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Implementation of Optimized Filter Order to the PSD Analysis of QRS Detected ECG Signal

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Abstract*: *Filtration of ECG signal is an important part in the analysis and signal processing of ECG signal. There are different types of digital and analog filters available for the filtration of an ECG signal. And choosing the right filter order for different filters has always been a tough task in biomedical signal processing. This study aims to solve this problem of filter order optimization by cascading digital filters and evaluating their performance based on SNR using ECG-ID Database from PHYSIONET. Besides, this optimized filter order has been applied to both normal and abnormal QRS detected ECG signals to choose the right filter order based on average power received from PSD analysis. QRS detection has been performed by differentiation technique. In this study, design of the filters has been carried out using MATLAB software based FDA tool in both monitoring and diagnostic modes. This analysis has strong potential for analyzing low amplitude based biological signals like ECG or EEG.

Keywords*: *ECG, FIR filters, IIR filters, QRS detection, SNR, Optimized filter order, PSD Analysis.

I. INTRODUCTION

As ECG is a non-stationary signal, noise filtration from ECG signal is a tough task. It is quite a normal problem that filtration of ECG signal may lead to the loss of information [1]. That's why proper choice of filters for denoising ECG signal with a minimal loss of information is an important step in ECG signal filtering. Various filtration techniques as well as various filter designs are available for ECG filtering, thus choosing proper method or proper filter is a problem [1]. It was marked that Butterworth, Chebyshev, Elliptic and Bessel filters are the most commonly used filters [2]. But it has been always a dilemma at which order they perform the best.

Low pass filtering is a commonly used technique to remove power line interference of ECG signal. Low pass filtration based SNR improvement as well as corresponding filter order has been evaluated in [1]. But the removal of base line wandering noise has not been emphasized here. Thus, a more convenient approach is needed to evaluate the right filter order. In a study, evaluation of different parameters at different times for different denoising techniques of ECG signal has been observed [3]. But the choice of a common parameter through which a filtering technique can be regarded as the best one has not been evaluated at all. In another study, the power spectrum density of the QRS complexes has been obtained from normal as well as diseased ECGs to compare the differences between their frequency components [4]. QRS complexes are chosen because it shows distinct differences for different heart diseases. The main drawback of this paper is that it does not show any distinct difference between the PSD of normal and abnormal ECG or more precisely. This paper lacks of the comparison between the two based on certain specific parameter like SNR, PSNR or average power. In paper [5], a great improvement has been showed in SNR by cascading different FIR filters for denoising ECG signal. MSE has also been calculated in their study. The main drawback of this paper is that evaluation of the right filter order at which the cascaded filters perform best. Thus a more sophisticated phenomenon is necessary to evaluate the best filter at the best filter order.

In this proposed study, to overcome the problems mentioned above a digital high pass filter of order one has been cascaded with different types of FIR and IIR low pass filters to improve SNR. The main focus of this study is to find out the optimized or minimum filter order at which the filters performs the best for both normal and abnormal ECG signals. Thus, after finding out the SNR based filter order this order has been applied to different normal and abnormal ECG signals to analyze their PSD. Thus, minimum average power based optimized filter order has been evaluated throughout the whole study.

II. METHODOLOGY

A brief explanation of essential steps which are performed in this study are given below:

A. Proper Database of ECG Signal

In this study, to evaluate the performance of optimized filter order based on SNR ECG-ID Database is chosen from PHYSIONET. This database is chosen because it provides a fixed amount of noise for a particular dataset. Thus, it becomes possible to choose the optimized filter order easily.

B. Cascading Digital Filters

Cascading digital filters improves the SNR to a great extent [6]. Here, for cascading different FIR and IIR based low pass filters and Chebyshev Type I high pass filter have been chosen. The low pass FIR and IIR filters that have been chosen for cascading are given below:

- Equiripple
- Least Square
- Constrained Least Square
- Different Window Based Filters
- Maximally Flat
- Butterworth
- Chebyshev Type I
- Chebyshev Type II
- Elliptic

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C. Monitoring and Diagnostic Mode Based Filtration

Filtering of ECG can be done for diagnostic or for monitoring purposes. The useful frequency used in diagnostic mode is 0.05 to 150 Hz [1]. In monitoring mode, the range of frequency is accepted as 0.5 to 40 Hz [1]. Several sets of raw unfiltered ECG data with sample frequency of 500 Hz are chosen in this study.

