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To Compare Various Filters for Removal of Noise from ECG Wave

Arpit Chitransh[1], Anshul Goyal[2], Krishan Choudhary[3], Pardeep Garg[4]

B.Tech (Student), Department of Electronics and Communications Engineering, Jaypee University of Information Technology, Waknaghat, Solan, Himachal Pradesh, India[1, 2, 3]

Faculty of Engineering, Department of Electronics and Communications Engineering,

Jaypee University of Information Technology, Waknaghat, Solan, Himachal Pradesh, India[4]

Abstract: An ECG or Electrocardiogram is the reflection of the on-going activities of our heart represented graphically. An ECG waveform tries to tell us how the mechanical movements are going on inside the heart and how better they are functioning. ECG is a good tool to analyse the condition of our heart and has a great clinical importance. There exists various types of noise, which here we can say artifacts, affect the quality of an ECG. Here quality refers to the different performance parameters like Signal to Noise Ratio, Mean Square Error etc. This paper deals with the study of various types of noise and applications of various filters and comparing their performance on the basis of these performance metrics. All the results are simulated in Matlab.

Keywords: ECG, Filter, AWGN, SNR, MSE.

I. INTRODUCTION

In this world of technology we have different techniques to deal with different situations and in case of signals we have signal processing. It is an important tool which gives us all the necessary information related to a signal. Therefore it helps us in analysing various aspects related to ECG wave and helps in the advancement of biomedical engineering.

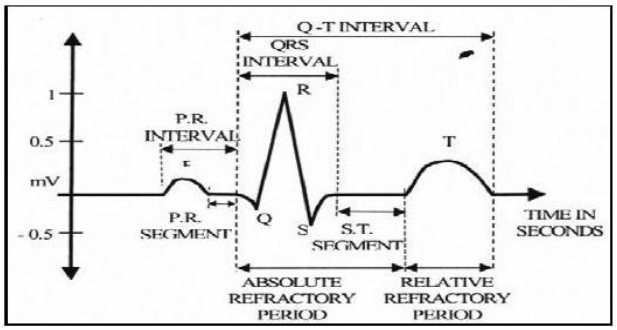

Fig. 1[1] A typical ECG wave

ECG stands for Electrocardiography. An ECG is a periodic waveform which detects electrical activity of our heart graphically[2]. ECG is recorded using ten electrodes placed on patient's body. A single period of waveform represents the flow of blood from heart to arteries which involve contraction and relaxation of atrium and ventricles of our four chambered heart. The ECG has amplitude in range of mV. The range of frequencies of the ECG wave is 0.5-100Hz but frequencies which contains most of the information is from 0.5 to around 50Hz[3].The purpose of doing Electrocardiography is to have information about heart's electrical activity which helps us in detecting any disorders. In heart there exists a SA node (sinoatrial node) which generates an electrical impulse in the right atrium of heart which causes its contraction and the blood is forced to flow to ventricles. This activity is represented by P wave. The time lapse between the flows of blood from atrium to ventricles through valves gives rise to PR interval. Then the QRS complex which represents the condition when ventricles contract themselves and the blood tends to flow from arteries to lungs to get oxygenated. The reason of QRS complex having a higher amplitude is because of purkinje fibers. T wave represents the relaxation of the ventricles. Exactly like this, the process repeats itself resulting in the formation of a periodic ECG wave [1], [4], [5].But ECG wave recorded is a mixture of signal and interference c[6].

II. BLOCK DIAGRAM

The block diagram of the work can be seen in figure given below

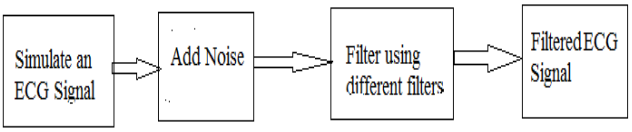

Fig. 2 Block diagram of the work

We are working on both Matlab simulated ECG wave and also on real time data. So Matlab ECG wave is Pure ECG wave which don't have any noise so we added different types of noises such as AWGN, AC interference in it that are actually present in real time ECG wave. Then we pass it through different filters and compare their results. But on real data we directly pass it through different filters as it is already corrupted with noise. And then we pass the noisy ECG wave using various filters. At last we compare various filters using performance parameters such as MSE and SNR.

