JOURNAL OF SCIENTIFIC RESEARCH IN ALLIED SCIENCES
ISSN NO. 2455-5800
DOI No. 10.26838/JUSRES.2021.7.5.509
Contents available at www.jusres.com

DESIGNING EFFICIENT ZERO PHASE OPTIMUM REDUCED ORDER IIR FILTER FOR EEG ARTIFACTS ERADICATION

Nitin Jain, Dr. Shanti Rathore
Electronics and Communication Engineering
Dr. C.V. Raman University, Bilaspur, India

ARTICLE INFO | **ABSTRACT** | **ORIGINAL RESEARCH ARTICLE**

Article History
Received: Sept 2021
Accepted: Oct 2021
Keywords:
EEG, Reduced IIR filter, Zero Phase filter, Motion artifact eradication, Optimization Techniques

Corresponding Author
*** N. Jain**

It is highly desired to smooth the noise and motion artifacts form the Electro-Encephalography (EEG) signals. The recorded scalp EEG data suffers from the eye blink and muscular motion artifacts. The IIR filter has been previously used for filtering the artifacts from EEG signals. But pass-band-stop band IIR filters usually suffers from the large delay and phase distortion. Thus in this paper it is proposed to design zero phase (ZP) filter with reduced order and delay. The proposed filter is combination of Forward-Backward (FB) filter designed for minimizing phase distortion and to improve performance. The proposed design smooth motion artefacts using ZP-IIR filter along with Min-Max optimization for reduced order design. The improvement in parametric performance shows the effectiveness of proposed ZP reduced order IIR filters. Three unique EEG scalp data is considering t for result evaluation. Parametric performance is evaluated for Ratio of signal to noise (SNR), and mean square error (MSE). Results show that the proposed algorithm provides good improvement in SNR over existing algorithm.

INTRODUCTION

There are many techniques were designed for removing the noise and artifacts from the EEG signals [1-4]. The basic IIR digital filters are designed using classical approaches [1, 2, and 3]. IIR filters often offers non-linear phase responses. That's why may lead to time shifted delayed signal. The unwanted artifacts are usually present randomly and motion artifacts are classified as eye-blink or EOG artifacts, and mussel artifacts (EMG). Ocular artifacts (EOG) may cause low frequency high peaks in signal. Usually filtering EEG signal mostly reduces the amplitude. Thus filter is usually followed by the amplifiers. The DC gain plays the significant role for filter deigns shown in Figure 1. There must be balance between the reduction in DC gain and the filtering quality. Thus this paper also evaluated the DC gain of the filter for performance betterment.

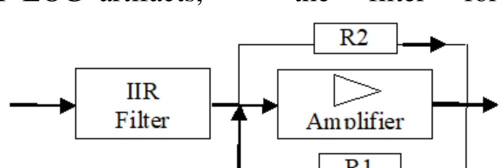


Fig. 1 filter with gain amplification

Reducing DC gain may ease the hardware requirement for filter design. Another major contribution of paper is to design the optimum ZP reduced order Infinite Impulse Response (IIR) filter using the optimization of transfer function coefficients. The proposed ZP filter is design using well defined Froward–Backward filter structure. The filter is a two stage process and with feedback involved.

The prime goal of the paper is to demonstrate the application of the ZP filter for the FFG artifact removal. The ZP filter is used to design the two stage IIR filter then the filter coefficients are optimizing to enhance the performance. The EEG artifact removal performance is compared with basic form-II IIR filter and the ZP filter.

There are many applications of the zero phases filter as shown in the Figure 2. Human machine integration (HMI [5]), measuring ultrasonic pressures [6], magnetic flux testing [7], brain computer interface (BCI [8]), compensating the physiological motions [9] uses of EEG signals processing [10].

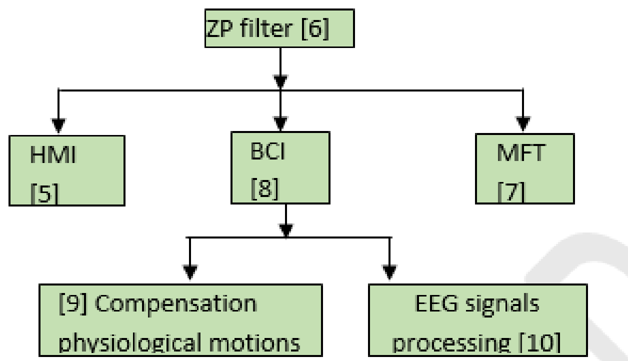


Figure 2 Application of the ZP filter design

The major application to focus here is the EEG signal processing. In this paper the concern is to design the ZP-IIR filter using the pass band - stop band filter design approach. Major contributions of the paper are;

1) IIR filter is designed as in our perilous approach [2] using pass-sop band filter for noisy EEG artifact signals filtering using the proposed ZP filter.
2) The filter coefficient optimization using Min-Max approach is proposed and then reduced order filter is design for EEG artifacts eradication.
3) Performance of form-II IIR filter is commixed with the proposed ZP filter.
4) The DC gains of the different filter stage are compared to demonstrate the effectiveness of proposed approach.

In the rest of the paper first basic design of the ZP filter is described in next section. Then the reviews of the various relevant researches for EEG filtering are presented in the section 3. The design of the basic optimum IIR Filter is presented n the section 4. The basic results of IIR filtering are validated for EEG filtering. Reduced order filter designs presented in the section 5. Results of proposed methodology with the ZP filter design are presented in section 6. It can be observed as the ZP filter minimizes the phase thus time delay in EEG signal is reduced and therefore filter performance is improved.

ZP FILTER DESIGN

The basic ZP filter is a concept of designing the filter with the linear phase responses. The basic concept is to design filter with the zero slope phase response. The prime concern of the ZP filter design is to satisfy the condition of the even impulse response.

$$h(n) = h(-n) \qquad (1)$$

The equation (1) signifies that the filter has to be symmetric across the t=0 axis.

