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Research Paper | Engineering

IIR Filter Design to remove noise from ECG signal

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ABSTRACT

Digital filters plays very significant role in the processing of the low frequency components in ECG signal. ECG signal contains the base line wander noise (BW), power line interference (PLI), and Electromyography interference (EMG). It is required to eliminate this noise as it can cause distortion to the important clinical information and create difficulty for doctors to interpret the diseases of patient. This paper presents the IIR filter design like Butterworth, Chebyshev I, Chebyshev II and Elliptic filter to remove noise from ECG signal. To test the performance of designed filter, ECG signal was generated using Bio-signal Simulator by Tektronix. 10000 samples were collected, acquired and stored using Keithley USB DAQcard. For the performance analysis and comparison we have calculated Power spectral density (PSD). Simulation results are shown. The tool used to design Digital filter is MATLAB®/SIMULINK®.

KEYWORDS: ECG signals, Noise reduction, Filter, MATLAB

I.Introduction

The electrocardiographic (ECG) signal is the electrical representation of the hearts activity. Computerized ECG analysis is widely used as a reliable technique for the diagnosis of cardiovascular diseases, and the ECG signal is most commonly used biomedical signal in clinical practice. This ECG signal is Commonly encountered artifacts include baseline wander, power-line interference, physiological signals generated by other organ of the body or included by muscular contractions related to breathing, and high frequency random noise. Baseline wander and power-line interference reduction is the first step in all electrocardiographic (ECG) signal processing. The baseline wander is caused by varying electrode-skin impedance, patient's movement and breath. This kind of disturbances is especially present in exercise electrocardiography, as well as during ambulatory and Holter monitoring. The ECG signal is also degraded by additive 50 Hz or 60 Hz power line (AC) interference. Another noise which affect ECG signal is Electromyography interference (EMG). These all artifacts are the dominant artifacts and strongly affect the ST segment, degrade the signal quality, frequency resolution, produces large amplitude signals in ECG that can resemble PORST waveforms and masks tiny features that are important for clinical monitoring and diagnosis. Hence the extraction of high-resolution ECG signals from recordings which are contaminated with background noise is an important issue to investigate. The goal of ECG signal enhancement is to separate the valid signal components from the undesired artifacts, so as to present an ECG that facilitates easy and accurate interpretation [1].

The typical DSP methods include z-transform, Fourier transform, convolution, correlation, and filtering, etc. The advantages of DSP methods are that they are programmable, reliable, high precision and maintainable, as well as easy to design and obtain a linear phase from which can ascertain that the filters won't distort the original signal [2], [3].

Many methods were proposed in the past for the removal of noise from the ECG [1]-[8].

II. The Related IIR Filter Mathematical Formula

IIR digital filters are commonly realized recursively by feeding back a weighted sum of past output values and adding these values to a weighted sum of present and past input values. In principle, IIR digital filters have infinite memory. In contrast, the non-recursive realization of FIR digital filters has finite memory, where an output sample is generated as a weighted sum of present and past input values.

The major advantage of IIR digital filters, compared to FIR digital filters, is that, for a given order N, highly selective recursive digital filters can be designed. In other words, the recursive realizations of IIR digital filters are computationally efficient. The disadvantage of the recursive realization is that the designer must pay attention to stability, parasitic phenomena, and phase non-linearity. [9]

The basic technique of IIR filter design transforms well-known analog filters into digital filters using complex-valued mappings. The advantage of this technique lies in the fact that both analog filter design (AFD) tables and the mappings are available extensively in the literature. This basic technique is called the A/D (analog-to-digital) filter transformation. However, the AFD tables are available only for lowpass filters. (We also want to design other frequency-selective filters (highpass, bandpass, bandstop, etc.). To do this, we need to apply frequency-band transformations to lowpass filters. These transformations are also complex-valued mappings, and they are also available in the literature. [10]

1) Butterworth Algorithm

The magnitude function is maximally flat at the origin and monotonically decreasing in both the passband and the stopband. The variation of the group delay in the passband is comparatively small. [11]

Eq. (1) gives the Butterworth approximation's magnitude response where ω0 is the passband edge frequency for the filter, n is the order of the approximation function, and ε is the passband gain adjustment factor. In this case, the subscript B indicates a Butterworth filter, and n indicates an nth-order transfer function.

