ISSN No. 0976-5697

Volume 4, No. 4, March-April 2013

International Journal of Advanced Research in Computer Science

RESEARCH PAPER

Available Online at www.ijarcs.info

De-noising of Functional Magnetic Resonance Imaging (fMRI) data using Nonlinear Anisotropic 1D and 2D filters

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Abstract: Functional magnetic resonance imaging (fMRI) is a noninvasive technique used for measuring the functionality of the human brain. Functional MR data suffers from low SNR due to Rician noise. Since this noise is multiplicative in nature which makes further processing of the data a challenging job. A number of conventional filters have been used for de-noising this low SNR data. In this work nonlinear anisotropic 1D and 2D filters are applied to simulated and actual fMRI data. A hybrid filter which consists of serial filtering by 1D and 2D filters is proposed in this work. Correlation results of the proposed filtered data show that its performance is better in terms of correlation from 1D and 2D filters.

Keyword: fMRI de-noising, Rician noise, Anisotropic filters

I. INTRODUCTION

Human brain functionality can be measured using different techniques like EEG (Electroencephalography), MEG , (Magnetoencephalography) and fMRI. fMRI is the most latest and noninvasive technique used for detecting functionally active voxels responsible for some physical or mental activity [1]. During fMRI experiment subjects are asked to perform some activity followed by some rest. This rest and activity cycles are repeated many times. Blood Oxygen Level dependent (BOLD) signal generated by each brain voxel is recorded by fMRI scanner. The real and imaginary parts of this data suffer from AWGN having equal variance [2,3]. This noise become Rician noise when this complex data is transformed into the magnitude signal [4,5,6].

Due to this inherent noise fMRI data suffers from low SNR. Furthermore nature of noise is not additive or AWGN which can be handled easily. In this case the nature of noise is multiplicative and thus it is a challenging job to de-noise fMRI data suffering from Rician noise. One of the conventional filters used for de-noising fMRI data is Gaussian filtering in which adaptive kernel size is required for different active regions [7]. Fixed kernel based Gaussian filtering make the data blurred and thus further reduce the quality which is not appropriate for further processing of the data [8]. In case of spatial averaging fine details of the image data are lost. This drawback of spatial averaging filter can be minimized by nonlinear filtering in which the most well known is the median filter [9].

Since medical imaging data contain patients diagnostic information, therefore it is the requirement of the filter that it should not produce blurring, and image degradation.

Other well-known techniques which are also used for fMRI data de-noising like temporal correlation based spatial filtering [10], anisotropic spatial averaging [11], wavelet based de-noising [12] and spectral subtraction [13] etc.

In this work we have suggested to use 1D and 2D anisotropoic filters developed by perona and Malik [14]. Perona and Malik have developed these filters for multi scale image smoothing and edge detection. Their proposed filters 1D and 2D have been used for general image de-noising and MR images as well [9]. Furthermore, in this work 1D and 2D filters are searialy used for fMRI data de-noising which makes the de-noising process more promising.

Remaining paper is organized as follows. Section 2 elaborates the model of anisoptropic filter while section 3 explains synthesizing of simulated fMRI data and actual fMRI data details. Section 4 explains performance results of the proposed hybrid anisotropic filter. Section 5 concludes the results.

II. PROPOSED TECHNIQUE

Anisotropic filtering technique was initially proposed by Perona and Malik [14]. Its mathematical model is inspired from diffusion process. Anisotropic process also considers intra-region smoothing and edge preserving details. It also considers local image structures keeping in view the statistics about the image noise level and edge strength details. Mathematical model of anisotropic filter proposed by [14] is as under.

A. *Mathematical Model of anisotropic filter:*

This section summarizes the mathematical model of nonlinear anisotropic filter.

Following mathematical model is a summary of the proposed method being based on [9] and [14]. The algorithm can best be modeled by equation (1) in which $m(i,j,t)$ is the filtered image, $d(i,j,t)$ is the diffusion function, $\nabla m(i,j,t)$ is the gradient of the image intensity and t is scaling factor which normally known as iteration step in case of its discrete implementation.

$$\frac{\partial}{\partial t} m(i,j,t) = div[d(i,j,t)\nabla m(i,\vec{j},t)] \quad (1)$$

The diffusion function $d(i,j,t)$ depends on the magnitude of the image intensity. It is generally a decreasing function represented by the equation (2).

$$d(i,j,t) = f(|\nabla m(i,j,t)|) \quad (2)$$

Two different diffusion functions have been suggested by [9], [14] and are shown here by equation (3) and (4).

$$d_1(i,j,t) = \exp[-(\frac{|\nabla m(i,j,t)|}{k})^2] \quad (3)$$

And

$$d_2(i,j,t) = 1 + (\frac{|\nabla m(i,j,t)|}{k})^{-(1+\alpha)} \quad (4)$$

Where α is >0.

