ECG DENOISING USING MODIFIED NON LOCAL MEANS ALGORITHM

PHARVESH SALMAN CHAUDHARY
Department of Electronics and Communication, Tezpur University, Naapam Tezpur, Assam, India
parvezsalmangmail.com

SATYABRAT MALLA BUJARBARUAH
Department of Electronics and Communication, Tezpur University, Naapam Tezpur, Assam, India
baruah.satyabrat@gmail.com

SOUMIK ROY
Associate Professor, Department of Electronics and Communication, Tezpur University, Naapam,
Tezpur, Assam, India xoumik@tezu.ernet.in

Abstract : Denoising of the raw signal while keeping the relevant information is one of the important issues in the domain of Electrocardiogram (ECG) analysis. Removal of noise from the desired cardiac signal by using standard filter tends to corrupt the signal of interest. The method proposed in this work is based on a modified version of the Non-Local Means algorithm. NLM algorithm has widely been used for 2D signal processing but has received little significance in 1D signal analysis. The work is done on a modified form of conventional NLM filter is used to denoise raw ECG signal by optimizing the parameters of filter, further a comparison is made between the results of conventional and modified NLM filter.

Keywords : Electrocardiogram; Nonlocal means; Denoising;

1. Introduction

One of the important aspects of physiological signal processing is the removal of noise and artifacts from the raw signal. The sources of noise in these signals are muscle artifacts, baseline drift, additive high frequency noise etc. Several methods are available for removing these noises from the raw physiological signal but the conventional filtering methods tend to deform the original signal, thereby decreasing the integrity of the information contained in the signal. This is particularly true for ECG signals, as certain features might be lost if proper filtering is not performed. This work focuses on denoising of ECG signal using an approach based on the method originally introduced by Buades et al. [2] but with specific adaptation to 1D signal processing.

The Non Local Means algorithm, a patch based method of image denoising is widely used for 2D signals, but its use for 1D signals is recently getting attention. A modified form of NLM algorithm is proposed for denoising raw ECG signal. The NLM based method involves comparing a selected patch of the signal within a neighborhood signal window for similarity and then the filtering is performed based on the weights of the similarity. Since the basic structure of ECG keeps on repeating after a certain interval with slight variations, patch based denoising method such as NLM filter is expected to give good results. The work also presents the shortcoming of the conventional NLM filter and the rectification which can be done by using a modified form of the conventional filter.

The text is structured as follows: Section 2, presents an overview of the Non Local means algorithm and the modifications done in the modified Non Local means algorithm. Section 3, briefly describes the ECG signal and denoising performed using the modified NLM filter. Section 4 shows the result of the analysis and the comparison of the results of both modified and the conventional filters.

2. Nonlocal means Algorithm

2.1. Basic nonlocal means algorithm

To fix the problems associated with local smoothing filters, nonlocal means filter was developed. NLM algorithm is based on the natural redundancy of information in images to remove noise. Depending on the fact that natural images often contain repeated patterns, NLM denoises the image by computing the average of patches from different regions of the image which having similar spatial structure. As proposed by Buades[2], given a noisy signal \( v(i) = u(i) + n(i) \), where \( u \) is the true signal and \( n \) is noise perturbation, its estimated values can be computed as weighted average of all pixels in the image. Considering \( \Delta \) as area of image, and \( p \) and \( q \) as two points within the image, then the algorithm is

\[
u(p) = \frac{1}{z(p)} \int_\Delta v(q)f(p,q)dq \tag{1}\]
Where \( u(p) \) is the filtered value of the image at point \( p \) 
\[ v(q) \] is the unfiltered value of the image at point \( q \) 
\[ Z(p) \] is the normalizing factor given by: 
\[ Z(p) = \int_{\Delta} f(p,q) dq \] 
\[ f(p,q) \] is the weighting function: 
\[ \exp\left(-\frac{|B(q)-B(p)|^2}{h^2}\right) \] 
\[ B(p) = \frac{1}{R(p)} \sum_{l \in R(p)} v(l) \] , where \( R(p) \subseteq \Delta \) and is a square region of pixels surrounding \( p \).

In eq.(2) \( h \) acts as the degree of filtering. It controls the decay of the exponential function and therefore the decay of the weight as a function of Euclidean distance. The above algorithm means that the denoised value at \( p \) is a mean of values of all points whose Gaussian neighborhood is similar to that of \( p \). The NLM filter not only compares the level in a single point but the geometrical configuration with similar gray value in a whole neighborhood. This fact allows a more robust comparison than neighborhood filters.

### 2.2 Modified Nonlocal Means algorithm

Even though there have been improvements in quality, but the computation cost is high. Also, the similarity of patches is only translation invariants. In other words, we can only match patches that are simply in different locations, but the orientation and scale unchanged. In 2010, Chen [5] proposed a modification in Nonlocal means algorithm, they modified the work factor by integrating the spatial distance into the existing weight factor. Instead of simply replacing the pixel value by a weighted average of pixels in their neighborhood, the improved NLM algorithm replaces the pixel value by a weight average of pixels selected using self similarity and spatial distance to achieve a texture preserving result. The Modified NLM filter is given as

\[ u(p) = \frac{1}{Z(p)} \int_{\Delta} v(q) f(p,q) g(p,q) dq \]  

Where \( g(p,q) \) is the additional weight factor giving the weight average of pixels.

\[ g(p,q) = \exp\left(-\frac{|B(q)-B(p)|^2}{h^2}\right) \] 

and, 

\[ f(p,q) = \exp\left(-\frac{|B(q)-B(p)|^2}{h_f^2}\right) \]

where \( B(q) \) is the image patch centered at spatial point \( q \). \( h_g \) and \( h_f \) controls the weight in spatial and intensity domains respectively. The weight of the average \( (h_f) \) increases as the pixel similarity around point \( p \) with respect to point \( q \) increases. Similarly as the distance between the point \( p \) and \( q \) increases, spatial weight \( (h_g) \) between the points decreases.

