	.999998
Order3	*.0036*	*.0478*	*54.1534*	*65.3458*	*.999998*
Order4	***.0034***	***.0463***	***54.3887***	***66.0391***	***.999998***
Order5	*.0036*	*.0483*	*54.0179*	*65.6683*	*.999998*
Order6	*.0040*	*.0501*	*53.6746*	*65.3251*	*.999998*
Order8	*.0044*	*.0532*	*53.1892*	*64.8396*	*.999998*
	Subject5				
	MSE	*MAE*	*SNR(in db)*	*PSNR(in db)*	*CC*
No filter	.0100	.0799	36.1873	48.0511	.999880
Order1	.0038	.0488	40.4464	52.3102	.999955
Order3	.0036	.0471	40.6212	52.5027	.999957
Order4	**.0034**	**.0467**	**40.8384**	**52.7022**	**.999959**
Order5	.0036	.0475	40.6624	52.5262	.999957
Order6	.0039	.0498	40.3032	52.1670	.999953
Order8	.0045	.0532	39.6846	51.5484	.999946

The performance parameters are calculated by applying varying order of Hanning window low pass FIR filter to 5 different subjects (EEG signals) loaded from Physiobank.With the increase in the order of the filter, the values of performance parameters are improved however in Subject1, 3, 4 and 5 after the order4 values start deteriorates and in Subject 2 after the order 3 values start deteriorates. This result shows that the best performance is obtained corresponding to minimum MSE and MAE maximum SNR, PSNR & CC with Hanning window low pass FIR filter possessing order 3 & 4.The performance parameters are calculated by applying varying order of Hamming window low pass FIR filter to 5 different subjects (EEG signals) loaded from Physiobank.

Table-III: Performance Parameters Of Noisy Signal And Filtered Signal Filtered Using Hamming Window Low Pass FIR Filter

Hamming Window	Subject1				
	MSE	*MAE*	*SNR(in db)*	*PSNR(in db)*	*CC*
No filter	.0101	.0802	43.0577	54.4124	.999975
Order1	.0037	.0488	47.3766	58.7314	.999991
Order4	.0037	.0484	47.4451	58.7999	.999991
Order5	.0036	.0478	47.5898	58.9446	.999991
Order6	**.0035**	**.0474**	**47.6323**	**58.9871**	**.999991**

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Order7	.0038	.0499	47.0386	58.5674	.999990
Order8	.0041	.0509	46.9944	58.3491	.999990
			Subject2		
	MSE	***MAE***	***SNR(in db)***	***PSNR(in db)***	***CC***
No filter	.0099	.0797	44.7118	52.9510	.999983
Order1	.0039	.0499	48.7638	57.0036	.999993
Order4	.0037	.0481	49.0778	57.3172	.999994
Order5	.0037	.0483	49.0512	57.2909	.999994
Order6	**.0036**	**.0478**	**49.1731**	**57.4128**	**.999994**
Order7	.0038	.0497	48.2995	57.0974	.999993
Order8	.0040	.0508	48.6464	56.8861	.999993
			Subject3		
	MSE	***MAE***	***SNR(in db)***	***PSNR(in db)***	***CC***
No filter	.0101	.0801	47.6896	55.3057	.999978
Order1	.0039	.0494	47.9265	59.5427	.999992
Order3	.0036	.0489	48.0065	59.7327	.999992
Order4	**.0034**	**.0469**	**48.3378**	**59.9939**	**.999993**
Order5	.0036	.0483	48.1265	59.7427	.999992
Order6	.0039	.0503	47.7469	59.3631	.999992
Order8	.0042	.0529	47.4245	59.0915	.999991
			Subject4		
	MSE	***MAE***	***SNR(in db)***	***PSNR(in db)***	***CC***
No filter	*.0100*	.0798	49.6251	61.2756	.999995
Order1	*.0038*	.0500	53.7373	65.3874	.999998
Order3	*.0037*	*.0486*	*53.9853*	*65.5248*	*.999998*
Order4	*.0035*	*.0474*	*54.1544*	*65.8048*	*.999998*
Order5	***.0034***	***.0469***	***54.2602***	***65.9107***	***.999998***
Order6	*.0036*	*.0480*	*54.0144*	*65.6649*	*.999998*
Order8	*.0039*	*.0502*	*53.6863*	*65.3367*	*.999998*
			Subject5		
	MSE	***MAE***	***SNR(in db)***	***PSNR(in db)***	***CC***
No filter	.0100	.0799	36.1873	48.0511	.999880
Order1	.0038	.0491	40.4134	52.2772	.999955
Order3	.0036	.0481	40.6359	52.5447	.999957
Order4	.0035	.0469	40.8204	52.6842	.999959
Order5	**.0034**	**.0468**	**40.8222**	**52.6860**	**.999959**
Order6	.0036	.0478	40.6195	52.4833	.999957
Order8	.0040	.0505	40.1598	52.0236	.999952

