# Computer Based Model to Filter Real Time Acquired Human Carotid Pulse

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**Abstract**

Acquisition and reliable parameter extraction of human bio-signals is extremely sensitive to interferences. Analogue filters have been used in the past to remove artefacts but they only help to suppress these contaminations and are difficult to realize. Their simulated computer based digital equivalents are however a viable and effective solution to this. But these filters are mostly tested on stored database and so there is a need to develop a system where real time acquired human signal is filtered and analyzed online on a computer. Present paper deals with design and simulation of digital techniques like FIR filter, IIR notch filter, spectrum analysis and convolution implemented on real time, non-invasively acquired carotid pulse wave on a computer based environment named Simulink using FDA tool. Results obtained show the accuracy of the designed techniques and gives an easy model to online acquire and filter bio-signals sitting at home.
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**Keywords:** Carotid Pulse, FIR Filter, IIR Filter, Non-Invasive, Real Time, Simulink

## 1. INTRODUCTION

Power line interference of 50 Hz considerably corrupts the bio-signals when detected using a computer based acquisition system. Human physiological parameters are also affected by EMG signals due to muscle movements. Filter algorithms can be implemented on microprocessors for conditioning the bio-signals. In a certain application, real time digital filters are used in cascade and are programmed on a microprocessor to obtain desired filtering task [1]. This is an old and cumbersome method of realizing digital filters. As an alternative, computer based digital signal processing has been widely utilized now-a-days to combat these artefacts. The clean ECG data is then analyzed quantitatively [2]. The study seems to be made on stored ECG data-base as no mention is done on the acquisition procedure of bio-signal. Self-adapting correlation method has been explored in another PC-based system [3]. The system discussed, digitally records ECG signal and claims fast elimination of 50-Hz interference from it. Adaptive digital notch filters are also investigated and their performance is verified on a noisy EEG signal [4]. A novel approach to eliminate the power line frequency from the ECG signal is designed using wavelets in MATLAB. An orthogonal basis is chosen to differentiate between signal and noise to obtain a clean ECG [5]. The work is relatively simple to implement in real time cases but is a simulated effort. Subtraction procedure has also been used in computer simulation to eliminate power line interference. In this work the filter is tested on animals using a signal generator to inject additive noise interference [6]. In another work, varied digital schemes have been used to remove power line noise but are tested on stored ECG tape [7]. Fast computation techniques are investigated for real-time digital filtration in home monitoring autonomous ECG systems [8]. The technique however, does not give satisfactory result in real time cases. Another paper compares the efficiency of notch filters and subtraction procedure for removal of power-line interference in ECG signals [9]. Yet another work has modified the subtraction procedure for use in ECG instruments and computer based applications, but gives only the analysis based on stored ECG database [10].

It is evident that biomedical instruments require inherent filtering stages and customized algorithm for parameter extraction [11]. Notch filtering of power line frequency is also considered essential in ECG signals so that they can be analyzed for calculation of heart rate variability (HRV) [12]. Digital FIR filters are explored in Simulink for removal of power line interference in ECG signal in yet another paper [13]. The results obtained are not so satisfactory. However computer simulation provides an easy means to test biomedical applications [14] and digital methods can be further investigated for better results. Summarized literature survey is presented in Table I.

**TABLE 1 :** Literature Survey.

| AUTHOR | YEAR | SIGNAL | METHODOLOGY | COMMENTS |
|---|---|---|---|---|
| M. L. Ahlstrom et al. [1] | 1985 | ECG | Digital adaptive 60-Hz interference filter, low-pass and a high-pass filter | Microcontroller based system |
| T. Starr et al. [2] | 2005 | ECG | IIR notch filter & type I FIR filter | Time & frequency domain analysis of bio-signal |
| B. F. Li et al. [3] | 2002 | ECG | Adaptive correlation method | Computer based digital system |
| M. Ferdjallah et al. [4] | 1994 | EEG | Constrained least mean-squared (CLMS) algorithm | Comparatively complex adaptive process |
| S. Poornachandra et al. [5] | 2008 | ECG | Wavelet coefficient threshold based shrinkage function using MATLAB | Simulation work to remove power line hum |
| R. M. Lu et al. [6] | 1993 | ECG | Subtraction procedure used to design digital notch filter | Can be used as filters in implantable pulse generators |
| C. D. McManus et al. [7] | 1993 | ECG | Digital notch filter & adaptive filter | Tested on stored signal database |
| S. Tabakov et al. [8] | 2008 | ECG | Online digital filters | QRS wave shifts leading to error |
| I. Dotsinsky et al. [9] | 2005 | ECG | Subtraction process & digital notch filters | Software digital filters recommended |
| C. Levkov et al. [10] | 2005 | ECG | Modified Subtraction process | An online computer based application |
| A. Shukla [11] | 2008 | ECG | Filters in Xilinx system generator simulation environment | Parameter extraction done for bio-signals |
| L. Hejjel [12] | 2004 | ECG | Analogue notch filters | HRV analysis done |
| M. S. Chavan et al. [13] | 2008 | ECG | Digital FIR equiripple notch filter | Results obtained can be further improved |