Another important property of ZP filter is that it is non-causal filter. Thus ZP filters can be used for the offline processing of the EEG signal for analysis and the disease detection and classification.

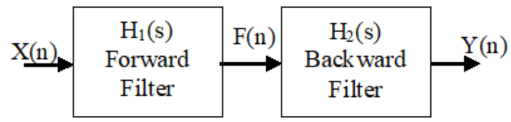


Fig. 3 structure of the ZP filter design

Usually the ZP filter is a combination of two back to back recursive filters designed as forward and reverse filters respectively. Due to cascade filtering structure the amplitude response becomes squared and due to reverse filtering phase response leads to zero phases. The ZP filter structure is shown in Figure 3. The time domain response of ZP filter design is given as multiplicative equation as

$$y(t) = h_n(t) * h_n(-t) * x(t) \qquad (2)$$

The response equation in Fourier domain respective to the equation (2) is expressed as;

$$Y(\omega) = H_n(\omega) * H_n(-\omega) * x(\omega) \qquad (3)$$

The overall response of the ZP filter is represented by the G(ω) is given as;

$$G(\omega) = H_n(\omega) * H_n(-\omega) \qquad (4)$$

Where, $H_n(\omega)$=$H_1(s)$ is response of the forward falter and the response $H_2(s)$ is reverse of $H_1(s)$. The * sign represses the operation of Convolution. Let the $x(n)$ would be input sequence then the then the basic forward filter discrete time relation is given as

$$u(n) = x(n) * h_n(n) \qquad (5)$$

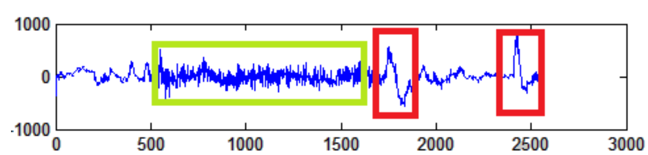
Then the discrete time response for the reverse filter $v(-n)$ is formulated by flipping the $u(n)$ as;

$$v(n) = h_n(n)\ Flip\ u(n) \qquad (6)$$

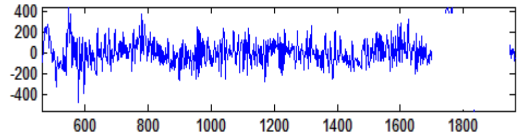
The ZP filtered output is determined by again flipping the response of the reverse filter $v(n)$ as represented by;

$$y(n) = h_n(n)\ Flip\ v(n) \qquad (7)$$

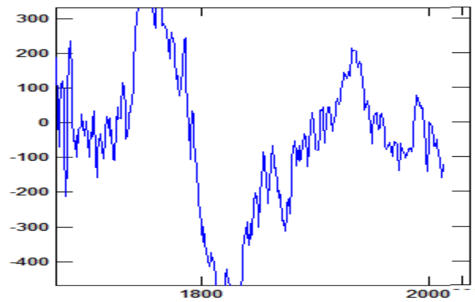
This paper is aimed to demonstrate the effective uses of ZP filter for EEG signal artifact removal. Usually the captured EEG signal suffers from motion artifacts doting acquisition. The examples of common kinds of artifact signals as muscular motion EMG, and eye blink EOG presented in EEG data are presented in the Figure 4.



a) EEG signal with artifacts



b) EMG motion artifact respective to green box



c) Zoomed EOG eye blink artifact of Red box 1

Fig.4 Representation of EEG artifacts consider for the evaluation and filtering in the paper

The signal in Figure 4 a) represents the recorded EEG signal of channel 9. The EMG and EOG artifacts are marked with green and Red box in the Figure. The EMG artifacts are presets with dense higher amplitudes of continuous 1000 to 1500 samples lengths. While the EOG artifacts are present due to sudden random motion of eye blink and of high amplitude short duration pulses. For the sake of celerity, the zoomed EMG and EOG signals under the green and Red box1 are presented in the Figure 4 b) and Figure 4 c) respectively where the amplitude variation can be clearly observed.

The problem of statement is eradication of the artifacts from the captured EEG channels by designing the efficient IIR filter. Our recent research work is improvement over our own previous work [2], where the Min-Ma optimization based IIR filter was proposed to eliminate the EOG artifacts from the EEG signals. In this paper the ZP filter is proposed along with same methodology as [2]. But in recent research in this paper the EMG and EOG both artifacts are expected the simultaneous eradication.

Related Work

In this section the various relevant related research works implemented for the EEG signal artifact eradication. Usually EEG data are degraded by the presence of the EMG and EOG motion artifacts. This paper sequentially reviewed the different EEG filtering methods were designed for artifact removal. The prime concern is on the IIR/FIR filtering based contributions.

An FIR filter is containing an impulse response of finite interval, and then the output is going to 0 and produces identical delays in any respected frequencies. Vivek Singh et al [1] have compared the performance of the EEG signal low frequency50 Hz line interferences using the FIR and IIR filters. Another filter is proposed based on the symlet wavelet transform which performs bettered over other two. Nitin Jain et al [2] we have proposed to designs the optimum reduced order IIR filter. They recently evaluated the three different filters for EOG artifacts. But IIR fitter may have leads to delay and distort the true nature of the EEG filtered signal. Thus in this paper it is proposed to improve the performance and removing the limitation of not maintaining the EEG nature.

Rayhan Habib [3] has proposed to eliminate the 50 Hz power line interference (PLI) from the EEG artifact signals. They have proposed and designed the IIR filters for detecting brain diseases. The designed filter was Chebyschff type II based IIR EEG de noising filter with improved SNR.

Deepak. Pancholi et al [8] have proposed to design CCA bas–ed EEG artifact removal brain computer interface application in robotics. The approach was based on EEMD-CCA. They also presented the reasons of artifact in EEG signals. Arman Roonizi et al [11] have proposed to design the non-causal zero phase IIR filter using the forward-reverse recursive IIR filters. Xiao Jiang et al [12], has presented a good survey of the method to review the EEG artifacts removal. Gustafsson et al [14] have proposed the designing of the ZP IIR filter using forward – reverse filter design approach [13]. They stated that these filters offer linear phase angle response.

