ECG signal preprocessing using Savitzky- Golay filter and Moving-average filter

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ABSTRACT

The paper has discussed the various types of biomedical signals and ventured deep into the topic of ECG signal preprocessing. MATLAB software was used for analysis and research work. Explanation of various types of errors while recording ECG is given in the paper. Various methods of removal of errors called as ECG preprocessing has been discussed such as removal of Powerline interference and baseline wander.

Keywords— ECG, preprocessing, Baseline Wander, Filter, Matlab, Sgolay, Smoothening, Powerline interference, Weighted average filter, Fir, Polyval, Polyfit
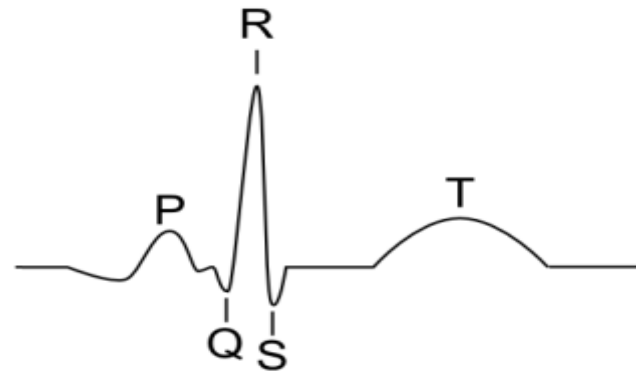
1. INTRODUCTION

ECG or the electrocardiogram signal is the process of recording of electrical activity of the heart over a period of time using electrodes placed on the skin. These electrodes detect tiny electrical changes in the skin that arise from the heart muscle's electrophysiologic pattern of depolarizing and repolarizing during each heartbeat. The etymology of the word is derived from the Greek electro, because it is related to electrical activity, kardio, Greek for the heart.

The ECG signal is used to obtain information about the function of the heart and can be used to detect various heart diseases such as strokes and cardiac arrest.

The different peaks of an ECG signal are used for interpreting various heart features such as heartbeat. The peaks can also help determine various heart diseases the patient is suffering from.

The major two interferences that cause distortions in an ECG signal are powerline interference and baseline wander. The paper has shed light on the above two and software methods of removal of these interferences using MATLAB software.

After removal of the interferences for smoothening of the ECG signal two methods are used that are moving average and Savitzky-Golay filter. After preprocessing we have plotted the QRS complex peaks on the ECG data.

Fig. 1: Basic ECG waveform

2. TYPES OF INTERFERENCES IN AN ECG SIGNAL AND METHOD OF REMOVAL

2.1 Power Line Interference or 50/60 Hz Interference

Modern biomedical amplifiers have a very high common mode rejection ratio. Nevertheless, recordings are often contaminated by residual power-line interference(generally of frequency 50 to 60 Hz). Sometimes the recordings are totally dominated by this interference. Since the heart of a human being beats around the same frequency of 50Hz powerline interference become a big issue because it can completely take over the ECG signal and cause errors in interpretation of the signal.

Fig. 2: ECG corrupted with power line interference

It degrades the signal quantity and disturbs the tiny features that may be crucial for monitoring and diagnosis. Some of the remedial methods include both hardware and software parts. Hardware part can be to ensure that electrodes are applied properly and there are no loose wires, and all components have adequate shielding. This can limit the amount of power line interference or PLI. The software part includes filtering of the 50Hz signal by using digital filters on the ECG signal. This

will completely block the 50Hz signal and thus will help in removing the powerline interference.
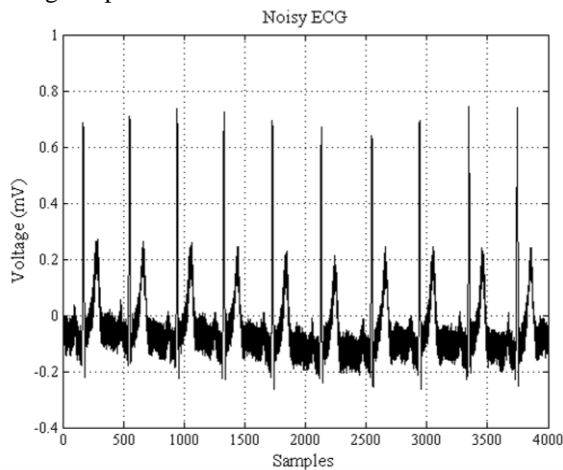

