Optimized Implementation of ECG Signal Noise Cancelation Using Fir and IIR Filter Techniques Based On FPGA

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ABSTRACT

The procedure of measuring the heart's electrical activity over time by putting electrodes on the human body places is known as an electrocardiogram (ECG). The long-term (ECG) patterns acquired in the intensive care unit are frequently distorted by different types of noises. These varieties of noises included with ECG signal such as power source interference, artifacts, muscular contraction, equipment noise, and electrode-contact noise may be present in the collected ECG signal. Which can cause several false alarms, including the incorrect diagnosis of atrial fibrillation. These noise types must be removed through preprocessing of the ECG data recording. This study proposes the ECG signal filtered design for elimination most of all these types of noise using a variety of techniques, including finite impulse response (FIR) and infinite impulse response (IIR). The least mean square adaptive filter and band pass filter is employ to improve the filter response and performance. The performance metrics include competition time, mean square error (MSE) and signal to noise ratio (SNR) are employed in order to determine which approach is best for the obtained noiseless ECG signal. The current work, applies the simulated ECG signal combined with a Gaussian white noise (GWN) and other type of noise as the input signal for filter testing and evaluating. The different implementation stricture methods are explored for filtering implementation process. The direct form-II second order section is chosen construction method as it more effective in term of hardware size reduction. Then, comparisons are conducted based on time, hardware use, and filter order requirement. There are several window techniques available to optimize the FIR filter design, the present paper utilize the Kaiser window for this design because it is one of the popular methods. Although there are alternative approaches for filtering the ECG signal through the IIR filters, the current investigation applies the Butterworth approach for IIR filters optimization for the system implementation, because it is one of the common procedures. The optimal filter order, construction, SNR, MSE, hardware consumption and processing speed for each the filtering technique are discovered. This investigation include the filter response in time and frequency domain for several filtering orders and techniques. The Matlab software is adopted in this work for identifying the best optimal filter among all these methods. In addition, the hardware evaluating is used to assessments the filter noise cancelation using several hardware implementation approachs. The Xilinx platform and field programmable gate arrays (FPGA) Board are employed for this task because the ability and flexibility of the FPGA for reconfiguration. Moreover, all these hardware filters are tested and examined in real time with artificial ECG signal generator mixed with disturbances including Electromyography (EMG) signals of the muscle surround the electrode and GWN.

Keywords: Noise cancelation, Electrocardiogram (ECG), FPGA, Finite impulse response (FIR), Infinite impulse response (IIR), FPGA

1. Introduction

The heart is the most important and necessary organ in the human body and human existence depends on it functioning normally. Cardiovascular illnesses are a group of dangerous conditions that affect the heart. Examples include cardiac arrest, high blood pressure, arrhythmia, congestive heart failure and stroke. For the diagnostic of the aforementioned disorders, careful study of how the heart works is crucial. Electrocardiography, which is the long-term monitoring of the electrical activity of the heart using electrodes on the skin, is so crucial. Because the heart expands and contracts, these electrodes can sense small pulses of heartbeats on the skin. The normal ECG signal frequency typically within the range from (0.5-100 Hz), as indicated in fig. 1[1]. Where the P wave, which indicates the atria depolarization, the QRS complex, it depicts the ventricular depolarization, and the T wave, which shows the ventricles depolarization of the ventricles, make up the three parts of the electrocardiogram.

The elimination of high frequency muscle contraction noise and signal interference with the electrocardiogram (ECG) signal is an issue that distorts the QRS portion of the ECG signal. Reducing noise from biomedical signals is still a difficult job and most important subject in many medical applications. The ECG signal's QRS complex shows ventricular contractions, while the R peak denotes a heartbeat. This QRS section is critical because it contains vital information about cardiac problems. Low pass filtering is the most popular way for eliminating these noises [2-3], in comparison to microcontrollers, digital signal processing (DSP) and costume integrated circuits such as (ASICs). However, the FPGAs have a faster time to synthesis due to their flexibility and low cost [2-4]

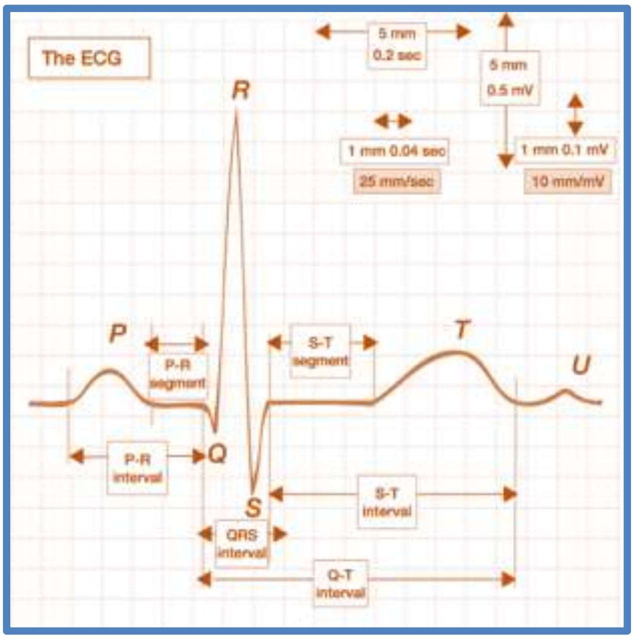

Figure 1: A normal sinus rhythm ECG of a heart.