D. Increasing Filter Order

After the evaluation of SNR for the filters in terms of minimum filter order, the filter order is increased for all filters up to 100 [1]. Thus, the filter order at which the value of SNR is the highest is chosen as the optimized filter order.

E. QRS Detection of ECG Signal

Differentiation technique has been applied for the detection of QRS complex of ECG signal. This technique basically acts as a high pass filter which amplifies the QRS portion while at the same time it attenuates the P and T waves of ECG signal [7]. Here, to filter the ECG signals including both normal and abnormal records the optimized orders of the filters are chosen and hence QRS portion is detected easily.

F. PSD Analysis of QRS Detected ECG Signal

After the QRS potion of different datasets including both normal and abnormal ECG collected from PHYSIONET is detected, then PSD analysis of ECG signal is done. For PSD analysis, the parameter average power is chosen to detect the best filter with optimized filter order.

III. RESULT AND DISCUSSION

A. Average Peak SNR and Corresponding Filter Order in Monitoring Mode

The average peak SNR for different datasets has been calculated for different cascaded filters in monitoring mode. The optimized filters orders including the average peak SNR is given in the table below:

Table. I: Data Table for Optimized Filter Order in Monitoring Mode

Filter	Average Peak SNR (dB) for Low Pass Filters	Average Peak SNR (dB) for Cascaded Filters	Filter Order
Equiripple	14.93631875	19.864869	21
Least Square	14.50701225	19.321479	4
Constrained Least Square	14.26443875	22.38511225	35
Rectangular Window	13.771703	22.23579425	18
Bartlett Window	12.19054725	16.5679485	5
Hanning Window	13.11502525	19.5068255	8
Hamming Window	12.869566325	18.684848	7
Blackman Window	12.56458975	17.77844725	7
Kaiser Window	13.7730295	22.28130275	18
Maximally Flat	13.3185895	20.272431	18
Butterworth	13.72208475	22.004844	4
	13.76400475	22.59232245	5
Chebyshev type I	11.3652865	14.0022275	1
Chebyshev type II	13.784355	22.8485005	7
	13.789689	23.0776795	8
	13.78134775	22.2572065	9
Elliptic	11.3652865	14.0022275	1

B. Average Peak SNR and Corresponding Filter Order in Diagnostic Mode

The average peak SNR for different datasets has been calculated for different cascaded filters in diagnostic mode. The optimized filters orders including the average peak SNR is given in the table below:

Table. II: Data Table for Optimized Filter Order in Diagnostic Mode

Filter	Average Peak SNR (dB) for Low Pass Filters	Average Peak SNR After (dB) for Cascaded Filters	Filter Order
Equiripple	11.74336975	12.1213835	7
	12.01311325	14.416147	38
Least Square	10.90302925	12.785854	5
Constrained Least Square	10.743479	13.383795	5
Rectangular Window	11.50268175	15.25031275	2
Bartlett Window	11.2935055	14.82404825	4
Hanning Window	11.25217625	14.74193825	4
Hamming Window	11.14826925	14.53823175	3
Blackman Window	11.1989815	14.637172	4
Kaiser Window	11.47891175	15.200943	2
Maximally Flat	10.67679425	13.66321575	8
Butterworth	13.128218	13.60449725	1
Chebyshev type I	11.48790375	13.58800225	2
Chebyshev type II	17.99943525	21.86041725	3
Elliptic	11.4880105	13.58814775	2

C. PSD Analysis Based on Optimized Filter Order in Monitoring Mode

The optimized filter order based PSD analysis is done on QRS detected ECG signal and thus average power has been calculated in the monitoring mode. The average power calculated from PSD is given in the tables below:

Table III. Optimized Filter Order for Supraventricular Arrhythmia in Monitoring Mode

Filter Order	Average power (Watt/Hz)	Best Filter Name
21	0.0077	Equiripple
4	0.008	Least Square
35	0.0143	Constrained L. S
18	0.0157	Rectangular
5	0.0063	Bartlett
8	0.008	Hanning
7	0.008	Hamming
7	0.007	Blackman
18	0.016	Kaiser
18	0.0097	Maxflat
4	0.0097	Butterworth
1	**0.004**	**Chebyshev1**
7	0.0133	Chebyshev2
1	**0.004**	**Elliptic**