Fig. 3: ECG with power line interference

The above figure shows the noisy ECG signal which contains the 50Hz interference. For experimental needs, a 50Hz noisy sine wave was added to the ECG to demonstrate the filter. To filter this noise, MATLAB command '*fir1*' (Finite Impulse Response) is used which designs an Nth order low pass FIR digital filter and returns the filter coefficients. The input parameters were the order of the filter, the normalized frequency of the filter and a string 'stop' to denote the notch filter to be used. MATLAB command '*filter*' is used on the noisy ECG data to use the filter coefficients on the noisy ECG to filter the 50Hz noise. The results were as shown below:
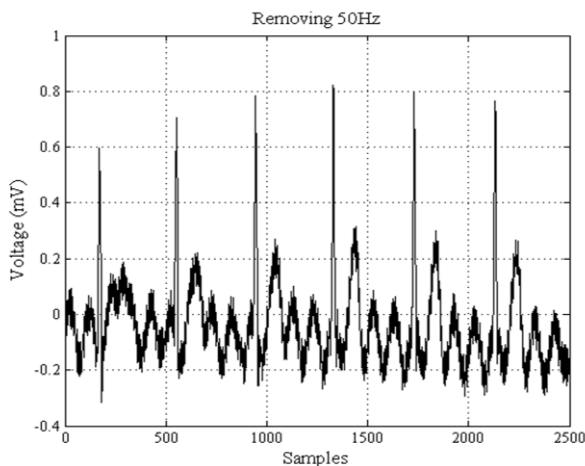

Fig. 4: ECG after removing power line interference

2.2 Baseline Wander
One type of predominant interference in dynamic ECG signals is the baseline wander (BW). By removing baseline wander the ECG becomes easier to read and to extract information from. The baseline wander can be seen in the noisy ECG image. Another example of baseline wander is given in the below diagram:
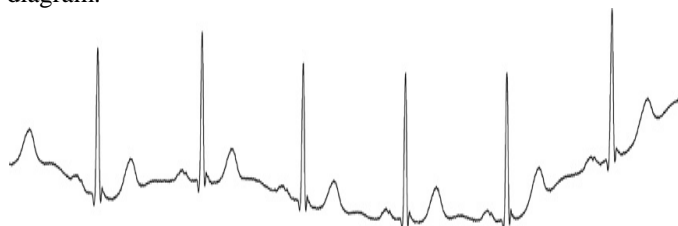

Fig. 5: ECG corrupted with baseline wandering

Variance in electrode-skin impedance and patients' movement and breath are the main reasons of baseline wander. Baseline wander can be removed by using appropriate methods to fit the

ECG polynomial in a single straight line using appropriate MATLAB functions and equations.