Vandana Roy et al [15] have also presented the modified GE-CCA based EEG artifact removal method. They compared the performance with basic wavelet based EEG smoothening approaches as EEMD -CCA-DWT. Ouyang et al [17] have presented the EOG artifact removal approach for the application in BCI. Paresh et al [19] designed the IIR filter for video motion smoothening application. Various other methods are reported [20-25]. Thus in this work our main concern is to design ZP filter for EEG filtering as summarized in Table 2.

Table 1 Summary of the review work on Filter designing

Authors	Filter Algorithm	Description	Optimization	Parameters
Vivek Singh et al [1] ProposedNitin Jain et al [2] ours	IIR, FIR and Wavelet filters Designed a reduced IIR optimum filter	Evaluating performance of the low frequency noise removal methods for the EEG MinMax optimization for reduced order EEG artifact removal by filter designing using transfer functions coefficients optimization	No Yes	Filtering quality and nature of signal.. PSNR Order of filter MSE and PSNR
Rayhan Habib [3]	IIR Filtered EEG signal	Has proposed to eliminate the 50 Hz power line interference (PLI) from the EEG artifact signals. Chebycheff filter is proposed to desong	No	signal to noise ratio (SNR) and CC of the EEG signals. .
Deepak Pancholi et al [8]	EEMD - CCA based filter design.	Presented the method for EEG artifact removal for BCI.. Also various related work were reviewed,	No	Quality of signal filted, entropy
Arman Roonizi et al [11]	A least square optimized single filtering	Forward –backward filter for signal filtering using optimization	Yes	PSNR and delay
Vandana Roy et al. [15]	Wavelet filter GE-CCA approach	artifact removal from EEG using EEMD-GE-CCA-SWT approach. they compared DWT based method performance	No	DSNR, MSE, ROC parameters
Paersh et al [19]	IIR motion filter	Have designed IIR filter for video motion smoothening.	No	PSNR, ITF, motion vectors
Masaaki Nagahara et al [23]	Min-Max optimized design of FIR filter	Optimization is proposed for FIR filters designing for signal de noising	Yes	Filter order, and MSE
Proposed	Optimum reduced IIR ZP filter	MimMAx optimization based IIR filter designing using the ZP filter for EEG artifacts removal,	Yes	RMSE, PSNR and the DC gain of Filter

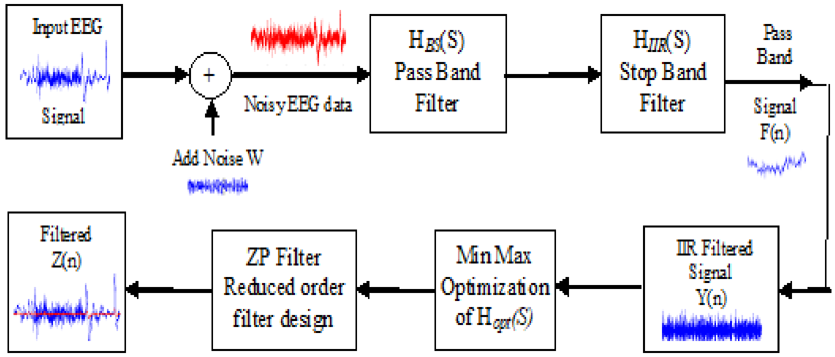


Fig.5 Proposed EEG eradication system diagram using ZP Filter Design

Anshul, Dipali et al. [11] have evaluated the windowing based IIR and FIR filter performance for EEG signal processing. Xiao Jiang et al [12] presented a good survey of the various artifacts removal methods for EEG signal context. Ibraheem Kasim et al [13] designed structure for IIR and FIR filters by adapting the least mean square (LMS) algorithm along with GA based optimization concept.

Paresh et al [18] have designed new method of GE-CCA for wavelet based filtering of the EEG artifacts. They designed the multi channel artifacts removal method. Multichannel EEG de noising is presented in [19, and 21]. GARIP et al [20] designed a FIR filter using the GA optimization. Similar approaches are given in [28, 29],

1. Optimum IIR Filter Design

The process of the proposed EEG artifact removal is sequentially shown in the Figure 5. Initially the captured EEG data is considered as the input with artifact to remove. The method proposed in this paper is similar to the approach implemented n our previous paper [2], but as a modification in proposed work the ZP filter is considered for artifact eradication. Initially noisy artifact signals are generated using the mathematical modeling by adding randomly generated Gaussian noisy signals as

;

$$EEG(n)_{Art} = S + N \qquad (8)$$

Where $EEG(n)$ is n[th] sampled value of EEG signal, S is original EEG and the N is additive Gaussian noise.

The two pass IIR filter is designed by designing the transfer function for pass band and stop band filters are designed as,Then as clear from the Figure 5 that using the coefficients of the transfer function the filtered EEG data is produced. The conventional Form-II filter was used in our previous work [2] for filtering the signals. In this paper it is proposed to use the ZP falter as a combination of forward and reverse filter to smooth the EEG data.

The filter design is based on the designing the transfer function of the filter block. Mathematical representation of the transfer functions for the pass band and stop band filters is H_{BP}, and H_{IIR}as defined in the Table 2. Table represents the transfer functions for the IIR filter design. The transfer function of the IIR filter is mathematically defined as

$$H_n(n) = \frac{C(n)}{R(n)} = \frac{a_{m+1}s^m + \cdots\cdots\cdots + a_1}{b_{m+1}s^m + \cdots\cdots\cdots + b_1} \qquad (9)$$

The coefficients of numerator are an, and denominators coefficients are bn. In this paper the designed transfer function (n) is of 16^{th} order as shown in the Table 2. But since the standard Form-II IIR filter suffer from delay response thus the filtered output does not follow the true nature of the EEG signal as shown in the Figure 6.

