A Preliminary Step to Realize Digital Filter for Electrocardiogram Signal Denoising

R. Chitra and E. Priya

Abstract The electrocardiogram (ECG) is one of the most commonly used technique in the assessment of cardiovascular disease. Cardiovascular disease is one of the major cause of death in many countries so it is important for interpretation of heart beat. The ECG signal during its acquistion gets commonly affected by baseline drift that hinders physician in the correct diagnosis of heart condition. In this work, ECG signal is preprocessed to alleviate noise. Digital filters such as Infinite Impulse Response (IIR) and Finite Impulse Response (FIR) filter are designed for the purpose of removal of artifacts from the signal. The IIR Butterworth low pass filter and least square linear phase low pass FIR filter are designed to reduce the baseline drift artifact in ECG signal. The preprocessing block is designed in MATLAB filter design and analysis tool. The corresponding model is realized in simulink environment. The performance measures of IIR and FIR filter are analyzed. The corresponding HDL code is generated and is targeted to a field programmable gate array board to observe the simulation results.

Keywords Cardiovascular disease · Electrocardiograph · Baseline drift · Infinite impulse response

1 Introduction

Biomedical signal processing helps in extracting the required signal in a proper way which helps the physician to diagnosis the condition of a human accurately. The necessity of extracting the required information from the measured ECG signal is to derive at a decision about the physiological condition of heart by the physician. The vital role of signal processing is to remove noise [1, 2]. Denoising is a process

R. Chitra (✉) · E. Priya
Department of Electronics and Communication Engineering, Sri Sai Ram Engineering College, West Tambaram, Chennai, Tamil Nadu 600044, India
e-mail: chitra.ece@sairam.edu.in

E. Priya
e-mail: priya.ece@sairam.edu.in

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to extract the original information from a noisy signal. ECG measures the activity of heart which is a continuous time varying signal. The ECG signal is acquired with help of electrodes, its frequency and voltage range lies between 0.05–100 Hz and 0.5–4 mV [3, 4].

ECG signal is contaminated by different noises such as power line interference, baseline drift, electrode contact noise, electromyography signal interference. Baseline drift may be due to breathing of the patient while measuring ECG. The frequency range of baseline wander signal is 0.5–0.6 Hz [5–7]. Many authors have worked on denoising the ECG signal by removing the baseline wander [8–11]. The authors have attempted denoising of ECG signal either in MATLAB environment or in FPGA including various optimization techniques. This work aims at incurring the advantages of both, denoising filter in MATLAB environment and FPGA implementation. The advantage includes complex design and processes large data.

Compared with analog filters, digital filters are more accurate [12]. Digital filters such as Infinite Impulse response (IIR) and Finite Impulse Response (FIR) filter process the input signal to extract the information required to analyze the condition of the heart [13]. IIR filter is unique in its feedback mechanism. The filter uses the current and past output whereas FIR filter uses no feedback so the system in inherently stable. Filter Design and Analysis Tool (FDATool) is one of the design tools in MATLAB environment to design and simulate digital filter such that the design specification are met [14]. FDATool helps in rapid design of the process using the specifications of digital filter. The performance measures Mean Absolute Error (MAE), Peak Signal to Noise Ratio (PSNR), Peak magnitude Root Mean Square (PRMS) and Fisher's ratio are measured to find the best of FIR and IIR filter. A model is realized from the FDATool which is simulated in MATLAB simulink environment. Compiling the filter design leads to a code in Hardware Descriptional Language (HDL). The generated code is programmed in to a Field Programmable Gate Array (FPGA) to analyze the performance of a filter [15].

In this work, the digital filter is designed in FDATool for the specifications that reduce the baseline wandering in ECG signal. The error measures of FIR and IIR filter are analyzed. A model is realized in a MATLAB simulink environment that generates a HDL code. Simulating the code in integrated software environment helps in providing an optimal design.

2 Methodology

The ECG signal is obtained from the standard MIT-BIH database. The signal is recorded in the laboratory from different people. The signal is digitized at 360 samples per second [16].

Digital filters possess linear characteristics which process input signal to produce an output signal of desired frequency range. Impulse response of FIR is finite whereas impulse of IIR is infinite [17]. FIR filter is designed by adding a delay element for

input signal. The algorithm involves multiplying each sample with corresponding coefficients and thereby the results are accumulated. FIR filter is expressed as

$$y[n] = \sum_{k=0}^{N-1} h[k] \cdot x[n-k] \tag{1}$$

where $x[n]$ is the input, $y[n]$ is the output and $h[n]$ is the impulse response.The symmetry between the coefficients are not required unless to reduce the hardware complexity [18].