The value of K is dependent on noise intensity and edge strength.

Further details of the mathematical model can be found in [9] and [14].

III. DATA

For fMRI data generally no ground truth is available which can be used for comparison of the achieved results. For this purpose simulated fMRI like data is synthesized and used for testing the validity of the proposed method. If the results on simulated data are satisfactory then the proposed technique is also considered as a valid for actual fMRI data. Here in this work we are first implementing our proposed algorithm on simulated fMRI like data so that the validity and quality of the filtered/ de-noised data can be checked. Simulated fMRI like data is freely available on the internet [15].

A. *Simulated fMRI like data:*

Simulated fMRI like data developed by [15] consists of eight sources and corresponding time courses as shown in Figure 1. These sources consist of Gaussian, sub Gaussian and super Gaussian sources. Corresponding time courses are also shown in front of each source. Each source image consists of 60X60 image . All images are concatenated in column matrices and then multiplied by the time series thus forming a mixture of images consisting of 100 images. Mixture image data is shown in Figure 2.

Since these images are simulated therefore, they are noise free. However for testing the validity of the proposed de-noising we need noisy data. For this purpose simulated data is corrupted by Rician noise with known noise levels.

Equation (5) is used for introducing noise in the simulated fMRI data.

$$\text{Noisy image} = \sqrt{a^2 + b^2} \quad (5)$$

Where

$$a = S.rand(n) + image$$

$$b = S.rand(n) \quad (6)$$

S controls the noise level in the image.

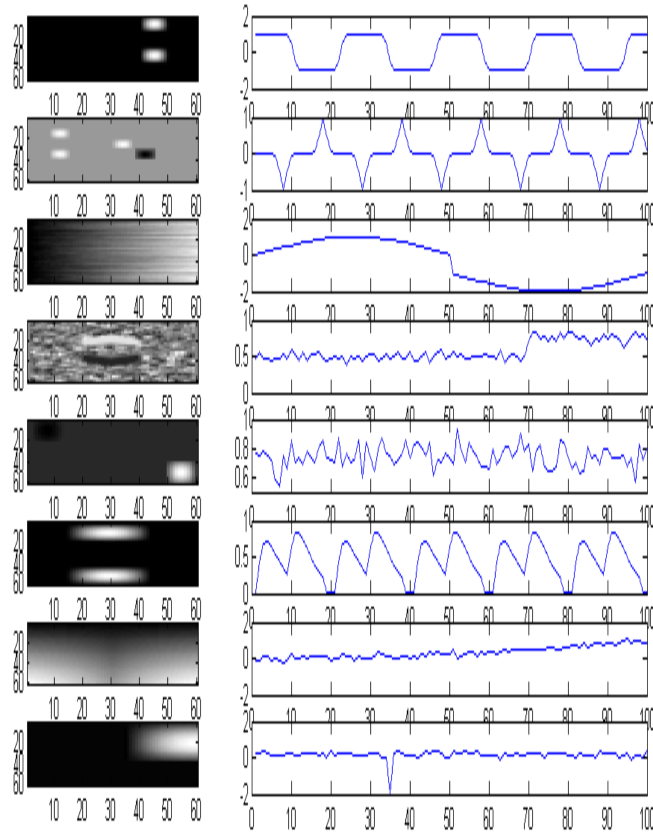

Figure. 1 (set of sources and corresponding time courses)

B. *Actual fMRI data:*

Actual fMRI data is downloaded from the online resource of Carnegie Mellon University, Computer Science department, Pittsburgh USA. Collection of this data was actually done by Marcel Just and his colleagues [16]. Details of actual fMRI data can be checked at [16].