This ECG is distorted by a variety of artifacts; the most frequent sources of noise in the recording of ECG signals are the interference from power lines, noise from electrode contacts, motion artifacts, noise from muscle contractions, base line drift, and noise from electronic instrumentation. These disturbances contaminate the ECG signal, which results in incorrect diagnosis. Digital filters are therefore often employed in biological signal processing to minimize and eliminate noises. These noises can also be eliminated using analog filters, although they create nonlinear phase shift, the analog filters lack the accuracy and precision of digital filters. The FIR and IIR digital filter are the most common digital filter type are used for noise cancellation method [5].

Based on Kaiser window, the FIR filter were employed by the researcher in [6] to remove disturbances from the ECG signal. In [6] they use sample rate a 1000 Hz and a filter order is 100, they developed Kaiser window-based low pass filters (LPF) for high range of frequency noise such electroencephalogram (EEG), high pass filters (HPF) for low frequency noise as baseline wander, and notch filters used for eliminate the noise from power line found in ECG signals. Also, they created the cascade of these filters[5]. Using several windows, such as the Blackman window, Kaiser window, and Gaussian window, in study [7] created a FIR filter for the elimination of ECG noise, and assessed the performance of the filters based on the output signal to noise ratio (SNR) and correlation.

In order to reduce source line interference in the ECG signal, the FIR filter with the rectangular window is used in [8, 9]. They used notch filters, low pass filters and high pass filters, as a three stages filter to create rectangular windows. Additionally, they compared the results of Kaiser, Hamming, Hanning, and Rectangular windows for baseline wander reduction and power line interference. Elliptical digital filters were created to reduce noise in the ECG signal.

Due to the linear phase features of the FIR filter, it was recommended in [10] that it be developed to remove baseline drift and power line interference. By employing the intended filter spectrum, they have also decreased the number of computations needed for digital filters. The IIR filter and FIR filter were first presented in [11] to remove noise from the ECG data. The FIR filter type Equiripple was created for reduction the power source interference in ECG signal to remove (50 or 60 Hz) power source interference[11]. A new technique proposed in [12,13] using deep factor analysis and wavelet energy and sub band smoothing filter for noise cancelation and enhancement the SNR of ECG waveform. However all these studies are not cover all the noise types in unity filter design.

In this study, different approaches have been used in the construction of the FIR and IIR filter to remove noise from the ECG signals. The optimal ordering of the filter for each filtering approach is chosen carefully to minimize the hardware and power consumption, while keeping the system stable. The filtering performance for the simulation and implantation are assessed using simulated ECG signal generator, which already designed in [14]. The FIR and IIR filters configured and evaluated using different type of windows with Matlab tools. The comparison demonstrates that, when it comes to FIR filters in term of performs and stability is much better than the IIR filters, .However FIR filter consumed more hardware and power compare with IIR filter.

2. Material And Methods

The input data for the filtering design the artificial ECG signals generator is employed, which clearly described in our previous study as explained in [14] to enables wide-ranging of testing results without the use of a normal human data and the high costs associated with real experimentation. The ability to modify the system component in this way is made possible by the FPGA's adaptability. Additionally, this device has the ability to generate multi-types of noise signal with heart rates in the 60 to 90 bpm band for a variety of tests. Each block of data consist of 1500 samples (about five heartbeats) was buffered and used as the filter's input. The filtered data was moved from the cache into a temporary storage after filtering to create way for the following block of data.

For the best ECG signal noise reduction in real-time applications, a mix of linear-phase band-pass filter with cascade band-pass filters have been created. The designed noise canceler consists of the following four phases and may be applied to many types of noisy ECG signals. The first processing unit is for large of data gathering yields 0.5 * 500 samples with a sampling frequency of 1000 Hz, which is a significant quantity of ECG data. This calls for some sort of data management procedure to separate the up into smaller group of data pieces. Buffering methods are used to accomplish this. To store a set quantity of data for execution, could we use hardware buffer or a first-in, first-out (FWO) software buffering might be used.