Table 2 Transfer functions representation for IIR filter design stages

Pass band	$\frac{0.2066 s^4 - 0.4131 s^2 + 0.2066}{s^4 + 0.5488 s^3 + 0.4535 s^2 + 0.1763 s + 0.1958}$
IIR Filter	$H_{IIR} = \frac{0.06531 s^{16} + 0.8693 s^{15} + 5.585 s^{14} + 22.93 s^{13} + 67.23 s^{12} + 149.1 s^{11} + 258.5 s^{10} + 357.2 s^9 + 397.4 s^8 + 357.2 s^7 + 258.5 s^6 + 149.1 s^5 + 67.23 s^4 + 22.93 s^3 + 5.585 s^2 + 0.8693 s + 0.06531}{s^{16} + 9.039 s^{15} + 39.16 s^{14} + 108.5 s^{13} + 215.7 s^{12} + 327.2 s^{11} + 392.2 s^{10} + 378.7 s^9 + 297.8 s^8 + 191.2 s^7 + 99.83 s^6 + 41.96 s^5 + 13.91 s^4 + 3.518 s^3 + 0.6403 s^2 + 0.075 s + 0.004266}$
Reduced Order filter	$H_{opt}(S) = \frac{s^2 + 4s + 15}{43}$

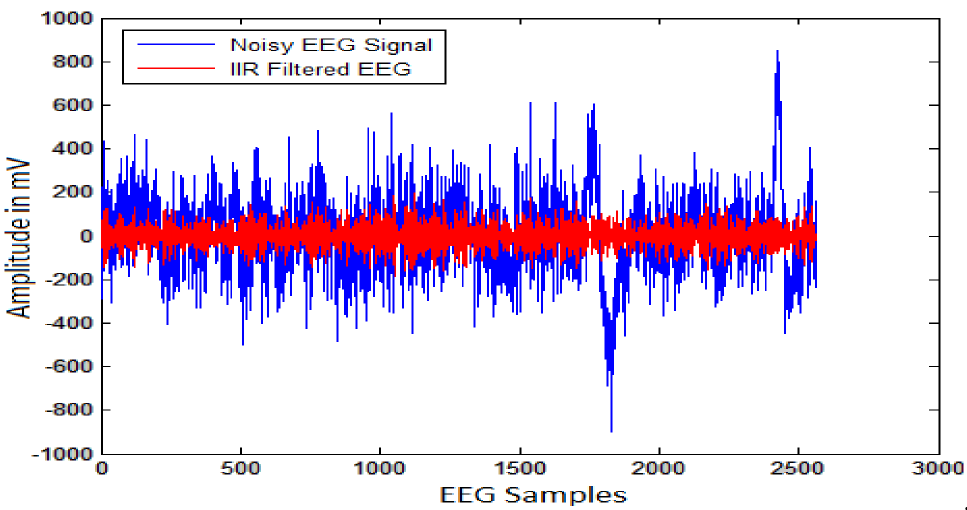


Fig. 6 IIR filtered EEG data with delayed from

The Figure 6 represents effect of delay filtering response. Thus data lost the nature and therefore it needs a great deal of improvement. Thus in this paper it is proposed to replace the Form-II IIR filter with the ZP –IIR filter design. As it is expected that the ZP filter can mitigate the delay effect till some extent, thus may improve filtering performance.

Before this the sequential filtered signals are represented in the Figure 7 for the IIR Filter design using Form-II IIR filter and the ZP filter designs.

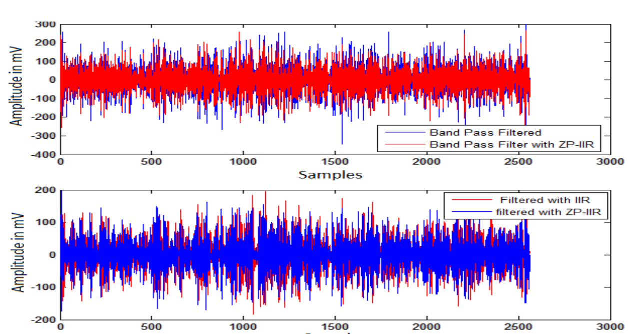


Fig. 7 Comparison of the sequential artifacts EEG signal of channel 9 Filtering with IIR filters

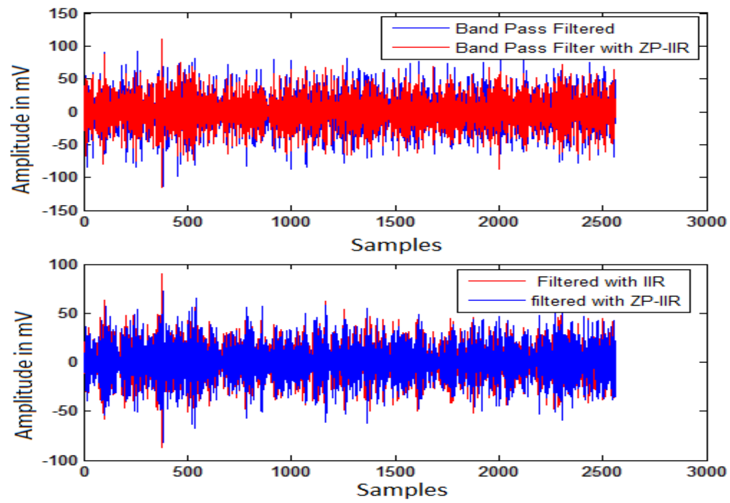


Fig.8 Sequential comparison of an IIR filtering for the Channel 4 of EEG database

Thus it can be clearly observed from the Figure 7 that the IIR filter signal is sequentially generated using band pass and band stop IIR filter. The cutoff frequencies used for the filter design are set to 90-190 for the pass band and 150-230 for the stop band for filtering. It can be observed from the Figure 7 a) and Figure 7 b) that proposed ZP falter design can improve the filter signal but still the nature of the true EEG is point of concern and has to process further. The respective pass band and stop band spectrums were already presented in our previous work as referred in [2]

Similarly the comparison of the IIR filtering is presented for the EEG channel 4 without artifacts in the signal. It can be observed from the Figure 8 a) and Figure 8 b) that proposed ZP falter design can improve the filter signal

The input data base of the open source PhysioNet is used for the 24 channel MIT data with EEG motion artifacts. For the sake of evaluation the Also the EOG data are taken from MIT scalp data base open-source interface [21] Foe testing the performance of proposed ZP filter design, four EEG channels out of 24 are identified to be considered for the evaluation in this paper.

