FPGA Based ECG Signal Noise Suppression using Windowing Techniques

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***Abstract*—*Heart related problems are increasing day by day and Electrocardiogram (ECG) signal are very important in diagnosis of heart related problems. There are various artifacts which get added in these signals and change the original signal, therefore there is a need of removal of these artifacts from the original signal .ECG signals are very low frequency signals of about 0.5Hz-100Hz and digital filters are very efficient for noise removal of such low frequency signals. In this paper we have studied Finite Impulse Response (FIR) filter based on various windows and Infinite Impulse Response (IIR) filters for noise removal of ECG signal. This paper shows FPGA implementation for noise suppression of electrocardiograph signals (ECG). The recorded ECG signal is taken from MIT-BIH Database. For FPGA implementation VHDL is used. This implementation gives good enhancement of QRS complex, P wave and T wave compared to traditional median filter technique. Also it removes baseline wondering. The Kaiser Window based FIR filter is better to remove artifacts from ECG signals.*

Keywords - *FPGA, ECG, FIR Digital filter, Window techniques, IIR Digital filter.*

I. Introduction

High frequency muscular contraction noise and power line interference removal from Electrocardiogram (ECG) is a problem which distorts the QRS segment of the ECG signal. Reducing noise from the biomedical signal is still a challenging task and rapidly expanding field with a large range of applications in ECG noise reduction. The QRS complex of the ECG signal represents the ventricular contractions and R peak indicates a heartbeat. This QRS segment is very important and has significant information related to abnormalities of the heart. The most common method of removing these noises is low pass filtering. Compared to microcontroller, DSP based medical kit and application specific integrated circuits (ASICs), field programmable gate arrays (FPGA), owing to their low cost and reconfigurable property, have a low time to market. This work proposes an approach to design and implement digital filter algorithms based on FPGA. Higher sampling rate is the advantages of FPGA approach to digital filter implementation than are available from traditional DSP chips, lower cost than ASIC for moderate volume application. Digital filter is the preeminent solution that caters to noise reduction up to a satisfactory level. This research work will be based on low pass filtering of ECG signal. Different Infinite Impulse Response (IIR) and Finite Impulse Response (FIR) filters are to be designed using MATLAB in order to check the feasibility of the specifications. Digital filters shall be designed in MATLAB to denoise the ECG signal with muscular noise and the performance will be evaluated based on error, accuracy and signal to noise ratio (SNR). Further the filters with the desired specifications are to be designed using VHDL. Simulation of the algorithms shall be done using MODELSIM 6.4a simulator for verifying the functionality of these designs and the architecture shall be implemented in Xilinx Spartan 6 FPGA. The VHDL simulation results of IIR and FIR filters are expected to give reliable the filtering functions matching with MATLAB design of the filters. The speed, power and area of the implemented algorithms shall be analyzed. The proposed FPGA based low cost ECG system will operate with high reliability, better performance and low maintenance.

Signal processing is very important and evident tool in fields of biomedical engineering. The biomedical signal processing field has advanced to the stage of practical application of signal processing and pattern analysis techniques for efficient and improved non-invasive diagnosis, online monitoring of critical patients, and rehabilitation. An ECG signal has very much significance in biomedical field to reflect the health status of cardiovascular system. Electrocardiography is a transthoracic interpretation of the electrical activity of the heart over a period of time, as detected by electrodes attached to the outer surface of the skin and recorded by a device external to the body. Most of the diseases are caused by improper functioning of heart, e.g. Arrhythmia. The extraction of QRS complex without noise is important task. Before analyzing any ECG signal it must be filtered. For filtration of ECG signal the information of exact frequency band of QRS complex is must but various people have taken various bands for detecting QRS complex. Use of bandpass filter gives good result for large band only but it is not deserved because large bands have many unwanted frequency component. For small band the shape of QRS is changed by bandpass filter. ECG signal is a graphical representation of cardiac activity and it used to measure the various cardiac diseases and abnormalities present in heart. ECG signals are composed of P wave, QRS complex, T wave and any deviation in these parameters indicate abnormalities present in heart. The standard ECG signal is shown in Fig. 1.