The algorithm in IIR filter involves, a recursive impulse response such that the signal is fedback to the filter.

It is expressed as

$$H(Z) = k\Pi_{K=1}^{n} \frac{1 + b_k z^{-1}}{1 + a_k z^{-1}} \Pi_{i=1}^{m} \frac{1 + d_{i1} z^{-1} + d_{i2}}{1 + c_{i1} z^{-1} + c_{i2}} \tag{2}$$

where k is the gain of the filter, a_k and b_k for $k = 1, 2, \ldots$ n are the first order coefficients and $c_{i1}, c_{i2}, c_{i3}, d_{i1}$ and d_{i2} for are the second order coefficients [19].

The FDATool is a user interface for designing and analyzing the digital filters in a faster way. It helps in analyzing the filters, such as magnitude response, phase response, pole zero plot, filter coefficients, filter information, magnitude response estimate and round off noise power spectrum [20]. The MAE, PSNR, PRMS and Fisher's ratio are computed and compared. MAE is the error measure and PSNR signifies the peak level of signal to the noise present in the signal. The peak magnitude to RMS ratio is the ratio of the largest absolute value to root mean square value. Fisher's ratio implicitly reveals correlation between two signals. Simulink model is realized from the design for the corresponding digital filter and simulated in the simulink environment.The Hardware Description Language (HDL) code i.e., Verilog code is generated using generate HDL option. The filter code is simulated using Isim simulator for device xc3s500e.The synthesis report summarize the synthesis option summary, HDL compilation, design hierarchy analysis, HDL analysis, HDL synthesis, partition report, device utilization of the design.

3 Results and Discussion

In this work, the 100.dat ECG signal obtained from MIT-BIH Arrhythmia database is combined with BW.dat from MIT- BIH noise stress database for analysis. The digital filter is designed to reduce the baseline drift from the contaminated ECG signal. The low pass FIR filter is designed in FDATool with the following specifications of order, cutoff frequency as 10 Hz and sampling frequency as 360 Hz. The filter order is chosen as 4 because as the order of the filter is increased it leads to instability. It

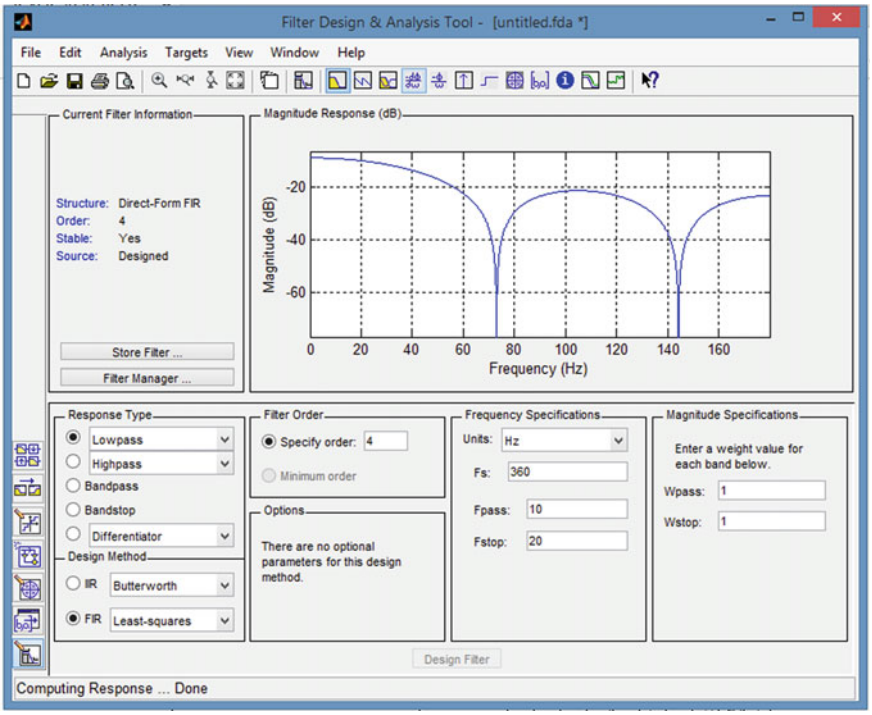


Fig. 1 A low pass FIR filter design in FDATool

is difficult to reconstruct the signal for lower order filters. The least square low pass FIR filter design is shown in Fig. 1.

