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Comparative Study on the Effect of Order and Cut off Frequency of Butterworth Low Pass Filter for Removal of Noise in ECG Signal

Subhadeep Basu
Electronics and Telecommunication Engineering Department
IIEST Shibpur
Howrah, India
subhadeep.basu680@gmail.com

Samiul Mamud
School of Mobile computing and Communication
Jadavpur University
Jadavpur,India
Samiulmamud1995@gmail.com

Abstract: Removal of noise in ECG signal is an important aspect for the processing and analysis of signal. Since ECG is a low frequency signal, it can easily be corrupted by the external noise and artifacts. The main aim of the filtering is to eliminate the undesired frequency components while preserving the originality of the signal. Butterworth low pass filter is a fundamental type of IIR filter which is used widely in signal processing. The nature of the filtered output signal depends largely on the cut off frequency and order of the filter. This study aims to provide a comparative analysis of the cut off frequency and order of the filter on the ECG signal.

Keywords: ECG, Butterworth Filter, cutoff frequency, order, noise removal.

I. Introduction

The electrical activities of heart are recorded in Electrocardiogram (ECG) [1]. The ECG is directly related to the functioning of the heart. Thus, from the ECG signal it can be observed whether heart is operating in normally or not.

However, the ECG signal is often contaminated with motion artifacts, high frequency noise, power line interference etc. Hence, filtering of ECG signal must be ensured for various applications [2-3]. As, ECG is not stationary signal, the removal of high frequency noise from this signal is a tedious job [4-5]. Since, noise is directly mixed with the ECG signal; removal of noise may lead to the loss of information. Hence, every technique must ensure the nominal loss of information with significant noise reduction. There are various techniques to remove noise in ECG signal. Hence selecting the appropriate filter is not an easy task. It was seen that Butterworth, Chebyshev and elliptic are the most commonly used Infinite Impulse Response (IIR) filters [6].

Wavelet based de-noising is another popular technique that can be applied for ECG signals. It has been observed that the performance of wavelet based filters is mostly dependent on the amount of noise. It has been observed that when the amount of noise is low, IIR filters are more effective to remove noise as compared to the wavelet based filters. If the amount of noise is significantly more (>50%), in that case wavelet based filters are more effective as compared to IIR filters. [7].

Butterworth and Chebyshev filters are commonly used IIR Filters. The transition band is more in Butterworth filter compared to Chebyshev filter. But, the magnitude response of Butterworth filter decreases monotonically as frequency increases. On the other hand, the magnitude response of Chebyshev filter exhibits ripple in the pass-band and monotonically decreasing in stop-band.

Butterworth filter is one of the most fundamental IIR filter. The filtered output from the Butterworth filter depends on various parameters, viz. order, attenuation in pass band, attenuation in stop band, cut off frequency of the filter etc. In this work, low pass butter worth filters are considered for high frequency noise removal in ECG signal. The effect of variation of order and cutoff frequency of the Butterworth low pass filter is studied in this work.

II. Analysis

The steps followed in this work have been elaborated below.

A. Load ECG Data

The primary and essential part of this study is the ECG data. There are several websites that provides the access of free ECG data. These data are also available as raw data or processed data. The ECG data which is mixed with noise is taken from [8]. The data is sampled at a sampling frequency of 1000Hz. The data is processed in MATLAB for the processing. The study has been performed in MATLAB(R 2013) on a computer with Intel Core i3 processor with 4GB internal memory.

B. Selecting Butterworth Filter

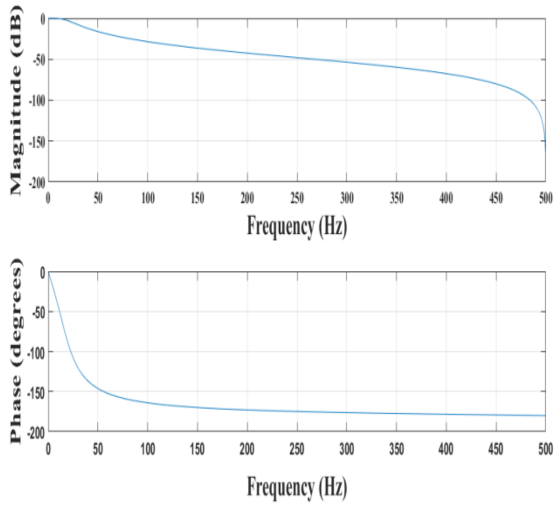

Fig. 1. Filter characteristics of second order low pass filter having cut off freq. 20 Hz.

