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An analysis of the ECG signal's denoising using an efficient hybrid window function

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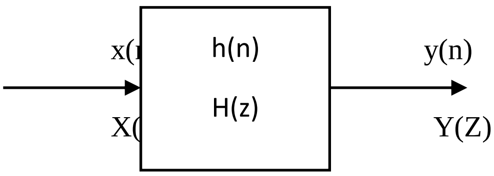
ABSTRACT
The main objective of this project is to denoise the Electrocardiogram signal which is corrupted by additive white gaussian noise. The noise may interrupt during an ambulatory patient monitoring in wireless ECG recording environment. So, in order to accomplish this objective an effective hybrid window function is established. A hybrid window function is proposed and a linear phase FIR low pass filter is designed by using the proposed windowing technique. The outcome of hybrid window is the multiplication of Blackman and flattop windows with an altered window coefficient. For proper identification, even at low SNR it is necessary to receive noiseless signal. Based on the relative analysis with other existing window functions the filter which is designed by proposed hybrid window function have qualified transition bandwidth. Even at low SNR, the ECG denoising is more accurate when filtered with designed hybrid window technique.
Key words: FIR filters, Electrocardiogram signal (ECG), Additive white gaussian noise, Hybrid window functions, Transition Bandwidth.

I. INTRODUCTION

The main purpose of filters is to eliminate the unwanted signal which is mixed within the original signal. These filters are classified into two types Analog filters and digital filters[6]. Among them digital filters give more accurate results for providing the valid outputs with the given input signals. These digital filters do not harm any component within the circuitry and simple to test and implement on any workstation. Despite of any changes in time and temperature, digital filters are extremely capable for responding and maintain its stability. So, digital filters plays a vital role in processing. Digital filters are classified into two major types like FIR [5](finite impulse response) and IIR (infinite impulse response). The selection of filter mainly depends on the design characteristics. One of them is linear phase[20]which prevent the loss of information. From this we can refer that FIR filters have linear phase characteristics and higher filter order which is more stable.

FIR filters are also known as non-recursive digital filters as they do not have the recursive part of a filter. The filter order and window functions come into existence whenever the characteristics of the transfer function and as well as its deviation from the ideal frequency response are evolved[17].



$$H(Z) = \frac{Y(Z)}{X(Z)} = \sum_{n-0}^{N-1} h[n].Z^{-n} \qquad ....(1)$$

II. ECG

The Electrocardiogram signal reflects the electrical activity of the heart observed from the strategic points of the human body and represented by quasi periodic voltage signal. ECGs are the real time processing signals which are very effective in identifying the continuous ambulatory patients. The machineries could monitor cardiovascular patients in their daily life and warns them in case of cardiac arrhythmia. The input considered is potential difference between the electrodes placed on the body surface[1]. From the evolutions of new technologies, the researchers were able to design a light weight system with low power consumption and low cost by recent advances and networking technologies and wireless communications [2].

Amplitude		Duration	
P wave	0.26mv	P-R interval	0.10 to 0.20 sec
R wave	1.50mv	Q-T interval	0.34 to 0.45 sec
Q wave	25% of R wave	S-T interval	0.05 to 0.15 sec
T wave	0.1 to 0.5mv	P wave interval QRS interval	0.10 sec 0.08 sec

Figure.1: Electrocardiogram signal(ECG)

Table.1 Amplitude and Interval Duration of ECG signal

BASELINE WANDER:

It is a low frequency artifact that occurs due to the movement and respiration of the patient. This effect makes the entire signal shift from its normal base i.e. either move up or down rather than being in a straight line[3].Its frequency is in the range of 0. 5hz.This frequency content of the bandwidth may increase by the movement of the body during exercise or stress test. By using Finite Impulse Response (FIR) high pass zero phase forward-backward filtering with a cut-off frequency of 0.5hz we can estimate and get rid of the baseline in the ECG[3].