$$\left|H_{B,n}[j(\omega/\omega_0)\right| = \frac{1}{\sqrt{1+\varepsilon^2\cdot(\frac{\omega}{\omega_0})^{2n}}}, \quad (1)$$

where

$$\varepsilon = \sqrt{10^{-0.1\cdot\alpha_{pass}} - 1} \quad (2)$$

The standard formula for the Butterworth order calculation is given in eq. (3).

$$n_B = \frac{\log\left[\frac{10^{-0.1\cdot\alpha_{stop}}-1}{10^{-0.1\cdot\alpha_{pass}}-1}\right]}{2\cdot\log\left(\omega_{stop}/\omega_{pass}\right)} \quad (3)$$

2) Chebyshev Type I

The magnitude function has equal ripple in the passband and decreases monotonically in the stopband. The variation of the group delay is somewhat worse than for the Butterworth approximation. [11] The magnitude response function for the Chebyshev I approximation is shown in eq. (4).

$$\left|H_{C,n}[j(\omega/\omega_0)\right| = \frac{1}{\sqrt{1+\varepsilon^2\cdot C_n^2(\frac{\omega}{\omega_0})}} \quad (4)$$

where the definition of ε is again

$$\varepsilon = \sqrt{10^{-0.1\cdot\alpha_{pass}} - 1} \quad (5)$$

The standard formula for the Chebyshev Type I order calculation is given in eq. (6).

$$n_C = \frac{\cosh^{-1}\left[\sqrt{10^{-0.1\cdot\alpha_{stop}} - 1/10^{-0.1\cdot\alpha_{pass}} - 1}\right.}{\cosh^{-1}(\omega_{stop}/\omega_{pass})} \quad (6)$$

3) Chebyshev II (Inverse Chebyshev)

The magnitude function is maximally flat at the origin, decreases monotonically in the passband, and has equal ripple in the stopband. The group delay has a variation similar to the Butterworth approximation, but much smaller overall group delay. The same filter order is required as for the Chebyshev I approximation. [11]. The magnitude response function for Chebyshev II approximation is shown in eq.(7)

$$\left|H_{I,n}[j(\omega/\omega_0]\right| = \frac{\sqrt{\varepsilon_i^2 \cdot C_n^2(\omega/\omega_0)}}{\sqrt{1+\varepsilon_i^2 \cdot C_n^2(\frac{\omega}{\omega_0})}} \quad (7)$$

where

$$\varepsilon_i = \frac{1}{\sqrt{10^{-0.1\cdot\alpha_{stop}} - 1}} \quad (8)$$

The order of the filter is given by eq. (9)

$$n_I = \frac{\cosh^{-1}\left[\sqrt{10^{-0.1\cdot\alpha_{stop}} - 1/10^{-0.1\cdot\alpha_{pass}} - 1}\right.}{\cosh^{-1}(\omega_{stop}/\omega_{pass})} \quad (9)$$

4) Elliptic Filter

The magnitude function has equal ripple in both the passband and the stopband, but the variation of the group delay is larger than that for the other approximations. The overall group delay is the smallest of the four filter approximations. The elliptic approximation's magnitude frequency response function is shown in eq. (10), where Rn is the Chebyshev rational function of order n. Rn is composed of both numerator and denominator portions, which allow an equiripple response in both the passband and stopband.

$$\left|H_{E,n}[j(\omega/\omega_0]\right| = \frac{1}{\sqrt{1+\varepsilon^2 \cdot R_n^2(\frac{\omega}{\omega_0})}} \quad (10)$$

The order of the elliptic approximation function is given by eq. (11)

$$\left|H_{E,n}[j(\omega/\omega_0]\right| = \frac{1}{\sqrt{1+\varepsilon^2 \cdot R_n^2(\frac{\omega}{\omega_0})}} \quad (11)$$

where CEI refers to the complete elliptic integral, and the ratio rt and the kernel kn are defined as [12]

$$rt = (\omega_{pass}/\omega_{stop}) \quad (12)$$

$$kn = \sqrt{10^{-0.1\cdot\alpha_{pass}} - 1/10^{-0.1\cdot\alpha_{stop}} - 1} \quad (13)$$

III. Simulation Results

Simulation result using Butterworth algorithm to remove noise from ECG signal is shown in Fig. 1. The order of lowpass filter is 3, highpass filter is 2 and notch filter is 2.