The next step after selecting the ECG data is to select the IIR Butterworth low pass filter. In this study, low pass filter with three different orders are considered, viz.2,4 and 8. Similarly, to analyze the effect of cutoff frequency on the filtered output signal three different cut off frequencies are also considered. The cutoff frequencies that are taken into considerations are 20, 40 and 60 Hz.

Some of the filter characteristics (magnitude and phase response) are also shown below. The magnitude response and the phase response of second order butter worth filter with cut off frequencies 20, 40 and 60 Hz is shown in Fig. 1, Fig. 2 and Fig. 3 respectively.

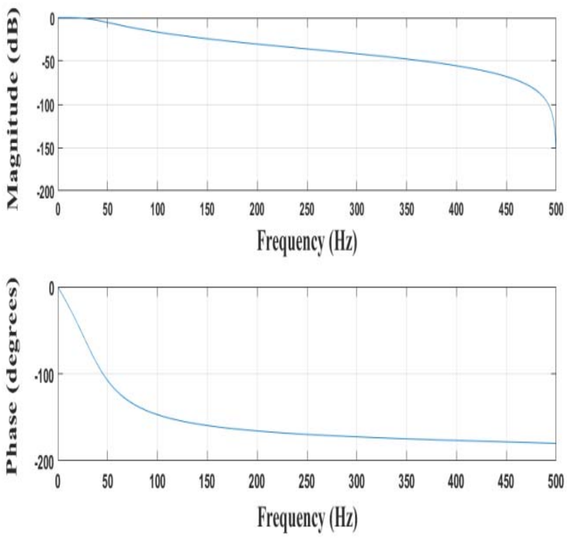

Fig. 2. Filter characteristics of second order low pass filter having cut off freq. 40 Hz.

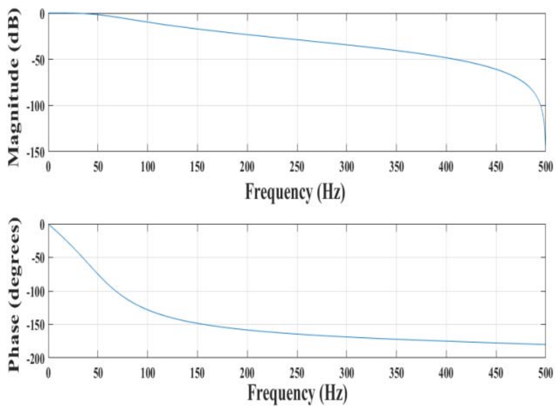

Fig. 3. Filter characteristics of second order low pass filter having cut off freq. 60Hz.

Similarly, the magnitude and phase response for higher order filters (n=4 and 8) with three different cut off frequencies described above are also obtained. From the above plots, it's clear that for same filter order, the kink in the phase response starts at different positions depending upon the cutoff frequencies.

C. Selecting Chebyshev Filter

In order to compare the filter performance of Butterworth filter with other kinds of IIR filter, a Chebyshev low pass filter is designed. This Chebyshev filter is examined with n=2, n=4 and n=8 with cut off frequency at 60 Hz. The sampling frequency is 1000 Hz, while pass-band attenuation is taken as 1dB. The filter characteristics is shown in fig 4,5 and 6 respectively.

