System for ECG signal Denoising

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Abstract—now a days ECG Signal plays an important role in diagnosis of Different Heart diseases. An ECG signal is very important for Medicine practice on heart. It is required to be noise free. This Paper is about an approach of Denoising ECG signal. Where a High Pass Filter, Weighted Window Filter and Savitzky-Golay Filter are used to Denoise the ECG signal. Different ECG signals are taken from MIT-BIH Database to verify our Proposed Method using MATLAB software.

1. INTRODUCTION

Electrocardiography is the process of producing an electrocardiogram ECG or EKG, a recording – a graph of voltage versus time – of the electrical activity of the heart using electrodes placed on the skin. These electrodes detect the small electrical changes that are a consequence of cardiac muscle depolarization followed by repolarization during each cardiac cycle (heartbeat). Changes in the normal ECG pattern occur in numerous cardiac abnormalities, including cardiac rhythm disturbances (such as atrial fibrillation and ventricular tachycardia), inadequate coronary artery blood flow (such as myocardial ischemia and myocardial infarction), and electrolyte disturbances (such as hypokalaemia and hyperkalaemia). The ECG signal represents the electrical activity of the heart. The overall goal of performing an ECG is to obtain information about the electrical function of the heart. Medical uses for this information are varied and often need to be combined with knowledge of the structure of the heart and physical examination signs to be interpreted. Some indications for performing an ECG include the following:

- Chest pain or suspected myocardial infarction (heart attack), such as ST elevated myocardial infarction (STEMI) or non-ST elevated myocardial infarction (NSTEMI)
- Symptoms such as shortness of breath, murmurs fainting, seizures, funny turns, or arrhythmias including new onset palpitations or monitoring of known cardiac arrhythmias
- Medication monitoring (e.g., drug-induced QT prolongation, Digoxin toxicity) and management of overdose (e.g., tricyclic overdose)
- Electrolyte abnormalities, such as hyperkalaemia
- Perioperative monitoring in which any form of anaesthesia is involved (e.g., monitored anaesthesia care, general anaesthesia). This includes preoperative assessment and intraoperative and postoperative monitoring.
- Cardiac stress testing
- Computed tomography angiography (CTA) and magnetic resonance angiography (MRA) of the heart (ECG is used to "gate" the scanning so that the anatomical position of the heart is steady)
- Clinical cardiac electrophysiology, in which a catheter is inserted through the femoral vein and can have several electrodes along its length to record the direction of electrical activity from within the heart.

ECGs can be recorded as short intermittent tracings or continuous ECG monitoring. Continuous monitoring is used for critically ill patients, patients undergoing general anaesthesia, and patients who have an infrequently occurring cardiac arrhythmia that would unlikely be seen on a conventional ten-second ECG. Continuous monitoring can be conducted by using Holter monitors, internal and external defibrillators and pacemakers, and/or biotelemetry. The figure of ECG signal is shown bellow

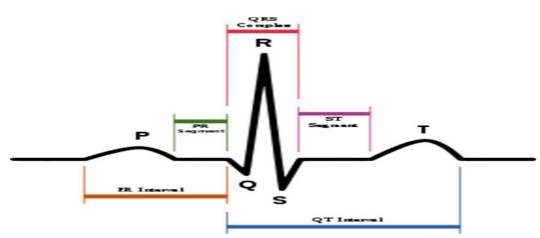

Figure 1:The Ideal and Theoretically formed ECG signal

The above shown ECG signal has P wave which lies in the frequency range of 0.67 Hz to 5Hz then a QRS complex which is the dominating part of the signal lies in the frequency range of 10 Hz to 50 Hz and then T wave which lies in the range of 1 Hz to 7 Hz. The Signal shown above is the ideal ECG signal, but in practice they are not that Ideal.

2.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. Thus, it is Very Important to denoise ECG Signal. The Noises in ECG are Baseline wander, Muscle artefact, Electromyogram noise The Noise Baseline wander originates due to the Respiration. The Muscle artefact noise typically caused by muscle activity near the head, such as swallowing or head movements, and are characterized by high-frequency activity nearly around 20 Hz and Electromyogram noise which a High frequency noise. The high pass filter is used to remove the baseline wander and the cascade of Savitzky-Golay filter and moving average window filter is used to remove motion artefact and electromyogram 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. The noises present in an ECG signal along with there dominant frequency are as follows:

Baseline wander noise: 0.5 to 0.67 Hz

Motion Artefact noise: 5 to 50 Hz

Electromyogram noise: 50 to 60Hz

Unfortunately, all the noises are dominating within the range of the maximum power of ECG signal, So Denoising of ECG signal is very difficult to perform. The denoising process is divided into two part 1st part is Removing of low frequency noise and the next part is the removal of high frequency noise.

