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Comparative study of FIR and IIR filters for the removal of Baseline noises from ECG signal

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Abstract-In signal processing, the function of a filter is to remove unwanted parts of the signal, such as random noise, or to extract useful parts of the signal, such as the components lying within a certain frequency range. This paper presents the comparisons of Digital FIR &IIR filter complexity and their performances to remove Baseline noises from the ECG signal hence it is desirable to remove these noises for proper analysis and display of the ECG signal.

Keywords: Baseline Noises, FIR filters, IIR filters.

I. INTRODUCTION

The impact of digital signal processing techniques promoted revolutionary advances in many fields of application e.g. biomedical engineering, speech communication, data communication, nuclear science and many others [1]. Electrocardiogram (ECG) is one of the most important electrical signals in the field of medical science which has a great need to be processed before further analysis. Arrhythmias or abnormalities of the heart rhythm can be detected using electrocardiograms (ECGs) that record the electrical activity of the heart. However, timely and accurate detection of arrhythmias is a complex decision-making process for a cardiologist due to contamination of ECG signals with different frequencies of noise. For reliable interpretation of real-time ECGs, computer based techniques based on digital signal processing of ECG waveform have been reported [2]. The ECG Signal is a graphical representation of the electromechanical activity of the cardiac system. It is one of the most important physiological parameter, which is being extensively used for knowing the state of cardiac patients. Fig 1 shows an example of normal ECG trace, which consists of P wave, QRS complex and T wave. The small U wave may also be sometimes visible [3].

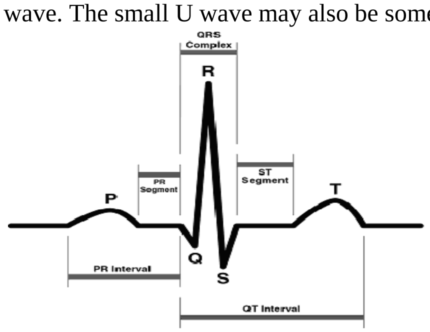

Fig: 1 Normal ECG trace.

ECG signal is non-stationary signal including valuable clinical information, but frequently this information is corrupted by noise.

Typical examples of these noises are Baseline noises, Power line interference, Electrode contact noise, Motion artifacts, Instrumentation noise generated by electronic devices, Electrosurgical Noise etc. Different digital filter structures are available to eliminate these diverse forms of noise sources [4]. Every type of filter has its strong point & weaknesses. In this paper, the main focus is to remove baseline noises because baseline noise elimination is often one of the first steps required in the processing of the electrocardiogram (ECG). Baseline noises make manual and automatic analysis of ECG records difficult, especially in the detection of ST-segment deviations. This segment is very important and has the information related to heart attack [5]. It is necessary that the filter allow removing the baseline noises while preserving the useful clinical information.

II. BASELINE NOISES

Baseline noise is of two types:

1) Baseline drift and
2) Baseline wander

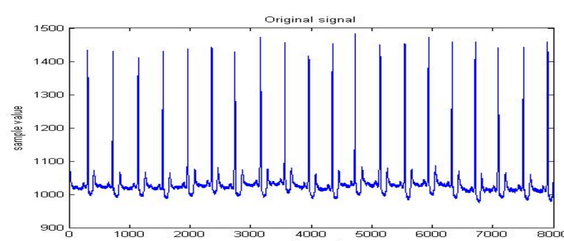

Fig 2: ECG signal with Baseline drift(114.dat)

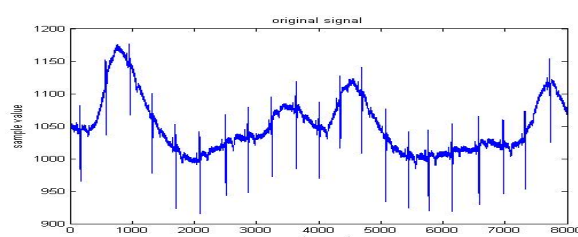

Fig 3: ECG signal with Baseline wander (113.dat)