The next process stage executed using a linear combined a high-pass and a low-pass filter for pre-noise filtration for eliminates most of the stationary noise components. These background noise encompass most noises in high band frequency range (normally more than 200 Hz) including EMG noise. The low frequency background in frequency band from 0 to 0.5 Hz, and power source interference and its harmonics. This was accomplished by choosing the band pass filter suggested by [15]. According to the data repository, the LPF is a linear phase filter with a cut-off frequency of around 20 Hz and a first side-lobe zero magnitude response located at 50 Hz (power source noise). Approximately 2 Hz, cut-off frequency is was chosen for the HPF while the filter gain is one. The filtering sequence is first passed through the filter in a forward direction, and then it is inverted and jump back and pass through the filter. The sequence that results has double the filter order and precisely zero phase distortion. The signal to noise ratio(SNR) is improved at this level of the noise canceller. However, the linear BPF filter's output still includes disturbances that are within the ECG signal's frequency range (0 to 200 Hz). The following stage aims to eliminate these disturbances.

In adaptive filter signal processing use algorithm the least mean square or the recursive least squares. Regarding processing and storage needs, the algorithm performs effectively. The least mean square approach is more fictive functionality in term of arithmetical operations and hardware needs. Additionally, it has no issues with numerical instability[16] . As a results, a self-tuning adaptive filter structure that use the LMS algorithm was chosen for the ECG noise reduction in order to minimize noise. The Fig. 2 shows the overall block diagram of ECG noise cancelation filtering system.

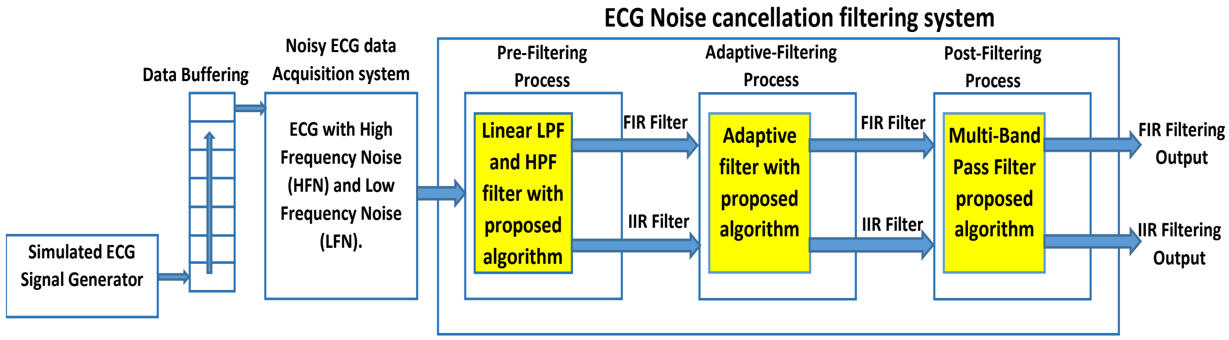

Figure 2. ECG noise cancellation filtering system block diagram in its entirety.

The signal to noise ratio (SNR) and the Mean squared error at the output for both IIR and FIR filter calculated using the eq(1) and eq(2) respectively[16].

$$SNR = 10log_{10}\frac{\sum_{i=0}^{N}(ECG\_r)^2}{\sum_{i=0}^{N}(ECG\_r - ECG\_f)^2} \qquad eq(1)$$

$$MSR = 10log_{10}\frac{\sum_{i=0}^{N}(ECG\_r - ECG\_f)^2}{N} \qquad eq(2)$$

Where ECG_r is the ECG signal input raw, ECG_f is the ECG filtered signal, N is the data cycle and i the data index.

2-1 Fir And Iir Filter Design

This study utilizing MATLAB toolbox for simulation, testing and evaluating the filter design using different approaches to achieve the optimum design. The input signal, an ECG signal, is combined with AWGN noise after being captured. The chaotic ECG signal is then subjected to several transformations, including DCT, DWT, FFT, and FWHT. Then, distinct orders of the noisy ECG signal are subjected to FIR and IIR filtering algorithms. On the basis of time, SNR, and cross correlation, comparisons are then done.

The robust design procedures available for FIR filters and their inherent stability make them quite popular. One can easily reach linear phase when non-recursive implementation is used. It is possible to create a FIR low pass filter using an Equiripple filter, the least squares approach, or a windowing method. When designing Kaiser, Rectangular, Hamming, Hanning, and Blackman functions, a windowing approach is employed. The fundamental requirements for filters design are the corner frequency and sampling rate are calculated depend on the noise type for each processing stage as mentioned in material and methods section above. The filter order for the FIR filter designed with Kaiser window method has a 12-length filter, a phase delay of 0.047 rad/Hz. The Kaiser window is chosen as an optimal design due to the best response and less hardware complexity.