Most of the literature work listed, have used stored bio-signal data for analysis in simulation environment and do not talk about real time acquisition and online digital filtering. An attempt has therefore been made here to implement and analyze the effect of various digital techniques like FIR Equiripple Bandpass filter, IIR notch filter, spectrum analysis and convolution filter on a computer based real time acquired bio-signal. The work is tested on carotid pulse waveform acquired online and the entire model is implemented using Simulink in MATLAB. Carotid pulse waveform is a tested physiological parameter, vastly explored these days for its amplitude and contour that helps in the assessment of cardiac details. The digital filter model is tested on carotid data as its acquisition does not require a complex electronic arrangement for research applications [15].

Rest of the paper is organized as follows: Section 2 briefly covers the various digital filtering techniques analyzed in this work. Section 3 details the material and methodology involved, followed by section 4 which discusses the results obtained. Section 5 finally concludes the work.

## 2. DIGITAL TECHNIQUES

Digital filters are broadly categorized into infinite impulse response (IIR) and finite impulse response (FIR) filter types. Convolution operation also plays an important role in various electrical signal filter algorithms. Spectrum estimation provides supplementary information about the signal as it is dealt in frequency-domain.

### 2.1 IIR Filter Design

The most important filter required to be designed for the task of removing noise from the bio-signal is a notch filter because it helps in removing the specific 50 Hz power line interference. The digital IIR notch filter is obtained from its analogue counterpart by applying bilinear transformation. Figure 1 shows the magnitude characteristic of the proposed IIR notch filter. A stable single notch IIR filter of order 2 with notch frequency 50 Hz and quality factor 100 is designed for this application.

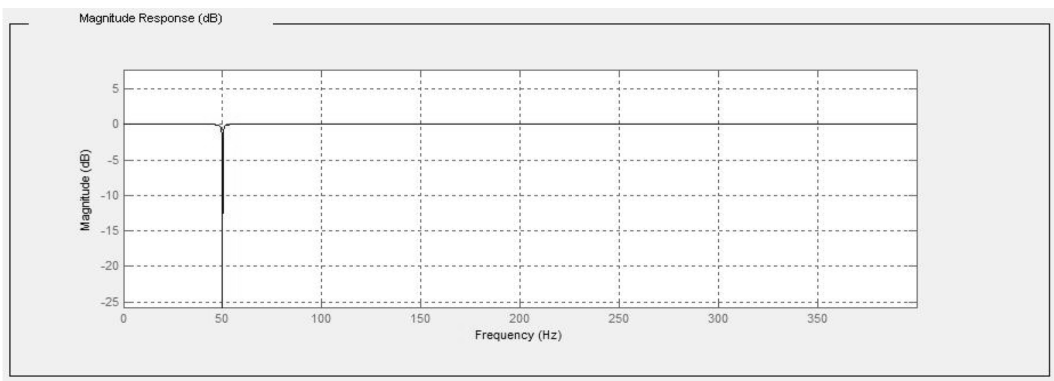


**FIGURE 1:** Magnitude Response Curve of Designed 50 Hz IIR Notch Filter.

### 2.2 FIR Filter Design

A FIR filter settles to zero in a finite duration in response to an impulse input and possesses some very desirable characteristics. All the poles are placed inside the unit circle and so these filters show stability and have linear phase characteristics. FIR filters are realized without any feedback, so are simple to implement and result in reduced rounding errors. However they require more computation power especially in low frequency applications like bio-signal processing. The magnitude response curve of the designed FIR Bandpass filter as obtained in Simulink is shown in Figure 2 which clearly indicates the filter specifications. The Equiripple design method is used to find the coefficients from frequency specifications [16]. A stable Equiripple band-pass FIR filter of order 10 is designed to filter the carotid signal. The FIR Bandpass filter parameters are: Fstop1=0.03 Hz; Fpass1=0.05 Hz; Fpass2=150 Hz; Fstop2=160 Hz.