2.1 Removing of low frequency noise.

In this section we are going to say about the low frequency noise that are present in the signal. Basically low frequency noise refers to the base line 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. The diagnosis of myocardial infraction or myocardial ischemia are based on specific , small changes in ST segment. Therefore even minor fluctuation in the baseline can lead to huge misleading diagnosis which in turn leads to a wrong treatment ,therefore it is strictly needed to remove this low frequency noise. To remove 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 should 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 Butterworth filter is a type of signal processing filter designed to have a frequency response as flat as possible in the passband. It is also referred to as a maximally flat magnitude filter**.** So this is chosen for noise removal. The frequency response of this filter of n orders is shown below

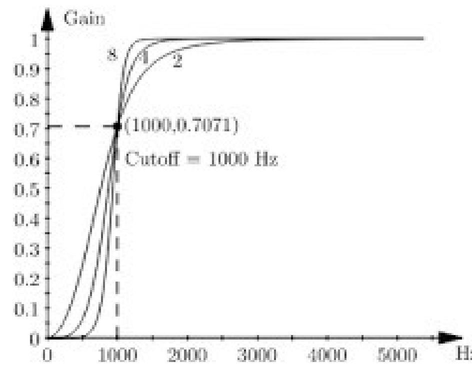

Figure 2: Example Frequency response of Butterworth filter

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

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

2.2 Removing of High frequency noise component from ECG Signal.

The high frequency noise component from the ECG signal using conventional filter is not efficient way to remove noise from the signal. Because in this case we need to design one filter which has very sharp cut-off frequency and also have flat bandpass 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. 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

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 = 15. A Savitzky-Golay Filter needs Pre-Determined values of order and frame size for its fabrication. This Method of filtering were proposed by Abraham Savitzky and Marcel J.E.Golay in the year of 1964. This filter aims to provide a generic framework for optimal design filter according to the order and frame size. It is discussed in details later section of this paper.

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 a calculation to analyse data points by creating a series of averages of different subsets of the full data set.

4.Moving weighted window filter

Window size = 7. Window type: Gaussian window. A weighted average is an average that has multiplying factors to give different weights to data at different positions in the sample 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 impulse response is a Gaussian function or an approximation to it, since a true Gaussian response is physically unrealizable

6.Median filter

Window size = 15. The Median Filter is a non-linear digital filtering technique, often used to remove noise from an image or signal.

7.Renctangular 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

w(n) = 1, n= 0,1, 2……, N

= 0, otherwise

8. Butter worth filter

Cut-off frequency: 50 Hz Order =10 Response = low pass. The Butterworth filter is a type of signal processing filter designed to have a frequency response as flat as possible in the passband. It is also referred to as a maximally flat magnitude filter.

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, it is given by.

$$\text{SNR value} = \frac{\text{Power of Signal}}{\text{Power of Noise}}$$

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 then,

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

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,

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

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 reconstructed signal is similar to the original clean 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 by,

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

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 $\bar{D}$.

Results got through the experiments

The experiment is carried out in the MATLAB software and got the performance evaluation of the filters as shown in the table below.

Table 1:Performance of different filters.

Filter	SNR(in dB)	COR
Savitzky-Golay	22.69	0.801557
smooth Filter	17.01	0.177373
Weighted window	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	0.386494

