System for ECG signal Denoising

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Abstract—presently a day's ECG Signal assumes a significant job in finding of Different Heart illnesses. An ECG signal is significant for Medicine practice on heart. It is required to be clean. This Paper is about a methodology of Denoising ECG signal. Where a High Pass Filter, Weighted Window Filter and Savitzky-Golay Filter are utilized to denoise the ECG signal. Distinctive ECG signals are taken from MIT-BIH Database to confirm our Proposed Method utilizing MATLAB programming.

Index —ECG, Savitzky-Golay filter, Gaussian window filter, Baseline-wandering, SNR.

I. INTRODUCTION

Electrocardiography is the way toward delivering an electrocardiogram ECG or EKG, a chronicle – a diagram of voltage versus time – of the electrical movement of the heart utilizing cathodes set on the skin. These cathodes identify the little electrical changes that are an outcome of cardiovascular muscle depolarization pursued by repolarization during each heart cycle (heartbeat). The ECG signal represents the electrical activity of the heart. ECGs can be recorded as short irregular tracings or constant ECG observing. The figure of ECG signal is shown below

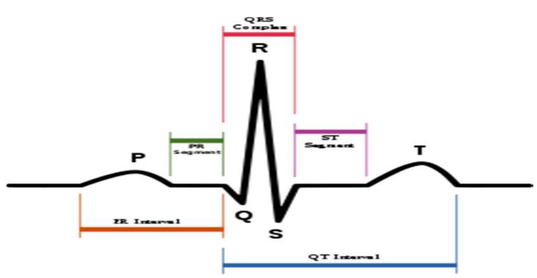

Fig.1. The Ideal and Theoretically formed ECG signal

The above demonstrated ECG signal has P wave which lies in the frequency range of 0.67 Hz to 5Hz then a QRS complex which is the overwhelming piece of the sign lies in the frequency range of 10 Hz to 50 Hz and afterward T wave which lies in frequency range of 1 Hz to 7 Hz. The Signal appeared above is the perfect ECG signal, yet by and by they are not unreasonably Ideal.

II. DENOISING OF ECG SIGNAL

Denoising of ECG Signal is needed because a Noisy ECG signal can lead to false alarm and can lead to wrong diagnosis thus it can lead to wrong treatment of the patient or over treatment of the patient. The Noises in ECG are Baseline wander, Muscle artefact, Electromyogram noise The Noise Baseline wander originates due to the Respiration. The Muscle artefact noise ordinarily brought about by muscle action close to the head, for example, gulping or head developments and Electromyogram noise which a High frequency noise. Maximum energy of the ECG signal lies in the range of 0.5 Hz to the 100 Hz. Objective is to denoise the ECG signal without losing a single information. QRS detector or any other ECG processing or thresholding blocks are not so robust they can miss any beat count so this pre-processing denoising system is required to pass a noiseless ECG signal to next stages. This paper first study the performances of different filters as in [1], [6] then it will be decided what will be the perfect system to clean the ECG signal.

A. Removing of low frequency noise

In this segment we are going to say about the low frequency noise that are present in the signal. Basically low frequency noise refers to the baseline-wander noise that shifts the baseline of the ECG signal. Abrupt changes in the ST segment are the most important ECG marker when dealing with acute coronary syndrome caused by ischemia or myocardial infraction. To supress this noise we are designing a high pass filter whose cut-off frequency should be greater than 0.5 Hz but we need to take care that it should not remove the P-wave whose frequency is from 1Hz to 7Hz. So taking the conditions into the account the cut-off frequency of the high pass filter ought to be between 0.5Hz to 1Hz. Butterworth IIR filter architecture is used here for building of high pass filter. Because Butterworth filter have no ripples in the stopband frequency which will not allow too much noise and more over the frequency response of such a filter is flat. The frequency response of this filter of n orders is shown below