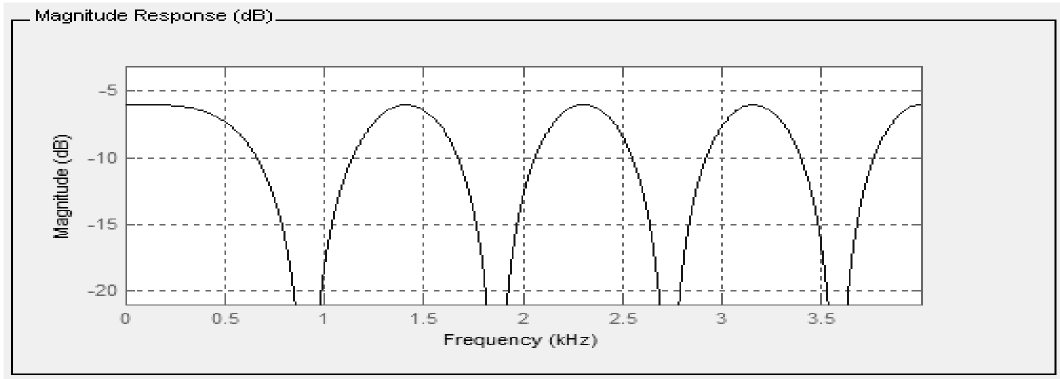


**FIGURE 2:** Magnitude Response Curve of Designed Equiripple Bandpass FIR Filter.

### 2.3 Convolution
Convolution is widely explored in engineering applications now-a-days and has become an integral part of signal processing algorithms. Of all the functions of convolution operation, filtering & windowing are the most useful ones in bio-signal processing. Biological signals when acquired using computer based systems are corrupted by undesirable frequencies which results in disturbed signal output. One of the methods to drop out unwanted frequencies is the multiplication of Fourier transform of bio-signal with a gate function having a width equal to the required cut off frequency. The inverse Fourier transform of this product gives the new filtered signal which represents convolution.

### 2.4 Spectrum Analysis
Representation in frequency-domain gives additional information about bio-signals since one of the most important advantages of the spectrum estimation is to determine and analyze small signals in the presence of large ones. Spectrum details can be obtained by calculating the power spectral density (PSD) either by parametric or nonparametric methods. Parametric methods use estimated model parameters to calculate the PSD. However, non-parametric is the classical method of calculating direct PSD using the fast Fourier transform (FFT) and is called the Periodogram approach which is used in this model. Selection of appropriate window function is important in calculating the Fourier transform using Periodogram approach as they help in deciding the spectral resolution and side lobes level. Various window functions like Rectangular, Hanning, Hamming, Gaussian etc are designed for the purpose [17].

## 3. MATERIAL & METHOD
The experimental set up for recording and digital filtering of carotid data mainly consists of Piezo-electric sensor and a MATLAB (7.4) based Simulink model. The pressure sensitive sensor has a metallic plate of diameter 2.0 cm and thickness 0.25 mm. This metal plate is coated with a ceramic layer of diameter 1.30 cm with a thickness of 0.1 mm. The arrangement also consists of computer sound card connector jack, windows sound card and a personal computer. The Simulink model designed to acquire and filter real time carotid signal is shown in Figure 3. Simulink blocks used in the model includes analogue input block, amplifiers, scopes, vector scope, IIR notch filter, FIR Equiripple Band-pass filter, convolution block, Periodogram and the Buffer block.

