International Journal of Current Engineering and Technology
ISSN 2277 - 4106

Available at http://inpressco.com/category/ijcet

Research Article

FPGA Based FIR Filter Design for Enhancement of ECG Signal by Minimizing Base-line Drift Interference

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Accepted 05 November 2013, Available online 01 December 2013, **Vol.3, No.5 (December 2013)**

Abstract

Baseline noise removal from Electrocardiogram (ECG) signal is a blind source separation problem. Various noises affect the measured ECG signal. Major ECG noises are base-line noise, power-line noise, electrode contact noise, muscle noise. Baseline noise distorts the low frequency segment of ECG signal. The low frequency segment is S-T segment. This segment is very important and has the information related to heart attack. There are various techniques to remove this noise from noisy ECG signal. Efficient removal of baseline noise might give us certain information that are hidden from the doctors until now which may save the life of a person. Baseline drift noise occurs due to respiratory signal and body movements. Respiratory signal wanders between 0.15Hz and 0.5Hz frequencies. One of the most common methods to remove baseline drift interference is high pass filtering. This research work is based on High pass filtering of ECG signal to remove this baseline wander while preserving the low frequency ECG clinical information. The results of different filter design techniques like equiripple, least square and various windowing methods are compared using MATLAB simulation tool and best suited technique is used for further implementation on FPGA platform.

Keywords: *ECG, Baseline Noises, FIR filters, Window methods, signals to noise ratio (SNR), FPGA.*

1. Introduction

The challenge for biomedical signal processing is to extract features to help to characterize and understand the information contained in a signal. These feature extraction methods can be designed to mimic manual measurement and support the diagnosis made by a physician whereas they are often designed to extract information which is not easy to find through simple visual assessment. For instance, small variations in heart rate cannot be perceived by the human eye but they have been found to contain very valuable clinical information.

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. The Fig.1 shows an example of normal ECG trace, which consists of P wave, QRS complex and T wave.

While dealing with the ECG, acquisition of the signal from the body surface is critical therefore design of the acquisition system is important and interesting job for the engineers. For the correct diagnosis of the heart; the ECG trace should be free from the noise. ECG signal may be corrupted by various kinds of noise like Baseline noises, Power line interference, Electrode contact noise, Motion artifacts, Instrumentation noise generated by electronic devices, Electrosurgical Noise etc. For the meaningful extraction of the ECG signal it is essential to remove these noise signals.

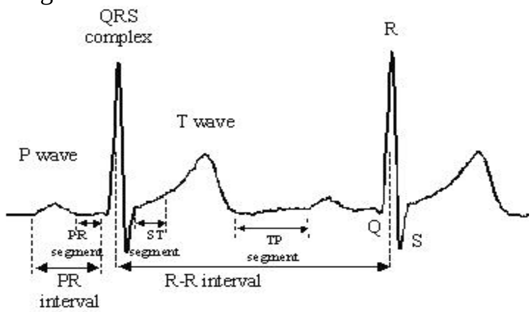

Fig.1 Typical ECG Signal

Different digital filter structures are available to eliminate these diverse forms of noise sources (M. Friesen *et al*,1990).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

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very important and has the information related to heart attack (Zahoor-uddin). It is necessary that the filter allow removing the baseline noises while preserving the useful clinical information.

The Baseline drift noise occurs due to respiratory signal and body movements. Respiratory signal wanders between 0.15Hz and 0.5Hz frequencies (A. V. Oppenheim *et al*,1989). One of the most common methods to remove baseline drift interference is high pass filtering.

2. ECG Dataset

In the present work the ECG signal required for analysis is 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, patients history and the detailed clinical information. In binary data signal file, the signal is stored in 212 format 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 (MIT-BIH).

Drift Generation in ECG Signal

The sample data file 114.dat from MIH/BIH arrhythmia database is extracted and considered as $S_0(n)$ be the original ECG signal with no noise and the sinusoidal waveform considered as V(n) to be added to the ECG signal, to make noisy signals before it is received for analysis or information extraction. The way to generate these drift is defined as:

$$S(n)=S_0(n)+V(n)\bullet Sin(q(n),n=1,2,...,N)$$

The purpose of the procedure of de-noising is to extract original ECG signal from $S_0(n)$ from noisy ECG signal S(n), so that it can be used for intended purposes. Noise added to the signal is lower in frequency as compared to the original signal.