2-2 Implementation The Fir And Iir Filter

To simulate hardware on the Spartan 3E-100-CP132, the Xilinx system generator platform Version 14.2 is employed. The FPGA block set needed for embedded system in the Matlab and Simulink libraries browser is installed by this program. The implementation and simulation procedure is shown in Fig. 3. The optimum design have been chosen after using various FIR and IIR filter techniques, the in and out pins blocks determine the hardware's border. Resource consumption has been estimated with the aid of the hardware implementation using Xilinx software such as net list, bits stream, and time analysis

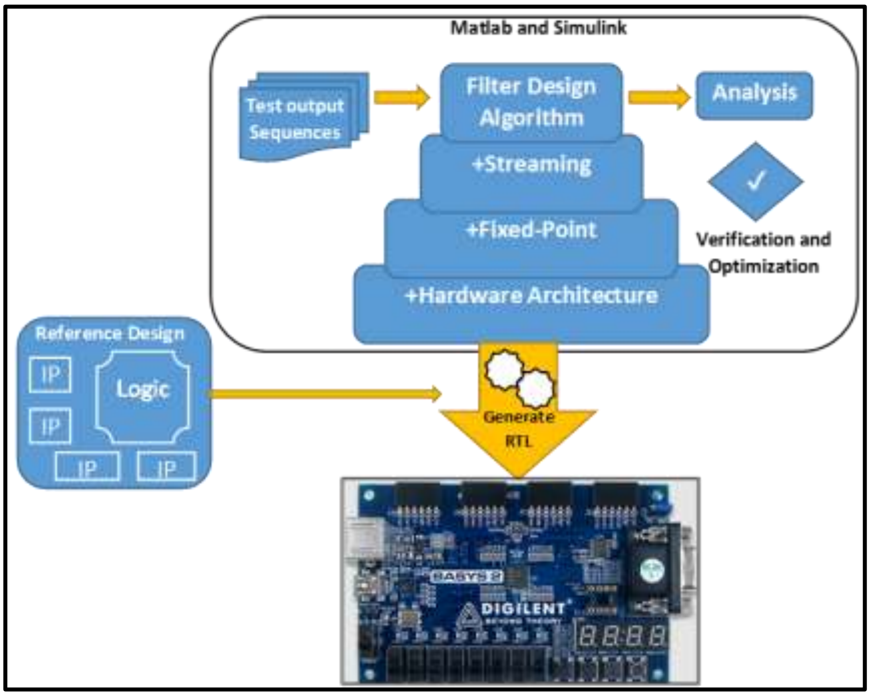

Figure 3: The design algorithm generates synthesizable RTL for an FPGA board

Digital FIR filters is more efficient if the implementation done on the FPGA structures using distributed arithmetic. In order to calculate sums of products with constant coefficients, the implementation stricture approach is frequently utilized. In this scenario, the partial product term is multiplied by a constant. In the system utilization summary , Shift Registers, and Scaling Accumulator components of the implementation arrangement method replace the normal object multipliers and considerably improve the performance of the implemented filter. These blocks must be effectively mapped onto the logic cells of an FPGA. When compared to current designs for FIR Filters, the suggested architecture offers an effective area-time-power implementation that entails much reduced latency and area-delay complexity.

For the design and execution of digital IIR filters, many methods are available. The present study selected a minimal hardware and power consumption design approach, since it is appropriate for our application. The target filter also offers a minimal level of hardware complexity and acceptable performance for design requirements. For the implementation of the IIR filter, the direct form-II construction seen in Fig. 2 was selected due to its benefits over alternative filter structures. The key advantage of this format is that the data samples require less memory storage. Additionally, preserving hardware results in smaller dimensions and reduced power usage. In addition, the IIR filters require fewer coefficients due to the use of feedback and poles. The digital filter design toolbox used to calculate the digital IIR coefficients using Butterworth method with sample frequencies corresponding to each stage of the filtering process. Using fixed-point arithmetic, convert all filter coefficients. To reduce the amount of hardware needed for the calculation, the word length and fraction size must be optimized to reduce the time and hardware. Word length was set to 12 bits, while fraction length was set to 12 bits. The IIR filter performances and characteristics are optimized to a 7th order type direct form-II construction. The design was put through a number of tests and investigations, including stability and time response.

3. Result and Discussion

A simulated ECG signal generator that also includes high frequency muscular noise produces a clean ECG. Simulink, a tool included with MATLAB, was used for the simulation. Figure displays a clean ECG Matlab database and Fig. 4(A) it shows a noisy ECG with an SNR of 20 dB that has real-time muscle noise added to it from the simulated ECG signal generator with noise database. Meanwhile, the Fig. 4(B) demonstrates simulated ECG signal generator without Noise