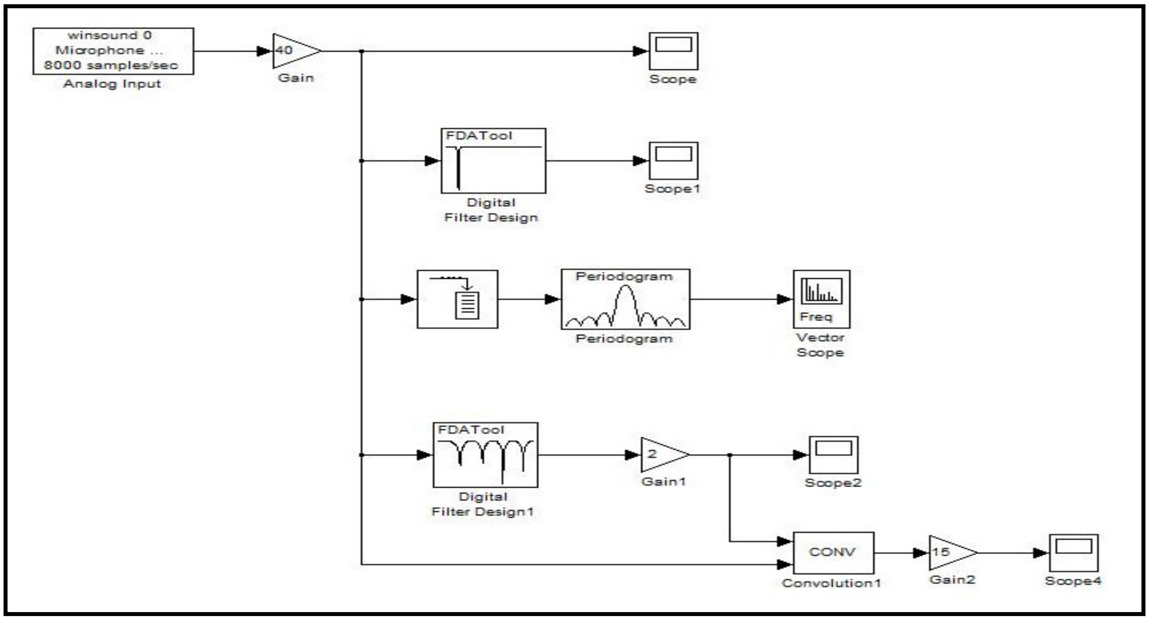


**FIGURE 3:** Simulink Model To Acquire and Filter Real Time Carotid Signal.

Measurements were made non-invasively on a healthy human subject using piezoelectric pressure sensor placed at the neck over the carotid artery to acquire the carotid data. The analogue output from the transducer is interfaced directly through the sound card into a computer in real time. Analogue input block in the data acquisition toolbox is used to acquire online real time analogue carotid data into Simulink model. The sound card is selected as the input device in the analogue input block. The analogue input data is acquired in asynchronous mode at a sample rate of 8000 samples/sec from the microphone-in (winsound) port of a computer. The asynchronous mode initiates the acquisition when the simulation starts and runs while data is being acquired into a FIFO buffer. No hardware amplifier is required for acquisition; however an amplifier block with a gain of 40 is used in Simulink to enhance the view of the acquired raw bio-signal. Scopes are used to view the real time obtained signal. Digital techniques are then employed in the model to filter out the interference in the carotid signal.

FDA tool in the filter design block of signal processing block set is used to design digital IIR Notch filter and FIR Equiripple Band pass filter as explained in section 2.1 and 2.2 respectively. The frequency response curves for both the filters are shown in Figure 1 and 2. Convolution block is also used to filter the bio-signal for comparison. The inputs to the convolution block are the raw carotid data and the FIR filtered output.

The Simulink model in this work also implements a spectral analysis method to compute the spectral content of the carotid signal. Non-parametric spectral estimation using the Periodogram method with Hanning window function is done in this work. The signal is buffered into frames, with 128 samples per frame using the buffer block. Each frame is then windowed using a Hanning window function, and the FFT for the windowed frame is computed. Fast Fourier transforms for successive frames are collected and plotted on the frequency vector scope [18]. A GUI front panel as shown in Figure 4 is created that provides a link to the Simulink model for easy viewing. The GUI can run the simulation and plot the results.