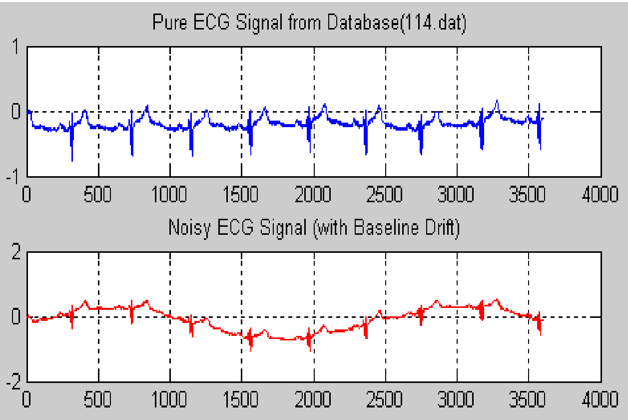

Fig.2 ECG Signal with Baseline Drift.

3. Implementation Techniques

Respiratory signal wanders between 0.15Hz and 0.5Hz frequencies (V. S. Chouhan *et al*). The design of a linear, time-invariant, high pass filter for removal of baseline wander involves several considerations, of which the most crucial are the choice of filter cut-off frequency and phase response characteristic. The cut-off frequency should be chosen so that the clinical information in the ECG signals remains undistorted while as much as possible of the baseline wander is removed. Hence, it is essential to find the lowest frequency component of the ECG spectrum. In general, the slowest heart rate is considered to define this particular frequency component; the PQRST waveform is attributed to higher frequencies. If too high a cut-off frequency is employed, the output of the high pass filter contains an unwanted, oscillatory component that is strongly correlated to the heart rate (Leif Sornmo *et al*, 2006). 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:

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

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 (Technikum Wien). This paper presents the design & implementation of various types of high pass FIR filter with cut-off frequency 0.5Hz & sampling frequency of 360 Hz.

Design of FIR filters

In this section, FIR Equiripple filter, windowing FIR filters with Kaiser, Rectangular, Hamming, Hann 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 Least Square design, pass-band ripple is 1 dB, stop-band ripple is 10 dB and the order of the filter was found to be 400. In case of window filters, cut-off frequency at the 3 dB point is 0.5Hz. 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 1200 and it increase the phase delay to 13.08rad/Hz.

4. 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 [x1,...., xN]. Periodogram uses an n-fft point FFT to compute the power spectral density.

B. Average Power

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

C. Signal to Noise Ratio (SNR)

SNR is a parameter used to quantify and compare the performance of algorithms and also determine the noise level in an ECG beats. The expression used to calculate SNR is as follows:

SNR= 10 log10 (variance (S0) / variance (S0-Sf))

where S0 = original Signal Sf = filtered signal.

4. Results & Discussions

MATLAB Simulation results of the designed filters to denoise the ECG signal with baseline noises are obtained as follows

Table 1 Simulation results of different filter design techniques.

Sr. No.	Filter Types	Order	I/P SNR	O/P SNR	MSE
1	Least Square	400	-4.1699	0.149	0.125
2	Equiripple	320	-4.1699	-0.653	0.125
3	Kaiser	450	-4.1699	-0.196	0.125
4	Rectangular	450	-4.1699	-0.296	0.125
5	Hamming	1000	-4.1699	-0.220	0.125
6	Hann	1000	-4.1699	-0.194	0.125
7	Blackman	1200	-4.1699	-0.304	0.125

By the analysis of above table, the Least Square method gives more improved output SNR with minimum order design. Also in Windowing technique, the Kaiser Window method is best suited one. Also, the 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, Hann 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.