A large number of techniques exist in the literature for the removal of baseline noises from the ECG. Many researchers have worked on development of methods for reduction of noises in ECG signal. Mahesh S. Chavan *et al*, design FIR filters using rectangular window for noise reduction in ECG signal [6]. V.S. Chouhan and S.P. Mehta developed an algorithm for total removal of Baseline drift from ECG signal & deploy least square error correction & median based correction [7]. Lisheng Xu *et al* presented an energy ratio-based method and a wavelet-based cascaded adaptive filter (CAF) for detecting and removing baseline drift from pulse waveforms [8]. Zahoor-uddin, presented Baseline Wandering Removal from Human Electrocardiogram Signal using Projection Pursuit Gradient Ascent Algorithm & shows the comparative study of the results of different algorithms like Kalman filter, cubic spline and moving average algorithms [5]. Mahesh S. Chavan *et al* has also presented the Comparative Study of Chebyshev I and Chebyshev II Filter for noise reduction in ECG Signal [9]. A. K. Ziarani, A. Konard used a nonlinear adaptive method to remove noise [10]. As baseline noises occur due to low frequencies normally 0.05 to 0.5Hz [2], so high pass filtering technique can be a good method to eliminate baseline noises.

III. ECG DATABASE

In the present work the ECG signal required for analysis are collected from Physionet MIT-BIH Arrhythmia Database where annotated ECG signals are described by a text header file (.hea), a binary file (.dat) and a binary annotated file (.atr). Header file consists of detailed information such as number of samples, sampling frequency, format of ECG signal, type and number of ECG leads, patient's history and the detailed clinical information. In binary data signal file, the signal is stored in 212format which means each sample requires number of lead times 12 bits to be stored and the binary annotation file consists of beat annotation. The database contains 48 records; each of the record is slightly over 30 minutes long. Each record is sampled at 360 Hz frequency with a resolution of 11 bits [10].

IV. DESIGN OF FILTERS

On the basis of Impulse Response, there are generally two types of digital Filters:

- Infinite Impulse response(IIR)
- Finite impulse Response(FIR)

Digital Filters can be described by the generalized discrete differential equation:

$$\sum_{m=0}^{M} a_m \cdot y[n-m] = \sum_{k=0}^{N} b_k \cdot x[n-k]$$

a, b : filter coefficients
x[n] : input signal
y[n] : output signal
M,N : filter order

The right side of above equation depends only on the inputs x[n] so it is called feed-forward & the left side depends on the previous outputs y[n] i.e. called feed-back. FIR Filters have only feed-forward components, they can be calculated non-recursively. IIR Filters have feed-back components also, they are calculated recursively[12].

A. *Design of FIR filters*

In this section, FIR Equiripple filter, windowing FIR filters with Kaiser, Rectangular, Hamming, Hanning and Blackman functions are designed. The basic specifications for design of filter are:

1. Cut-off frequency 0.5Hz
2. Sampling frequency 360Hz (MIT/BIH database sampled at 360 Hz)

The other parameters are pass-band ripples and stop-band ripples. In the design of FIR equiripple design, pass-band ripple is 1 dB, stop-band ripple is 30 dB and the order of the filter was found to be 320. The transition band of this filter is approximately 0.5 Hz. The phase delay is 2.8 rad/ Hz. In case of window filters, cut-off frequency at the 3 dB point is 0.5 Hz. The window length in case of rectangular and Kaiser Window is 451 which is selected according to filter order 450 (window length is order plus one). The phase delay is 3.92 rad/Hz. But in other windows, order becomes very high and reaches up to 1500 and it increase the phase delay to 13.08rad/Hz.