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III. DIFFERENT TYPES OF ARTIFACTS INVOLVED

Artifacts can be seen as those types of noises whose occurrence is not natural i.e. they are the result of the faults originated artificially. Artifacts are the major cause of false-positive and false-negative interpretations [7]. Artifacts are extremely common and their knowledge is necessary in order to remove them. Thus various artifacts that frequently affect ECG are:

A. Reversed Leads

It is due to the misplacements of the red and white lead cables which results in an ECG waveform as shown below. The placement of each lead at its correct position is very important as any error in placing of lead would give wrong results. It should also be kept in mind that the leads are properly plugged with the machine as it could also be the reason for the existence of this type of noise [8].

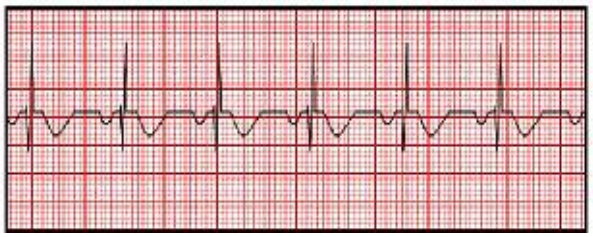

Fig. 3[8] ECG wave corrupted with reversed lead

B. AC Interference

This is the most common artifact that is present in ECG wave. It is due to the interference of power supply. In India we have 50 Hz supply i.e. 50 cycles of sinusoidal wave per second. So this noise occurs due to loose contact with power supply or the poor grounding of the machine giving rise this zigzag pattern having frequency 50Hz [8].

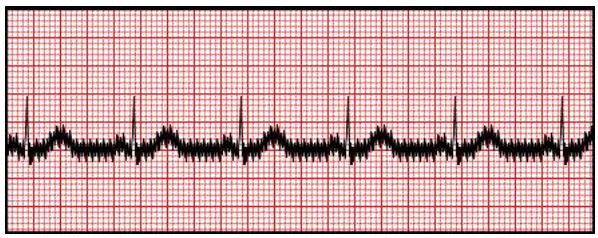

Fig. 4[8]ECG wave corrupted with 50Hz AC interference

C. Muscle Tremor

There are other organs which produce electrical impulses in our body besides from our heart. When the electrical activities of the other organs interfere with the electrical activity of heart we have wave like shown below. This noise is extremely rare and very complex to filter [8].

Fig.5 [8] ECG wave corrupted with muscle tremor

D. Wandering Baseline

Wandering Baseline is the variation in the position of is electric line. Patient movement, dirty lead wires/electrodes, loose electrodes, and a variety of other things can cause this as well [8], [9].

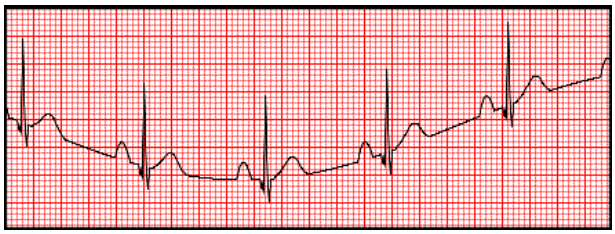

Fig. 6[8] ECG wave corrupted with wandering Baseline

IV. FILTER

In general a filter is a device or process that removes some unwanted components or features from a compound. Similarly in signal processing filter is device or process which removes unwanted signal components from a signal. Filtering belongs to class of signal processing, the defining feature of filters being the complete or partial suppression of some aspect of the signal. It means removing some frequencies and not others in order to suppress interfering signals and reduce background noise. However, filters do not exclusively act in the frequency domain. The response of the filter can be obtained by convolution in time domain but in can be obtained by multiplication in frequency domain. Filter knowledge is necessary in signal processing.