The basic criterion for channel selection is based on the true EEG nature and the simultaneous presence of the EMG and the EOG artifact sin the channel. The four respective input EEG channels are presented in the Figure 9. These channels are Channel [1, 4, 9, and 13 respectively. Out of these channel [1, 9 and 13] contains the motion artifacts

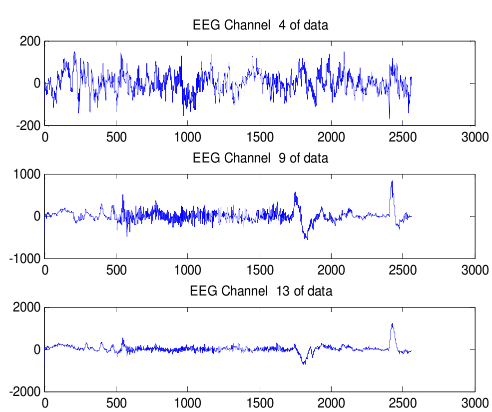


Fig.9 data base of the EEG and Edfm signals used for the study a-c) Raw EEG data d) Edfm based EOG Artifact signal 13 with muscular and eye blink artifacts

V. Reduced Order Min-Max Optimized IIR Filter

In this paper it is proposed to improve the performance of the IIR filter using the problem of the filter coefficient optimization. It is proposed to design the reduced order filter to minimize the hardware complexity. Before this the coefficients of designed IIR filter are optimized using the Min-Max optimization is proposed. Based on the option the reduced order transfer function is design for filtering is given in the equation (10) given as;

$$H_{opt}(s) = \frac{s^2 + 4s + 15}{43} \qquad (10)$$

Where the is the transfer function for reduced order filter.The parameters used for optimization used in this paper for reduced order filter designing are shown in the Table 3. It can be observed that the window W is required to define initially and number of bits representation.

The advantage of the reduced order filter is the reduction in filter order which represses the number of times previous information is consider in other word the number of taps. Therefore in turn minimizes the hardware complexity and also requires less DC gain. In the next section the DC gain evaluation of different design stages are compared for showing the effectiveness.

The sequential procedure for optimization and the reduced order filter design are given in the Flow chart of Figure 10. The presented flow chart is restricted to the Min-Max optimization procedure.

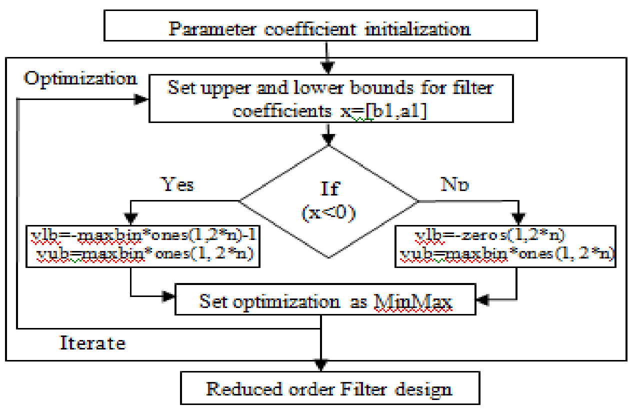


Fig. 10 Sequential Flow chart of optimized reduced order filter design

Table 3 Parameters used for the optimization

Parameters	Descriptionss
N = 4	Filter order + 1
nbits = 8	bits to realize filter
W=	frequency points utilization
X=[b1, a1]	Filter coefficients to optimize
F=maxbin/m	Scaling factor
Bin=maxbin	Maximum value of bins

RESULTS AND DISCUSSION

This discussion demonstrates few results and there quantitative evaluation for the proposed ZP filleting approach. The paper aimed to represent the effective application of optimum reduced order ZP filter to eradicate the motion artifacts from the EEG channels. Experimentations were performed by adding the synthetic noise to EEG data.

In order to demonstrate the effectiveness of the proposed ZP filter methodology the comparison of filtered signal is presented in the Figure 11. The comparison is given for an IIR filtered using standard Firm-II filter and the filtered signals with proposed ZP filter design for the EEG channel 4. It is clear from the Figure that proposed ZP filter design significantly performs over the Form-II IIR filter. The ZP filter closely maintains the true nature of the EEG signal. It is because ZP filter is having no delay in the filtered signal in time domain.