POWER LINE INTERFERENCE:

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It has interfering voltage of frequency 0.5Hz. The interference occurs due to stray effect of the alternating current fields because of loops in the patient's cable and also by loose contacts on the patient's cable as well as dirty electrodes[2]. This noise is easily recognisable because of its frequency ranges. It completely superimposes the low frequency ECG waves like P wave and T wave[1]. So, by using Adaptive filtering we can get rid of this noise[4].

ELECTROMYO-GRAPHY:

It is high frequency noise above 100hz occurred due to muscle movement rate and pressure on it. It cannot be removed by narrow band filtering like baseline wander[3], but filtering becomes difficult since the spectrum content of the muscle activity considerably overlaps that of the PQRST complex.

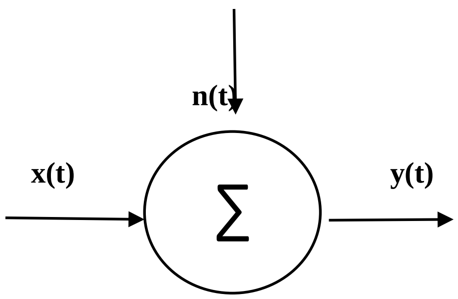
ELECTRODE MOTION ARTIFACTS:

Motion artifact is the noise which is the outcome from motion of the electrode in relation to the patient's skin.In order to get rid of the noise use an accelerometer for measuring the body gesture simultaneously with ECG detection.

III. ADDITIVE WHITE GAUSSIAN NOISE

Additive white gaussian noise is a basic model used in an Information theory. The term "Additive" refers to the fact that noise signal values are added to the transmission signal while "white" refers to the property that implies the uniformity of the noise power and "gaussian" refers to the random amplitude values of thermal noise in time[4].

Random process which is the combination of both the gaussian and white is called as white gaussian noise which means x(t) exhibits the gaussian property and white noise property. For a typical communication system, consider AWGN.



Here consider x(t) is a transmitted signal and n(t) is a noise signal; y(t) is received signal. The addition of noise signal to the original signal is as additive noise[20].

$$y(t)=x(t)+n(t) \qquad \ldots\ldots\ldots\ldots(2)$$

IV. EXISTING WINDOW TECHNIQUES

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RECTANGULAR WINDOW:

$$w_R(n) = 1; for\ -\frac{(l-1)}{2} \leqslant |n| \leqslant \frac{l-1}{2}$$

$$0; otherwise$$

…………. (3)

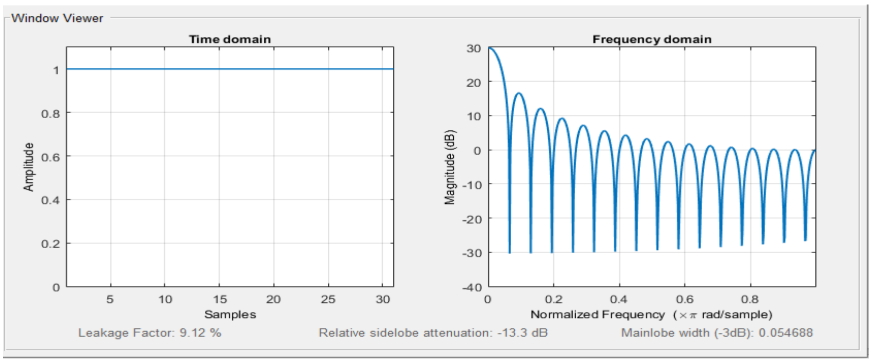

Figure 2. Time and Frequency response of rectangular window for l=31

RAISED COSINE WINDOW:

HANNING WINDOW:

$$w_{Hann}(n) = 0.5 - 0.5\cos\left(\frac{2\pi n}{l-1}\right) \qquad ; for\ n = 0\ to\ l-1$$

0 ; for other n …………… (4)