The corresponding model of a low pass FIR filter is realized from FIR filter design by using realize model option. The realized model simulated in MATLAB simulink environment for the contaminated ECG signal obtained from database is presented in Fig. 2. The filtered signal received as output from the realized model is viewed with a scope. The corresponding input output signal of the filter is shown in Fig. 3.

In a same way IIR Butterworth filter is designed in FDATool with same specification as FIR. Corresponding low pass IIR filter design using FDATool is shown in Fig. 4.

The corresponding model of a low pass IIR filter is realized from the IIR filter design by using the realize model option. The realized model simulated in MATLAB simulink environment for the contaminated ECG signal obtained from database is presented in Fig. 5. The output of the realized model is viewed with a scope. The input output signal of the realized model is shown in Fig. 6.

It is observed from Table 1 that FIR filter has low MAE than IIR filter. The PSNR is high for FIR filter and this indicates the signal value being high after denoising when compared with IIR filter. Increase in peak magnitude to RMS ratio increase distortion in the signal but it is observed that the value of peak to RMS ratio is less

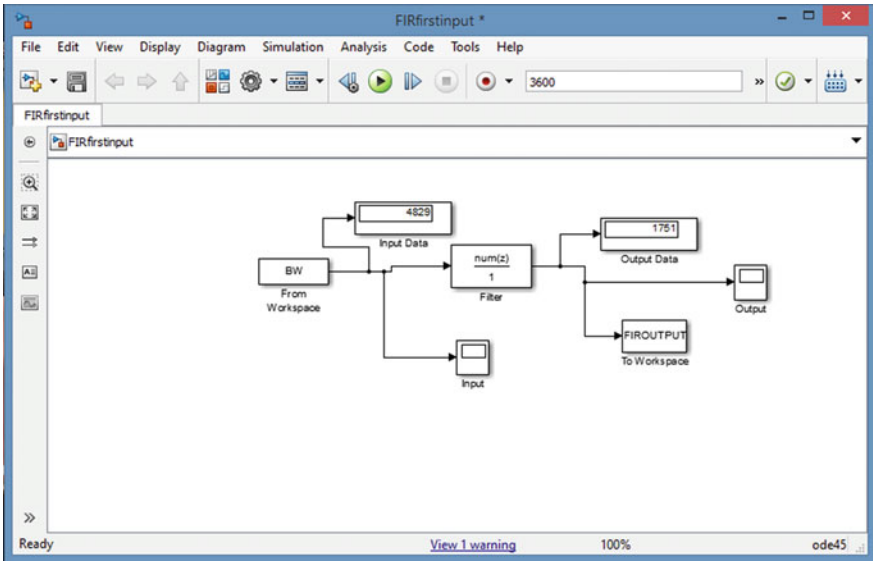
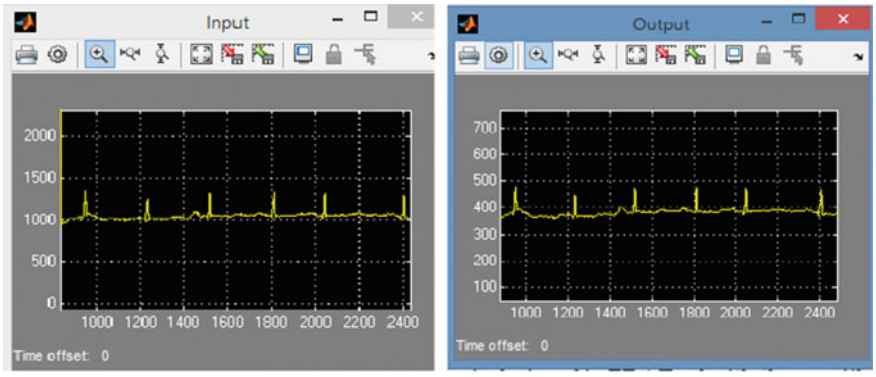


Fig. 2 A low pass FIR filter model



(a) Input (b) Output

Fig. 3 Input–output waveform captured in the scope for the realized FIR filter model

in FIR than IIR filter. Lower Fisher's value indicates FIR filter having reduced noise better than IIR filter.