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

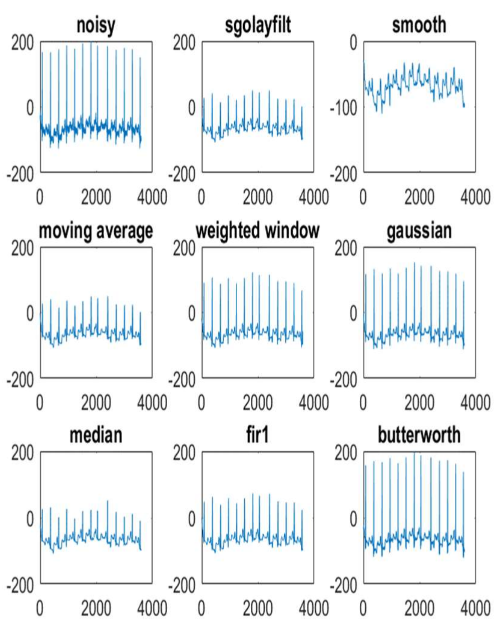

Figure 3: Time domain response on ECG signal by different filter

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 it's 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. So According to the check in performance parameter the combination of Butterworth for low frequency and for high frequency the cascaded system of Weighted window filter and Savitzky-Golay filter wins the match. The result of the performance of the overall system is discussed in the result and discussion section, where the reason of choosing the combination of choosing cascade system of weighted window and Savitzky-Golay filter. So, from here will be able to build a proposed system for denoising of ECG signal.

3.THE SYSTEM FOR REMOVING NOISE FROM ECG SIGNAL

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

Figure 4:The block diagram for Denoising an ECG signal.

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

3.1 High Pass Filter

The 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 this noise shifts the 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 0.5 Hz cut off frequency is sufficient to remove the 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 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 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.

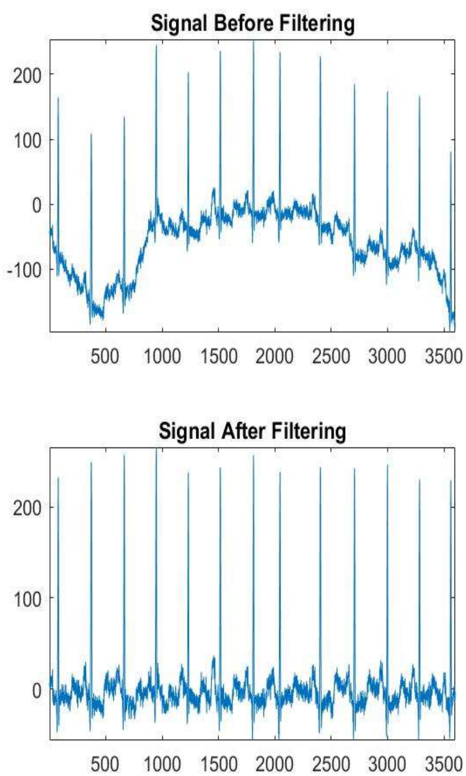

Figure 5: Removal of Baseline Wander noise from ECG signal through High pass Butterworth filter.

3.2. Gaussian window filter

Weighted window filter is one type of filter where the window uses weight function in filtering. So, what is weight function? A weight function is a mathematical device used when performing a sum, integral, or average to give some elements more "weight" or influence on the result than other elements in the same set. The result of this application 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 also the window is movable on the signal. This filter uses the movement of the Gaussian window and performing Gaussian Window transform in some samples of the signal, Thus adding weight to some of the samples. Now here is the discussion about the gaussian window The Gaussian bell curve is possibly the only smooth, nonzero function, known in closed form, that transforms to itself. Since the true Gaussian function has infinite duration, in practice we must window it with some usual finite window, or truncate it. The coefficients of a Gaussian window are computed from the following equation:

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

where $-(L-1)/2 \le n \le (L-1)/2$, and α is inversely proportional to the standard deviation, σ, of a Gaussian random variable. The exact correspondence with the standard deviation of a Gaussian probability density function is $\sigma = (L-1)/(2\alpha)$.

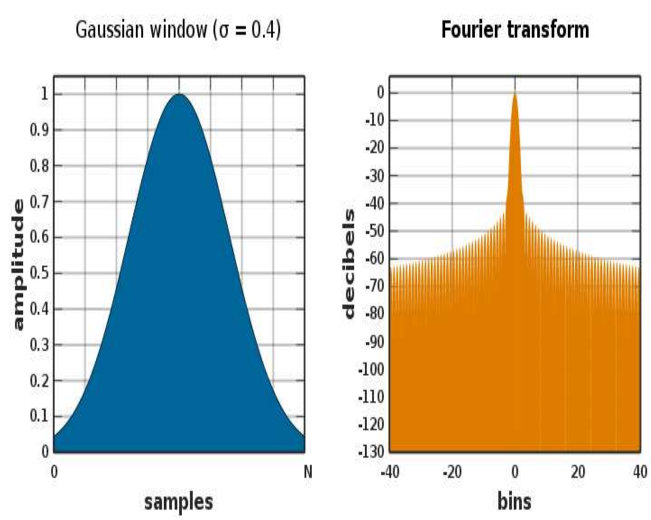

Figure 6: Frequency response of gaussian filter.