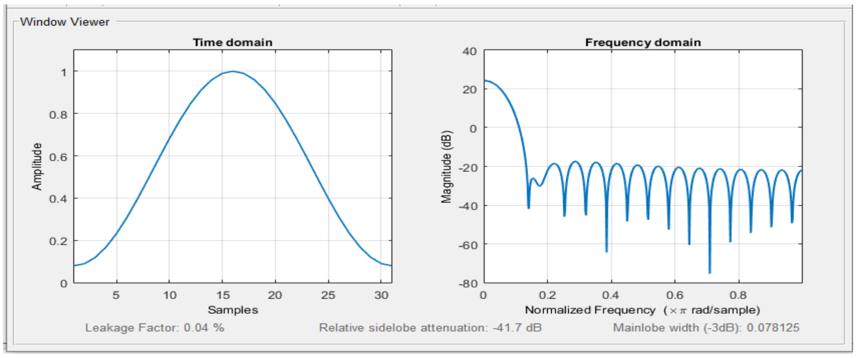

Figure 3. Time and Magnitude response of Hanning window for l=31

HAMMING WINDOW:

$$w_{Hamm}(n) = 0.54 - 0.46\cos\left(\frac{2\pi n}{l-1}\right); for\ \ n = 0\ to\ (l-1)$$

0 ;for other n

…..……… (5)

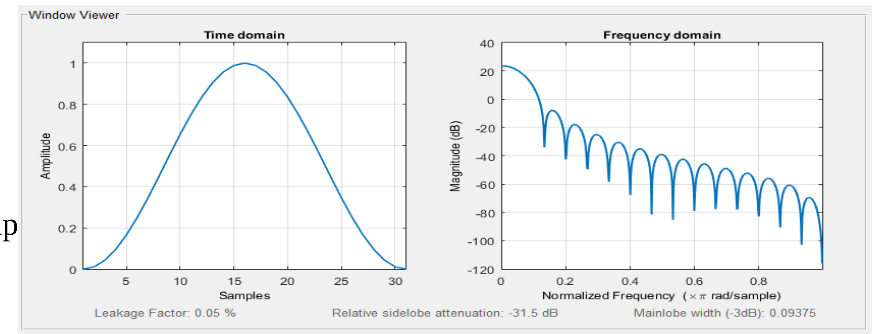

Figure 4. Time and Magnitude response of Hamming window for l=31

KAISER WINDOW:

$$w_{Ka}(n) = (I_o(b))/(I_o(a)); for\ -(l-1)/2 \leq |n| \leq (l-1)/2$$

0 ; otherwise

Where b=a$[1-\left(\frac{2n}{l-1}\right)^2]^{0.5}$;

a = Tuning parameter,

…………… (6)

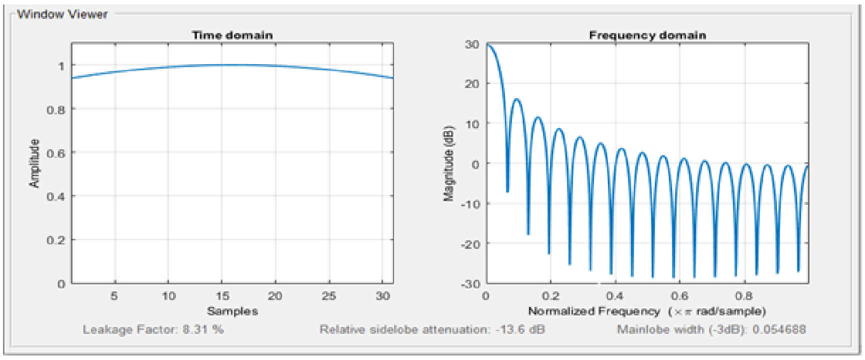

Figure 5. Time and Magnitude response of Kaiser window for l=31

BLACKMAN WINDOW:

$w_B(n) = 0.42 - 0.5\cos((2\pi n)/(l-1)) + 0.08\cos((4\pi n)/(l-1))$; for n=0 to (l-1)

0 ; for other n

…………… (7)