To remove baseline wander, MATLAB functions '*polyfit*' and '*polyval*' are used. The prior of which is used to find the coefficients for a polynomial P(X) of degree n that is the best fit (in a least-squares sense) for the data in Y. In this case, least squared sense means in a straight line. It also returns a structure of the function to be used later and the mean and variance of the function to increase the numerical properties of both the polynomial and fitting algorithm. The later command '*polyval*' is used to return the value of a polynomial P evaluated at X. The input arguments for the *polyval* function are the coefficients calculated by the *polyfit* method, the structure calculated by the *polyfit* function and the mean returned by *polyfit*. We then subtract the newly created function of noisy ECG with the old data to get a detrended data. By plotting the ECG after performing the above actions we get the following:
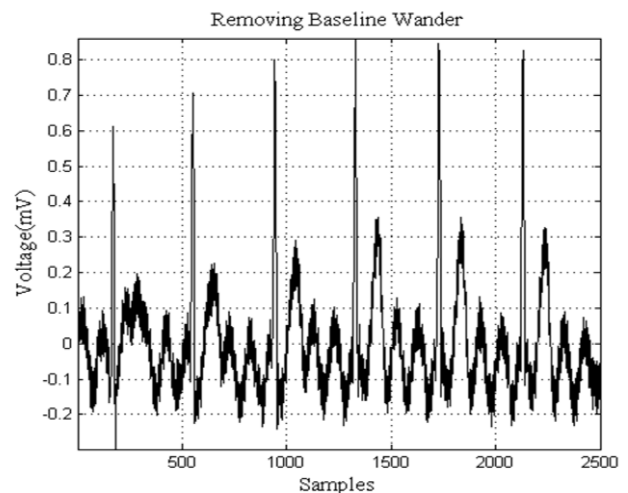

Fig. 6: ECG without baseline wandering

3. FILTERING THE ECG SIGNAL WITHOUT INTERFERENCE
Even after removal of the interferences, one can see that ECG signal is not smooth enough to perform analysis on. ECG smoothening can be done as follows:

3.1 Moving Average Filter
The moving average filter is a simple Low Pass FIR filter commonly used for smoothing an array of sampled data/signal. It takes M samples of input at a time and takes the average of those M-samples and produces a single output point. It is a very simple Low Pass Filter structure that is used to filter unwanted noisy component from the intended data. By increasing the length of this filter, one can increase the smoothness of the filter. For a data, if we want to design a *n*-size filter we use the formula:

$$SMA = \frac{p_M + p_{M-1} + ... + p_{M-(n-1)}}{n}$$

$$= \frac{1}{n}\sum_{i=0}^{n-1} p_{M-i}$$

P_m denotes the value of the function. The mean of the function is taken up to the desired value, added an exact value is replaced by the mean or the SMA (Simple Moving Average) at that point.

So it is clearly observed that there was smoothening of data by using the filter.

3.2 Savitzky-Golay Filter

Savitzky-Golay filter is a digital filter that can be applied to a set of digital data points for the purpose of smoothing the data, that is, to increase the signal-to-noise ratio without greatly distorting the signal. When the data points are equally spaced, an analytical solution to the least-squares equations can be found, in the form of a single set of "convolution coefficients" that can be applied to all data subsets, to give estimates of the smoothed signal, (or derivatives of the smoothed signal) at the central point of each sub-set. The method, based on established mathematical procedures [1][2] was popularized by Abraham Savitzky and Marcel J. E. Golay.

$$g_i = \sum_{n=-n_L}^{nR} C_n f_{i+n}$$

Here n_L is the number of points used "to the left" of a data point i, that is earlier than it, while nR is the number used to the right, that is, later.

4. RESULTS

In this section, the proposed Savitzky-Golay filter and Moving average filter will be used to smoothen the noisy ECG signal without interference followed by plotting the QRS complex of ECG signal. For moving-average in MATLAB smoothening of the ECG signal is done and the result is as shown:
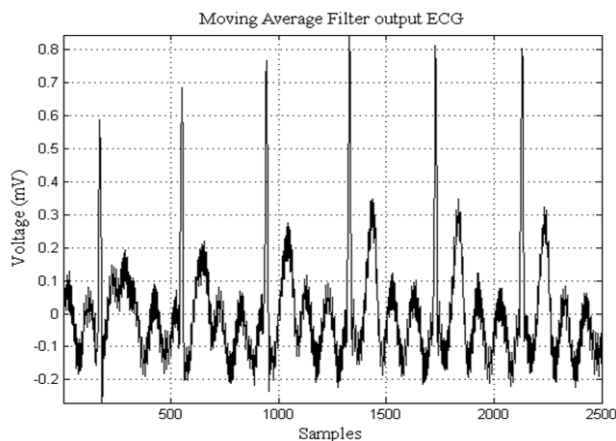