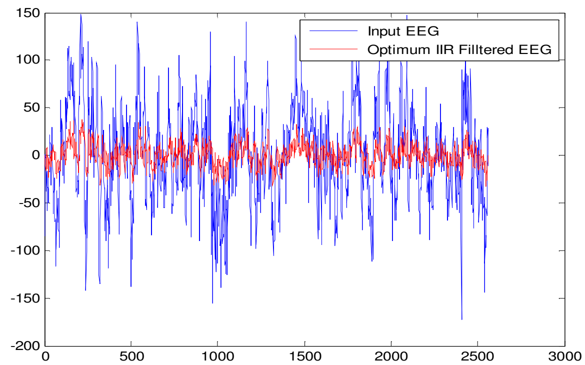


Fig. 11(a) Filtering performance comparison the form –II Filter

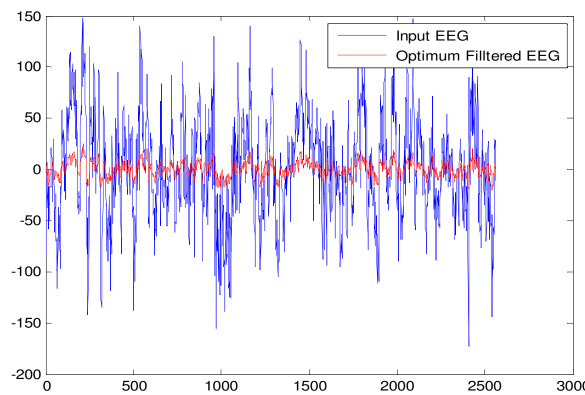


Fig.1(b) The proposed zero phase Filter for EEG channel 4

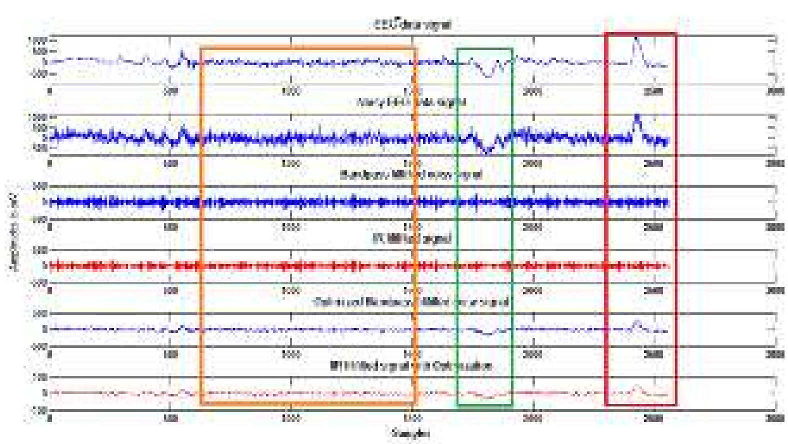


Fig. 12 sequential results for the proposed ZP-IIR filter for EEG channel 13 with EOG artifacts

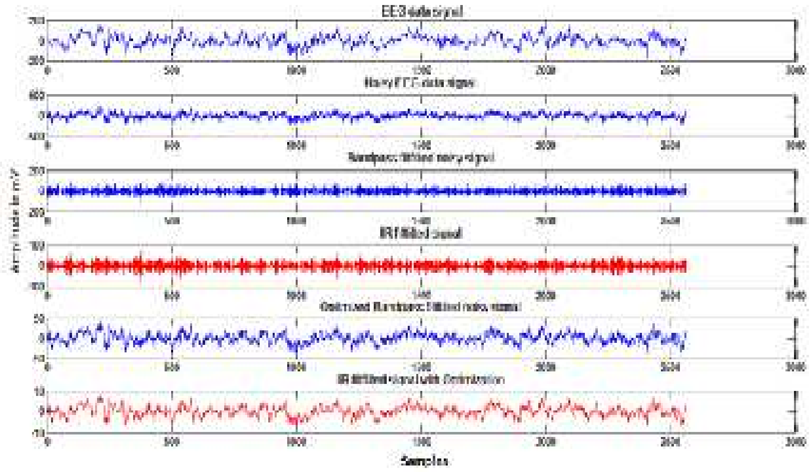


Fig.13 Results of the ZP IIR filtering with Min- Max optimization for EEG channel 4

Similarly the sequential results comparisons of the designing of IIR filtering with Min- Max optimization for the EEG channel 9 are shown in the Figure 12. For the performance comparison band pass Butterworth filter, IIR filter, optimum IIR filter and the reduced order filters. the orange box compares the EMG artifact removal and green and Red box in Figure 12 represses the effectiveness of the EOG artifact removal. It can be observed that the EOG peak of the order of 1100 mV reduces to order of < 100. And the nature of the EEG is also preserved.

The reduced order optimum filter performs significantly good to smoothen and preserve the nature of the signal. The nature of the filtered signal can be clear visible in the results of the optimum ZP-IIR filter for the EEG channel 4 as shown in the Figure 13.

To further demonstrate the efficiency of the proposed ZP filtering method the results of the artifact signs filtering are plotted in the Figure 14 for the three variants of EEG channels as [1, 9, and 10]

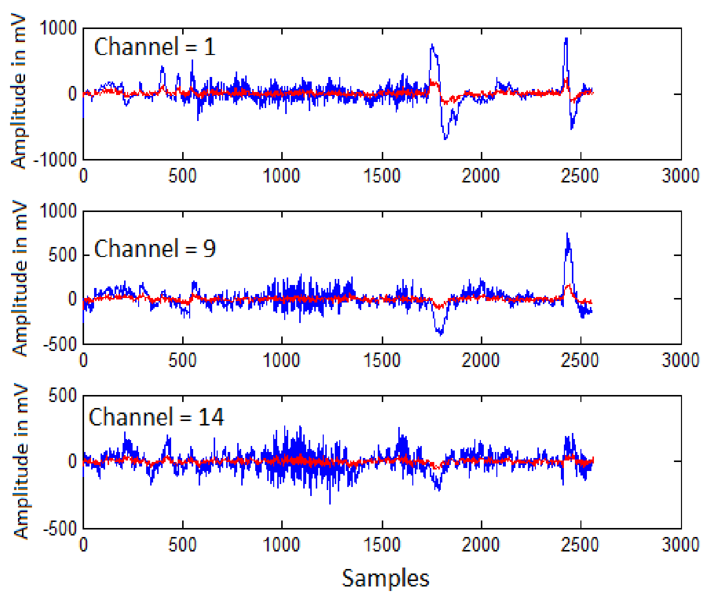


Fig. 14 results of artifact removal for EEG channels

6.1. Quantitative Performance Evaluation

The performance of the EEG artifact eradication algorithms are evaluated to identify effectiveness of filtering quality. This section presents quantitative evaluation of the performance. Since signal amplitude is reduced significantly with use of reduced order filter. Therefore, as in [2] in this paper the evaluation of optimum filtered data is proposed by scaled amplitude by a scaling factor as the , relation is mathematically given as;

$$EEG_{ZP-filter}(s) = \mu * EEE_{channel} \qquad (11)$$

The quantitative evaluation of the data is done on the three EEG channel of the MIT scalp data base for motion artifacts. The parameters used for evaluation are Root Mean Square Error (RMSE) and the Peak Signal to Noise Ratios (PSNR).