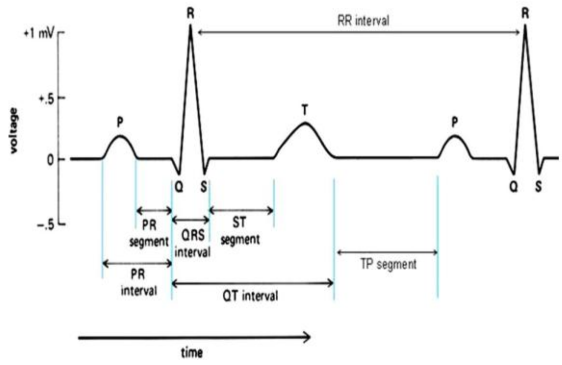

Fig 1 A standard ECG waveform

The frequency of ECG signal is between 0.5Hz-100Hz.This ECG gets corrupted due to various kinds of the artifacts.

1. Power line interference
2. Electrode contact noise.
3. Motion artifacts.
4. Muscle contraction.
5. Base line drift.
6. Instrumentation noise generated by electronic devices.

The ECG signal corrupted due to these noises leads to wrong diagnosis. Therefore, to reduce and remove the noises, digital filters are widely used in biomedical signal processing. Analog filters can also be used to remove these noises, but nonlinear phase shift is introduced by them. Digital filters are more accurate and precise than analog filters. Digital filters are of two kinds:-

1. Finite Impulse Response (FIR),
2. Infinite Impulse Response (IIR).

II. LITERATURE REVIEW

$$\alpha = \begin{cases} 0 & ;\beta \le 21 \\ 0.5842(\beta - 21)^{0.4} + 0.07886(\beta - 21); & 21 < \beta \le 50 \\ 0.1102(\beta - 8.7) & ;\beta > 50 \end{cases}$$

Mbachu C.B. has used the FIR filter with Kaiser window for removal of noises present on ECG signal. They have designed Kaiser window based low pass filter for removing high frequency noise like EEG, high pass filter for removing low frequency noise like baseline wander and notch filter for removing power line frequency noise present in ECG signal with sampling frequency of 1000Hz and they have used filter of the order 100.They have also designed the cascade of all these filters

K.D.chinchkhede et.al have developed FIR filter for ECG noise removal using various windows like Kaiser Window, Blackman Window, Blackman Harris Window, and Gaussian Window and compared their performance based on their output SNR and correlation.

Mahes S Chavan et.al has worked on interference reduction of ECG signal by using fir filter with rectangular window. They have designed rectangular window using low pass filter, high pass filter, notch filter and cascade of the three. They have also compared the baseline wander reduction result and power line interference result of Rectangular window, Hamming window, Hanning window and Kaiser Window. Elliptical digital filter for noise reduction of ECG signal were developed .

A. Van Alste et.al has developed the FIR filter for removal of baseline wander and power line interference due to the linear phase characteristics of FIR filter. They have also reduced the no. of computations involved in digital filters using desired filter spectrum. Neeraj kumar et.al have introduced the Butterworth IIR filter and FIR type –I filter for removal of noise present in ECG signal .In “Reduction of Power Line Interference in ECG Signal Using FIR Filter” equiripple FIR filter has been designed for removal of 50/60Hz power line interference present in ECG signals [9].In “Improved SNR of ECG signal with new window-FIR digital filters” a new window is introduced and compared with other windows of FIR digital filter. In this paper high pass filter, low pass filter and band reject filter is used.

III.THEORETICAL FRAMEWORK

FIR FILTER: - FIR filters have the impulse response of finite duration and can be implemented without feedback. Window techniques used in FIR filter are:-

A. *Rectangular window :-* the weighting function of rectangular window is given by,

$$\omega_R(N) = \begin{cases} 1, for\ |N| \le \frac{M-1}{2} \\ 0, otherwise \end{cases} \quad \text{----- (1)}$$

B. *Kaiser window:*To achieve the proper stop band attenuation kaiser window with is designed maximum stop band width and minimum stop band attenuation an FIR filter with side lobe attenuation of β dB, Kaiser window parameter α that affects the side lobe attenuation of the Fourier transform of the window is given by

---- (2)

C. *Hamming window:*-The hamming window function can be expressed as

$$\omega(n) = \begin{cases} 0.54 - 0.46\cos\frac{2\pi n}{N-1}, & 0 \le n < N-1 \\ 0 & ,otherwise \end{cases}$$

------ (3)

D. *Hanning window :-* The hamming window function will be expressed by equation

$$\omega(n) = \begin{cases} 0.54 - 0.46\cos\frac{2\pi n}{N-1}, 0 \le n < N-1 \\ 0 \quad ,otherwise \end{cases}$$ ----- (4)

