Comparative Study of various Noise Filters for Magnetic Resonance Images

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Abstract— *Magnetic Resonance Images gets affected from different kind of noises which comes from different sources while doing the MRI of a patient. It is very important to have a clear and noise free image of the organ to get precise measurements of the lesion/tumour in the organ for a proper diagnosis and to decide about the lesion that whether it is a benign or malignant. The noises that usually found in the MR Images are of different nature. Hence noise removing filters vary in functionality for the various noises found in MR Images. Here a comparative study based on the performance parameters of MR Images having different kinds of noise is given in this paper.*

Keywords— Impulse Noise, Gaussian Noise, Rician Noise, Median Filter, Weiner Filter, Gaussian Filter, SNR, MSE, RMSE, PSNR

I. INTRODUCTION

Magnetic Resonance (MR) Images have become a great and an important tool for the medical diagnosis purpose. However use of good quality images is a critical aspect in such applications for providing a better and accurate medical facility to the patient. In clinical diagnosis, the visual quality of Magnetic Resonance Images plays an important role. But during acquisition or transmission these images are corrupted with noise, which hinders the medical diagnosis based on these images. Noise means, the pixels in the image show different intensity values instead of true pixel values. The main sources of noise in the MRI images are the electronic items used and sometimes the patient itself. Physiological and respiratory distortions by the patients and the molecular movements in the body may also cause the noise to enter in MR images. Also thermal noise caused by the eddy current losses in the object to be imaged which is inductively coupled with the RF coil. Even acoustic sources (the sound produced by the pulse sequences in the magnet) are sometimes referred to as a source of noise.[1,2]

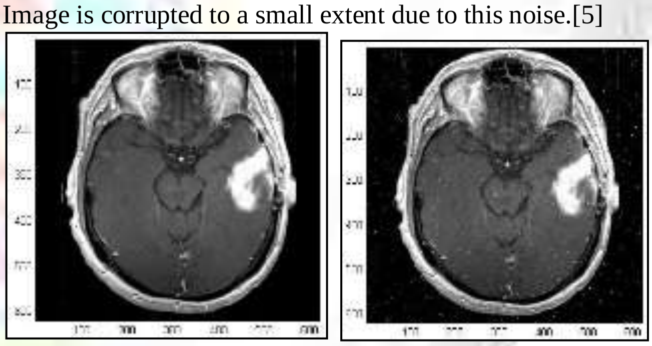
The main kind of noise present the MR images are stochastic type, random in nature. Usually additive white Gaussian noise corrupts the both (real and imaginary) parts of the complex MR raw data. By taking the magnitude of this complex data, the noise thus follows the Rician probability distribution function (pdf). Noise in magnitude MR Images can be well modelled using Rician pdf. Unlike additive Gaussian noise, Rician noise is signal-dependent and consequently separating signal from noise is a difficult task. [3] Many methods have been proposed for restoration of the images corrupted by noise. By taking neighbouring pixels into consideration; extreme “noisy” pixels can be filtered out. [4] Unfortunately, extreme pixels can also represent original fine details, which can also be lost due to the filter process. There is no unique technique for noise removing from noise affected image. Different algorithms[4] are used for denoising to improve the clarity of an image for better visualization, diagnosis and therapeutic planning. These depends on noise model [5] and modelling of noise depends on many factors like data capturing instrument, transmission media, and quantization of image. Denoising of image is necessary and foremost step to be taken before the image data to be analysed. Image denoising is still challenging as removal of noise causes artefacts and image blurring.

II. NOISE IN MR IMAGES

In the MRI images noises are low as well as high frequency components. Removing high frequency components is very easy as compared with low frequency components as real signal and low frequency noise cannot be distinguished easily. Different types of noises that may affect images may be summarized as follows.

A. Impulse Noise (Salt and Pepper Noise)

Impulse noise corrupts some pixels of the image and that is why it is also called as Data drop noise. The pixels values are replaced with the maximum or minimum pixel value which are 255 and 0 in case of 8 bits data. Black and white dots appear in the image as a result of this noise and hence it is also known as salt and pepper noise.[6] This noise arises in the image because of sharp and sudden changes of image signal. Dust particles in the image acquisition source or over heated faulty components can cause this type of noise. Image is corrupted to a small extent due to this noise.[5]



(a) (b)

Fig. 1: (a) Original Image, (b) Image with added Salt & Pepper noise.