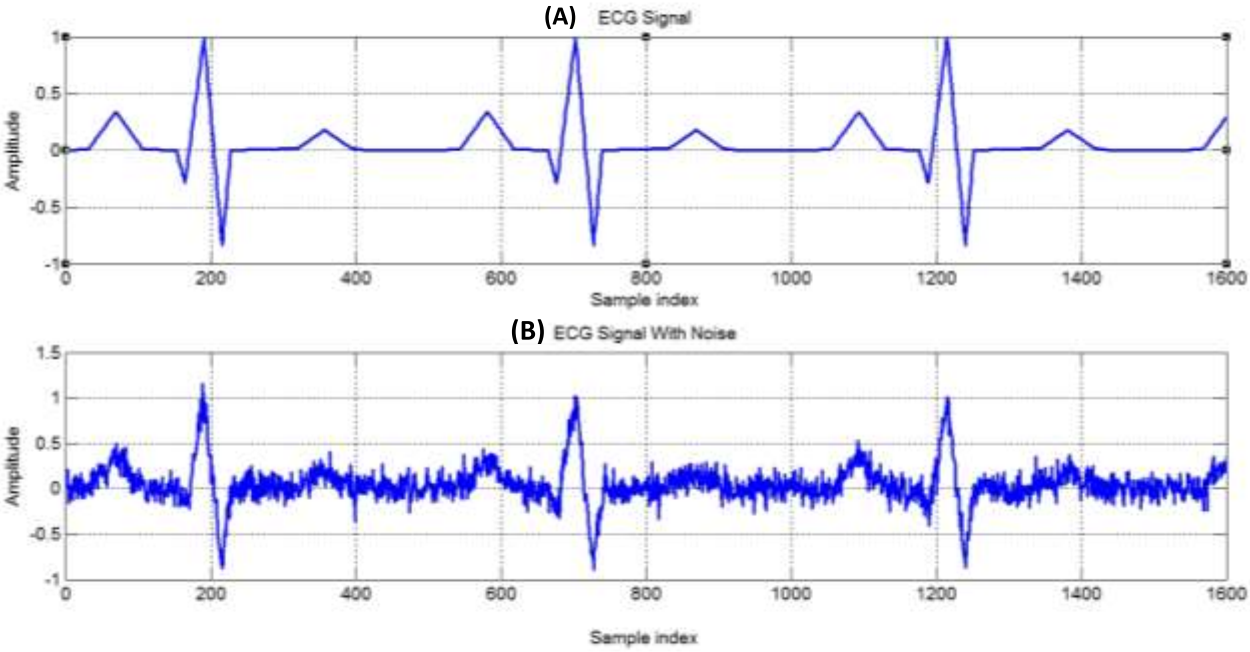

Figure 4: (A) Simulated clear ECG signal in Matlab, (B) Simulated noisy ECG signal in Matlab

Fig. 5. (A) illustrates the use of FIR filter window approaches (Kaiser) on high range frequency of EMG noise (SNR =1 dB) determined using eq (1) and MSE equal to (-35 dB) is calculated using eq (2)for unfiltered signal. While the fig. 5 (B) shows the filtered ECG improvement in SNR and MSE term.

Figure 5: (A) Simulated Noisy ECG signal (SNR=1) in Matlab, (B) Simulated filtered ECG signal in Matlab with FIR filter.

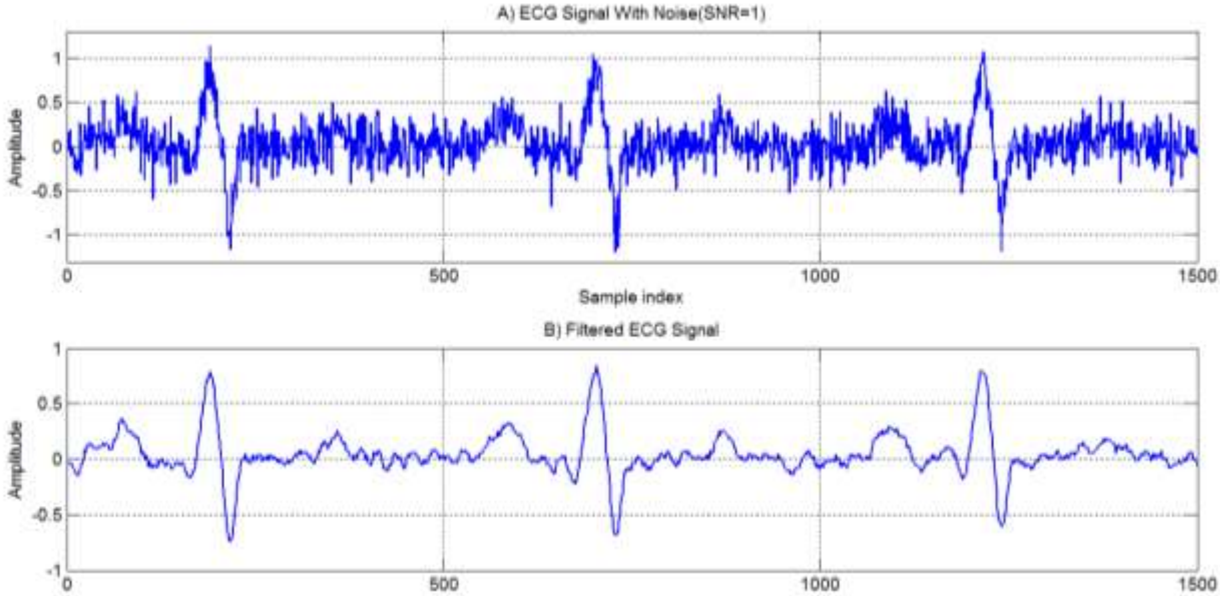

Figure 6: (A) Simulated Noisy ECG signal (SNR=1) in Matlab, (B) Simulated filtered ECG signal in Matlab with IIR filter.