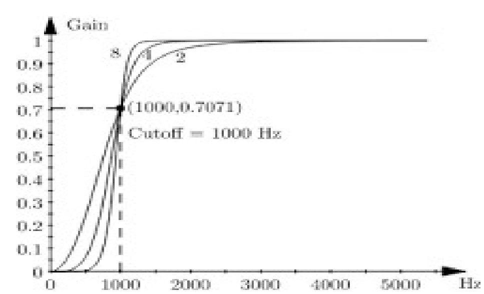

Fig.2. Example Frequency response of Butterworth filter

As seen in the figure shown as an example, as the order of the filter n increases the response gets stricter and clearer and gives more better performance. The transfer function of the butter worth filter [12] is given by

$$H(\omega) = \frac{\omega^n}{\sqrt{1+\omega^{2n}}} \qquad (1)$$

B. Removing of High frequency noise component from ECG Signal.

Suppression of high frequency noise component from the ECG signal using conventional filter is not efficient way .Because in such case we need to design one filter which has very sharp cut-off frequency and also have flat band pass as well, which is very much difficult to design. So instead of using normal filtering technique it is needed to perform test on the filters choose proper candidate for the ECG denoising as mentioned in [1]-[16] and some of them are my own. The list of filters that are to be tested are as follows:

- Savitzky-Golay filter
- Smooth Filter
- Moving average filter
- Moving weighted window filter
- Gaussian filter
- Median filter
- Rectangular window fir filter
- Butterworth filter

C. *Parameters that are fixed for the testing and some information about them.*

1. Savitzky-Golay filter: Order of the polynomial of the filter = 0. Frame length = 17. A Savitzky-Golay Filter needs Pre-Determined estimations of order and frame length for its manufacture. This Method of filtering were proposed by Abraham Savitzky and Marcel J.E.Golay in the year of 1964.
2. Smooth Filter: Window size = 30. Smooth Filter is used for creating approximated output wave by removing noises.
3. Moving average filter: Window size = 15. This filter runs by calculating average in a particular frame given by us and calculating moving average, a moving average is an estimation to dissect data points by making a progression of averages of various subsets of the full data collection.
4. Gaussian Window filter: Window size = 7. Window type: Gaussian window. A weighted average is an average that has increasing variables to give various weights to data by a factor at various points in a window. It is discussed in detail in the later section of the paper.
5. Gaussian filter: Window size =7. Gaussian filter is a filter whose drive reaction is a Gaussian function or an estimation to it, since a genuine Gaussian response is not realized physically
6. Median filter: Window size = 15 The Median Filter is a non-linear digital filtering technique, frequently used to supress noise from a picture or signal
7. Rectangular window FIR filter: Window Size = 15. It is a FIR filter designed by using rectangular window function with frame length of N, it is given by [12]

$$w(n) = \begin{cases} 1, & n = 0,1,2\ldots\ldots, N \\ 0, & \text{otherwise} \end{cases} \quad (2)$$

8. Butter worth filter: Cut-off frequency = 50 Hz Order =10 Response = low pass. The Butterworth filter is a kind of filter intended to have a frequency as flat as conceivable in the passband. It is likewise alluded to as flat band filter. So this is chosen for noise removal.

D. *Parameters that are to be evaluated*

SNR: It is termed as Signal to Noise Ratio which means the ratio of the power of signal to the power of the unwanted noise signal [8], it is given by.

$$\text{SNR value} = \frac{\text{Power of Signal}}{\text{Power of Noise}} \quad (3)$$

When the SNR is to be found in dB i.e Decibel scale then there are two formulas, when we are finding them on the basis of power[8] then,

$$SNR = 10 \log_{10}\left(\frac{P}{N}\right) \quad (4)$$

Where P is termed as Signal power and N is termed as Noise power. Meanwhile on the other hand, When it is to be found on the basis of rms values of Signals and noise then [9],[10]

$$SNR = 20\, log_{10}\left(\frac{V_s}{V_N}\right) \quad (5)$$

Where V_s is termed as the rms value of information signal and V_N is termed as rms value of unwanted noise signal. Even if there is high SNR it does not mean the filter is good, it signifies that the Signal is dominating than the noise which signifies that the filter has good noise removing capability, it does not tell that how far the recreated signal is like the first perfect signal. For this we need to evaluate another parameter which is called correlation co-efficient which is denoted by COR. The correlation coefficient is the measure of the relation between two signals. If the value of COR is 1 then it means the reconstructed signal is exactly match the clean signal and it is the ideal value of COR. The value or mathematical expression of COR is given [13] by,

$$COR = \frac{\sum_{i=1}^{n}(C_i - \bar{C})(Di - \bar{D})}{\sqrt{\sum_{i=1}^{n}(C_i - \bar{C})(Di - \bar{D})}} \quad (6)$$

Where C_i is the set values of n samples of clean signal which has mean value of $\bar{C}$. Where as Di is the set values of denoised signal which has mean value of $\bar{D}$.