The filter design HDL coder user interface generates the HDL code for the filter design and test bench.The filter design and testbench code is generated in VHDL. The 100.dat ECG signal obtained from the database is given as input stimulus of 3600 samples length. The compilation of generated code is done in ISE Design suite 14.5. The Isim graphical user interface provides the waveform of input output signals of FIR and IIR filter. The respective waveforms are presented in Fig. 7 and Fig. 8.

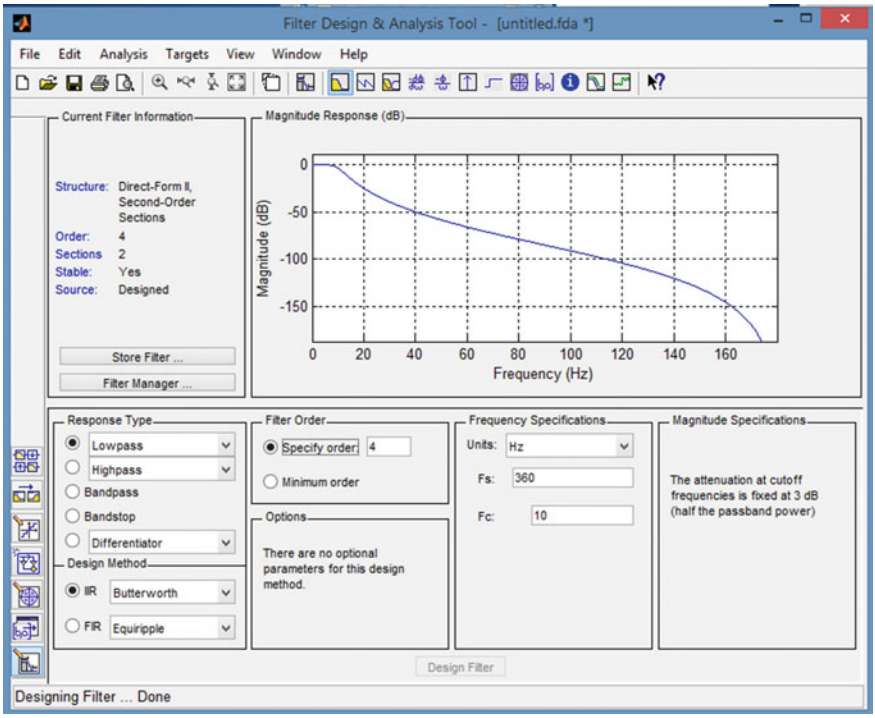


Fig. 4 A low pass IIR filter design in FDATool

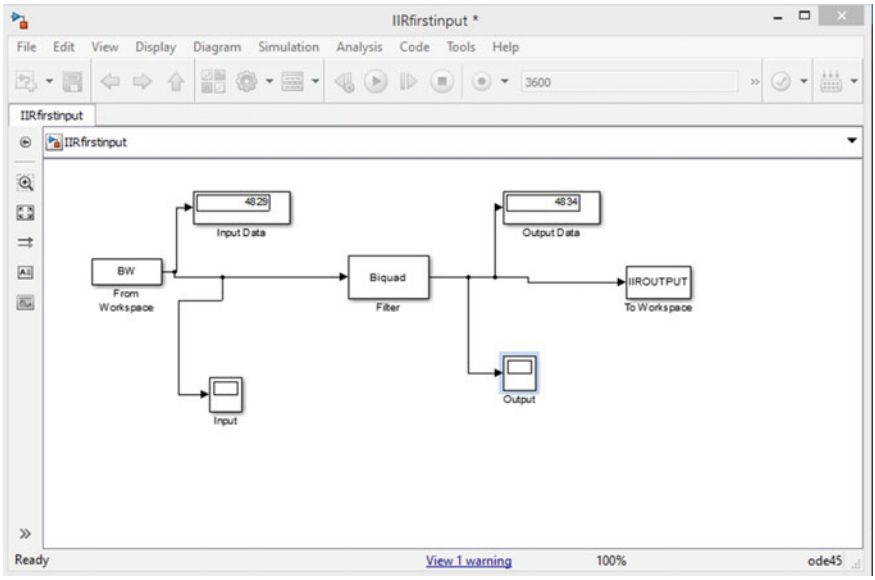
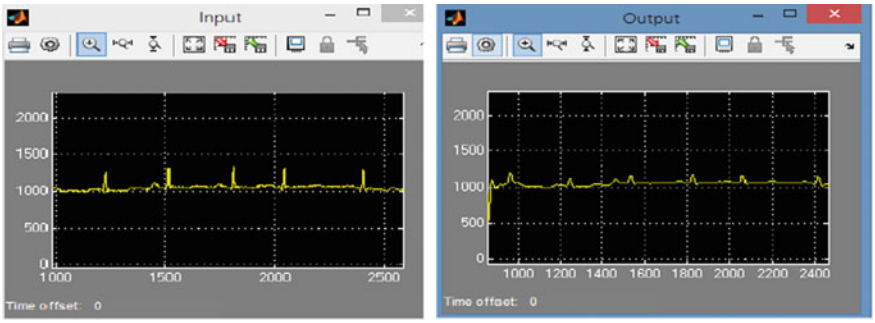


