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A Recursive Trim-Mean Filter for Denoising Biological Signals

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Abstract: To address the inadequacies of the mean and the α-trim mean filter, we introduce a class of non-linear filters that are a variation of the existing filters. The proposed filters use the concepts of recursion and trimming of extremities to give a better SNR and RMSE performance and are more effective in denoising Biological signals, when compared to the conventional ones. The filters are simulated with ECG signals added with standard Gaussian Noise using MATLAB.

Key-words: α-trim filter, recursion, mean filter, order statistics, SNR, RMSE.

1 Introduction

Biological signals are electrical signals generated by biological activity in the human body. Of these, the Electrocardiogram (ECG), which describes the activity of the heart, is a useful non-invasive diagnostic tool. The ECG signal obtained is not always free from noise. Hence recovering the ECG signal from the noisy environment is a crucial activity for efficient diagnosis. This can be accomplished by using various filtering techniques. For effective denoising, the filter used,

- must enhance SNR and reduce MSE.
- should preserve the peaks and transitions of the PQRST waveform of the ECG.

The digital filters used for denoising Biological signals are either linear or non-linear. A linear filter applies a linear operator to a time-varying input signal, which satisfies both the superposition and proportionality principles. Linear filters were easy to design and implement. However, they cannot be used in cases where system non-linearities are present. Hence non-linear filtering techniques were considered since 1958 [1]. A non-linear filter is a signal-processing module whose output is not a linear function of its input. One of the popular families of non-linear filters that are used for noise removal is the order statistic filters. The other filters that are used for this purpose are the α-trim mean filter, geometric mean filter, harmonic mean filter and the L-filters [2,3].

The arithmetic mean filter is the average of the input samples of a particular window size. There are many types of non-linear mean filters that are used in practice [4]. Some of them are discussed below; the geometric mean of a set of positive data is defined as the product of all the members of the set, raised to a power equal to the reciprocal of the number of members. The geometric mean of a data set is always smaller than or equal to the set's arithmetic mean (the two means are equal if and only if all members of the data set are equal). The arithmetic mean of the reciprocals of a specified set of numbers gives the reciprocal of the harmonic mean. The harmonic mean is never larger than the geometric mean or the arithmetic mean.

Median filters were first introduced by Tukey in 1971 and has been used extensively for noise reduction. The generalization of the median filter is the order statistic filter, which was introduced by Bovik, Huang and Munson [5]. A modification of the median filter is the recursive median filter. A recursive filter is one, which in addition to input values also uses previous output values for determining the present output [6].
An important filter obtained from the family of L-filters is the α-trim mean filter [7] The α-trim mean of data samples is obtained by sorting the samples into ascending order, removing (trimming) a fixed fraction alpha ($0 \le \alpha \le 0.5$) from the high and low ends of the sorted set, and computing the mean of the remaining values. [8,9] When applied to a sliding window of length *n*, the α-trimming process is called α-trim filtering.

Section 2 gives an account of the proposed mean filters, with Section 2.1 explaining the trim-mean filter and 2.2 elucidating on the recursive trim-mean filter. Section 3 illustrates the results obtained and enables a comparison of the proposed filters with the existing ones.

2 Proposed Mean Filters

2.1. Trim-Mean Filter

This filter has been developed by incorporating the properties of trimming into the process of mean filtering. Trimming involves the removal of extreme values from the input data set before the actual filtering. This filter is found to give a very good SNR and RMSE value when compared to the α-trim mean filter that is currently in use. The general algorithm for this filter is explained below.

$$y(i) = f(trim(sort(x(i-v)....x(i+v))))$$

Algorithm:

1. The input values are obtained.
2. The extremities of the ordered samples of the input are trimmed.
3. Mean filtering is used on the resultant samples to produce the output.

2.2. Recursive Trim-Mean Filter

This filter is a new variant of mean filter, which utilizes the properties of trimming along with recursion to yield better stability. A recursive filter is one, which uses the values of the previous outputs to calculate the output of the present output. This filter is found to give a good SNR and RMSE performance particularly at high noise levels. For comparison, a recursive α-trim filter is evaluated against the conventional α-trim filter. The general algorithm for this filter is explained below.

$$y(i) = f(trim\ (sort\ (x(i-v)....\ x(i+v))))$$

Algorithm:

1. The input values are obtained.
2. The extremities of the ordered samples of the input are trimmed.
3. Recursion is employed into the signal while filtering it through the mean filter to produce the output.

3 Results and Analysis

To analyze the performance of the filters, the ECG signal [9] and a Gaussian noise have been used and the simulation is done in MATLAB. Different levels of noise are obtained with reference to the amplitude of the ECG signal. The signal is then added with the noise levels and the filtering action of the various filters is evaluated and compared.

The SNR values illustrated in fig.1 exemplifies the performance of our proposed mean filters against the existing mean and alpha trim-mean filters. The proposed filters apart from showing very high values of SNR at low noise levels, also recovers the signal without any loss at considerable noise levels. It is to be noticed from the chart that the recursive filters perform well under cases of high noise corruptions.