The Time domain Response on the ECG signal by the moving weighted window filter is given in the figure below.

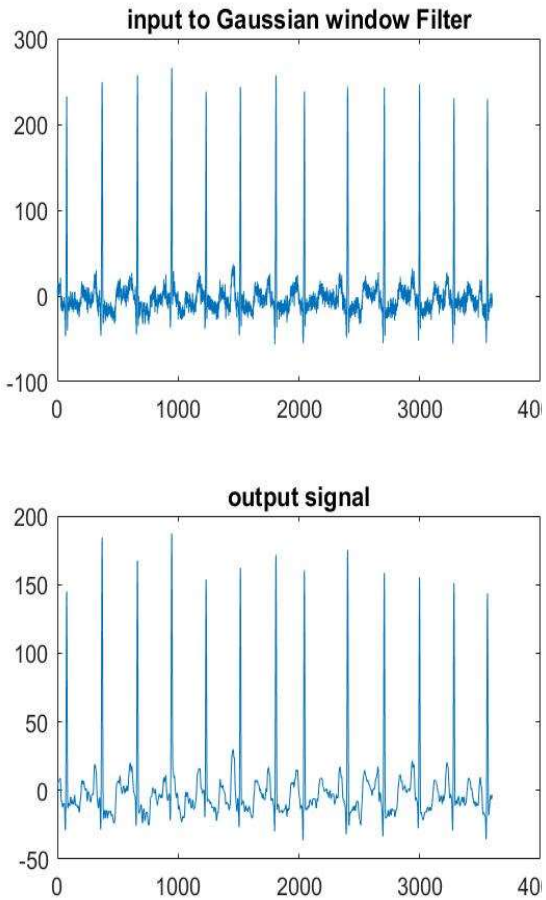

Figure 7: Time domain response of moving weighted window filter

Still some part of the signal is very much distorted because the Gaussian window could not effectively supress the distortion. That's why It is needed to cascade another section of filter which is discussed in the next section.

Smoothing function is done by the next stage.

3.3 Savitzky-Golay Filter

A Savitzky-Golay Filter needs Pre-Determined values of order and frame size for its fabrication. This Method of filtering were proposed by Abraham Savitzky and Marcel J.E.Golay in the year of 1964. This filter aims to provide a generic framework for optimal design filter according to the order and frame size. This method of filtering is carried out on a series of digital datapoints. Lower order polynomial gives better performance than that in the higher order polynomial. The Filtering of signal is based on local least square polynomial approximation. In Lower order the polynomial will be fitted by linear least squares, first of all the change of variable is made

$$z = \frac{x - \bar{x}}{h}$$

Where h is the interval of adjacent datapoints of signal x where $\bar{x}$ is the value of central point. The polynomial of degree k is defined as

$$Y = a_0 + a_1 z + a_2 z^2 \dots + a_k z^k$$

The coefficients a_0, a_1 etc. are obtained by solving the normal equation, in the below given equation a represents a Vector and J represents a matrix.

$$a = (J^T J)^{-1} J^T y$$

or,

$$a = Cy$$

where,

$$C = (J^T J)^{-1} J^T$$

C is called convolution coefficient

In general,

$$(C\Theta y)_j = Y_j = \sum_{i=-\frac{m-1}{2}}^{\frac{m-1}{2}} C_i y_{j+i} \;, \quad \frac{m+1}{2} \le j \le n - \frac{m-1}{2}$$

Following the above equation, the filtering of signal is done. This filtering algorithm is also present for two- dimensional as well as three-dimensional Signal but this paper is about ECG signal so in this paper everything is limited up to One Dimensional Signal.

The performance is evaluated and verified in the software of MATLAB by putting desired order and frame length as an argument to it's own built in function. The Savitzky-Golay filter is the last stage of our proposed design. The figure given below shows the time domain response of Savitzky-Golay filter on the ECG signal whose high frequency noise were majorly removed by the weighted window filter on the second stage.

In this stage we get a completely clean denoised ECG signal. Which goes for pre processing in some other stages for example QRS detection or any other processing purpose. This is the last stage of our proposed system of our ECG denoising.

The time domain response of the Savitzky-Golay filter is shown in the figure below.