E. *Results got through the experiments*

The experiment is carried out in the MATLAB software using the databases from [5] and got the performance evaluation of the filters as shown in the table below.

TABLE I. PERFORMANCE RESULT OF DIFFERENT FILTERS.

Filter	**SNR(dB)**	**COR**
Savitzky-Golay	22.69	0.801557
Smooth Filter	17.01	0.177373
Weighted window (Gaussian)	16.86	0.957624
Gaussian Filter	17.01	0.100202
Median Filter	22.82	0.896177
Rectangular Window FIR Filter	22.73	0.250770
Butterworth	22.69	0.801557
Moving Average	22.68	0.38644

The time response of the filters on the ECG signal is shown below.

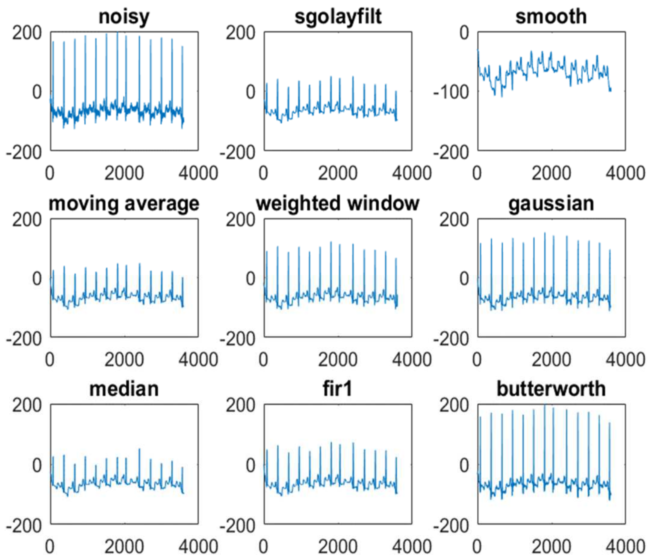

Fig.3. Time domain response on ECG signal by different filter

On the basis of the table and after the evaluation of the filter for denoising is chosen by considering both the parameter SNR and COR It is seen that those filter like Weighted window filter has a sufficient SNR which might be less compared to other filters but when it comes in case of the correlation coefficient it is the best filter. Another suitable competitor is the median filter its SNR is much more than the Weighted Window filter but the correlation coefficient is much less than that of the weighted window filter. And for the smoothing operation Savitzky-Golay filter is the best option because of its good SNR and also good COR as well. So, the solution for the removing of high frequency noise removing is the cascading of any two filters. So, we have again performed the experiment but this time there is cascading of filters. Our first candidate is weighted window Savitzky-Golay filter i.e the cascaded system of weighted window filter and Savitzky-Golay filter, and second candidate is median Savitzky-Golay filter i.e the cascaded system of median filter and Savitzky-Golay filter. The comparison experiment is carried out by adding high pass Butterworth filter also. Now let's talk about that match the result of the match is as shown below.

TABLE 1: PERFORMANCE COMPARISON TABLE

System	SNR(dB)	COR
HPF+WWF+SG	10.345474	0.998486
HPF+MF+SG	8.220329	0.995429

In the above shown table HPF means High pass filter, SG means Savitzky-Golay Filter and MF signifies Median filter and WWF means Weighted window filter (Gaussian Window filter).As shown in the table above there is not too much difference between the two systems in case of correlation coefficient but when comes to SNR the system consisting of Median filter gives poor performance compared to the system consisting of Weighted window filter. So According to the check in performance parameter the cascaded system of Butterworth filter, weighted window filter and Savitzky-Golay filter wins the match.