E. *Blackman window:-*The Blackman window function is given by

$$\omega_B(n) = \begin{cases} 0.42 - 0.5\cos\frac{2\pi n}{N-1} + 0.08\cos\frac{4\pi n}{N-1} ; 0 \le n \le N-1 \\ 0, \quad ; \ otherwise \end{cases}$$ ------ (5)

IIR FILTER:-IIR filters have the infinite impulse response and it can be designed using filters like,

A. *Butterworth filter:-* The magnitude response of Butterworth low pass filter is given as

$$|H(j\Omega)| = \frac{G}{\left[1+\left(\frac{\Omega}{\Omega_c}\right)^{2N}\right]^{1/2}}$$ ------- (6)

where G is the filter gain and Ω_C is 3-dB cut off frequency

B. Chebshav filter- The magnitude response is given by

$$|H(j\Omega)| = \frac{G}{\left[1+\varepsilon^2 C_N^2\left(\frac{\Omega}{\Omega_c}\right)\right]^{1/2}}$$ ------ (7)

Where G is the filter gain and Ω_C is 3-dB cut off frequency, ε is a constant and $C_N(x)$ is a Chebyshev polynomial of N^{th} order.

SNR CALCULATION:

The SNR (signal to noise ratio) is defined as the ratio of signal power to noise power. For any other signals SNR should be positive but in case of ECG, SNR should be negative. The more negative SNR the more noise free ECG signal. The SNR (Signal to Noise ratio) is calculated as follows.

$$SNR = \frac{\sum_{n=0}^{N-1} \{y[n]\}^2}{\sum_{n=0}^{N-1} \left(x[n]-y[n]^2\right)}$$ ---- (8)

Where N is number of sampling points in ECG signal. Large SNR means high capability of rejection of noise.

IV. COMPARISON AND FIGURES

In the present work, various ECG de-noising algorithms using FIR and IIR filters are developed to remove high frequency noise with the help of MATLAB (R2011a). An ECG data sample from the directory of Physionet MIT-BIH Arrhythmia database is chosen and it will be corrupted by adding artificial noise. The filter algorithms are designed and compared statistically in terms of signal to noise ratio, error and accuracy. Matlab code of digital filters converted into VHDL hardware description language and then simulated in Modelsim. Finally the algorithms will be implemented on Sparton 6 FPGA.

The results show that the digital FIR filter with Kaiser Window removes the artifacts from ECG with less modification in the waveform. Use of rectangular window gives the more distorted signal hence lead to improper diagnosis. Here the results of various papers are summarized and are shown in table 1 below.

Type of Filter	Signal power before Filtration in dB	Signal power after Filtration in Db	Effect on PQRST Waveform
Rectangular Window	-27.18	-29.58	More Distortion
Hanning Window	-27.18	-28.77	Less Variation
Hamming Window	-27.18	-29.18	Less Variation
Kaiser Window	-27.18	-29.59	Less Variation
Butterworth	-27	-100	Not modified
Chebyshev	-30.93	-52	Not modified

Table 1 Result of reduction in PLI using different windows

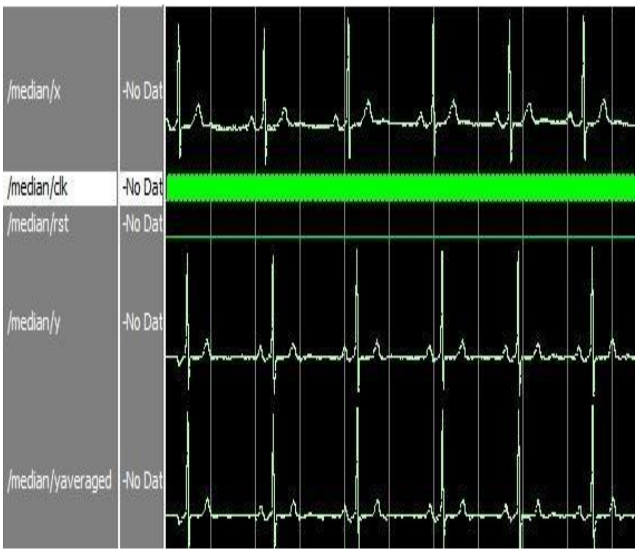

Figure 3 Waveform for traditional median filter based system (analog mode)

Work	SNR
Traditional Method	-9.7438 dB
Proposed Method	-10.290 dB

Table 2 SNR comparison with traditional method and proposed method.