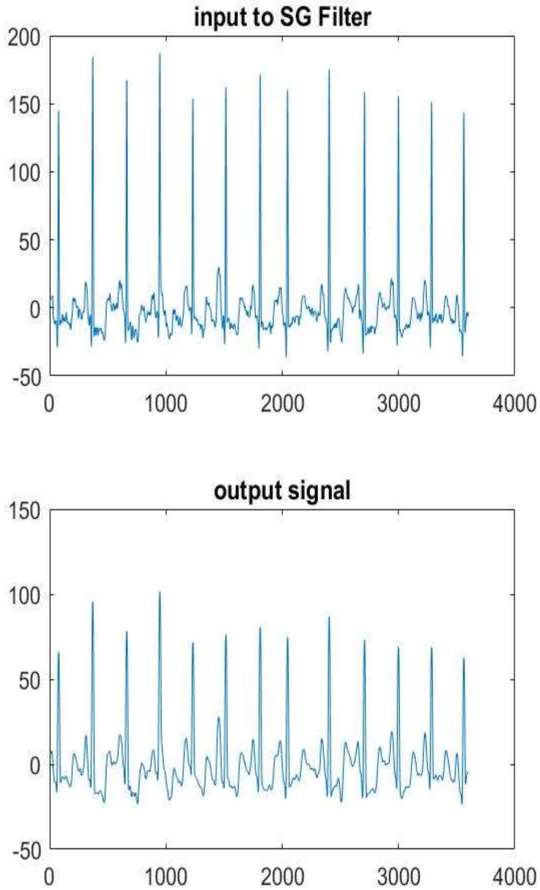

Figure 8: Time domain response of Savitzky-Golay filter on ECG signal.

4. RESULT AND RECOMMENDATION.

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

Now lets talk about that match the result of the match is as shown below.

Table 2:Performance comparison table

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

Index:

HPF: High Pass Filter

WWF: Weighted Window Filter

MF: Median Filter

SG: Savitzky-Golay 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.

The requirements behind making this system that recommended to make this project are:

- High pass filter: Butterworth filter is sufficient for this purpose with cut-off frequency of 0.99Hz with sampling rate of 360 Hz and of order 7.
- Weighted window Filter: Window size of 7 is sufficient. Effective will be using the gaussian window.
- Savitzky-Golay filter: For proper functioning of filter order of polynomial of 0 and frame length of 15

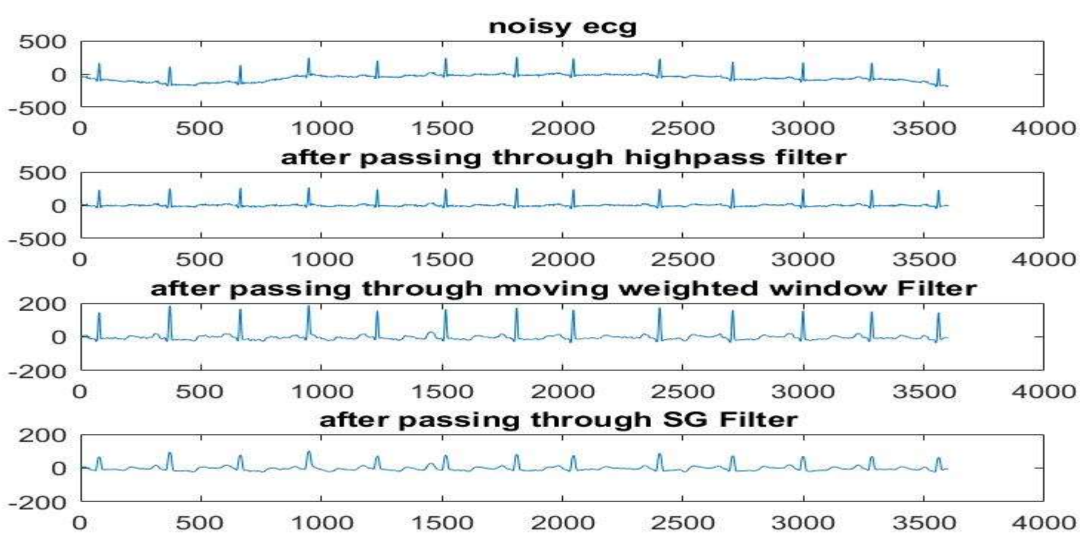

Figure 9:The summarized output

5. LIMITATION

The limitation in this model is that both the operation on Weighted window filter and Savitzky-Golay filter takes signal frame by frame so the operation of the system will be slow.

6.CONCLUSION

Successfully achieved the desired result of getting clean signal within specified parameters, which is obtained after lots of trial and errors.

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