With the increase in the order of the filter, the values of performance parameters are improved however in Subject1 and 2 after the order6 values start deteriorates, in Subject 3 after the order 4 values start deteriorates and in Subject 4 and 5 after the order 5 values start deteriorates. This result shows that the best performance is obtained corresponding to minimum MSE and MAE maximum SNR, PSNR & CC with Hamming window low pass FIR filter possessing order 4 to 6.The performance parameters are calculated by applying varying order of Blackman window low pass FIR filter to 5 different subjects (EEG signals) loaded from Physiobank.

Table-IV: Performance Parameters Of Noisy Signal And Filtered Signal Filtered Using Blackman Window Low Pass FIR Filter

Blackman Window			**Subject1**		
	MSE	***MAE***	***SNR(in db)***	***PSNR(in db)***	***CC***
No filter	0.0101	0.0802	43.0577	54.4124	0.999975
Order1	Doesn't work for order 1				
Order4	0.0101	0.0802	43.0577	54.4124	0.999975
Order5	0.0036	0.0477	47.5688	58.9236	0.999992
Order6	**0.0035**	**0.0473**	**47.6772**	**59.0321**	**0.999992**
Order7	0.0035	0.0479	47.5253	58.9432	0.999991
Order8	0.0036	0.0481	47.4881	58.8429	0.999991
			Subject2		
	MSE	***MAE***	***SNR(in db)***	***PSNR(in db)***	***CC***
No filter	0.0099	0.0797	44.7118	52.951	0.999983
Order1	Doesn't work for order 1				
Order4	0.01	0.0799	44.6823	52.922	0.999982
Order5	**0.0036**	**0.0478**	**49.102**	**57.3418**	**0.999994**
Order6	0.0037	0.0485	49.0395	57.2792	0.999994
Order7	0.0037	0.0485	49.0097	57.2496	0.999993
Order8	0.0037	0.0486	48.9796	57.2193	0.999993
			Subject3		
	MSE	***MAE***	***SNR(in db)***	***PSNR(in db)***	***CC***

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No filter	0.0101	0.0801	43.6896	55.3057	0.999978
Order1	Doesn't work for order 1				
Order2	0.01	0.0798	43.6773	55.3697	0.999979
Order5	0.0036	0.0484	48.3311	59.8373	0.999992
Order6	**0.0034**	**0.0462**	**48.4882**	**60.1044**	**0.999993**
Order7	0.0036	0.0471	48.2357	59.9415	0.999992
Order8	0.0037	0.0484	48.1005	59.7167	0.999992
	Subject4				
	MSE	***MAE***	***SNR(in db)***	***PSNR(in db)***	***CC***
No filter	0.0101	0.0801	43.6896	55.3057	0.999978
Order1	Doesn't work for order 1				
Order3	0.01	0.0798	43.6773	55.3697	0.999979
Order4	0.0036	0.0484	48.3311	59.8373	0.999992
Order5	**0.0034**	**0.0462**	**48.4882**	**60.1044**	**0.999993**
Order6	0.0036	0.0471	48.2357	59.9415	0.999992
Order8	0.0037	0.0484	48.1005	59.7167	0.999992
	Subject5				
	MSE	***MAE***	***SNR(in db)***	***PSNR(in db)***	***CC***
No filter	0.01	0.0799	36.1873	48.0511	0.99988
Order1	Doesn't work for order 1				
Order2	0.0101	0.0801	36.1693	48.0331	0.999879
Order5	0.0035	0.0475	40.7579	52.6217	0.999958
Order6	**0.0034**	**0.0465**	**40.9152**	**52.779**	**0.99996**
Order7	0.0035	0.0471	40.7934	52.6922	0.999958
Order8	0.0036	0.0479	40.6371	52.5009	0.999957

With the increase in the order of the filter, the values of performance parameters are improved however in Subject1, 3 and 5 after the order6 values start deteriorates and in Subject 2 and 4 after the order 5 values start deteriorates. This result shows that the best performance is obtained corresponding to minimum MSE and MAE maximum SNR, PSNR & CC with Blackman window low pass FIR filter possessing order 5 & 6.The performance parameters are calculated by applying varying order of Kaiser Window low pass FIR filter to 5 different subjects (EEG signals) loaded from Physiobank.