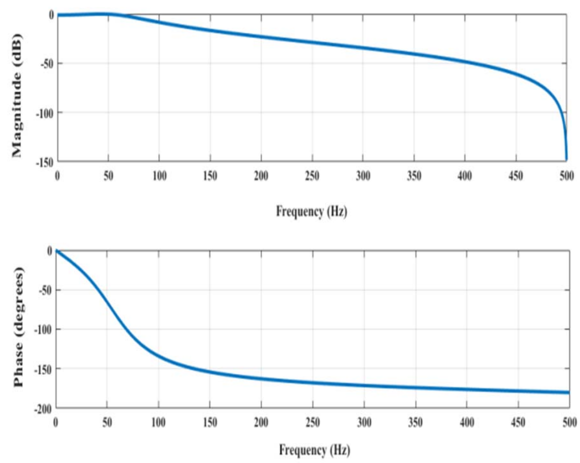

Fig. 4. Chebyshev LPF characteristics with n=2.

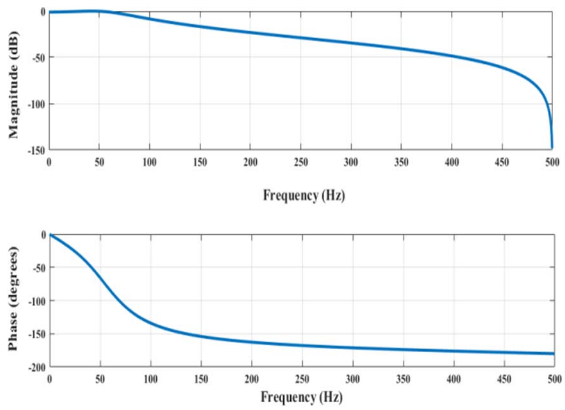

Fig. 5. Chebyshev LPF characteristics with n=4.

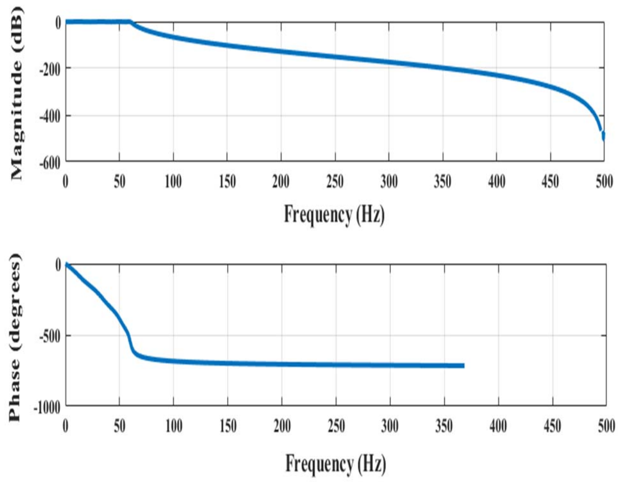

Fig. 6. Chebyshev LPF characteristics with n=8.

III. Results

These Butterworth filters are used to remove the noise that are present in the ECG signal. The original ECG signal and the filtered output of the ECG signal for second order Butterworth filter with cut off frequencies 20, 40 and 60 Hz are shown in fig 7,8 and 9.

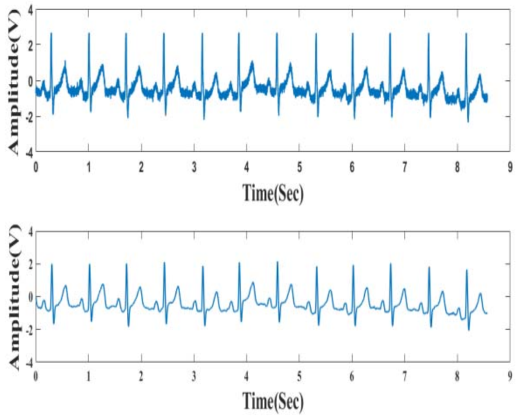

Fig. 7. Original signal and filtered ECG output for second order low pass filter having cut off freq. 20Hz.