Fig. 5 A low pass IIR filter model



(a) Input (b) Output

Fig. 6 Input – Output waveform captured in the scope for the realized IIR filter model

Table 1 Performance measures of IIR and FIR filter

Filter	MAE	PSNR	Peak to RMS ratio	Fishers ratio
IIR	2893.21	3.7081	13.7933	2.1266
FIR	34.2609	25.3692	1.5241	9.3792×10^{-7}

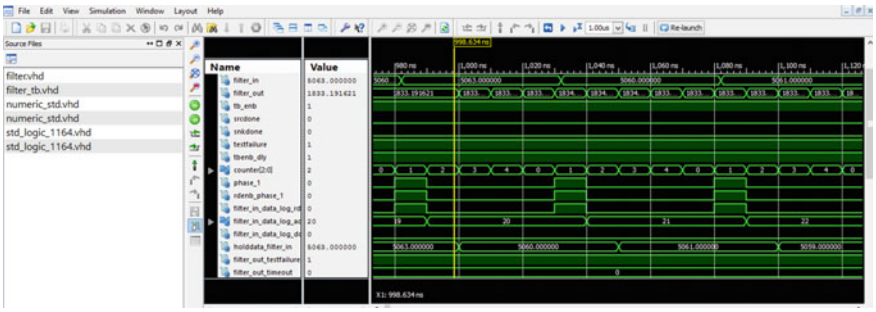


Fig. 7 A low pass FIR filter in ISim

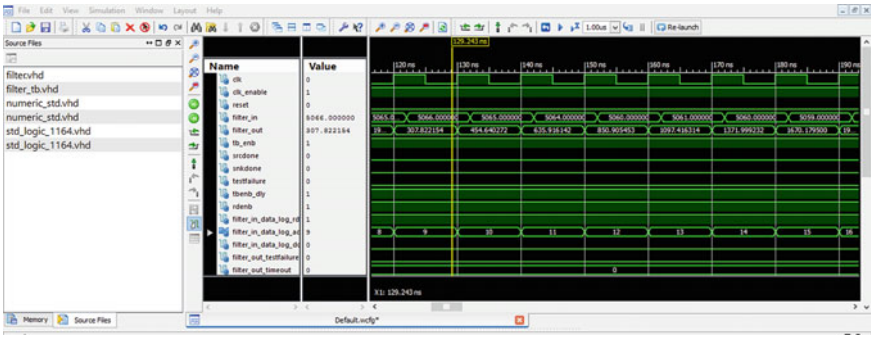


Fig. 8 A low pass IIR filter in ISim

4 Conclusion

ECG signal is the prime signal among all bioelectrical signals. It characterizes the electrical activity of the human heart. As ECG comprises of low frequency components with less amplitude, it is prone to different internal and external noises [21]. In this work, it is attempted to filter the baseline wander noise from the ECG signal obtained from the standard MIT-BIH database. The FIR with least squares method and IIR Butterworth low pass filter designed with appropriate specifications are designed to remove the baseline wander noise. The FIR and IIR filter is designed by FDATool. It is observed from the performance measures that FIR filter is better than IIR filter in removing the baseline wandering. The model for corresponding FIR and IIR filter are realized in the MATLAB simulink environment. The simulated waveform of IIR and FIR filter in Isim validates the output obtained from the realized model of MATLAB simulink environment. The simulation result helps in synthesis of design to implement in field programmable device. The FPGA device work in parallel manner when compared to microprocessor and digital signal processor and well suited for image and digital signal processing application.

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