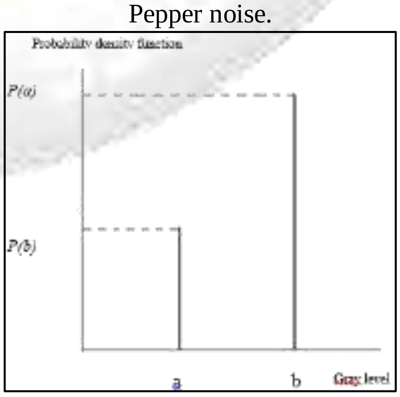


Fig. 2: PDF of Salt and Pepper noise.

Points ‘a’ and ‘b’ in the above graph belongs to the pixel points of the image having salt & pepper noise i.e. all the pixel points having minimum intensity(0) are denoted by point 'a' and all the pixel points having maximum intensity(255) are denoted by point 'b' in above graph. pdf of all pixels at point 'a' is p(a) and pdf of all pixels at point 'b' is p(b).

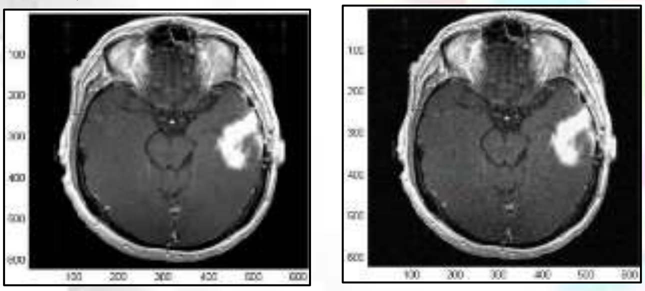
B. Gaussian Noise

The Gaussian noise arise in digital images because of the natural sources such as thermal vibrations of the atoms and discrete nature of radiations in the warm object (Patient body temperature) whose MRI is to be taken. Gaussian noise model follows the additive nature i.e. in the noisy image each pixel is the sum of original image pixel value and the noise value which follows Gaussian distribution in nature. The noise is independent of the pixel value and follows the Gaussian probability distribution function which is given as[6]:

$$p(x) = \frac{1}{(\sigma\sqrt{2\pi})} * \mathrm{e}^{(x-\mu)^2/2\sigma^2}$$

Where $p(x)$ the Gaussian distribution of noise in image, μ and σ are the mean and standard deviation respectively; x is the gray value of the image pixels.

In White Gaussian noise the noise values are statistically independent which describes the correlation of noise pixels is not possible. Gaussian noise modelled as additive white noise is termed as additive white Gaussian noise. Autocorrelation of white noise is zero. White Gaussian noise has stochastic nature. In additive white Gaussian noise a constant random value is added to each pixel of image which has distribution as the Gaussian PDF.[6,5]



(a) (b)

Fig. 3: (a) Original gray MR image, (b) Image with added White Gaussian noise.

The PDF of the Gaussian noise is given as:

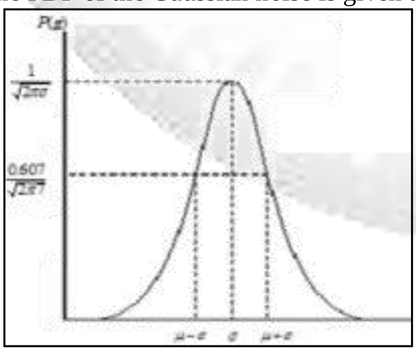


Fig. 4: PDF of Gaussian noise.

The PDF of Gaussian noise is bell shaped and this PDF shows that the maximum number of pixels around 70% to 90% of noisy image are in between μ–σ and μ+σ.

C. Rician Noise

Gaussian noise present in MR images disturbs the values of both (real and imaginary) parts of each pixel in the image. Magnitude image of the noisy MR image has noise which follows Rician probability distribution function and thus called the Rician noise. In images with low SNR this noise creates a big problem and reduces the image contrast as well. The Rician PDF is given by the equation[3]:

$$p(x) = \frac{x}{\sigma^2} * e^{-\left(\frac{x^2+A^2}{\sigma^2}\right)} * \mathrm{I}_0\left(\frac{\mathrm{A_x}}{\sigma^2}\right)$$

Where σ is the standard deviation, x is the pixel value of the magnitude image and I_0 is the zeroth order Bessel function and A is the true image intensity without noise and is given by: $A=A_R+A_I$, where A_R & A_I are real and imaginary data respectively.