It can be observed from eq. 3 that the modified NLM filter is a hybrid of bilateral filter [2] and the classical NML filter. when \( h_f = \infty \), the modified NLM filter behaves as bilateral filter. Similarly when \( h_g = \infty \), the modified NML filter behaves as classical NML filter. Therefore, the modified NML filter takes advantage of both the filter. The NML filter approximates the true signal at the cost of image blurring and the bilateral filter preserves the edges from over smoothing.

### 3. ECG denoising using modified NLM filter

The electrocardiogram refers to a clinical test that gives information about different heart conditions by measuring the electrical activity of the heart. It involves positioning of electrodes on the body of subject in certain standard locations. An ECG waveform typically comprises of a P-wave which is a low voltage fluctuation caused by the depolarization of the atria prior to contraction, followed by the ‘QRS’ complex which is caused by the ventricular depolarization and then the T-wave which is caused by ventricular repolarization. A typical ECG waveform is shown below.
Despite of advances in the field of biomedical engineering, the extraction of high resolution cardiac signal from the noisy raw ECG signal remains a challenge. Due to presence of inevitable noises certain weak signal components of ECG are lost. The sources of noise typically include Electromyographic (EMG) noise, which is due to contraction of the muscles near the heart, instrumentation noise from the ECG measuring equipments, motion artifacts due to movement of electrodes etc. Conventional filtering techniques are of little or of no significance in case of physiological signals such as ECG, due to the fact that certain signal components gets corrupted and many finer details either lost. In some cases standard filtering technique can also adversely affect the cardiac signal of choice such as in case of low-pass filtering which suppress high-frequency noise but also distorts waveform spikes ECG signal [7].

The NLM filter, described in section 2, performs the denoising of the raw signal by taking the average of patches from different regions having similar spatial structure. Physiological signals such as ECG has a regular repeating structure with slight variations, therefore NLM filter can be used for the denoising of ECG signal. While performing denoising of the raw ECG with conventional NLM filter as described in section 2.1, eq. 1 it was found that the high frequency desired signal content was lost and there was over smoothing of the peaks which was due to the fact that conventional NLM filter behaves as Gaussian low pass filter which removes high frequency content of the signal including finer details of the signal components of higher frequency which are desired, moreover it was found that the morphological behavior of the ECG was altered by the conventional NLM filter as segmentation result of QRS complex was erroneous. The morphological properties of S wave was made similar to the Q wave, the segmentation algorithm was unable to differentiate between the Q and S wave of the ECG.

To overcome the problems associated with the conventional NLM filter the modified version as described in section 2.2 by eq.3 is used. The modified NLM filter was able to preserve the fine peaks of the ECG signals, which were getting corrupted by using the conventional algorithm and also the morphological properties of different waves in the ECG were unaltered, which can be seen from the result of the segmentation algorithm.

4. Result and Discussion

The data used for simulations is taken from the Physionet MIT-BIH arrhythmia database. The simulations were carried out using MATLAB. The raw ECG was fed to both conventional and modified NLM filters and the results and waveforms are compared.
The Raw ECG Signal as shown in the figure 2, was fed to the conventional NLM filter, whose response is shown in figure 3. The response of Modified NLM filter for the same raw ECG signal is shown in figure 4. The pattern window size of 19 samples was used and the neighborhood window size was set to 55 samples and the filtering parameter $h_f$ was set to 0.1 for both conventional and modified NLM filters. The filtering parameter $h_g$ for the modified NLM filter was set to 10. Both the filters were able to remove substantial amount of noise from the noisy ECG signal but by comparing the responses of both the filter it can be noted that there have been over smoothing of the signal in $s$ wave region in case of conventional NLM filter, which has made the $s$ wave to be in the same level as of the $q$ wave. Therefore, segmentation of $Q$ and $S$ wave from the data of conventional NLM filter will be erroneous. The morphological error of the conventional NLM filter was eliminated by the use of modified NLM filter, as it has faithfully preserved the structure of the $S$ wave. Following are the results of the segmentation algorithm performed on the outputs of both conventional and modified NLM filter for $Q$ and $S$ wave segmentation.
Fig 6: segmentation of QRS waves on the ECG signal filtered with modified NLM filter

5. Conclusion

The paper presented a patch based denoising algorithm which is extensively used for image processing to denoise ECG signal. The results showed a significant reduction of noise without any distortion in the true signal, validating the use of NLM filter on a single dimensional signal. Limitations of the conventional method were analyzed, which was redressed by the modified method of the algorithm. The overall result of the modified NLM filter on ECG signal was found promising and its use can also be extended to other physiological signal.

References