FPGA Implementation

For implementation of FIR high pass filter on FPGA, the distributed arithmetic method is chosen. The system generator tool enables the use of the MathWorks model based design environment Simulink for FPGA design. So the filter design model is developed with the use of system generator tool as follows

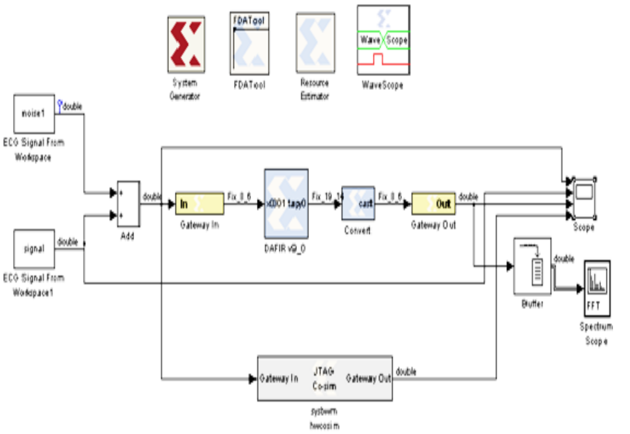

Fig. 3 FPGA implementation of FIR High pass filters design with System Generator Tool.

The design of filter with Kaiser Window and Least Square technique is carried out. The cut-off frequency is taken as 0.5 Hz and for implementation on **Spartan xc3s500e-4fg320 board,** the order of each filter method is used as 300, and the results of filter implementation using Kaiser window method is as follows

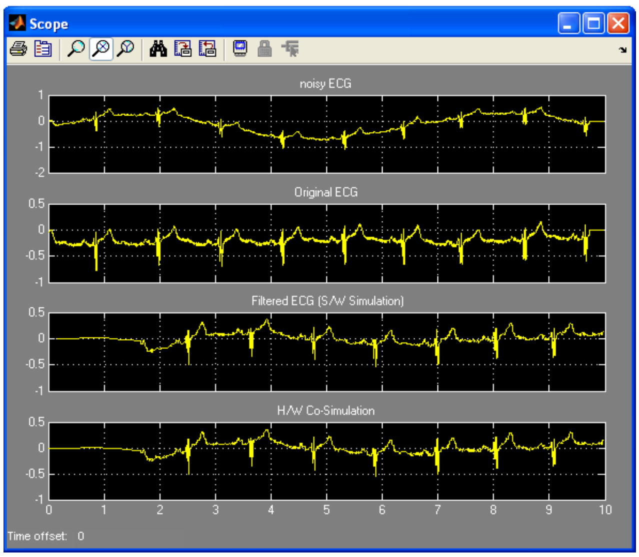

Fig. 4 Output Wavaforms of S/W and H/W Simulation.

sysbwm_cw Project Status (05/08/2013 - 12:02:36)			
Project File:	sysbwm_cw.ise	**Current State:**	Synthesized
Module Name:	sysbwm_cw	• **Errors:**	No Errors
Target Device:	xc3s500e-4fg320	• **Warnings:**	851 Warnings
Product Version:	ISE 10.1 - WebPACK	• **Routing Results:**	
Design Goal:	Balanced	• **Timing Constraints:**	
Design Strategy:	Xilinx Default (unlocked)	• **Final Timing Score:**	

sysbwm_cw Partition Summary [-]
No partition information was found.

Device Utilization Summary (estimated values)			[-]
Logic Utilization	**Used**	**Available**	**Utilization**
Number of Slices	4581	4656	98%
Number of Slice Flip Flops	8271	9312	88%
Number of 4 input LUTs	5436	9312	58%
Number of bonded IOBs	17	232	7%
Number of GCLKs	1	24	4%

Fig. 5 Resource utilization report of Kaiser Window FIR filter design.

As per the above results, FPGA implementation of FIR high pass filter with Kaiser Window technique requires less hardware resources, less time **(7.247 nsec)** and less power consumption **(83mW)** than any other design methods.

Conclusion

In this paper we have investigated the improvement of raw and noisy ECG signals by various window based FIR filters. In order to measure the performance of de-noising, SNR of processed ECG is calculated and correlation coefficient was determined to find the degree of mismatch between noisy ECG and filtered ECG. In Window techniques, the designed FIR filter with Kaiser Window works excellent in removing baseline wandering and also the efficient way of implementation in FPGA is carried out.

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