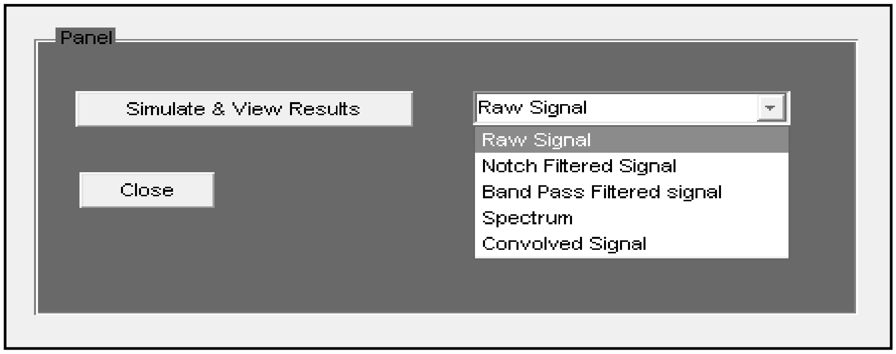


**FIGURE 4:** GUI Front Panel That Links to The Designed Simulink Model.

## 4. RESULTS & DISCUSSIONS

The Simulink model designed successfully acquires the human carotid pulse in real time. The carotid pulse waveform obtained is the result of the analogue voltage produced at the output of the piezoelectric sensor and quantifies the pulsation of the carotid artery. The raw carotid data obtained is shown in Figure 5 which however does not exactly match the theoretical carotid wave contour. The positive peak on the contour represents contraction during systole and the negative peak signifies the sudden reduction in arterial pressure during diastole. The other signal seen is basically the noise interference due to the 50 Hz power line hum. This noise interference is reduced to a great extent by using digital IIR notch filters and Equiripple FIR band-pass filters as can be visually observed in Figures 6 and 7 respectively. Unwanted spikes can be seen at some places in these plots which arise because sensor body interface is not stationary with time. Figure 8 shows the convolved output of the raw carotid data and the filtered carotid waveform. Figure 6, 7 and 8 represents the real time acquired carotid signal in time domain using different processing techniques. The result can be utilized to measure the peak to peak period and also to analyze HRV as the peaks are highlighted and noise is greatly reduced in this plot. However, further algorithm can be developed for mathematical analysis and comparison. Frame 1001 of the spectrum scope is captured in Figure 9.