IV. EXPERIMENTAL RESULTS

Simulated fMRI like data corrupted by different known noise levels is de-noised first by 1D and then by 2D anisotropic filters. De-noised images are correlated with non noisy images and the results are shown in Figure 3 and Figure 4. In Figure 3 it can be seen that the correlation of noisy image with non noisy image at SNR 0db is 0.54 while after 1D filtering the correlation is 0.57. However in case of 2D filter this value is 0.66 and hence a reasonable improvement in the quality of the image. However if noisy image is passed from Hybrid filter which is basically the combination of 1D and 2D, the results are further enhanced and correlation value is 0.76 as shown in Figure 5. It is thus clear that Hybrid filter performance is good in terms of correlation from 1D and 2d filters. Figure 6 and Figure 7 shows non noisy one fMRI slice and noisy fMRI slice, while Figure 8,9 and 10 shows filtered images by 1D,2D and hybrid filters respectively. It can be seen that performance of hybrid is better.

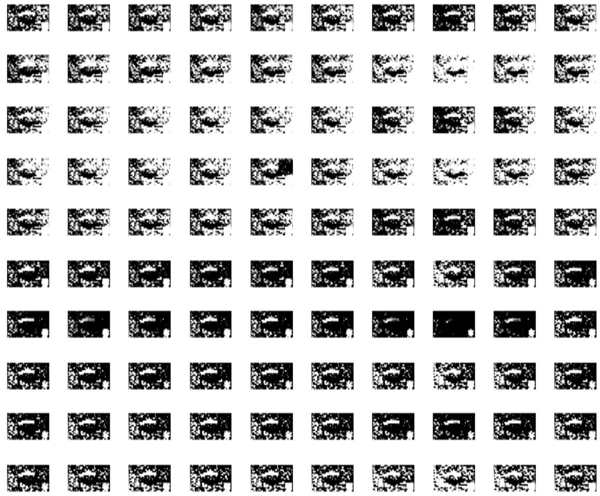

Figure.2 (100 images of a single slice)

Anisotropic 1D, 2D and hybrid filters are applied and the results are compared visualy using actual fMRI data. This data is taken from online resource [16] from where data of trial 5 which consists of 55 images is de-noised. A representative noisy and non noisy image by all methods is shown in Figure 11. It can be seen that the proposed method is preserving image details and is not producing any blurring effect.