Table-V: Performance Parameters Of Noisy Signal And Filtered Signal Filtered Using Kaiser Window Low Pass FIR Filter

Kaiser Window	**Subject1**				
	MSE	***MAE***	***SNR(in db)***	***PSNR(in db)***	***CC***
No filter	.0101	.0802	43.0577	54.4124	.999975
Order1	.0039	.0498	47.1763	58.5310	.999990
Order3	.0031	.0445	48.1465	59.5013	.999992
Order4	**.0029**	**.0430**	**48.3999**	**59.7547**	**.999993**
Order5	.0037	.0471	47.4929	58.8475	.999992
Order6	.0049	.0532	46.2104	57.5652	.999990
Order8	.0089	.0701	43.6193	54.9741	.999982
	Subject2				
	MSE	***MAE***	***SNR(in db)***	***PSNR(in db)***	***CC***
No filter	.0099	.0797	44.7118	52.9510	.999983
Order1	.0038	.0494	47.6921	57.8318	.999993
Order3	.0035	.0482	49.7237	57.9481	.999993
Order4	**.0034**	**.0474**	**49.7927**	**57.9853**	**.999994**
Order5	.0042	.0512	48.3681	55.0326	.999992
Order6	.0064	.0709	47.5766	54.8163	.999988
Order8	.0089	.0756	46.1661	53.1459	.999982
	Subject3				
	MSE	***MAE***	***SNR(in db)***	***PSNR(in db)***	***CC***
No filter	.0101	.0801	43.6896	55.3057	.999978
Order1	.0039	.0496	47.8705	59.4867	.999992
Order4	.0021	.0364	50.5812	62.1973	.999996
Order5	.0019	.0346	50.9844	62.6006	.999996
Order6	**.0016**	**.0324**	**51.5486**	**63.1647**	**.999996**
Order7	.0017	.0326	51.4238	63.0925	.999996
Order8	.0018	.0329	51.3870	63.0032	.999996
	Subject4				
	MSE	***MAE***	***SNR(in db)***	***PSNR(in db)***	***CC***
No filter	.0100	.0798	49.6251	61.2756	.999995

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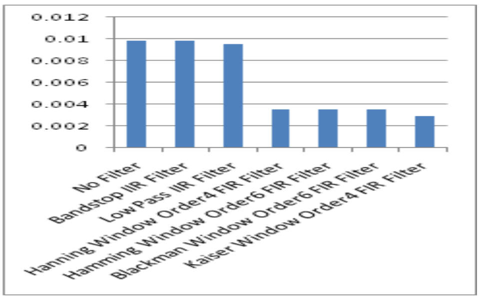
Order1	.0038	.0491	53.8495	65.4999	.999998
Order4	.0022	.0378	56.1526	67.8030	.999999
Order5	.0020	.0355	56.7148	68.3653	.999999
Order6	**.0019**	**.0350**	**56.7841**	**68.4346**	**.999999**
Order7	.0100	.0798	49.6251	61.2756	.999995
Order8	.0038	.0491	53.8495	65.4999	.999998
	Subject5				
	MSE	*MAE*	*SNR(in db)*	*PSNR(in db)*	*CC*
No filter	.0100	.0799	36.1873	48.0511	.999880
Order1	.0038	.0490	40.3991	52.2630	.999954
Order3	.0029	.0407	42.0023	54.1572	.999972
Order4	.0022	.0375	42.7116	54.5754	.999974
Order5	**.0020**	**.0359**	**43.0991**	**54.9629**	**.999976**
Order6	.0022	.0364	42.8524	54.7162	.999975
Order8	.0026	.0393	42.0783	53.9421	.999972

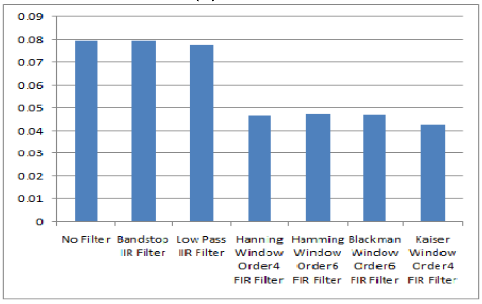
With the increase in the order of the filter, the values of performance parameters are improved however in Subject1 and 2 after the order4 values start deteriorates, in Subject 3 and 4 after the order 6 values start deteriorates and in Subject 5 after the order 5 values start deteriorates. This result shows that the best performance is obtained corresponding to minimum MSE and MAE maximum SNR, PSNR & CC with Hamming window low pass FIR filter possessing order 4 to 6.