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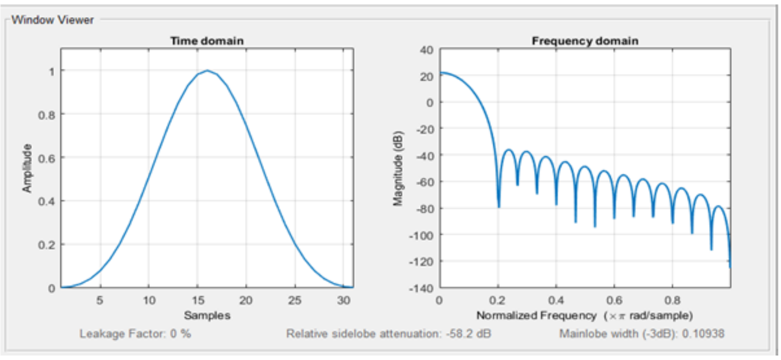


Figure 6. Time and Magnitude response of Blackman window for l=31

FLATTOP WINDOW:

$$w_F(n) = \delta_o - \delta_1 \cos(\Psi) + \delta_2 \cos(2\Psi) - \delta_3 \cos(3\Psi) + \delta_4 \cos(4\Psi)$$

where, $\Psi = \frac{(2\pi n)}{l-1}$; l = order of the filter, $0 \leqslant n \leqslant (l-1)$

$$\delta_0 = 0.2155789 , \delta_1 = 0.4166316, \delta_2 = 0.27726316 , \delta_3 = 0.08357895. \delta_4 = 0.00694737$$

…………… (8)

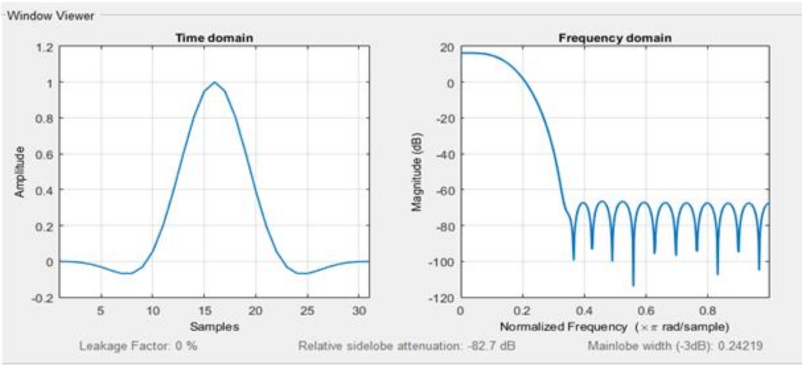


Figure.7 Time and Magnitude response of Flattop window for l=31

PROPOSED WINDOW TECHNIQUE:

For the better performance of a window, the parameters i.e., side beam attenuation must be low. Out of existing window techniques if we compare Blackman and flattop, they have side beam attenuation as -58.2 dB and -82.7 dB respectively. So, the product of these windows yields better result.

$$w(n) = w_B(n) \times w_F(n)$$

$$= \sum_{i=0}^{6} (\delta_i \times \cos(i \times \varphi))$$

………(9)

The proposed window function is examined that the response of the blackman and flattop window functions are very smooth and flexible.

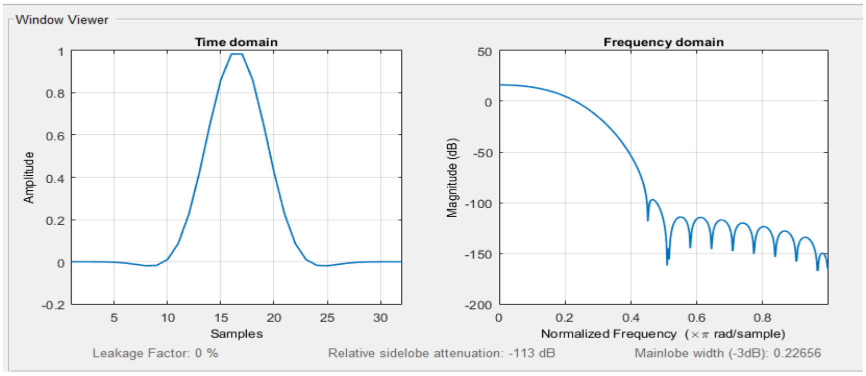


Figure. 8 : Time and magnitude response of proposed hybrid window function for l=31