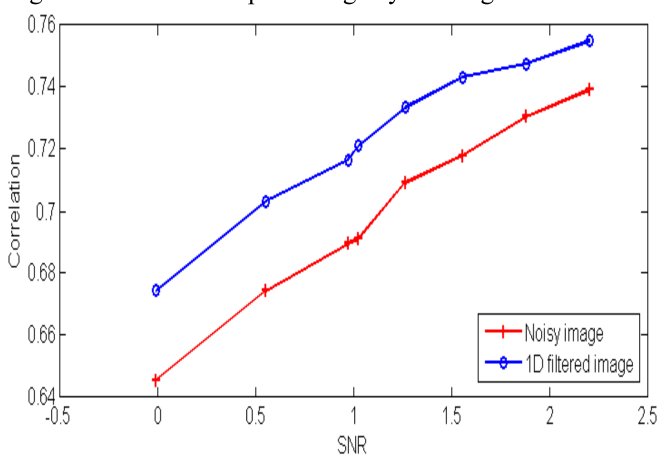

Figure. 3 SNR vs Correlation of Noisy,1D image with original image

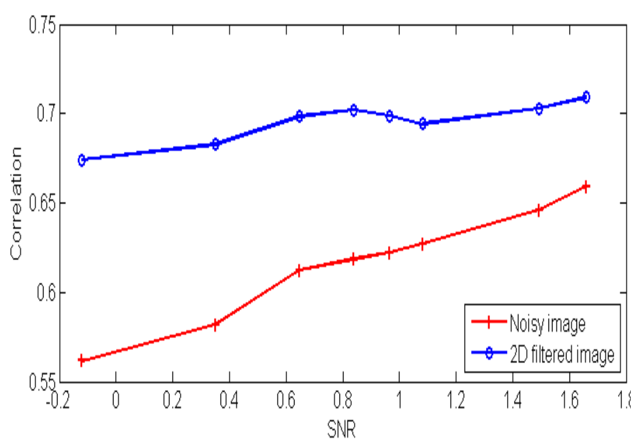

Figure. 4 SNR vs Correlation of Noisy and 2D de-noised image

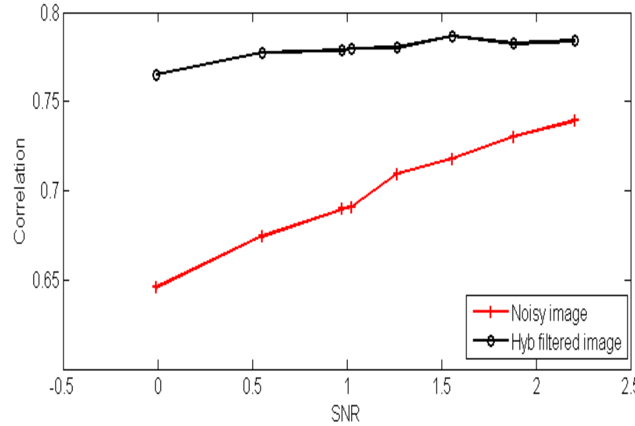

Figure 5: SNR vs Correlation of Noisy and Hybrid de-noised image

Figure 6 Original image

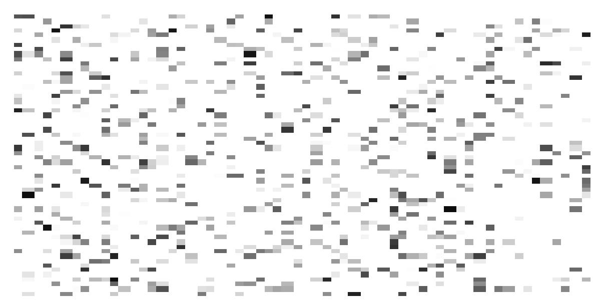

Figure.7 Noisy image

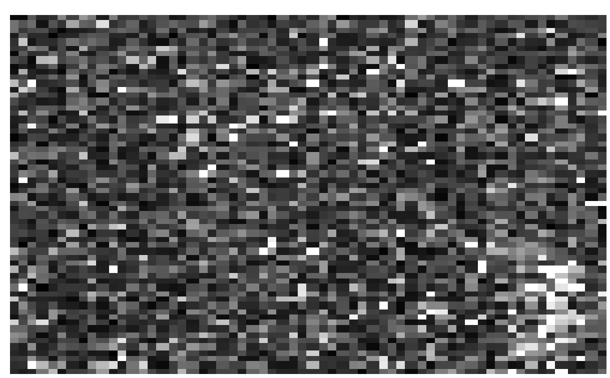

Figure 8 Image Processed by 1D anisotropic filter

Figure 9 Image processed by 2D anisotropic filter

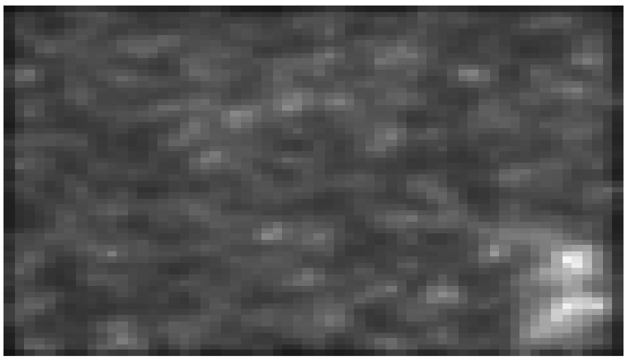

Figure 10 image processed by proposed hybrid method

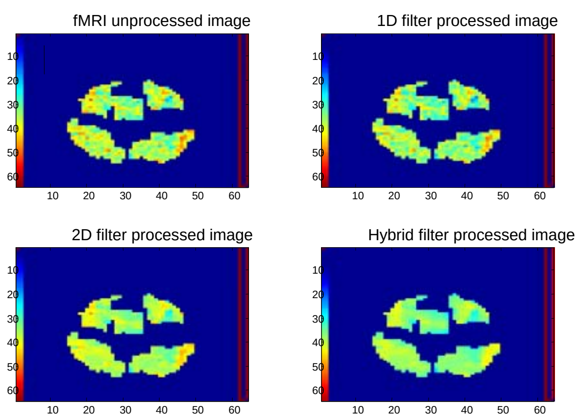

Figure 11(a) Actual fMRI original image (b) processed by 1D, (c) processed by 2D, (d) processed by Hybrid filter

V. CONCLUSION

After going through all experimental results, it can be concluded that performance of anisotropic 2D filter is better than 1D anisotropic filter on fMRI data which is corrupted by Rician noise. It can further be concluded that performance of hybrid filter is more prominent than 1D and 2D filters in terms of correlation results. This hybrid filter can be applied other than fMRI where Rician noise exists.

VI. ACKNOWLEDGMENTS

We would like to acknowledge and thank

(i) Machine learning and Processing Lab University of Marryland Baltimore county USA for providing the simulated fMRI like data.

(ii) School of computer science, Carnegie Mellon University, Pittsburgh USA for providing the actual fMRI data.

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