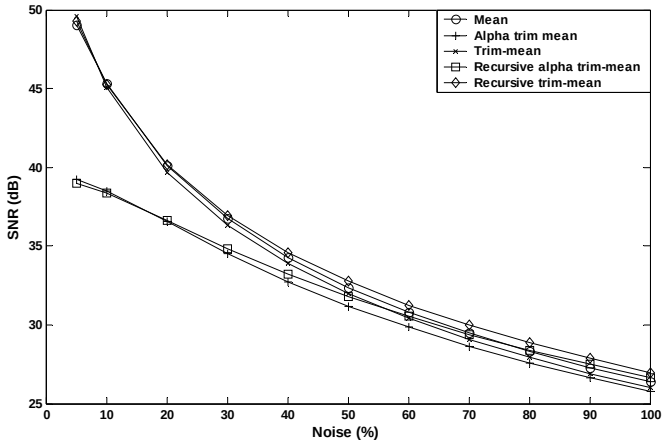

Fig.1 SNR (dB) vs. Noise percentage (%)

The *Root Mean Square Error* (RMSE) is a parameter, which signifies the level of reconstruction of the input signal. A low value of this error i.e. difference between input and output signal indicates good performance of the filter. From fig.2 we infer that this error is low for recursive trimmed mean filters compared with the rest.

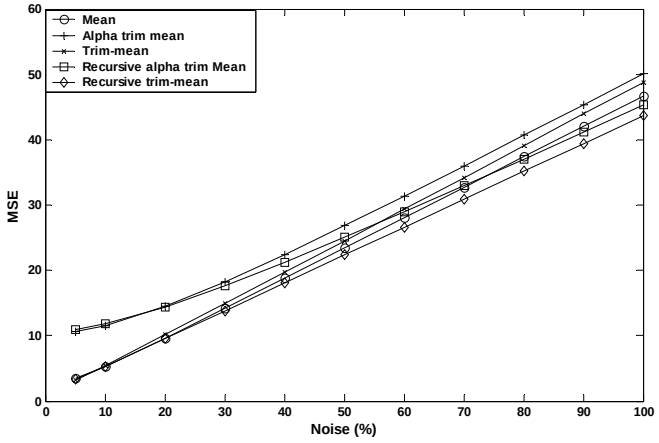

Fig.2 RMSE vs. Noise percentage (%)

The superior functioning of the recursive trim-mean filters is evident from fig.3. The outputs obtained are for 15 percent of Gaussian noise normalized with respect to the amplitude of the signal. The denoised outputs of the mean filter and the conventional α-trim mean filter are almost similar, while the trim-mean filter produces a slightly better output waveform. A significant improvement in denoising is displayed by the recursive trim-mean filter and the recursive α-trim mean filter.

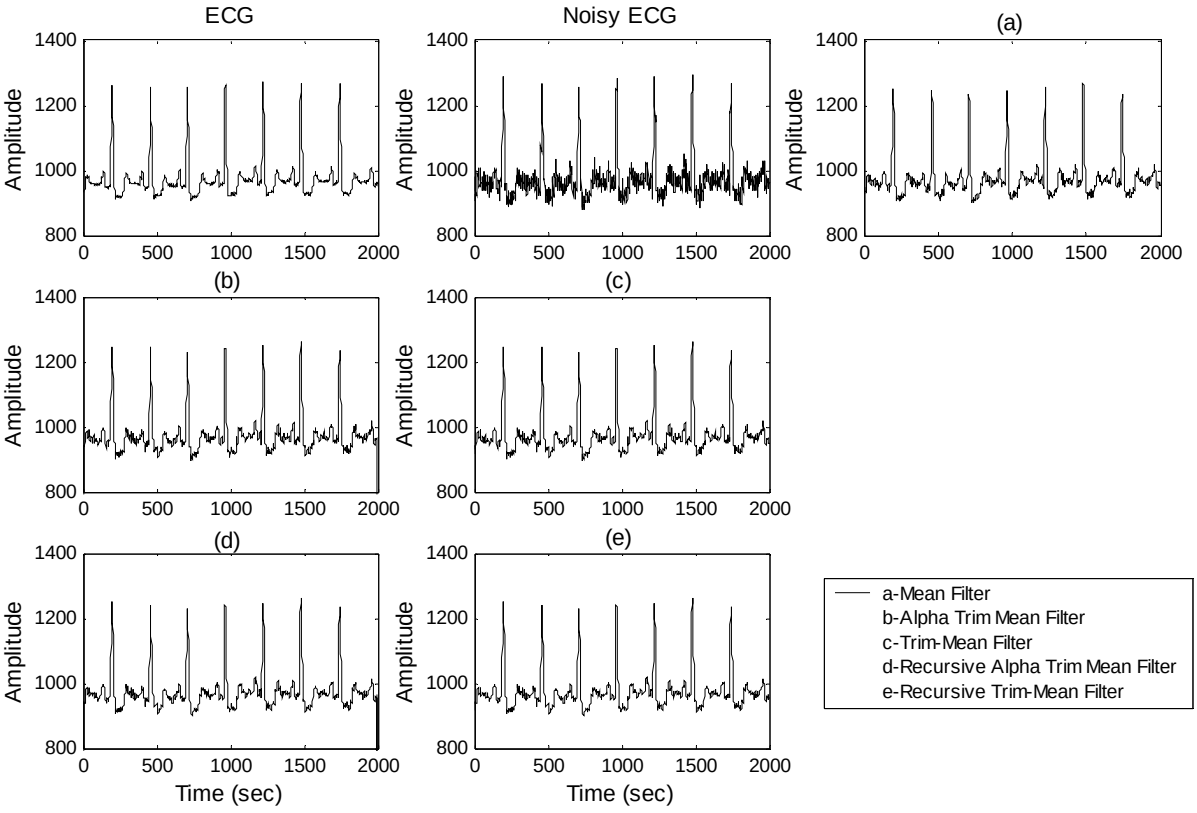

Fig.3 Denoised ECG signals of various mean filters

4 Conclusions

The proposed mean filters are found to yield better values of SNR and RMSE when compared to the conventional mean filters. This improvement in the filter performance would aid an efficient denoising of the biological signals, which would in turn enable a better diagnosis.

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