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Table IV. Optimized Filter Order for Arrhythmia in Monitoring Mode

Filter Order	Average Power (Watt/Hz)	Best Filter Name
21	0.0043	Equiripple
4	0.0047	Least Square
35	0.005	Constrained L.S
18	0.005	Rectangular
5	0.0043	Bartlett
8	0.0047	Hanning
7	0.0047	Hamming
7	0.0043	Blackman
18	0.005	Kaiser
18	0.005	Maxflat
4	0.0047	Butterworth
1	**0.0043**	**Chebyshev1**
7	0.005	Chebyshev2
1	**0.0043**	**Elliptic**

Table V. Optimized Filter Order for Atrial Fibrillation in Monitoring Mode

Filter Order	Average Power (Watt/Hz)	Best Filter Name
21	0.0063	Equiripple
4	0.0053	Least Square
35	0.0067	Constrained L.S
18	0.0063	Rectangular
5	0.0053	Bartlett
8	0.0057	Hanning
7	0.0057	Hamming
7	0.0053	Blackman
18	0.006	Kaiser
18	0.0053	Maxflat
4	0.0063	Butterworth
1	**0.0057**	**Chebyshev1**
7	0.0067	Chebyshev2
1	**0.0057**	**Elliptic**

Table VI. Optimized Filter Order for Normal Sinus Rhythm in Monitoring Mode

Filter Order	Average Power (Watt/Hz)	Best Filter Name
21	0.0117	Equiripple
4	0.0103	Least Square
35	0.0133	Constrained L.S
18	0.0133	Rectangular
5	0.0087	Bartlett
8	0.0103	Hanning
7	0.01	Hamming
7	0.009	Blackman
18	0.0133	Kaiser
18	0.0117	Maxflat
4	0.013	Butterworth
1	**0.008**	**Chebyshev1**
7	0.0133	Chebyshev2
1	**0.008**	**Elliptic**

D. PSD Analysis Based on Optimized Filter Order in Diagnostic Mode

The optimized filter order based PSD analysis is done on QRS detected ECG signal and thus average power has been calculated in the diagnostic mode. The average power calculated from PSD is given in the tables below:

Table VII. Optimized Filter Order for Supraventricular Arrhythmia in Diagnostic Mode

Filter Order	Average Power (Watt/Hz)	Best Filter Name
7	**0.0023**	**Equiripple**
5	0.0033	Least Square
5	0.004	Constrained L.S
2	0.004	Rectangular
4	0.004	Bartlett
4	0.004	Hanning
3	0.004	Hamming
4	0.004	Blackman
2	0.004	Kaiser
8	0.004	Maxflat
1	0.004	Butterworth
2	0.0037	Chebyshev1
3	0.0107	Chebyshev2
2	0.0037	Elliptic

Table VIII. Optimized Filter Order for Arrhythmia in Diagnostic Mode

Filter Order	Average power (Watt/Hz)	Best Filter Name
7	**0.0033**	**Equiripple**
5	0.004	Least Square
5	0.004	Constrained L.S
2	0.0043	Rectangular
4	0.004	Bartlett
4	0.004	Hanning
3	0.004	Hamming
4	0.004	Blackman
2	0.0043	Kaiser
8	0.004	Maxflat
1	0.004	Butterworth
2	0.004	Chebyshev1
3	0.005	Chebyshev2
2	0.004	Elliptic

Table IX. Optimized Filter Order for Atrial Fibrillation in Diagnostic Mode

Filter Order	Average Power (Watt/Hz)	Best Filter Name
7	**0.0043**	**Equiripple**
5	0.005	Least Square
5	0.005	Constrained L.S
2	0.0057	Rectangular
4	0.0057	Bartlett
4	0.0057	Hanning
3	0.0057	Hamming
4	0.0057	Blackman
2	0.0057	Kaiser
8	0.0053	Maxflat
1	0.0057	Butterworth
2	0.0053	Chebyshev1
3	0.0063	Chebyshev2
2	0.0053	Elliptic