RMSE ***is calculated as:***

$$E_{rms} = (s(x,y) - ZPF_{xn1}(x,y))\text{^}2;$$

$$E_{RMSE} = \frac{1}{c}\sum(t_1 + E_{rms})^{1/2} \qquad (12)$$

$PSNR_{Art}$:

PSNR o is calculated as:

$$\mathrm{PSNR}_{ZP\_filter} = 10\log_{10}\sqrt{\frac{{\mathrm{EEG}_{org}}^2}{[\mathrm{EEG}_{org}(n) - \mathrm{EEG}_{filter}(n)]^2}} \qquad (13)$$

The quantitative performance of ZP filtered EEG signal is evaluated by RMSE in the Table 4. It can be observed from Table that the proposed ZP based optimum reduced order filter minimizes the MSE significantly for EEG artifact removal for motion artifacts. Especially for the EEG channel 9 and the EEG channel 13. It is to observe that the MSE is relatively having higher values because of the difference in the amplitude of t the input and filtered signals.

Similarly the PSNR is evaluated for the same three channels in the Table 5. The significance improvement in PSNR can be observed from the Table by proposed ZP-optimum filter. In addition it is also to observe that, the PSNR of the IIR filter is less since due to delay involved the nature of true EEG is changed.

Table 4 Comparison of the MSE for filter

Data	ZP IIR Filter	Notch Filter	Optimum ZP Filter
ECG_9	144.3896	114.3383	72.13557
ECG_4	50.44945	39.7737	24.58848
EEG_13	182.6687	141.6445	76.6395

Table 5 Comparison of the PSNR for filter

Data	ZP IIR Filter	Notch Filter	Optimum ZP Filter
ECG_9	0.4409	1.89267	6.49881
ECG_4	0.5546	1.82299	6.63229
EEG_13	0.6651	1.87840	8.02048

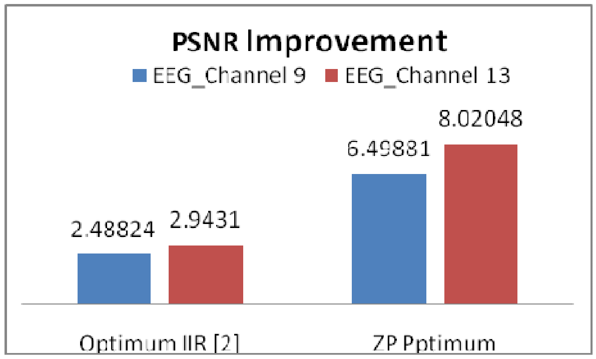


Fig. 15 Result of Improvement in PSNR by proposed ZP-IIR filter over basic Form-II IIR filter for EEG smoothening.

The performance improvements in PSNR by proposed ZP-IIR filter over basic Form-II-IIR filters are represented in the Figure 15. The improvement is shown for two EEG channels having EMG and EOG artifacts as Channel 9 and 13 of MIT data base.

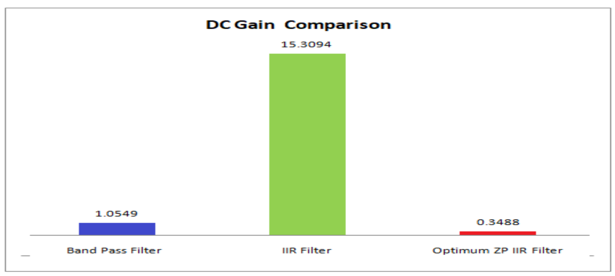


Fig. 16 Reduction in the DC gain of the transfer function of proposed ZP filter

Another major contribution of the paper is to demonstrate the DC gain improvement with proposed method. The DC gain is evaluated for the IIR filter, Notch filter and the proposed ZP optimum filter designs in the Figure 16. The proposed method just offers the 0.3288 because of reduced order filter design. This signifies reduction in the hardware complexity and amplifier gain.

CONCLUSIONS

The aim of paper is to design the efficient ZP filter using the optimum reduced order transfer function. Paper demonstrated the significant improvement in the EEG artifact removal over our previous approach of using the Form-II IIR filter. It is due to the uses o the forward – reverse ZP IIR filter. The EMG and EOG artifacts are consider for evaluating the performance.

It is concluded that ZP-IIR filter reduces the required DC gain of filter transfer function due to order reduction. It is proposed to design optimum IIR filter using the Min-Max optimization. The ZP filter offers the DC gain of 0.3288.

The qualitative performance democrats that proposed ZP based optimum reduced order filter minimizes the MSE significantly for EEG artifact removal for motion artifacts. In addition the PSNR performance is nearly improved by around more than 3 times over Notch filter and more than of 10 times over the basic IIR filter. It is because IR filter offers 16 order filter and offer the delay. But proposed ZP-IIR filter maintain the true nature of the EEG data.

Overall paper concludes that ZP filter using the optimization performs better than the IIR filter for EEG artifact removal.

FUTURE SCOPE

In future research the stability and transient analysis of the designed filter performance can be carried out and performance can be tested over different kind of applications.

ACKNOWLEDGEMENT

Author acknowledge to each individual who contributing to successful completion of the current research in any form. We also acknowledge to all authors and co authors referred.

REFERENCES

[1] Vivek Singh, Reecha Sharma, "Performance Comparison of Denoising Methods of Electroencephalogram" "International Journal of Engineering Research & Technology (IJERT)", Vol. 3 Issue 9, September- 2014.