III. IMPLEMENTATION OF NOISE REMOVING SYSTEM

In this section the whole system is realized. First of all the signal will first go to high pass filter for baseline correction then going to Gaussian window filter to remove some high frequency noise and finally go to Savitzky-Golay filter for smoothing. The figure given below is the diagram of the proposed framework.

Fig. 4. The diagram for denoising an ECG signal.

Now we are going to explain each and every block of the block diagram.

A. High Pass Filter

High pass filter is the first block of this design it is used to remove the low frequency noise of baseline wander which originates from the respiration by lungs which shifts baseline of the ECG signal due to which can make it difficult to detect the R-peak of the signal. In order to remove this noise, we need a high pass filter the cut-off frequency of the high pass filter should be such that it does not remove the p-wave of the signal. So Ideally 0.5Hz cut off frequency is sufficient for supressing noise but in practice we need to do a lot of trial and error first we need to know the fundamental frequency of the noise and also that of P wave then decide how much cut-off frequency should be used in design of filter. Butterworth filter is sufficient for this purpose with cut-off frequency of 0.99Hz with sampling rate of 500 Hz and of order 7.The response of the input to the filter is the noise effected ECG signal we are getting a baseline wonder removed noise signal. The input and output Response of the filter in Time domain is as shown below.

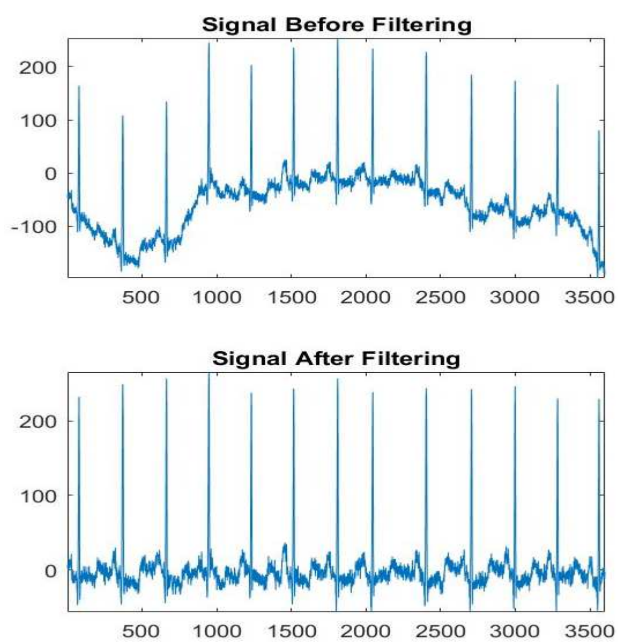

Fig.5. Removal of Baseline Wander noise from ECG signal through High pass Butterworth filter.

B. Gaussian window filter

What is weight function? A weight function is a mathematical gadget utilized when performing an operation to give a few components more "weight" or effect on the result than different components in a similar set [11]. The aftereffect of this use of a weight function is a weighted sum or weighted average. Weighted Window is called in the sense that the coefficients of the window function are giving some samples of the signal a more weight than the others this is only possible when the window function will be non- planar, non-rectangular so in this case Gaussian window is used to create this filter. Since the genuine Gaussian capacity has unending span, practically speaking we should window it with some standard limited window, or shorten it. The coefficients of a Gaussian window are processed from the accompanying condition:

$$w(n) = e^{-\frac{1}{2}\left(\alpha\frac{n}{(L-1)/2}\right)^2} \qquad (7)$$

Where – (L – 1)/2 ≤ n ≤ (L – 1)/2, and α is conversely corresponding to the standard deviation, σ, of a Gaussian arbitrary variable. The careful correspondence with the standard deviation of a Gaussian likelihood thickness work is σ = (L-1)/(2α).

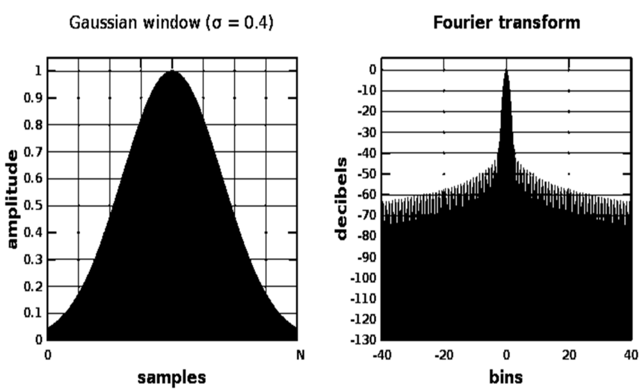

Fig. 6. Gaussian expansion

Window size of 7 is sufficient. Effective will be using the Gaussian window. Giving a 15 coefficient FIR filter.The Time domain Response on the ECG signal by the Gaussian window filter is given in the figure below.