Fig. 7: Noisy ECG after passing through the Moving-average filter

For Savitzky-Golay filter, MATLAB the function '***sgolayfil***' is used to smooth any given signal. The input arguments for the same are the input signal, the order of filter which has to be an odd number due to properties of the Savitzky-Golay filter and the frame length of the filter. By increasing the filter length we can increase the smoothening of the signal. The observed results are as follows:
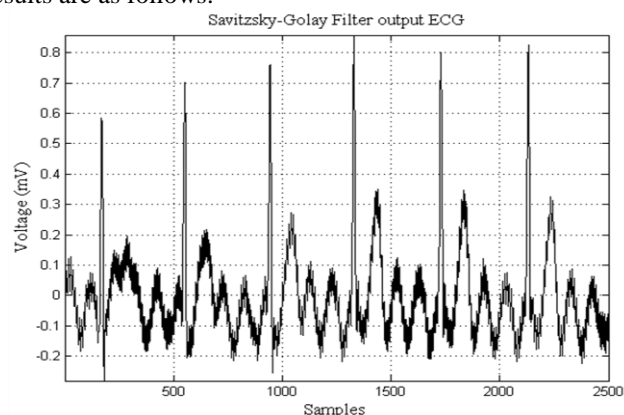

Fig. 8: Noisy ECG after passing through Savitzky-Golay filter

The next point is to mark the QRS complex peaks in the filtered and smooth ECG signal. To find the R peak the

function '***find peaks***' is used, which take the input signal, the min peak height and the min peak width between the two peaks and plot the R peaks. To plot the S peak similar method is used, only the signal is inverted before applying the find peaks function. For finding, Q peaks *find peaks* are used and then the peaks are filtered which satisfy the conditions of a Q peak. The result is as shown:
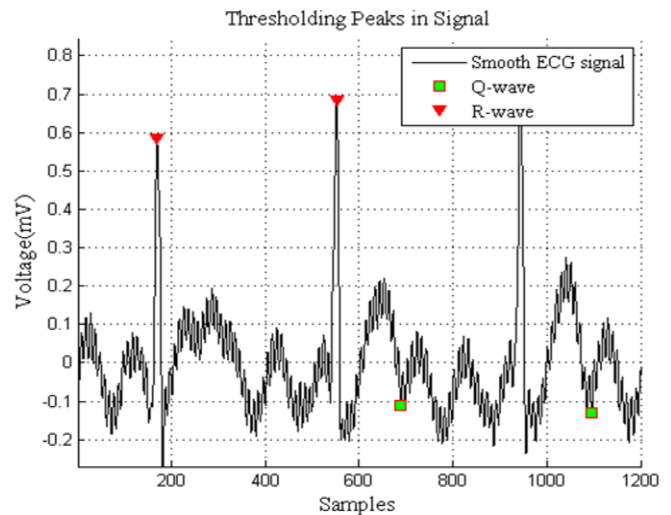

Fig. 9: A QRS complex of ECG

Due to the similar height of the third and fourth peak, the function marked both of them as Q waves even though they are not.

5. CONCLUSION

This paper presents a technique to preprocess the ECG signal using a Savitzky-Golay filter and Moving average filter which is used for smoothening the data by increasing the signal-to-noise ratio. It was demonstrated that the proposed Savitzky-Golay filtering algorithm achieved better smoothening as compared to the Moving-average filter. Simulation results show that the technique proposed in this paper can improve the preprocessing of the ECG signal. The results of simulations and the quantitative evaluation prove that the Savitzky-Golay filter and Moving-average filter are smoothening the signal.

6. REFERENCES

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