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Table X. Optimized Filter Order for Normal Sinus Rhythm in Diagnostic Mode

Filter Order	Average Power (Watt/Hz)	Best Filter Name
7	0.0057	Equiripple
5	0.0073	Least Square
5	0.008	Constrained L.S
2	0.008	Rectangular
4	0.008	Bartlett
4	0.008	Hanning
3	0.008	Hamming
4	0.008	Blackman
2	0.008	Kaiser
8	0.0077	Maxflat
1	0.008	Butterworth
2	0.0073	Chebyshev1
3	0.0123	Chebyshev2
2	0.0073	Elliptic

E. Graphical Representation of SNR versus Optimized Filter Order

Each cascaded filter is analyzed both for low pass filters (before) and cascade filters (after) in terms of SNR versus filter order to find out the minimum filter order at which each individual filter performs the best. All the graphs are evaluated. But only Chebyshev Type I and Elliptic filter in the monitoring mode and Equiripple in diagnostic mode outperform other filters. Their evaluation graph is shown below:

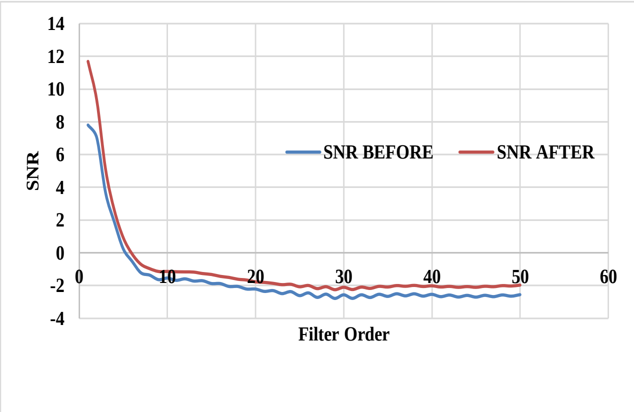

Fig. 1. SNR versus Filter Order – Chebyshev Type I Filter in Monitoring Mode

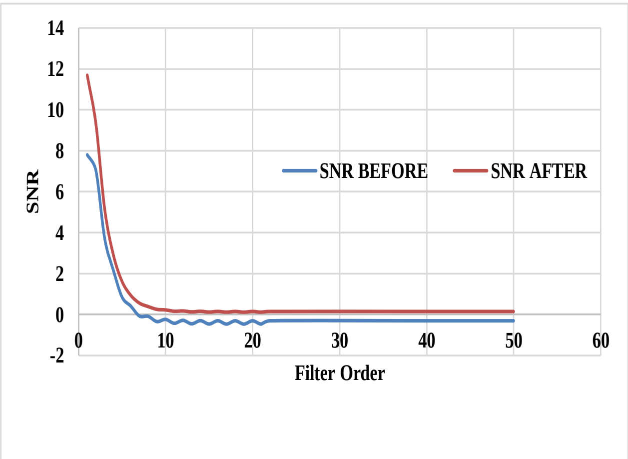

Fig. 2. SNR versus Filter Order – Elliptic Filter in Monitoring Mode

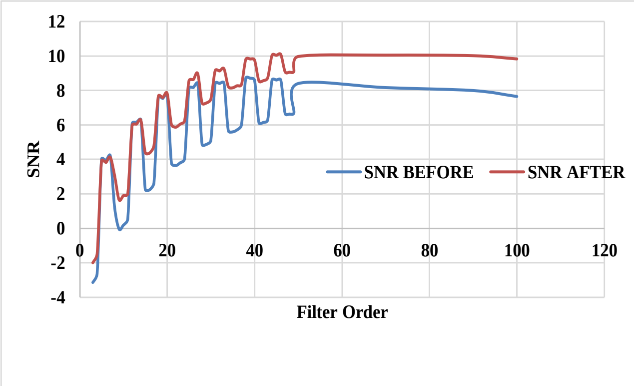

Fig. 3. SNR versus Filter Order – Equiripple Filter in Diagnostic Mode