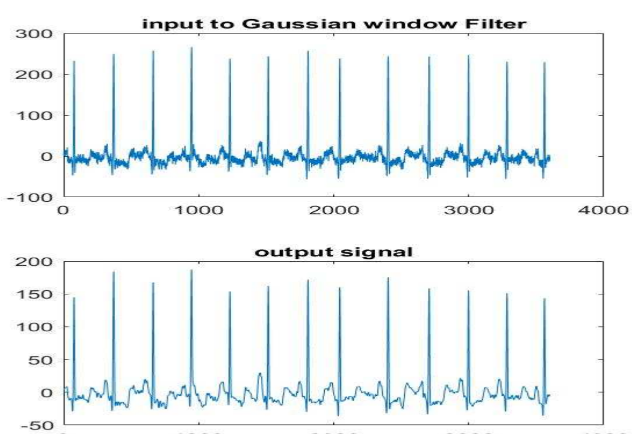

Fig.7. Time domain response of moving weighted window filter

C. Savitzky-Golay Filter

A paper named "smoothing and differentiation of data by simplified least square procedure" by Abraham Savitzky and M. J.E.Golay in the year of 1964 in the journal Analytical Chemistry[15]. Later on S.Hargittai[4] and S.S.Mostafa[3] gave an idea that this procedure can be used to make a filter which smooth the data of an ECG signal. Shivangi Agarwal used lot of combinations of this filter[13] and also applied on EEG signal[16]. From the lecture note by Ronald.W.Schafer[14] using those knowledge the savitzky golay filter is created. A polynomial filter are often considered as piece-by-piece fitting of a polynomial function to the signal. The fitting is completed by a method of least squares (LS) estimate between the X matrix and therefore the y vector:

$$y = Xa \qquad (8)$$

Where X is the design matrix for polynomial approximation problem. The standard Least Square solution is given by:

$$a = (X^TX)^{-1}X^Ty \qquad (9)$$

or,

$$a = Z.y \qquad (10)$$

where,

$$Z = (X^TX)^{-1}X^T \qquad (11)$$

Z is called the convolution coefficient. When we want to suit a polynomial function of order p, we get a series of equations within the following form:

$$Y_i = a_p.x_i^p + a_{p-1}.x_i^{p-1} + \ldots a_1.x_i^1 + a_0.x_i^0. \qquad (12)$$

for i = 1...2n+1

Or, in general,

$$(C*y) = Y_i = \sum_{i=-\frac{m-1}{2}}^{\frac{m-1}{2}} C_i y_{j+i}\,, \qquad (13)$$

$$\frac{m+1}{2} \le j \le n - \frac{m-1}{2}$$

Using the above convolution equation in 13 or the using the polynomial function equation in 12 those two equations are used in making of Savitzky-Golay filter. The figure shown below is the frequency response of our Savitzky-Golay filter.