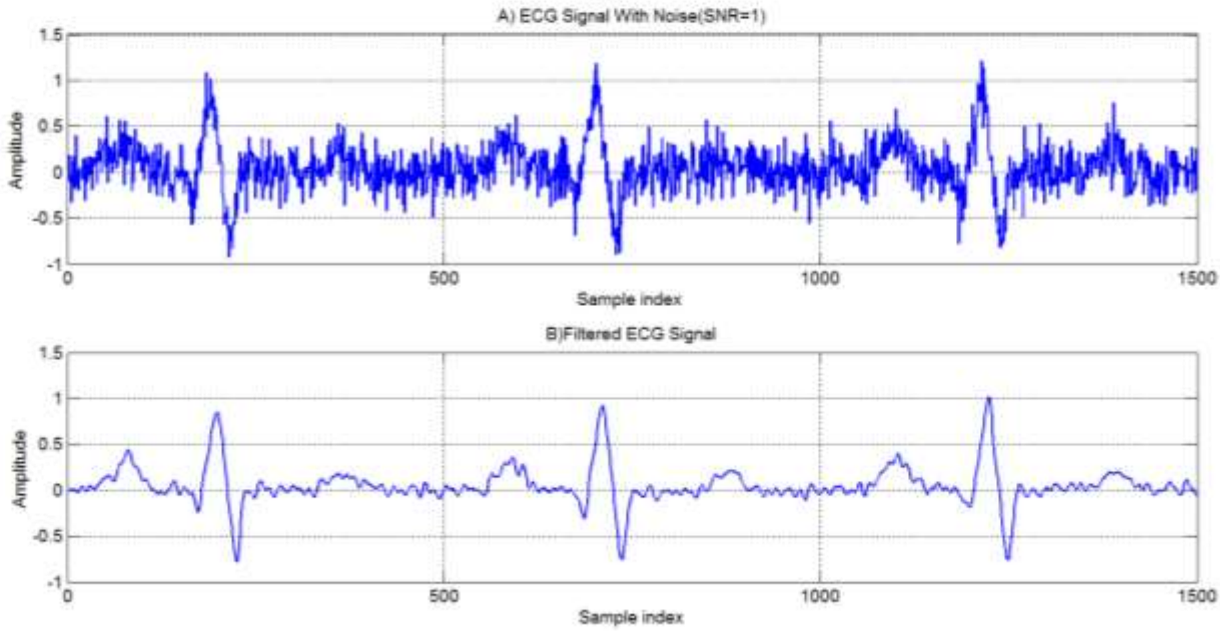

Table 1 compares performance for the FIR using Kaiser window and IIR Butterworth techniques in term of SNR, MSE and execution time. The FIR window approaches reduce EMG noise effectively and without degrading the ECG signal. However, The FIR filter order is higher than IIR filter, which makes designing the filter more difficult. The trade-off between the main lobe and the side lobes is controlled by a variable parameter in the Kaiser window approach. Kaiser's FIR filter has a higher SNR (11dB) than other types of filters. The filter length can easily increase significantly when using different window approaches, because of filter order increment, the coefficients rises, this causes a substantial increase in memory usage and issues with hardware implementation.

Table 1: FIR filter performances and assessment using Matlab simulation

Filtering Approach Type	Filter Order	Signal to Noise Ratio (SNR) in dB	Mean Squared Error (MSE) in dB	Execution Time Required
FIR Filter (Kaiser window)	26	11	-15.33	21ms
IIR Filter (Butterworth)	7	6	-10.21	9ms

The Direct Form II second order section parallel biquad construction is used for IIR filter hardware implementation. The forward filter has utilized the input storage in parallel biquad. Thus, optimization was used in this study to reduce the size of the hardware. A hardware device is used to capture and filter a real-time signal from the output of a simulated ECG signal generator.

The following implementation on an FPGA board is illustrates the experimental hardware simulation and configuration as depicted in Fig. 7. For the best IIR and FIR filters, the design hardware consumption from the FPGA resources has been determined. The Kaiser window technique have been chosen because it uses fewer resources than other windows approaches. However, the hardware size and power consumption for the IIR filter implementation is lowest than the FIR filter as shown in table 2. While, the FIR filter stability, response, MSR and SNR are significantly better than IIR, and that is very important for the biomedical application target.

Figure 7: The results of the filtering are shown on the wave scope of the system generator.