B. *Design of FIR filters*

In this case, four IIR filters i.e. Butterworth filter, Chebyshev Type I, Chebyshev Type II and Elliptic filter are designed. In the design process of IIR filters, filter order is only 2. The design parameters of Butterworth filter are only cut-off frequency, filter order and sampling frequency as there are no ripples in passband and stopband. In this paper Butterworth filter of cut-off frequency 0.5Hz is implemented on ECG signal. The Chebyshev Type I has passband ripples of 1dB but no stopband ripples. The phase delay is exactly zero in both filters. On the other hand, Chebyshev Type II filter has stopband ripples of 20 dB; there were some phase delay at low frequencies which is upto 1.3rad/Hz. In case of elliptic filters, there are both stopband and passband ripples of 30dB and 1dB respectively. Due to which phase delay is present at low frequencies nearly upto 20 Hz and it becomes zero after this frequency

V. EVALUATION PARAMETERS

The two important parameters to check the suppression of Baseline noises are Spectral density and Average Power of signal.

A. Power Spectral Density (PSD)

The periodogram power spectrum estimate represents the distribution of the signal power over frequency. From the spectrum the frequency content of the signal can be estimated directly. Power spectral density (PSD) of ECG signal is calculated as follows:

$$S(f) = \frac{1}{FsN} \left| \sum_{n=1}^{N} x_n e^{-j(2\pi f/Fs)n} \right|^2$$

where Fs is sampling frequency.

The periodogram is an estimate of the PSD of the signal defined by the sequence [$x_{1,....}, x_N$]. Periodogram uses an nfft-point FFT to compute the power spectral density [11].

B. Average Power

The area under the PSD curve is the measure of the average power [11].

VI. RESULTS & DISCUSSIONS

On implementation of above designed filters on ECG signals with baseline noises, the following results are obtained.

Table 1: Comparison of FIR filters for Removal of Baseline drift (114.dat)

FIR Filter	Order of filter	Spectral density before filtration (dB/Hz)	Spectral density after filtration (dB/Hz)	Average power (dB)	Ringing effect
FIR Equiripple	320	40.74	16.83	37.5	Small
Kaiser	450	40.74	27.72	38.78	Small
Rectangular	450	40.74	26.89	38.84	Small
Hamming	1200	40.74	27.47	38.74	Large
Hanning	1200	40.74	28.12	38.74	Large
Blackmann	1500	40.74	27.61	38.87	Large

Table 2: Comparison of FIR filters for Removal of ECG Baseline wander (113.dat)

FIR Filter	Order of filter	Spectral density before filtration (dB/Hz)	Spectral density after filtration (dB/Hz)	Average power (dB)	Ringing effect
FIR Equiripple	320	42.19	14.83	34.09	Small
Kaiser	450	42.19	26.95	36.53	Small
Rectangular	450	42.19	25.92	36.64	Small
Hamming	1200	42.19	26.91	36.66	Large
Hanning	1200	42.19	27.60	36.65	Large
Blackmann	1500	42.19	26.84	36.87	Large

Table 3: Comparison of IIR filters for Removal of ECG Baseline drift (114.dat)

IIR filter	Order	Spectral density before filtration (dB/Hz)	Spectral density after filtration (dB/Hz)	Average Power of signal (dB)	Ringing Effect
Butterworth	2	40.74	32.77	39.48	Large
Chebyshev Type I	2	40.74	31.39	38.97	Large
Chebyshev Type II	2	40.74	27.23	39.87	Small
Elliptic	2	40.74	31.13	39.00	Large

Table 4: Comparison of IIR filters for ECG Baseline wander (113.dat)

IIR filter	Order	Spectral density before filtration (dB/Hz)	Spectral density after filtration (dB/Hz)	Average Power of signal(dB)	Ringing Effect
Butterworth	2	42.19	32.16	37.54	Large
Chebyshev Type I	2	42.19	30.62	37.30	Large
Chebyshev Type II	2	42.19	17.09	35.60	Small
Elliptic	2	42.19	26.22	37.42	Large

Table 1 and 2 shows the comparison of different FIR filters. It has been observed that the fall in value of spectral density after filtering is very large in case of FIR equiripple filter in both signals as compared to all windows. Kaiser window and rectangular window is also showing better results at the expense of some more computational load as the order of filter is large. Kaiser window has an adjustable parameter which controls the trade-off between main lobe width and side lobes. But in case of remaining windows i.e. Hamming, Hanning and Blackman windows, the order of filter easily grow very much high. It increases the number of filter coefficients which leads to the large memory requirement and problems in hardware implementation. Table 3 and 4 shows the comparison of different IIR filters. The best trade-off between spectral density and average power is shown by Chebyshev Type II filter.