The performance parameters are calculated by applying various IIR & FIR filters to EEG signals of five different subjects. The value of MAE & PSNR of the first noisy EEG signal is found to be 0.802 and 54.4124db. The value of the lowest value of MAE & highest value of PSNR of the first noisy EEG signal is found to be 0.0430 and 59.7547db when Order4 Kaiser Window low pass FIR filter is implemented. With signal 2, the value of MAE & PSNR of the noisy EEG

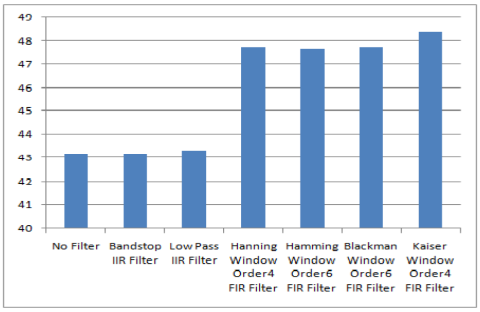
signal is found to be 0.0797 and 52.9510db. The value of the lowest value of MAE & highest value of PSNR of the noisy EEG signal is found to be 0.0474 and 57.9853 dB when Order4 Kaiser Window low pass FIR filter is implemented. The trends of signal 3,4 and 5 same as signal1, at signal 3 improved results are obtained at Order6 Kaiser window, at signal4 improved results are also obtained at Order6 Kaiser window and at signal 5improved results are obtained at Order5 kaiser window. The comparison of data obtained reveals that the best performance is obtained corresponding to minimum MSE and MAE and higher SNR, PSNR and CC with Kaiser Window low pass FIR filter possessing order 4 to 6 respectively.



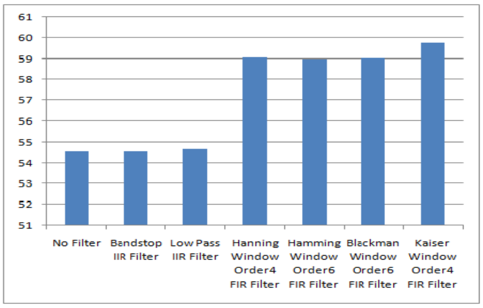
(a)



(b)



(c)



(d)

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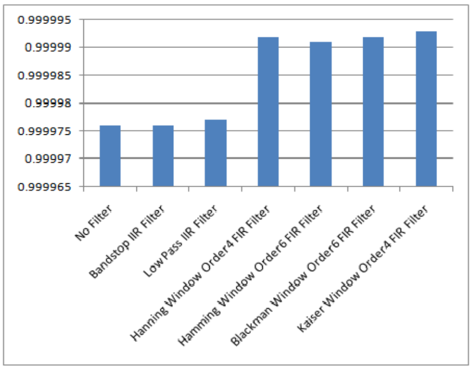

(e)

Fig.8. Performance analysis of IIR and FIR filters for EEG signals of Subject1 using (a) MSE (b) MAE (c) SNR (d) PSNR (e) CC

The performance analysis of implemented IIR and FIR filter structures for EEG signal for Subject1 preprocessing is depicted in Fig.8. The above bar graph represents the values of IIR and different FIR filters of order where best performance is analyzed. Similar trends are obtained from EEG signals for other Subjects. The analysis reveals that the minimum value of MAE,MSE and maximum value of SNR, PSNR and CC are obtained when an order4 to 6 Kaiser window low pass FIR filter are applied to an input noisy EEG signal. There are few disadvantages of the FIR filter that while implementing the filter, huge arithmetic operations are involved which confines its speed and more power is required. The Kaiser window offers the minimum main-lobe width and a sharper cut-off which indicates kaiser window has less transition width [24].Reference [25] also shows that to eliminate power-line noise from the EEG signal, Kaiser window FIR filters gives better performance than other FIR and IIR filters.

IV. CONCLUSION

In this paper, IIR & FIR digital filter of different orders were designed and analyzed. The performance parameters (MAE, MSE, PSNR, SNR, and CC) have been calculated to evaluate the performance of designed filter structures which implies Kaiser window low pass FIR filter with order 4 to 6 possesses better filtering capacity with lower MAE, MSE and higher PSNR, SNR and CC than the IIR & other FIR filters in denoising different EEG signals loaded from the Physiobank ATM database. Thus results show that windowing technique of FIR filters prove out to be the best filtering approach to remove noise for EEG signal. The future scope of this research is to apply designed filter structures on real-time acquired EEG signals.

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