V. PERFORMANCE METRICS

So far we understood what a filter is and what its function is but to compare which filter is doing best we should have some performance parameters. Here we are taking SNR and MSE as performance parameters.

A. SNR

Signal-to-noise ratio (SNR or S/N) is a parameter used in engineering that compares the level of a desired signal to the level of noise. It can be obtained by dividing the signal power by the noise power. It is unit less quantity but often expressed in decibels. SNR higher than 1 or greater than 0 dB indicates more signal power than noise power. A ratio of 1 or 0db means both signal and noise power are equal. Higher the SNR value better is the filter. [10]

$$\mathrm{SNR} = 10 \times \log \frac{\sum_0^{N-1} (\mathrm{Xs(n)})^2}{\sum_0^{N-1} (\mathrm{Xs(n)} - \mathrm{Xr(n)})^2}$$

Where, $X_r(n)$ is the original signal, $X_s(n)$ is the filtered signal and N is the total number of samples.

B. MSE

MSE stands for Mean square error. MSE is the average of the square of the error. Error is simply the difference between what the actual value is and what is estimated. We have to take the mean of the square of all the error values. We want error as minimum as possible. So the

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MSE should be as minimum as possible. Lower the MSE better is the filter [11].

$$\mathrm{MSE} = \frac{\sum_0^{N-1}(\mathrm{Xs(n)} - \mathrm{Xr(n)})^2}{N-1}$$

Where, $X_r(n)$ is the original signal, $X_s(n)$ is the filtered signal and N is the total number of samples.

VI. TREATMENT OF AWGN IN ECG

AWGN stands for Additive white Gaussian Noise. Additive means it is added with the actual signal. White stands for all the frequencies are present in it and Gaussian because noise PDF is Gaussian in shape. AWGN noise is very basic noise and present in most of the signal. So to remove AWGN we have applied four basic filters which are as following:

A. Butterworth Filter
B. Median Filter
C. FIR Filter
D. Savitzky- Golay Filter

VII. RESULTS AND DISCUSSIONS

We have used ECG wave simulated in Matlab. ECG wave is provided as a function in Matlab and added AWGN noise to it which simply gave us the following waves:

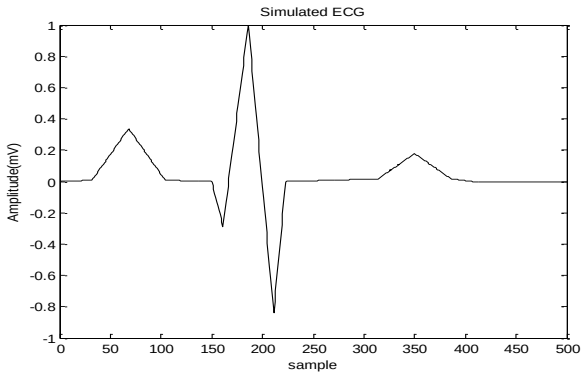

Fig. 7 Simulated ECG wave

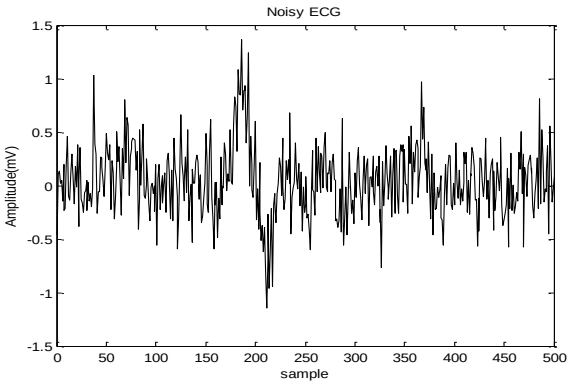

Fig. 8 Noisy ECG

When different types of existing filters are applied on the noisy ECG wave the following outputs are obtained:

A. Butterworth Filter

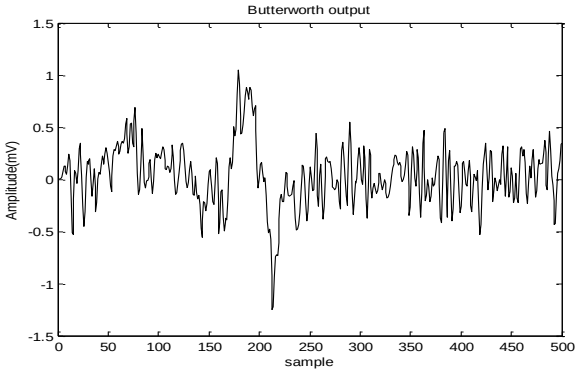

Fig. 9 Filtered ECG using Butterworth Filter

B. Median Filter

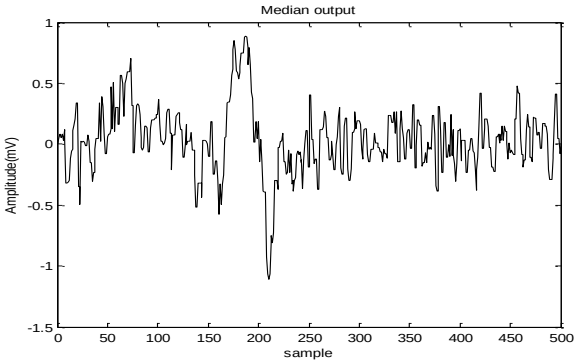

Fig. 10 Filtered ECG using Median Filter

C. FIR Filter

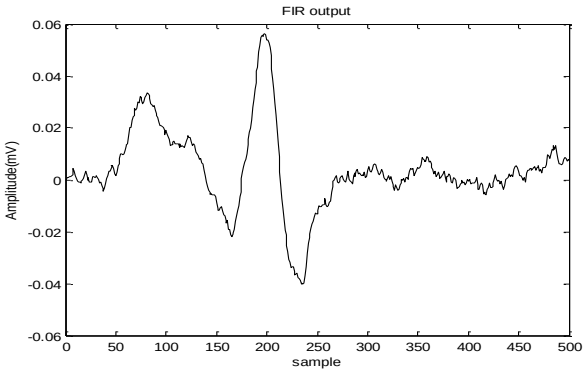

Fig. 11 Filtered ECG using FIR Filter

D. Savitzky-Golay Filter

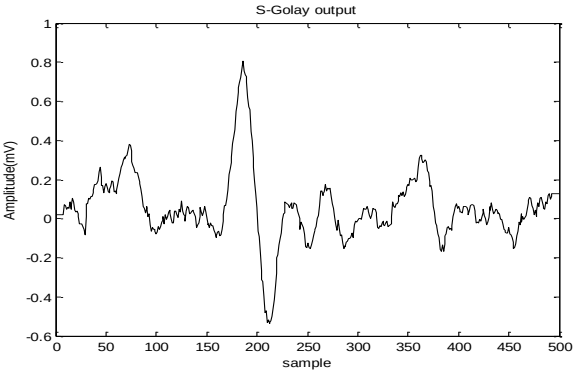

Fig. 12 Filtered ECG using Savitzky-Golay Filter

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From the outputs it is very clear that S. Golay filter is giving some satisfactory results but we can't conclude at this moment. We have analysed performance parameters of all filters will depicts their abilities power of filtering.

Table 1 Comparison Table of Filters for AWGN noise

Filters	SNR Before Filtering(db)	SNR After Filtering(db)	MSE
Butterworth	-2.6156	-0.6713	0.0483
Median	-2.6156	0.3611	0.0381
FIR	-2.6156	0.1377	0.0401
Savitzky-Golay	-2.6156	8.0711	0.0064

Thus as per the table 1 we can clearly see that S. Golay performs the best in terms of both SNR and MSE.