When A→0 noise is found to end with Rayliegh distribution and with high values of A it approaches to Gaussian distribution. Rician noise is caused due to Gaussian noise in the frequency domain of the original image.[4,8,9,13 and 15]

III. NOISE REMOVAL METHODS

Filtering is a process of removing noise from noisy image and increasing the visual quality of the image. This make the image fit for further processing like segmentation and feature detection from the image. There are two types of filtering techniques available one is linear and the other is nonlinear. In linear filtering a Gaussian filter and an averaging filter can be used. Averaging filter, calculate the average of a certain part/mask of the image and replace the central pixel of the mask with the average value. This filter causes blurring affect also and cannot preserve the edges of the image, causing loss of information. The other may include nonlinear techniques for removing noise such as the one based on calculating the variance or central tendency of a mask/part of the image which replace the central pixel value by this calculated value. These filtering techniques also add some artefacts in the image. All these noise removing techniques have their own advantages as well as disadvantages. In medical images it is important to preserve the edges of the image as well to add minimum number of artefacts. This is required to get accurately measured information regarding the organ being imaged, like the size and the character of the brain tumour, to diagnose it accurately.

Fig. 5: Filters

Filters used for noise removal from noisy MR Images are described as follows:

A. Mean Filter

The Mean Filter computes the average value of a predefined area of the noisy image and the central pixel value is replaced with the average value of neighbouring pixels. Hence this is also called averaging Filter. The average can be computed as:

$$f(x,y) = \frac{1}{mn} \sum_{(s,t)\in S_{xy}} g(s,t)$$

Where $f(x,y)$ is the restored image using averaging filter and $g(x,y)$ is the noisy image and S_{xy} represents the set of coordinates in a rectangular sub image window, cantered at point(x,y).

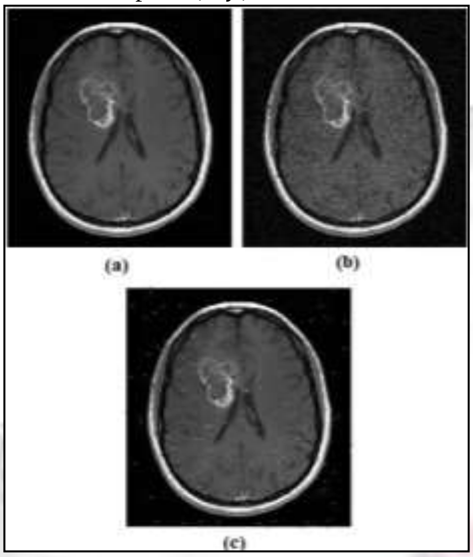


Fig. 6: (a) Original gray MR Image of brain, (b) MR Image added with Gaussian noise, (c) MR Image added with added Impulse noise,

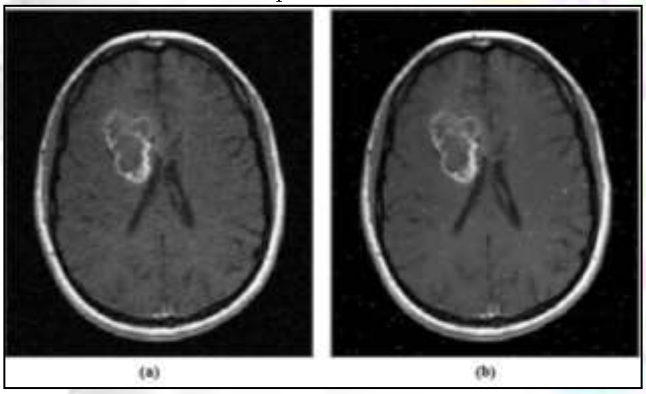


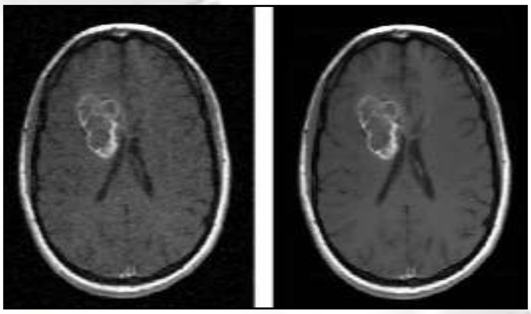
Fig. 7: (a) Image after applying 3X3 Mean filter on image added Gaussian noise shown in 'Fig.1(b)', (b) Image after applying 3X3 Mean filter on image with added Salt & Pepper noise shown in 'Fig.1(c)'.

B. Median Filter

The Median filter is a nonlinear filter and preserves edges and sharpness of the image as compared to the mean filter and hence Median filter is more advantageous over the Mean filter. It does a great job in removing impulse or Salt & Pepper noise. In Median filtering technique each pixel of the image is replaced by the median computed from a neighbourhood of the pixel. This neighbourhood window is of square size. This method does not cause much loss to the boundary information as compared to the Mean filter. It is very good in removing the Impulse noise. This filter can be used repetitively more number of times as it causes less loss to the boundary and sharpness of the image.