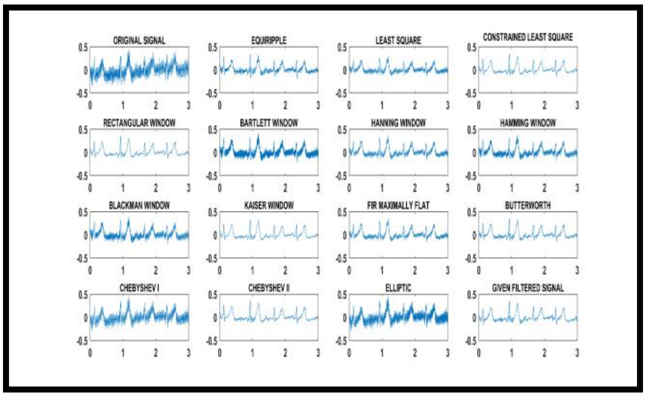

Fig. 4. ECG Filtration in Monitoring Mode

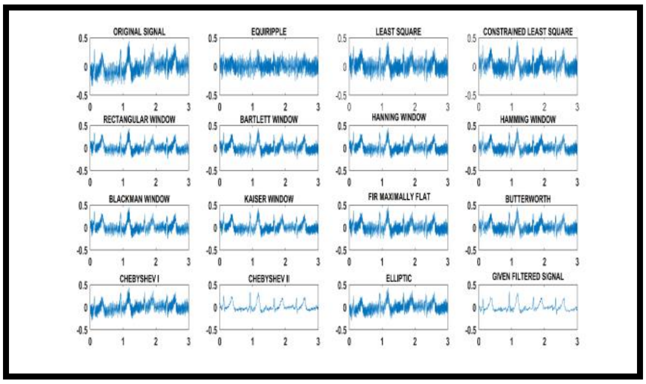

Fig. 5. ECG Filtration in Diagnostic Mode

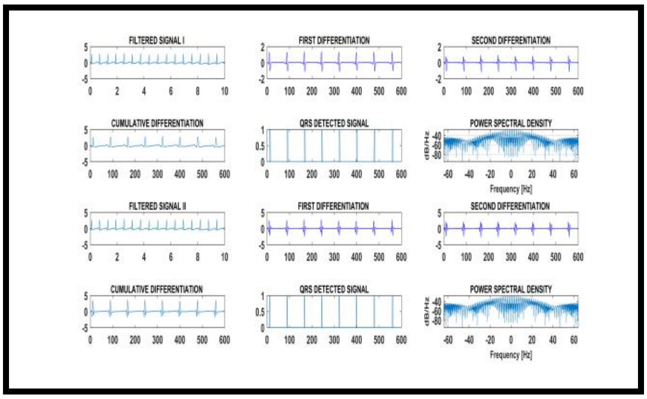

Fig. 6. PSD Analysis of QRS Detected Normal Sinus Rhythm ECG

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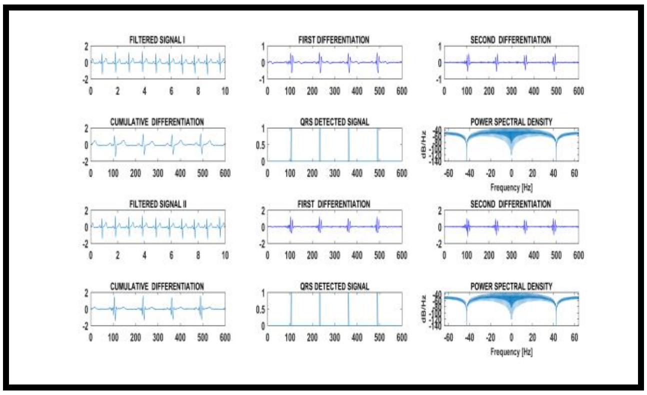

Fig. 7. PSD Analysis of QRS Detected Supraventricular Arrhythmia ECG

IV. CONCLUSION

Optimized filter order or minimum filter order at which digital filters performs the best has always been a problem. This study solves this problem by evaluating performance of different cascaded based digital filters for both normal and abnormal ECG datasets. For finding out the optimized filter order at first SNR has been chosen as a parameter for evaluation. Then this optimized filter order has been applied to different datasets of QRS detected ECG signal to analysis PSD. Based on the parameter average power it has been found that in monitoring mode Chebyshev type I and Elliptic filter perform the best for all datasets while for diagnostic mode Equiripple filter shows the best performance. Several datasets have been examined for this study.

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