From the above figures, we can observe that the response of the effective hybrid window functions. The advantages of flattop and Blackman windows are as follows:

1. In window sequence function[9], Blackman and flattop windows have more terms compared to remaining other windowing functions.
2. There is an existence of extra cosine terms in Blackman window function in which it will be a factor to deduce the side lobes for better performance. By reducing the side lobes there will be an increase in efficiency with low power loss.
3. Flattop window has greater accuracy compared to all existing window functions. So, this will be a major advantage for an effective window function[20].

So, it is obvious that the Blackman and Flattop window techniques are more powerful compared to other window techniques and perfect for fir filter designing.

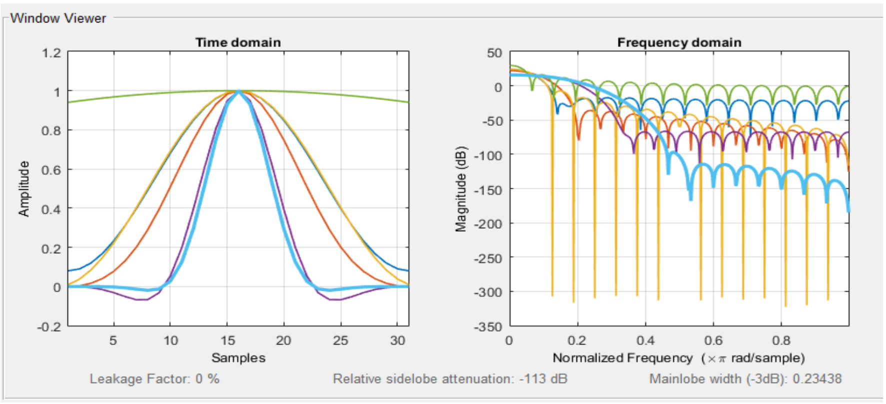
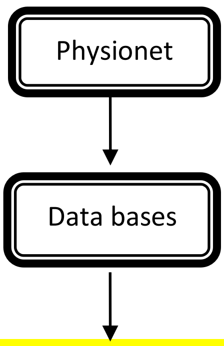


Figure.9: Comparison analysis of exiting window techniques with proposed window

METHODOLOGY:



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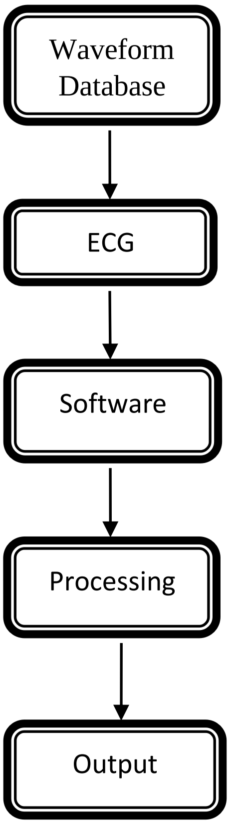

Step 1: Firstly, open physionet which is a free web based access to collect all different types of signals.
Step 2: From the physionet the available option is physionet bank in which the databases are stored for the processing.
Step 3: The waveform databases is collected from the physionet ATM in which it consists of various kinds of ECG signals with different specifications.
Step 4: From the specification listed, collect the desired ECG signal i.e. MIT-BIH arrhythmia signal[20] is selected for further signal evaluations.
Step 5: Load the ECG signal in software called Matlab and add noise to the original loaded ECG signal.
Step 6: Processing is done by denoising the signal using FIR filter[16] designed by the hybrid window function.
Step 7: At last, the outcome of filtered ECG signal is observed with-out any loss.