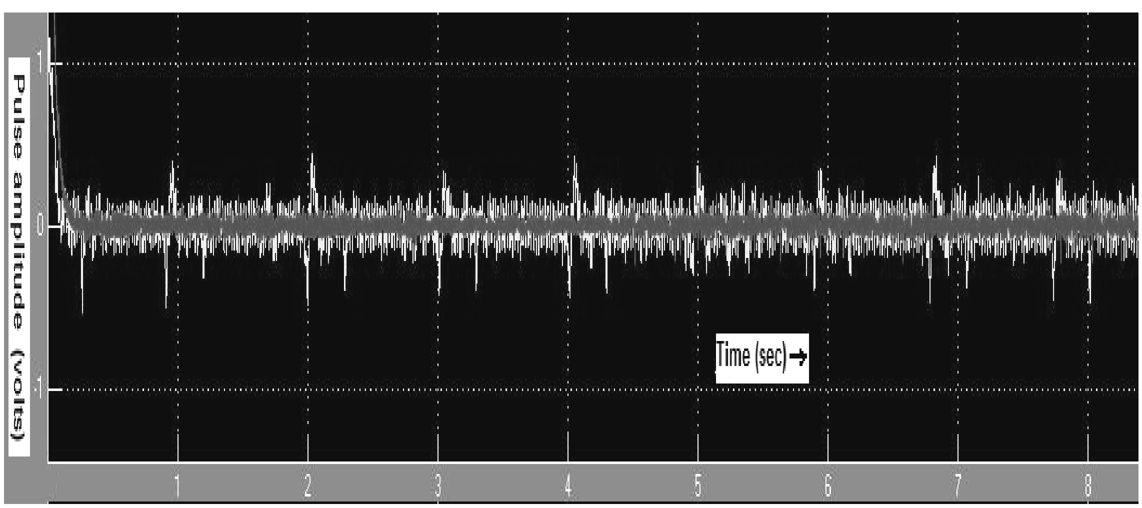


**FIGURE 5:** Raw Carotid Waveform and Noise Acquired in Real Time Using Simulink Model.

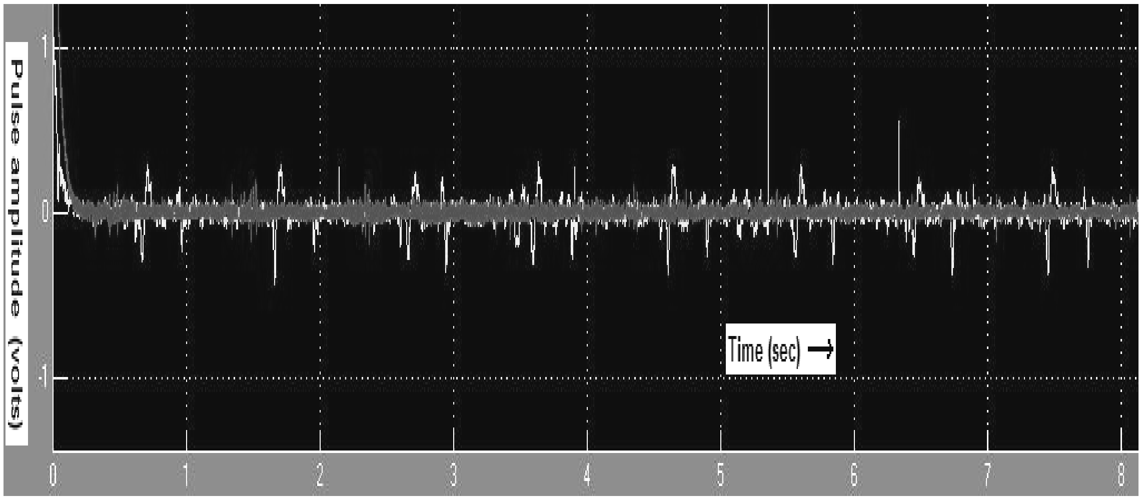


**FIGURE 6:** IIR Notch Filtered Carotid Waveform and Noise Acquired Using Simulink.

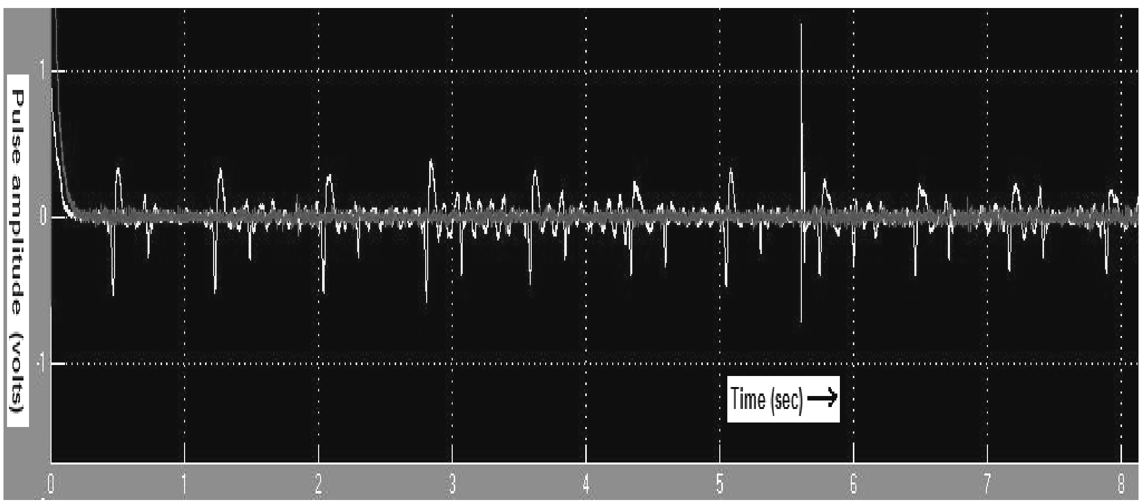


**FIGURE 7:** FIR Digitally Filtered Carotid Waveform and Noise Acquired Using Simulink.

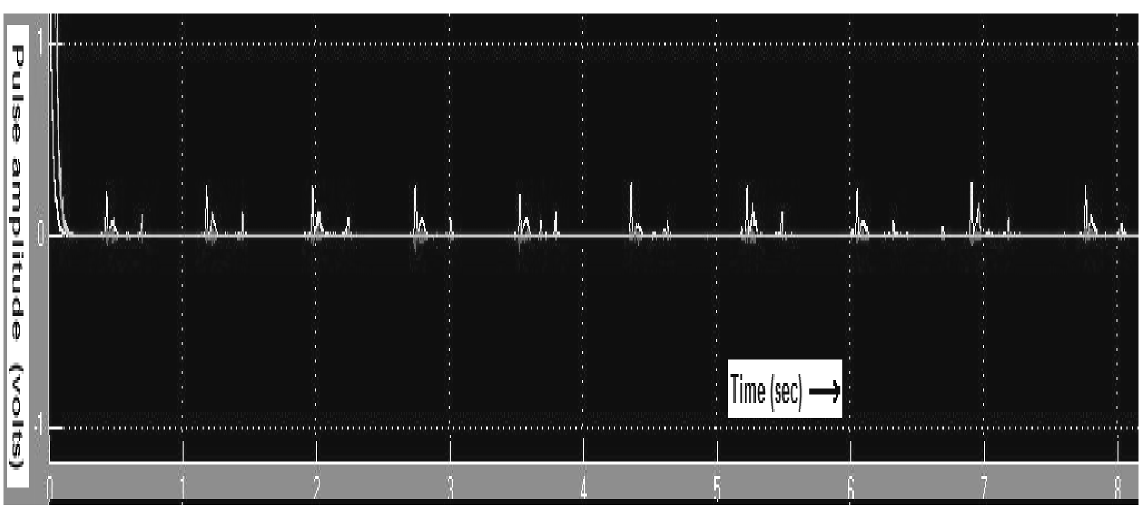


**FIGURE 8:** Convolved Carotid Waveform Obtained Using Simulink.

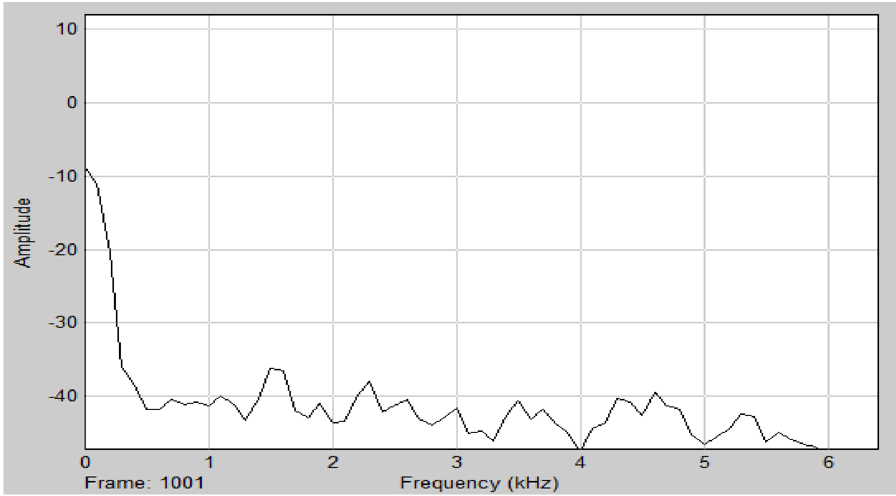


**FIGURE 9:** Spectrum Details of Real Time Acquired Carotid Wave in Simulink.

Computerized bio-signal processing has the potential to remove interference easily and effectively. T. Starr has worked on 10 seconds of real clinical stored ECG signal sampled at 360Hz and has applied IIR notch filter and three Type 1 FIR filters of varying order to analyze filter parameters to conclude their effectiveness and practical considerations. The work lacks its implementation on real time acquired data [2]. M. S. Chavan *et. al.* have explored Digital FIR filters in Simulink environment for removal of power line interference from real ECG data acquired using proprietary data acquisition unit. The results obtained are however, not so satisfactory [13]. In yet another work varied digital schemes have been used to remove power line noise but are tested on stored ECG tape [7]. S. Poornachandra *et. al.* have attempted a novel and less complex adaptive approach to distinguish between signal and noise using orthogonal basis, where signal enhancement is obtained using shrinkage function which discards values below a predetermined threshold in real time applications. The technique is however, a simulation effort tested in MATLAB [5]. R. M. Lu *et. al.* have explored subtraction procedure to adaptively eliminate power line interference injected using a signal generator in animals [6]. I. Dotsinsky *et. al*. have modified the subtraction procedure for computer based ECG systems, but the analysis is based on stored ECG database [10]. Thus, it can be said that computer simulation provides an easy platform to test bio-signal processing applications and digital techniques can be further explored for better results.

## 5. CONCLUSIONS

Analogue hardware notch filters and their microprocessor based digital equivalents have their own limitations in removing noise components from bio-signals. The aim of proposed virtual instrument in Simulink was to utilize the knowledge of digital signal processing in removing interference from the real time acquired carotid pulse waveform. The present work describes a simple simulation method that helps in online digital filtering in personal home monitoring systems since such systems are prone to artefacts. The blocks used in the model are from the main Simulink library that gives satisfactory results and has no hardware limitations. The system provides a PC based testing platform for acquisition, viewing and digital processing of bio-signals and provides the flexibility of being used with different data acquisition units. A model may further be designed using LabVIEW, where Adaptive Digital Filters with enhanced efficiency may be used along with proprietary data acquisition units for improved display and analysis of real time bio-signal.

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