VIII. TREATMENT OF VARIOUS ACTUAL ARTIFACTS IN ECG

A. AC Interference

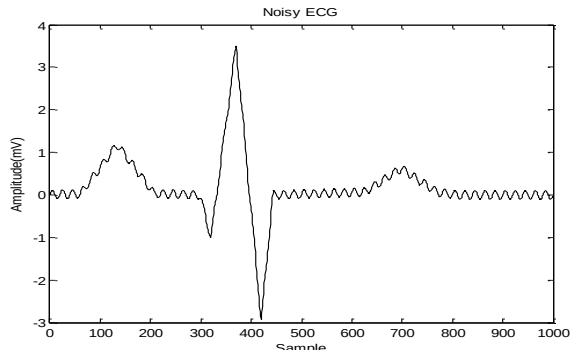

Fig. 13 Noisy ECG wave

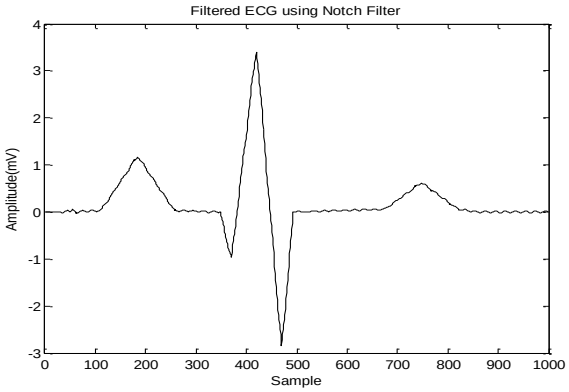

Fig. 12 Filtered ECG using Notch Filter

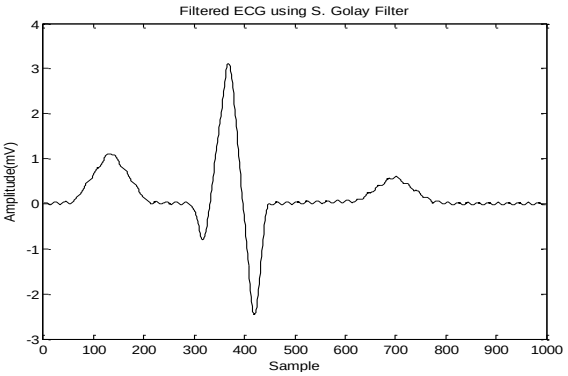

Fig. 13 Filtered ECG using S. Golay Filter

Table 2 Comparison Table of Filters for AC interference

Filters	SNR Before Filtering(db)	SNR After Filtering(db)	MSE
Notch	20.03	23.60	0.0032
Savitzky-Golay	20.03	25.30	0.0021

Thus as per table 2 shown above we can clearly see that for AC interference also Savitzky Golay performs the best in terms of both SNR and MSE.