Median filter does a smoothing of the image pixels by removing noise, but it smoothes only those pixels whose value differs more from others in its surroundings and does not change other pixel values.

Using Median filter reverse filtering can also be done for restoration of the pixels without having Impulse noise. The pixels which are not having Salt & Pepper noise i.e. not having a maximum (255) or minimum (0) intensity levels can be retained as it is as in the original image. The pixels which are having Salt & Pepper noise are replaced with the median value of a neighbourhood window. In this way Median filter becomes a great tool for removal of Impulse noise without causing artefacts and blurred effect.[3,4,5 and 15]



(a) (b)

Fig. 8: (a) MR Image after applying Median filter on image with added Gaussian noise shown in fig.1, (b) MR Image after applying Median filter on image with added Salt & Pepper noise shown in fig.1

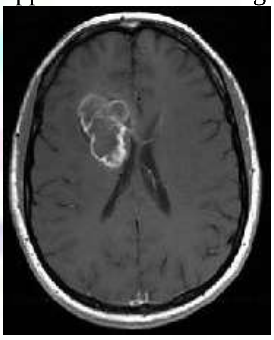


Fig. 9: Image filtered applying Median filter and restored by applying reverse Median filter on image with Salt & Pepper noise.

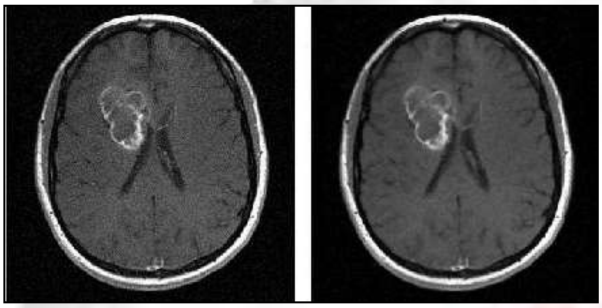
C. Wiener Filter

The Wiener filter is a filter used to remove noise from a noisy image and also deblurring the image using a stochastic approach. It basically minimizes the mean square error between noisy image and the original MR image as lower as possible. Main purpose of this statistical approach is to diminish the noise present in a signal by comparing it with an estimation of the desired noiseless signal. Wiener filters are characterized by an assumption that signal and (additive) noise are stationary linear random processes and their spectral characteristics are calculated. The Performance can be measured using Minimum Mean-Square Error. The orthogonality principle implies that the Wiener filter in Fourier domain can be expressed as follows:

$$\mathrm{W}(\mathrm{f_1},\mathrm{f_2}) = \frac{\mathrm{H^*}(\mathrm{f_1},\mathrm{f_2})\mathrm{S_{xx}}(\mathrm{f_1},\mathrm{f_2})}{|\mathrm{H}(\mathrm{f_1},\mathrm{f_2})|^2\mathrm{S_{xx}}(\mathrm{f_1},\mathrm{f_2}) + \mathrm{S_{\eta\eta}}(\mathrm{f_1},\mathrm{f_2})}$$

Where, $\mathrm{S_{xx}}(\mathrm{f_1},\mathrm{f_2})$ and $\mathrm{S_{\eta\eta}}(\mathrm{f_1},\mathrm{f_2})$ are power spectral density of original image and additive noise and $\mathrm{H}(\mathrm{f_1},\mathrm{f_2})$ is the blurring filter.

Wiener2' function in MATLAB is a 2-D adaptive noise removal filter function. The 'wiener2' function applies a Wiener filter which is a type of linear filter to an image adaptively, tailoring itself to local image variance. Where the variance is large, 'wiener2' performs little smoothing. Where the variance is small, 'wiener2' performs more smoothing. This approach often produces better results than linear filtering. The adaptive filter is more selective than a comparable linear filter, preserving edges and other high frequency parts of an image. In addition, there are no design tasks; the 'wiener2' function handles all preliminary computations, and implements the filter for an input image. Wiener Filter is best suitable to remove Gaussian noise.[4,6,7,9,10 and 11]



(a) (b)

Fig. 10: (a) Images with added white Gaussian noise, (b) filtered image using Wiener filter of size 5X5.

IV. Performance parameters

Different kinds of statistical measurement can be used to analysis the performance of the output image. The root mean square error (RMSE), signal-to-noise ratio (SNR), and peak signal-to-noise ratio (PSNR) are used to evaluate the enhancement performance. [4,5,6,7,10 and 11,14]

Signal-to-noise ratio (SNR) is a measure to quantify how much a signal has been corrupted by noise. The root mean square error (RMSE) is used to find the total amount of difference between two images. It indicates the root of average difference of the pixels throughout the image. The peak signal to noise ratio (PSNR) is the ratio between the maximum possible power of a signal and the power of corrupted noise that affects the fidelity of its representation. A higher PSNR would normally indicate that the reconstruction is of higher quality.