WINDOW SPECIFICATIONS:

There are various factors available for the calculation of the windowing coefficients. This measurements are carried out by an processing method called matlab. By careful analysis the factors are specified according to the functionalities of window functions[20]. They are:

MAIN BEAM WIDTH:

Main lobe width is defined as the minimum distance about the centre such that the window-transform magnitude does not exceed the specified side lobe level anywhere outside the particular interval. To represent fine structures in the spectrum it is essential that the response should consists of very narrow bandwidth. So, the greater the main lobe width, the more the test signal will be distorted in the frequency domain.

2. SIDE BEAM ATTENUATION:

Side beam attenuation refers to reduction of the side lobes which are existed within the particular response of a window function. The outcome of the windowing function is combination of time response and frequency response, frequency response consists of combination of main lobes and side lobes. It should be as low as possible.

3. LEAKAGE FACTOR:

Leakage factor usually refers to the outcome of windowing in which there will be a multiplication factor of any signal with a different kind of a window function. For the better functionality there will be a existence of less percentage of leakage factor[20]. Spectral leakage is a factor in which the it is caused by discontinuity in the original signal so it can be overcome by using a method called windowing method. Windowing reduces the amplitude of the discontinuities at the

Boundaries of each finite sequence acquired by the digitizer.

4. SIDE LOBE ROLL OFF RATIO:

The outcomes of any window function consists of more number of side lobes presence as we can observe in time and frequency response of window technique.However, they roll-off i.e. they will be an attenuation with certain frequency with some rate factor. Depend upon the value of the side lobe roll off ratio the windowing is selected. So as high as the value of side lobe roll of ratio is predicted as the best suitable window for further designing purposes.

RESULTS AND DISCUSSIONS:

The results are obtained for various ECG signals i.e. MIT-BIH arrhythmia database like 100,107,115,118,124 signals which are different in amplitudes and timing responses.