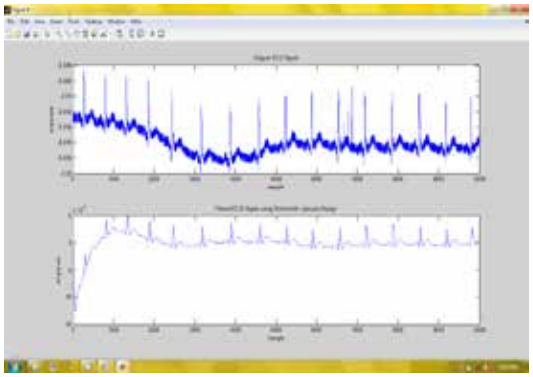

Fig. 1 Butterworth Cascade Filter Output

Simulation result using Chebyshev I to remove noise from ECG signal is shown in Fig. 2. The order of lowpass filter is 2, highpass filter is 2 and notch filter is 2.

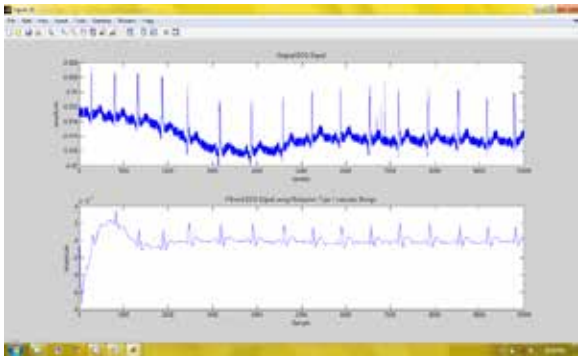

Fig. 2 Chebyshev Type 1 Cascade Filter Output

Simulation result using Chebyshev II to remove noise from ECG signal is shown in Fig. 3. The order of lowpass filter is 3, highpass filter is 4 and notch filter is 2.

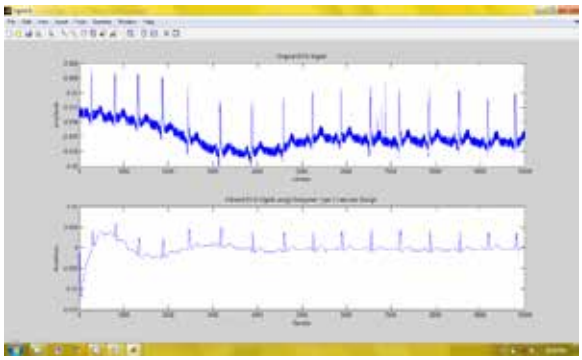

Fig. 3 Chebyshev Type 2 Cascade Filter Output

Simulation result using Butterworth algorithm to remove noise from ECG signal is shown in Fig.4. The order of lowpass filter is 2, highpass filter is 2 and notch filter is 2.

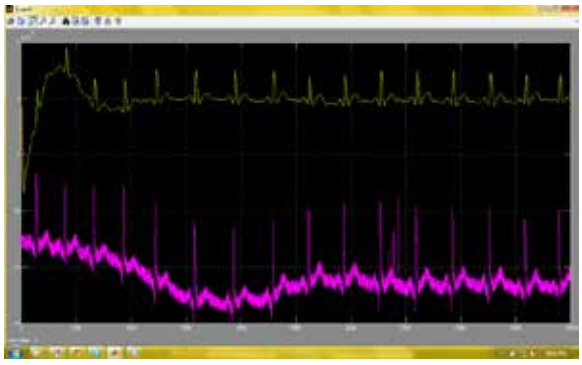

Fig. 4 Elliptic cascade filter output

Table 1 Comparison of IIR filter design

Filter type	PSD before filtration (dB)	PSD after filtration (dB)	Effect on PQRST wave
Butterworth	-36.87	-57.85	Modified
Chebyshev I	-36.87	-63.36	Modified
Chebyshev II	-36.87	-58.70	Modified
Elliptic	-36.87	-61.63	Less Modified

IV. Conclusion

In this paper IIR filter is designed using different algorithm for suppression of interference from ECG signal. From the simulation results we can say that the nature of the ECG signal is better retrieve using elliptic

algorithm. The filter order is lower using elliptic algorithm compared to Butterworth algorithm and chebyshev type I and II algorithm. We can see that the Baseline is not clearly removed using chebyshev type II algorithm. Also the improvement in power spectral density is shown in above table.

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