A. Mean Square Error (MSE)

This is one of the error measurement criteria used in comparative study of various noise filters. MSE is the squared difference between the original and the denoised image using any one of the previously mentioned filter methods. MSE is computed as follows:

$$\mathrm{MSE} = \frac{1}{mn}\sum_{k=0}^{m-1}\sum_{l=0}^{n-1}(y(k,l) - y'(k,l))^2$$

Where $y(k,l)$ is the original image and $y'(k,l)$ is denoised image with relation to image dimension (m,n). MSE should be as low as possible for an image to make sure it is noise free.

B. Root Mean Square Error (RMSE)

RMSE should be as low as possible for an image to make sure it is noise free.

$$\mathrm{RMSE} = \sqrt{\mathrm{MSE}}$$

C. Signal to Noise Ratio

SNR is very useful way of comparing the relative amount of signal and noise. Signal to noise ratio estimates the quality of a reconstructed image compared with an original image. Higher value of SNR have very little amount of noise and lower value of SNR shows a high amount of noise.

$$\mathrm{SNR} = \frac{\sigma_s}{\sigma_n}$$

Where σs and σn are the variance of the original image and recorded image. This gives us the difference between original image and the denoised image.

D. Peak Signal to Noise Ratio

It is the ratio between maximum possible power of a signal and the power of corrupting noise that affects the quality and reliability of its representation. PSNR is calculated as:

$$\mathrm{PSNR} = 10\log_{10}\frac{\mathrm{MAX}^2}{\mathrm{MSE}}$$

Where MSE is mean square error and MAX is the maximum pixel value of the image.

V. Comparison of filter methods using performance parameters

MR Image	MSE (db)	PSNR (db)	RMSE
MR Image after adding Gaussian Noise of level 0.005	257.58	24.06	16.05
MR Image after adding Salt & Pepper Noise of level 0.005	121.43	27.32	11.02
MR Image with stochastic type additive white Gaussian noise	100.25	28.15	10.01
MR Image after applying Median Filter of size 3X3 on image with added Gaussian Noise	47.77	31.37	6.91
MR Image after applying Median Filter of size 3X3 on image with added Salt & Pepper Noise	3.38	42.87	1.84
Restored MR Image by applying Median Filter on image with added Salt & Pepper Noise	3.07	43.29	1.75
MR Image after applying Average Filter of size 3X3 on image with added Gaussian Noise	52.12	31.00	7.22
MR Image after applying Gaussian Filter on Image with additive white Gaussian noise	42.09	31.92	6.49
MR Image	MSE (db)	PSNR (db)	RMSE
MR Image after filtering using Average Filter (3X3) on Image with added white Gaussian noise	18.05	35.60	4.25
MR Image after filtering using Median Filter (3X3) on image	20.89	34.96	4.57

with added white Gaussian noise			
MR Image after applying Wiener Filter (3X3) on Image with added white Gaussian noise	16.17	36.08	4.02
MR Image after applying Wiener Filter (5X5) on Image with added white Gaussian noise	9.14	38.56	3.02
MR Image after applying Wiener Filter (9X9) on Image with added white Gaussian noise	13.10	36.99	3.62

Table 1: Comparison of filter methods using performance parameters

VI. CONCLUSION AND RESULTS

On the basis of the comparative study, it can be concluded that Median filter is the best method to filter the image which is corrupted by Salt & Pepper noise and this filter gives minimum value of MSE and maximum value of PSNR, which shows that median filter has removed a maximum of the noise present in the image. Wiener filter is the best filter for removing the additive white Gaussian noise as it gives the minimum value of the MSE and maximum value of PSNR. Also as it is shown in the table if we increase the order of Wiener filter, its performance i.e. MSE & PSNR will decrease and increase respectively up to an order of 5X5 and then MSE will start increasing and PSNR will start decreasing on further increment in its order. As shown in above table MSE for wiener2 function will first decrease from 16.17 to 9.14 and PSNR increases from 36.08 to 38.56 then MSE starts increasing to 13.10 and PSNR decreases to 36.99.

Hence it can be concluded that for the MR Images, having noise which is stochastic with Gaussian characteristic in both real and imaginary parts of the MR images which follows Rician distribution in magnitude MR Images, the Median filter and the Wiener filters are best to remove such type of noise present in MR Images.

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