[2] Nitin Jain, Dr. Shanti Rathore , Prashant Kumar Shukla "Designing Efficient Optimum Reduced Order IIR Filter for Smoothening EEG Motion Artifacts Signals", Journal of Design Engineering Issue: 6, pp: 5080-5101 , 2021.

[3] Rayhan Habib Jibon, Etu Podder, Abdullah Al-Mamun Bulbul, Ramendra Nath Bairagi, Md. Salim Ahmed, Imtiaj Ahmmed Shohagh, "Performance analysis of IIR filter in removing PLI from EEG signal" International Journal of Engineering & Technology, 7 (4) pp 5363-5367: 2018

[4] Jiang, Xiao et al. "Removal of Artifacts from EEG Signals: A Review." Sensors (Basel, Switzerland) vol. 19,5 987. 26 Feb. 2019,

[5] Jinhua Zhang1, Baozeng Wang1, Cheng Zhang1, Yanqing Xiao, Michael Y. Wang. "An EEG/EMG/EOG-Based Multimodal Human- machine Interface to Real-time Control of a Soft Robot Hand". Frontiers in Neurorobotics, march 2019.

[6] Z. Ling, F. Liu, S. Kong, Y. Qian and M. Zheng, "Application of zero-phase digital filter in ultrasonic pressure measurement," 2011 International Conference on Electric Information and Control Engineering, 2011, pp. 3021-3023.

[7] Liu, Fu Jun, Zhang Wei Ling, Shuai Kong, and Mu Lin Zheng. "Application of Zero-Phase Digital Filter in Magnetic Flux Leakage Testing for Tank Floor Inspection." Applied Mechanics and Materials 333–335 (July 2013):

[8] Deepak. Pancholi, M. Vekatadri and Paresh Rawat, "EEG Motion Artifacts Removal for Robotic Motion Control Using Brain Computer Interface," 2019 4th International Conference on Robotics and Automation Engineering (ICRAE), pp. 207-212,, 2019,

[9] Wei Tech Ang, M. Krichane and Terence Sim, "Zero Phase Filtering for Active Compensation of Periodic Physiological Motion," , The First IEEE/RAS-EMBS International Conference on Biomedical Robotics and Biomechatronics, pp. 182-187 , 2006,

[10] Khatter, Anshul & Bansal, Dipali & Mahajan, Rashima.. Design and Implementation of Efficient Digital Filter for Preprocessing of EEG Signals. Proceedings of the 6th International Conference on "Computing for Sustainable Global Development", 13th - 15th March, 2019

[11] Arman Roonizi, Christian Jutten. Forward-backward Filtering and Penalized Least-Squares, Optimization: A Unified Framework. Signal Processing, Elsevier, 2021, 178, pp.107796. ff10.1016/j.sigpro.2020.

[12] Xiao Jiang, Gui-Bin Bian and Zean Tian "Removal of Artifacts from EEG Signals: A Review", In MDPI International Journal of Sensors Vol. 19, 987; 2019,

[13] A Garcés Correa, E Laciar, H D Patiño , M E Valentinuzzi, "Artifact removal from EEG signals using adaptive filters in cascade", Journal of Physics: Conference Series 90 , (2007)

[14] Gustafsson, F. Determining the initial states in forward-backward filtering. IEEE Trans. SignalProcess. 44, 988–992, in 1996,

[15] Vandana Roy, Shailja Shukla , Piyush Kumar Shukla, Paresh Rawat, " Gaussian Elimination - Based Canonical Correlation Analysis Methof for EEG Motion artifact Removal,", International Journal of Heath Care Engineering Vol. ouct. 2017

[16] Ashmita. Bera, N. Das and M. Chakraborty, "Optimal Filtering of Single Channel EEG Data using Linear Filters," 2020 Sixth International Conference on Bio Signals, Images, and Instrumentation (ICBSII), Chennai, India, pp. 1-6, 2020

[17] Ouyang, Gaoxiang, Malik M. Naeem, M. Ahmad, Shinil Kang, Myung Yung "Effect of EOG Signal Filtering on the Removal of Ocular Artifacts and EEG-Based Brain-Computer Interface: A Comprehensive Study", Journal Complexity of Hindawi 2018

[18] Sutradhar, Shapna & Sayadat, Nazmus & Rahman, Ashfiqur & Munira, Sirajum & Haque, A.K.M Fazlul & Sakib, Syed. (2017). IIR based digital filter design and performance analysis. Proceding of the pp, 1-6. TEL-NET.8343596. 2017

[19] Paresh. Rawat and J. Singhai, "Performance Evaluation of various Temporal Derivatives for Stabilization of Videos with Large Moving Objects," 2018 International Conference on Recent Innovations in Electrical, Electronics & Communication Engineering (ICRIEECE), pp. 81-86, 2018.

[20] Al-Qazzaz, N. K., Ali, S., Ahmed, S. A., Islam, M. S., &Ariff, M. I.. Selection of mother wavelets thresholding method in denoising multichannel EEG signals during working memory task. *Sensors*, 15, 29015-29035. (2015).

[21] PhysioNet. Motion artifact-contaminated EEG and EEG data (motion artifact). [Online]. http://physionet.org/cgi-bin/atm/ATM.

[22] Mmeremikwu V. O, Mbachu C. B and Iloh J. P, "A Finite Impulse Response (FIR) Filtering Technique for Enhancement of Electroencephalographic (EEG) Signal", IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE) Vol. 12, Issu 4 Ver. I Jul. –, PP 29-35 Aug. 2017.

[23] Masaaki Nagahara "MIN-MAX Design of FIR Digital Filters By Semidefinite Programming", Applications of Digital Signal Processing, PP. 193-210, INTECH, 2011 available at arXiv

[24] A. Betser, and E. Zeheb, "Reduced Order IIR approximation to FIR Digital Filters", IEEE Transactions on Signal Processing Vol. 39, No. 11 November 1997