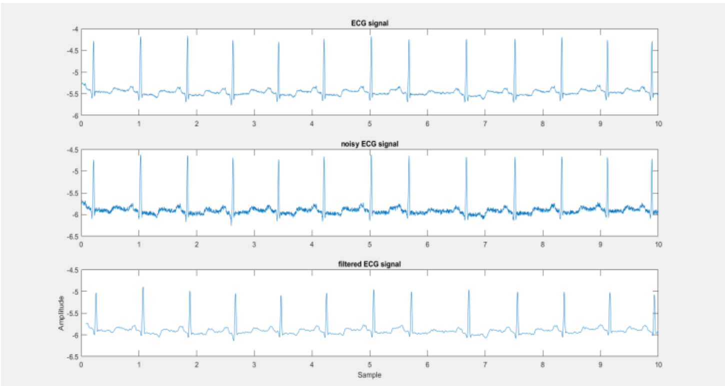

Figure.10: Proposed filter response for MIT-BIH arrhythmia (100m.mat) database

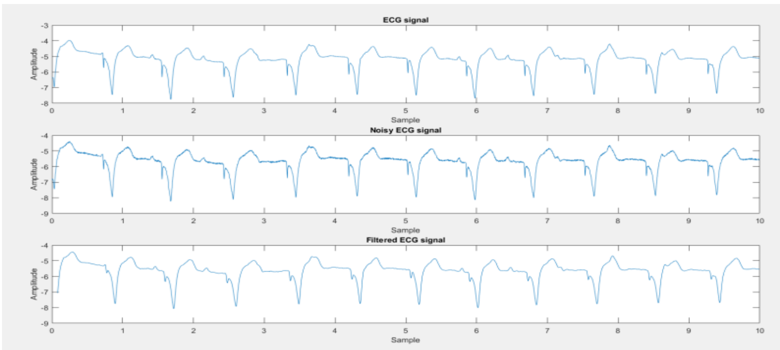

Figure.11: Proposed filter response for MIT-BIH arrhythmia (107m.mat) database

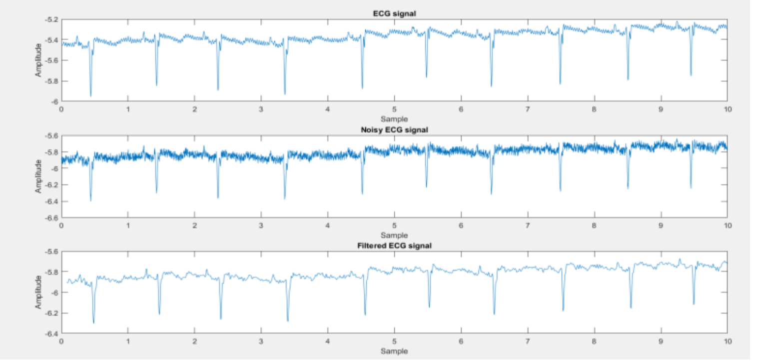

Figure.12: Proposed filter response for MIT-BIH arrhythmia (115m.mat) database

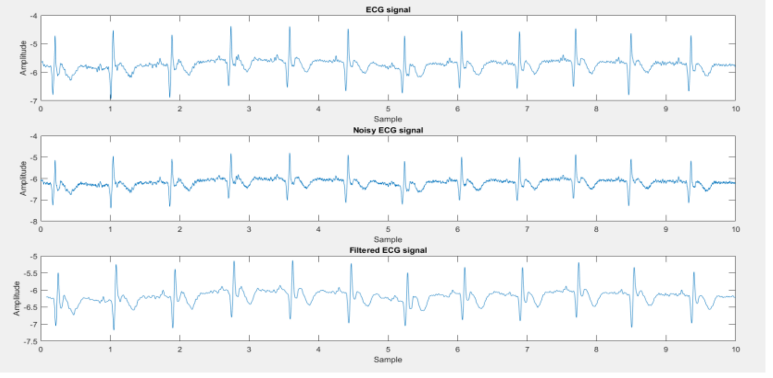

Figure.13: Proposed filter response for MIT-BIH arrhythmia (118m.mat) database

Figure.14: Proposed filter response for MIT-BIH arrhythmia (124m.mat) database

From the careful analysis it is decided that the various ECG signals are considered and for those ECG signals the additive white gaussian noise is added. From the Noisy ECG signal obtained we can denoise the ECG[14] which is corrupted by noise using various types of filters so for accurate results FIR filters[13] are the best suitable technique used to remove the noise added to the original signal.

FIR Filter is designed using various methods but better results are obtained only by windowing analysis[18]. So, from the existing window functions there will be a effective hybrid window function is obtained by product of two window technique So, by using this window function a filter is designed with the desired filter coefficients for deducing the maximum amount of noise present in the ECG signal while processing into the visualized electrical machines.

OBSERVATIONS

WINDOW	SBA(dB)	MLW(3dB)	LF	SLRR

Blackman	-58.2	0.10938	0%	-18dB
Flattop	-82.7	0.24219	0%	-6dB
Rectangular	-13.3	0.054688	9.12%	-6dB
Hamming	-41.7	0.078125	0.045%	-6dB
Hanning	-31.5	0.085938	0.05%	-18dB
Kaiser	-13.6	0.054688	9.31%	-6dB
Proposed	-113	0.23438	0%	-6dB

Figure.15: Comparison table of all window functions with proposed window function

CONCLUSION

As of now, it is concluded that the proposed window function has many advantages related to designing of the FIR filters for the removing of the noise in the ECG signals. From the applications of biomedical signals there is a chance of occurrence of random noise in a signal due to various kinds of effects like ambulatory patient's position, distance between electrodes and skin etc may cause the random noise to corrupt an original ECG signal. So, in order to remove the noise presence in the signal we have to use the suitable techniques for designing of the filters. The best method is windowing method to design the FIR filter because it has good main lobe width and lower side lobe attenuation, especially it is used to design the prototype filters like low pass, high pass, band pass, band reject filters. From the observations, it is observed that proposed window has an advantage of having lower side lobe attenuation and as the length increases the main lobe width decreases. The major factor considered is leakage factor compared to all existing windows the proposed window has zero percent in leakage factor so, it is more suitable for designing an FIR filter accurately.

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