Table 2 shows SNR results obtained for traditional method and proposed method. The calculation of SNR is discussed in section III. This table shows good SNR is obtained by this work compared to traditional method. Also this work has used extra averaging filter which gives smoothening effect for ECG signal. The FIR filters have the following advantage over IIR filters.

1. FIR filter are always stable as they have non- recursive structure.
2. They gave the exact linear phase.
3. Efficiently realizable in hardware.
4. The filter response is of finite duration.

Thus noise removal using FIR digital filter is better option in comparison with IIR digital filter

V. Conclusions

Thus this paper indicates the method used to remove ECG noise is more efficient than the traditional median filter method. Also, the implantation of this work on FPGA is easier. The based on FPGA`s are more flexible than ASIC due their reprogram ability i.e. in future also the design can be modified with very short span of time as compared to ASIC based design.

Acknowledgment

We place on record and warmly acknowledge the continuous encouragement, invaluable support and timely help offered by Dr. Pramod Patil, Principal, Dr. D. Y. Patil Institute of Technology, Pimpri, Pune-18.

References

[1]. Mico Yee Man Wong, "Comparison of Median Filter and Discrete Dyadic Wavelet Transform for Noise Cancellation in Electrocardiogram," Bulletin of Advance Technology Research,vol.4,No. 6, pp. 16-20,Jun. 2010.

[2]. Jaykumar S. Kamewar, Millind V. Sarode, "The Combined Effect of Median and FIR Filter in Pre-processing of ECG Signal using MATLAB," IJCA, National Level Technical Conference,X-PLORE 13, pp. 30-33.

[3]. Mohamed Elgendi, MirjamJonkman, and FrisoDeboer, "Frequency Bands Effect on QRS Complex," Proceedings of Third International Conference on Bio Inspired Systems and Signal Processing, Jan 2010.

[4]. Sarala Singh, Ravimohan, "A review on the Median Filter based Impulsive Noise Filtration Techniques for FPGA and CPLD," IJETAE, Vol. 3, Issue 3, pp. 821-824, March 2013.

[5]. Vasily G. Moshnyaga, Koji Hashimoto, "An Efficient Implementation of 1-D Median Filter," 52nd IEEE International Midwest Symposium on Circuits and System, pp. 451-454, 2009.

Willis J. Tompkin, "Book: Biomedical Digital Signal processing".

Rangaraj M. Rangayyam, "Book: ENEL 563 Biomedical Signal Analysis

[6]. Neeraj kumar, Imteyaz Ahmad, Pankaj Rai "*Signal Processing of ECG Using Matlab*" International Journal of Scientific and Research Publications, Volume 2, Issue 10, October 2012 pg no.1-6

[7]. Dr.A.K.Wadhwani,Manish Yadav "*Filtration of ECG signal By Using Various Filter*" International Journal of Modern Engineering Research (IJMER) , Vol.1, Issue2, pg no-658-661 ISSN: 2249-6645.

[8]. Aung Soe Khaing and Zaw Min Naing "*Quantitative Investigation of Digital Filters in Electrocardiogram with Simulated Noises*" International Journal of Information and Electronics Engineering, Vol. 1, No. 3, November 2011,pg no-210-216.

[9]. Mbachu C.B., Onoh G.N., Idigo V.E., Ifeagwu E.N., Nnebe S.U. "*Processing ECG Signal With Kaiser Window- Based FIR Digital Filters*" International Journal of Engineering Science and Technology, Vol. 3 No. 8 August 2011 pg no.6775-6783.

[10]. K.D.chinchkhede, Govind Sharan Yadav, S.R.Hirekhan, D.R.Solanke "*On the Implementation of FIR Filter with Various Windows for Enhancement of ECG signal*" International Journal of Engineering Science and Technology Vol. 3 No. 3 March 2011pg no.2031-2040.

[11]. Bansal D. (2013) 'Design of 50 Hz notch filter circuits for better detection of online ECG', International Journal of Biomedical Engineering and Technology, Vol. 13, No.1, pp. 30 - 48.

[12]. Bansal D. and Singh V.R. (2014) 'Algorithm for online detection of HRV from coherent ECG and carotid pulse wave', International Journal of Biomedical Engineering and Technology, Vol. 14 No.4, pp. 333 - 343.

[13]. Barick S. and Bagha S. (2013) 'Removal of 50Hz power line interference for quality diagnosis of ECG signal', International Journal of Engineering Science and Technology, Vol. 5, No.05, pp. 1149-1155.