IX. RESULT OF FILTERING ON DATABASE (AVAILABLE ONLINE)

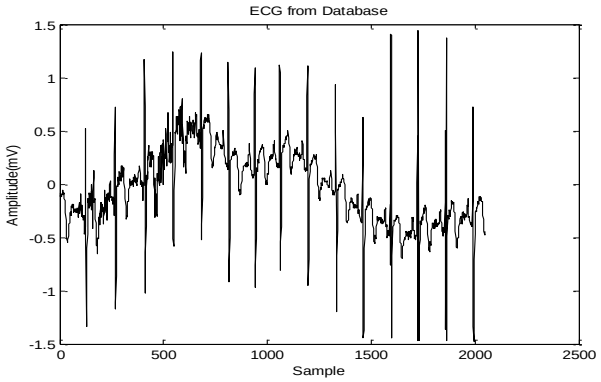

Fig. 14[12]ECG from Database

A. To Remove wandering base line Using S. Golay Filter

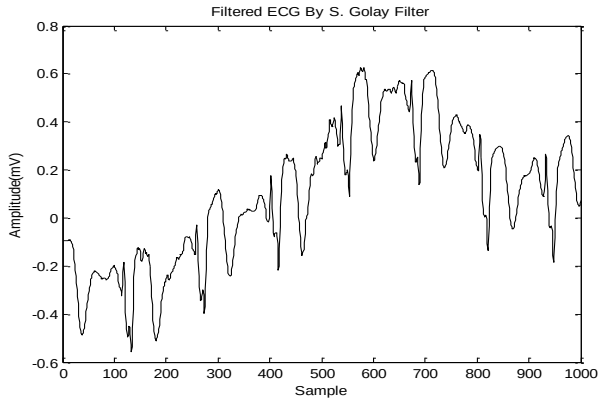

Fig. 15 S-Golay Output

Using Moving Average Filter

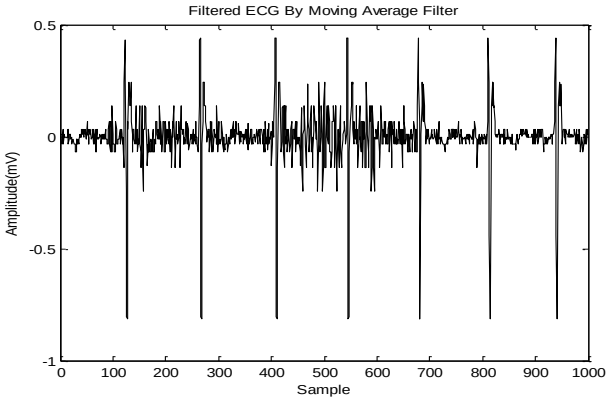

Fig. 16Moving Average Output

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B. To remove AC interference Using Notch Filter

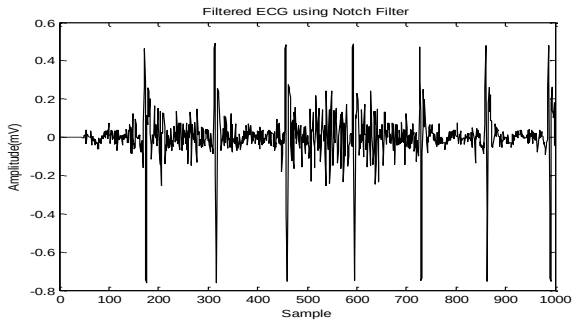

Fig. 17Notch Filter Output

Using S. Golay Filter

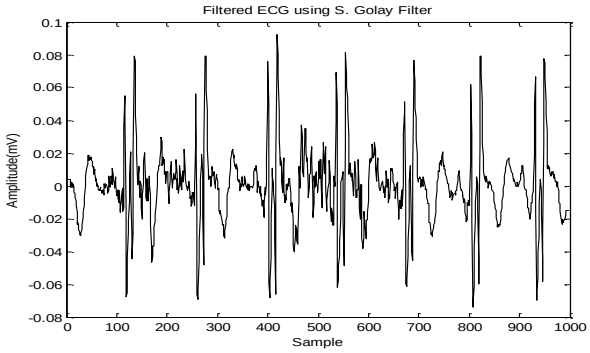

Fig. 18 S. Golay Filter Output

As in real time data we don't what is actual noise present in ECG wave so we are not able to calculate SNR and MSE.By just looking at the waveforms we can make some conclusions. On real time data For baseline wandering we pass it through two filters. First S. Golay because it is doing well in most of the noises but here it didn't work. Secondly we applied moving average filter which actually performed well. For AC interference again we applied S. Golay and Notch filter. But from the graph it looks S. Golay is doing well.

X. CONCLUSION

From all the comparison Tables and graphs we conclude that Savitzky-Golay filter is the best filter for AWGN and AC interference noises. And whereas Moving Average Filter is the best filter for the wandering baseline.

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