VII. CONCLUSIONS

The order of performed IIR filter is 2 and it is a recursive filter. Thus, IIR filters require less computation-power, and their implementation is easier than that of FIR filters. The transition band is very narrow (0.1 Hz) as compared to FIR filters. The phase delay is also approximately zero. However, IIR filters have a phase distortion that is caused by nonlinear phase response of IIR filters. If we increase the order of filter then infinite oscillations can get produced. But to remove Baseline noise we require only filter of order 2 at which there are only small oscillations at the starting of waveform which is called Ringing effect. This problem can be solved by applying the IIR filter to the ECG signal in both directions. Table 5 shows the comparison of complexity between FIR and IIR filters. FIR and IIR filters both have removed the baseline noises (shown in Figs. 4-7) at the expense of some ringing effect at the starting of waveform. But their comparison shows that due large order of FIR filter there is a phase delay in FIR filtered waveforms. The computational complexity of FIR filter is far greater than IIR filters. It increases the memory requirement and power dissipation of FIR filter. So, IIR filters can be the better choice for removal of Baseline noises.

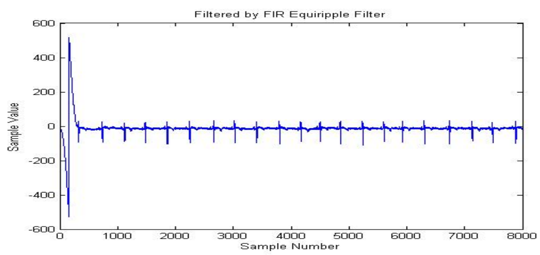

Fig 4: ECG signal (114.dat) filtered by FIR equiripple filter

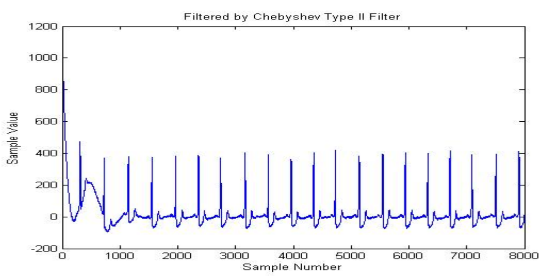

Fig 5: ECG signal (113.dat) filtered by FIR equiripple filter

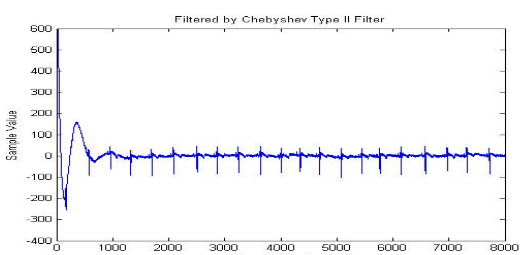

Fig 6: ECG signal filtered (114.dat) by Chebyshev Type II filter

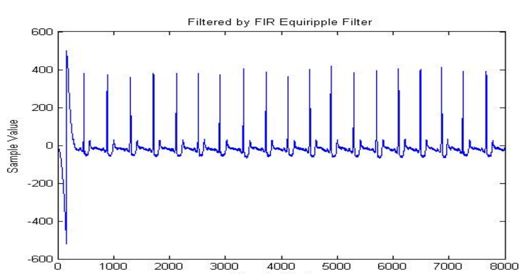

Fig 7: ECG signal (113.dat) filtered by Chebyshev Type II filter

Table 5: Comparison of complexity FIR and IIR filters

Filter Type	Minimum order used	No. of adders	No. of Multipliers	No. of delays
FIR	320	320	321	320
IIR	2	4	4	2

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