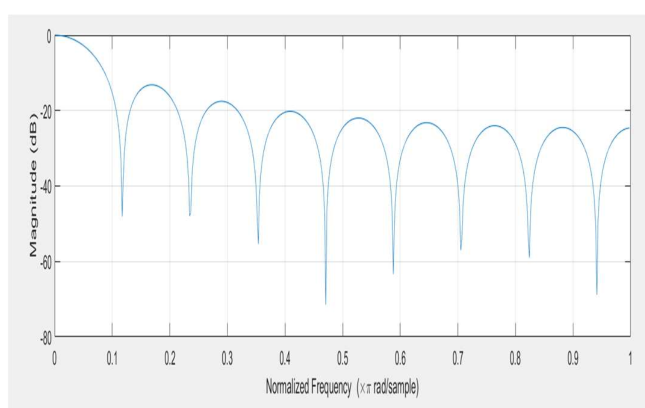

Fig.8. Frequency Response of Savitzky-Golay Filter

According to Schafer [14] and Hargittai [4] for filter to work properly it is found that the polynomial order should be in even number and frame length order should be in odd number. If the frame length is high or order is low or both the possibility the filter will work as a smoothing filter and when the frame length is low or order is high or both occurs then the filter will focus more on detail capturing. So in this paper the ECG signal is needed to be smooth so it is required to have low order and big frame length by ensuring that is does not change the signal. So order of polynomial of 0 and frame length of 17 is eligibleThe time domain response of the Savitzky-Golay filter is shown in the figure below.

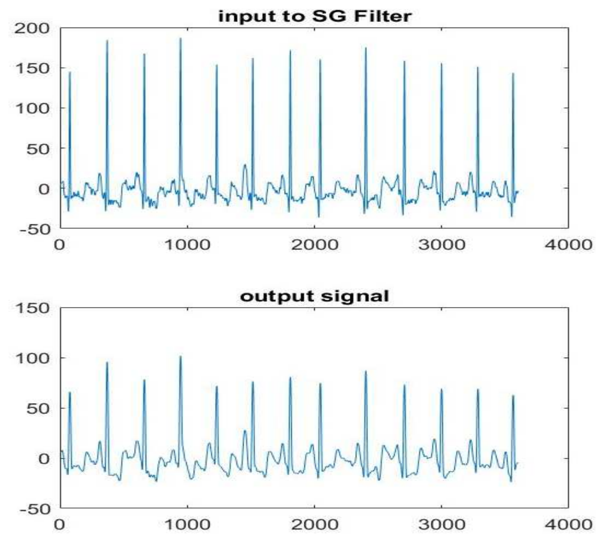

Fig. 9. Time domain response of Savitzky-Golay filter on ECG signal.

The desired result is achieved what is needed so the result is shown below in summarised manner as shown below.

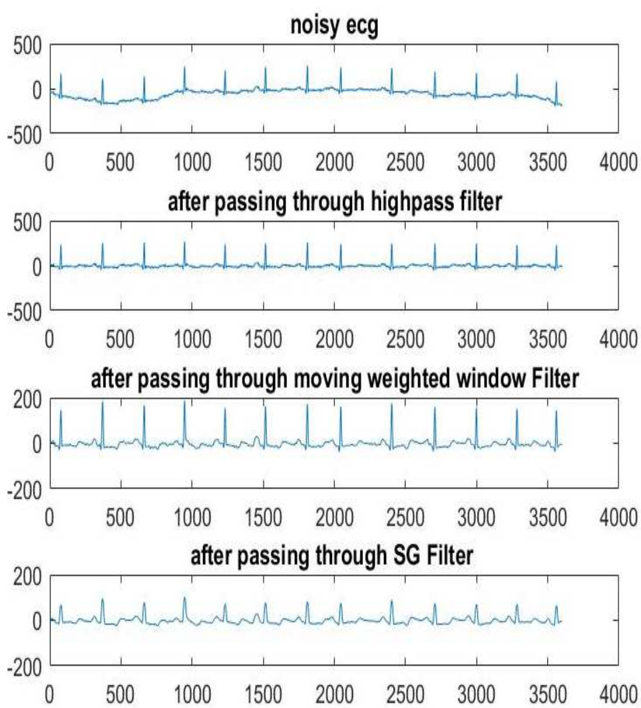

Fig.10. ECG Denoising by various filter

IV. CONCLUSION

From Fig.10. it is shown, The noise corrupted ECG signal is passed through the Butterworth filter for baseline wander removal because of it's flat-band response after the removal of baseline wander noise the high frequency noise corrupted signal then passed to Gaussian window filter because of it's high amount of correlation value (COR = 0.957624) then to smooth the signal Savitzky-Golay filter do this job is is choosen because of it's high SNR value (SNR =22.69 dB) .The technique used for Denoising the ECG signal is the system obtained by cascading Butterworth filter , Gaussian window filter and Savitzky-Golay filter, It is giving an clean ECG signal with SNR value of 10.345474 dB and correlation value of 0.998486.

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