Table 2: Hardware consumption comparison using Spartan 3E-100 CP132 FPGA

Logic Utilization	IIR Filter (Butterworth)		FIR Filter (Kaiser window)		Available
	Used	Utilization	Used	Utilization	
Number of Slices	200	2%	702	8%	8677
Number of Slice Flip Flops	103	0%	110	0%	17344
Number of 4 input LUTs	420	2%	1214	7%	17344
Number of bonded IOBs	18	8%	32	13%	250
Number of Mult18X18SIOs	10	35%	11	46%	28
Number of GCLKs	1	4%	1	4%	24

Further hardware real time assessment is applied using Vivado and ModelSim platform for evaluating the filtered output signal using FPGA board implementation as demonstrates in fig 8. The result in fig 8 is clearly close to the results captured using Matlab simulation and is an additional proof for the capability for the present approach

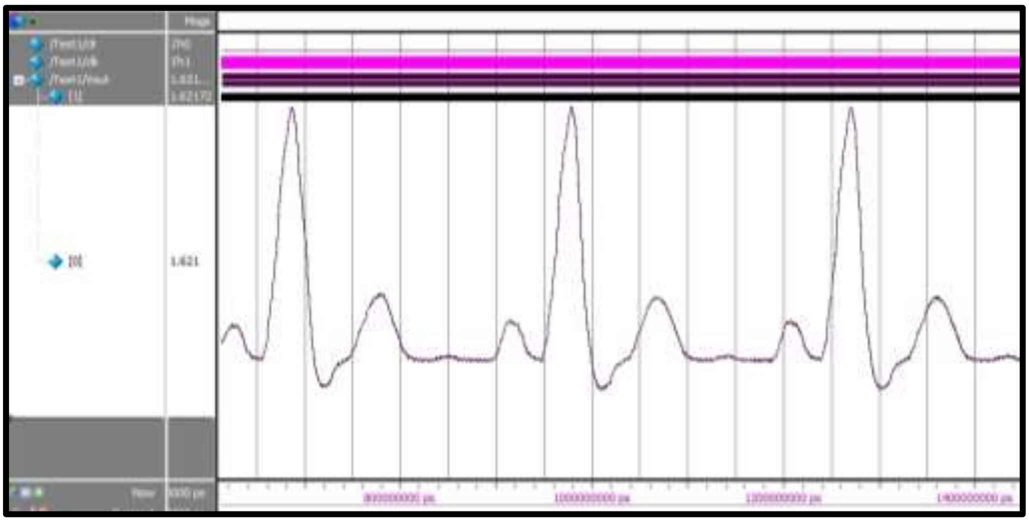

Figure 8 Simulated filtered ECG signal in using Vivado and ModelSim platform and FPGA.

The final step for assessment the design is the hardware evaluating by applying real time noisy ECG signal generator through the hardware filter, which already design, and synthesis on the FPGA board and the output captured using Oscilloscope device as illustrated in fig 9. The filtered and unfiltered ECG signal captured using Oscilloscope device, by setting the noisy ECG signal as input signal for suggested FIR and IIR filters for real time and hardware evaluating. The input signal is produced from the FPGA board number one as a simulated ECG signal generator, and then passed to the filter design on different FPGA board number 2 as a hardware design for the offered filter. After that the filtered through the FPGA NO. 2 to the Oscilloscope for captured the real signal as displays in Fig. 10. Furthermore, the simulated signal processing in Matlab and in hardware design is very similar to each other, and it is clearly satisfy the requirement of the filter hardware design. Finally, this research's development effort involves investigation the best performance between FIR and IIR filter design techniques, for identifying the best response, and integrating converters into the FPGA. Furthermore, this filter could implement using a CMOS integrated technology for more reduction close to 90% of consumed power, emphasis needs to be given to reducing consumed power. These improvements brought from the optimization approach to select the best coefficient magnitude, filter order, processing structure and flter type, which could be very different with different choices for the filter and maybe increase the system complexity and reduce accuracy