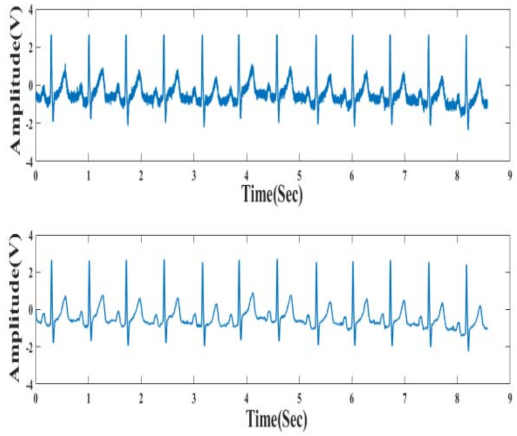

Fig. 8. Original ECG signal and filtered output of second order low pass filter having cut off freq. 40Hz.

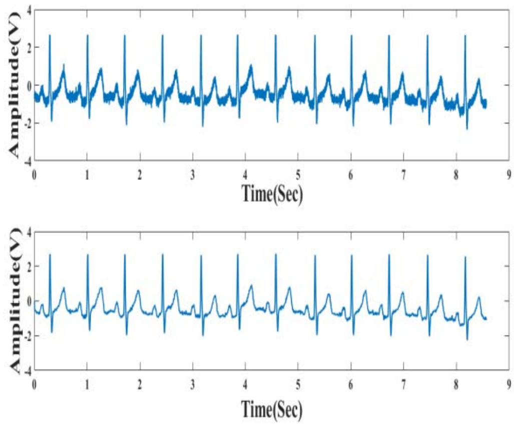

Fig. 9. Original ECG signal and filtered output of second order low pass filter having cut off freq. 60Hz.

The filtered output of ECG signal using fourth order low pass Butterworth filter is also studied. These are shown in fig 10,11 and 12.

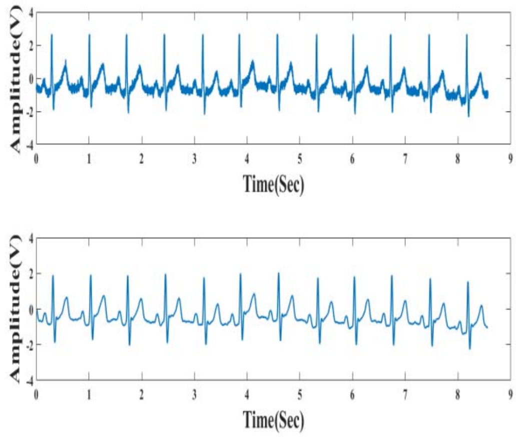

Fig. 10. Original ECG signal and filtered output of fourth order low pass filter with cut off frequency 20Hz.

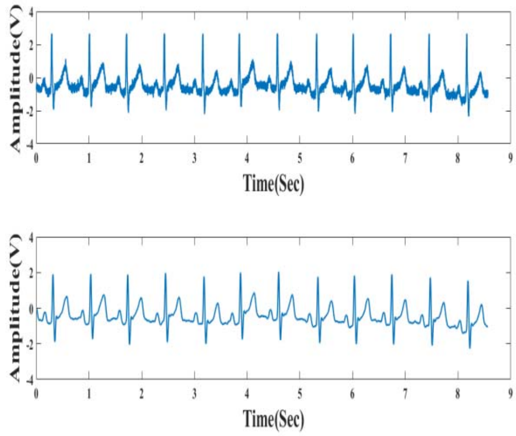

Fig. 11. Original ECG signal and filtered output of fourth order low pass filter with cut off frequency 40Hz.

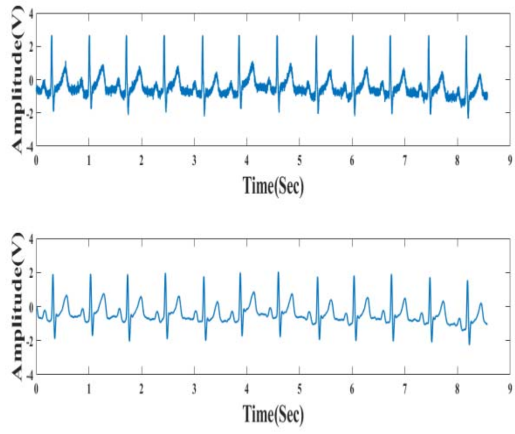

Fig. 12. Original ECG signal and the filtered output of fourth order low pass filter with cut off frequency 60Hz.

Similarly, the noisy ECG signal is also processed using the higher order (n=8) Butterworth low pass filter. As sated earlier, different low pass filters are analyzed with three different cut off frequencies.

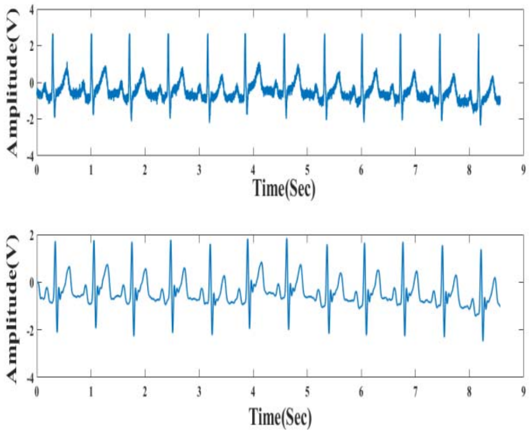

Fig. 13. Original ECG signal and filtered output of eighth order low pass filter with cut off frequency 20Hz.

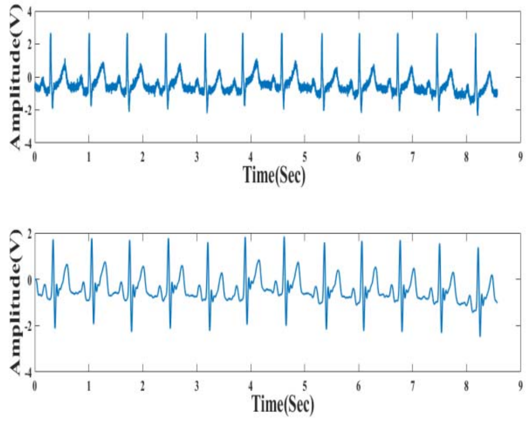

Fig. 14. Original ECG signal and filtered output of eighth order low pass filter with cut off frequency 40Hz.

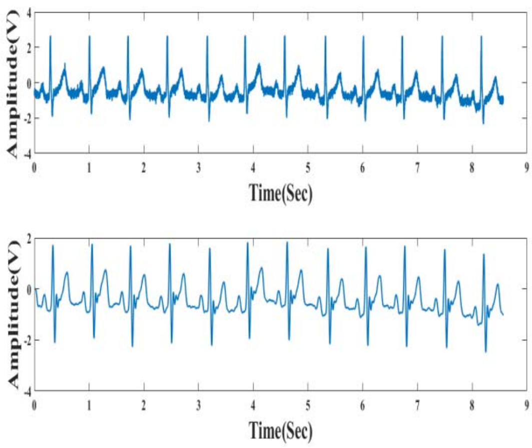

Fig. 15. Original ECG signal and filtered output of eight order low pass Butterworth filter with cut off frequency 60Hz.

The noisy ECG signal is processed using the Chebyshev LPF with cut off frequency 60Hz. The original ECG signal and the filtered outputs of it are shown in fig 16, 17 and 18 respectively.

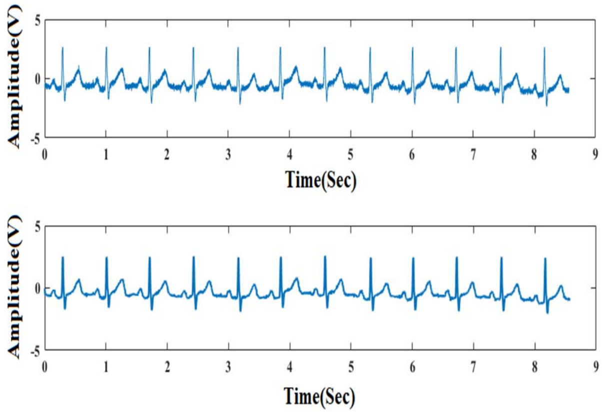

Fig. 16. Original ECG signal and the filtered output of 2nd order Chebyshev LPF.