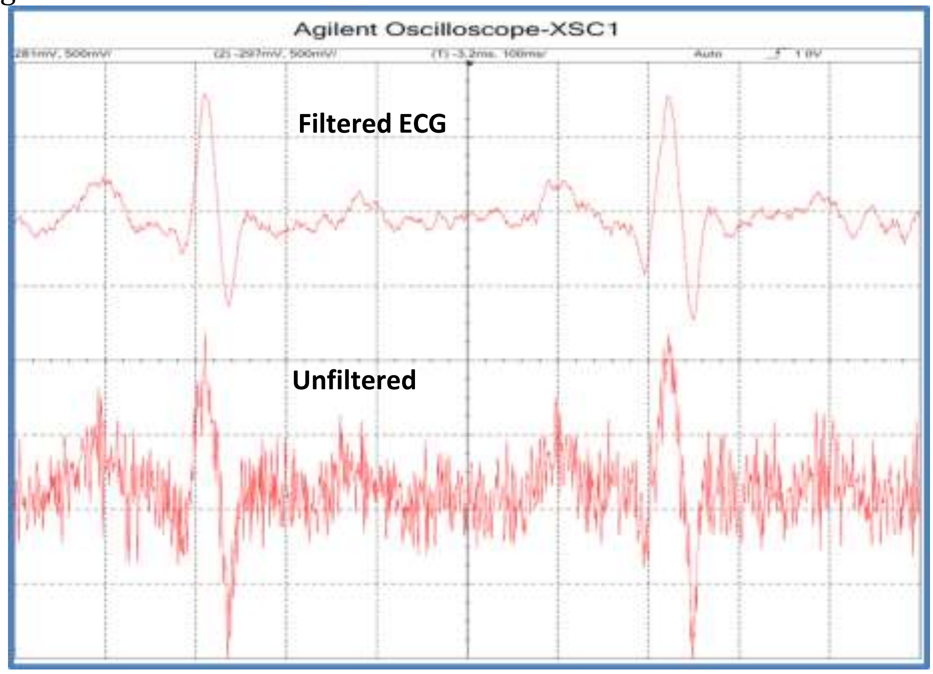

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Figure 9 Unfiltered and Filtered ECG signal using hardware design and Oscilloscope.

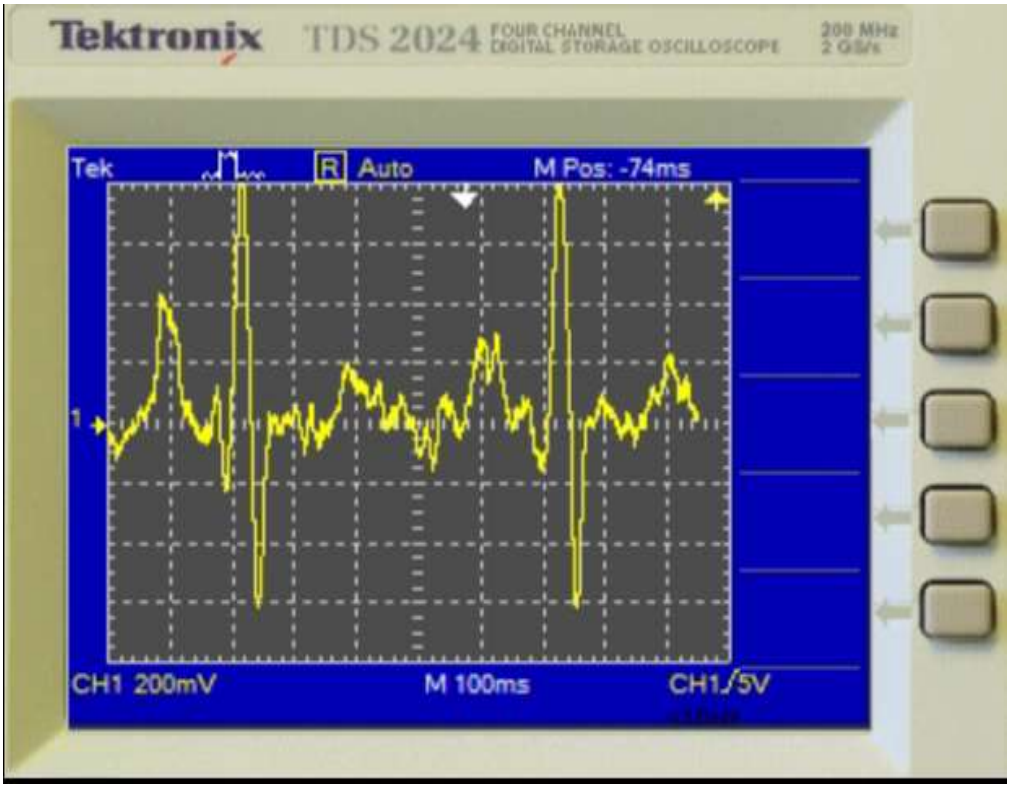

Figure 10: Filtered ECG signal showed on the Oscilloscope from FPGA Board No. 2.

4. Conclusion

The most often utilized signal in the biomedical industry is the electrocardiogram. The ECG signals are distorted by many noise types, including high- and low-frequency noise. The method presented in this research can enhance the effectiveness of filtering for signals of this nature. High frequency and low frequency noise are removed in this work using FIR and IIR filters. The output of an IIR filter is less valuable than the desired output, but the output of a FIR filter is extremely close to the target value and has high elimination of high frequency and low frequency noise. Another significant finding from the observation is that the IIR filter's standard deviation is significantly closer to the intended output than the FIR filter's standard deviation with high frequency noise, which is less critical. In comparison to IIR filter, the results produced by the proposed algorithm's FIR filter are significantly more accurate.

Additionally, the findings of this experiment demonstrated that both band-pass and adaptive filtering techniques can effectively use for eliminate significant noise components from the ECG signal. The SNR gets better as the order of section of the digital filter system rises. However, the filter length is the issue that increases the computational burden, which is unacceptable for real-time signal processing applications. The suggested filter construction is based on real-time evaluation of the ECG data and meeting both the MSE and SNR. With modest adjustments, this technique may be used to analyze various biological data.

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