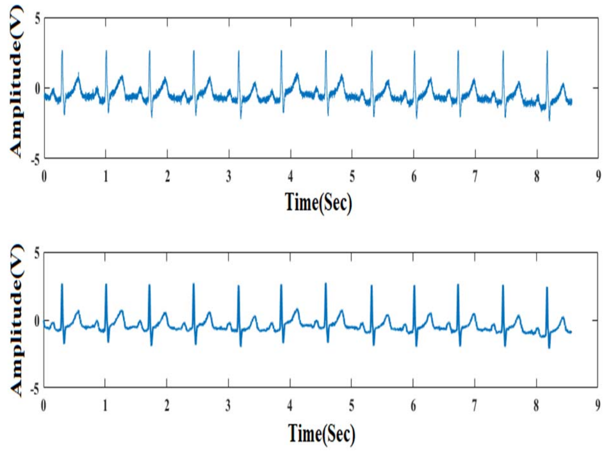

Fig. 17. Original ECG signal and the filtered output of 4th order Chebyshev LPF.

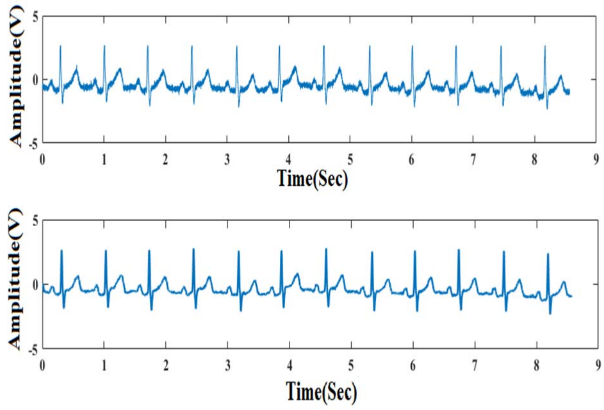

Fig. 18. Original ECG signal and filtered output of 8th order Chebyshev LPF.

SNR CALCULATIONS

Signal to Noise ratio(SNR) provides an idea about how much a system is immune to noise.SNR is generally expressed in dB. Since, Power of a signal is proportional to the square of amplitude level, SNR can be estimated easily. Let, A_{sig} is the amplitude of the original signal and A_{noise} is the amplitude of the noise signal. Then SNR can be obtained as:

$$SNR= (A_{sig}/A_{noise})^2 \quad (1)$$

Noise = Given ECG signal – Filtered ECG signal.
SNR is generally expressed in dB as

$$SNR(dB) = 10\log_{10}(SNR) \quad (2)$$

The values of SNR in different cases are listed in the following table.

TABLE I. VALUES OF SNR IN DB

Order	Cut off Freq	SNR(dB)
2	20	4.38
2	40	5.39
2	60	5.65
4	20	7.45
4	40	8.24
4	60	8.6
8	20	9.59
8	40	10.36
8	60	11.84

From the above table it's clear that as the filter order and cut off frequency increases, the values of SNR also increases.

Similarly, SNR is calculated for Chebyshev LPF of 2nd, 4th and 8th order . This is given in table 2.This is for filter with cut off frequency 60 Hz.

TABLE II. COMPARATIVE VALUES OF SNR

Filter	Order	SNR(dB)
Butterworth Low Pass Filter	2	5.65
	4	8.6
	8	11.84
Chebyshev Low Pass Filter	2	6.12
	4	9.1
	8	11.96

IV. CONCLUSION

The original noisy ECG signal has a prominent amplitude range that varies from -2V to +2V. Moreover the amplitude of T-wave is around 1.5V. When lower order filter (n=2) is considered for signal processing, then a significant part of the signal (T-wave) is lost in the filtered output. However, when higher order filters (n=4 and 8) are considered, then a significant amount of noise is removed from ECG signal. The difference between the maximum amplitude of R and T reduces as the filter order is increased. Similarly, when the cut off frequency is low (20 Hz), the QRS complex can't get recovered. When cut off frequency is increased to 40Hz and 60Hz, there is an improvement in QRS complex.

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