An Efficient MRI Noise Removal Technique using Linear and Nonlinear Filters

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ABSTRACT

For the study of anatomical structure and image processing of MRI medical images techniques of noise removal have become an important practice in medical imaging application. In medical image processing, precise images need to be obtained to get accurate observations for the given application. The goal of any de-noising technique is to remove noise from an image which is the first step in any image processing. The noise removal method should be applied watchful manner otherwise artefacts can be introduced which may blur the image. In this paper, performance evaluation of the of MRI image de-noising techniques is provided. The techniques used are namely the median and Gaussian filter, Max filter [11], Min filter [11], and Arithmetic Mean filter [8]. All the above filters are applied on MRI brain and spinal cord images and the results are noted. A new method is proposed which modifies the existing median filter by adding features. The experimental result of the proposed method is then analyzed with the other three image filtering algorithms. The output image efficiency is measured by the statistical parameters like root mean square error (RMSE), signal-to-noise ratio (SNR), peak signal-to-noise ratio (PSNR).

General Terms

Image processing, filtering, noise removal

Keywords

Noise removal, median, mean filter, MRI

1. INTRODUCTION

Image de-noising is an important task in any type of image processing. The main aim of any image de-noising model is that it should preserve the edges while removing noise as far as possible. There are two major models which are widely used- linear model and non-liner model. The major benefit of linear noise removing models is the execution speed but the limitation here is, these models cannot preserve the edges of the images in an efficient manner i.e any edge, recognized as a discontinuity in the image, is blurred out. On the other hand, non-linear models handle the image edges in a more efficient manner than linear models. Rician noise is present in MR images which unlike additive Gaussian noise, is signal-dependent and consequently separating noise from signal is a challenging task. [11]

Image-de-noising techniques are used to retain as much of the important signal features as possible while removing the noises. Filters are used for this purpose and filters in image processing are used to enhance an image or to detect edges in an image. Several such filters are present and are used to remove noise by retransforming the image into a more accurate version of pixels [2]. The noisy pixels in an image can be filtered out by taking the neighbouring pixels into consideration. Unfortunately, such noisy pixels can also sometimes represent the original finer details, which can be lost during the smoothing process. Since there is no specific technique for noise removal from an image affected with noise, depending on the type of noise model or noise distribution present, different algorithms are used. The most commonly used averaging or mean filtering technique can remove noise from the affected image successfully but the output image suffers from the blurring effect. In this technique, the value of any output pixel is a linear combination of the values of the pixels in the input pixel's neighborhood. So all pixels, affected and unaffected pixels, are used to calculate the mean and the resultant mean value replaces the original pixel value. The most common non-linear filter was the median filter, as it had good de-noising power [5] and computational efficiency [6]. But the main disadvantage of this method was that it replaced the noisy pixels by some median value in its vicinity without taking into account the presence of edges in the image [7]. When the noise level was high, details and edges were not regained sufficiently. Three commonly used noise removal algorithms are examined in this paper and a new algorithm for noise reduction from medical images is introduced that combines both mean and median filtering to calculate a sufficiently more accurate pixel value of the noisy image. This experimental result shows the effectiveness of the proposed method.

2. IMAGE NOISES

Noise in any image produced by a sensor and a circuitry of a scanner or camera is the stochastic fluctuation of brightness or colour information. This noise can also originate due to grains in the film or due to the inevitable noise present in an ideal photon detector. The undesirable by-product of image capture is essentially this image noise. The important factors which influence the noise models in any image are the instrument used for capturing the image, the media used for data transmission, the image quantization method and the discrete source of radiation. Natural images are affected by Gaussian noise, whereas magnetic resonance images (MRI) are affected by Rician noise. [9]

2.1 Rician Noise

Scattered signals take different paths to a receiver and a Rice or Rician distribution (also known as a Nakagami-n distribution) is one way to model these paths. Specifically, this distribution model is efficient for line-of-sight scattering — transmissions between two stations other that have an unobstructed path between them and are in clear view of each other. Line-of-sight scatter includes MRI images, FM radio waves, and microwaves in the presence of noise. The Rician probability density function is calculated as follows. The original image pixel intensity in the absence of noise is denoted by O. The probability distribution for x in the presence of noise can be shown to be given by

$$p(x) = \frac{x}{\sigma^2} \exp\left(\frac{-(x^2 + O^2)}{2\sigma^2}\right) I_0\left(\frac{xO}{\sigma^2}\right) \quad (1)$$

where I_0 is the modified zeroth order Bessel function of the first kind and σ denotes the standard deviation of the Gaussian noise in the real and the imaginary images.[10]

2.2 Gaussian Noise

Gaussian noise is statistical with a probability density function which is identical to that of normal distribution which is also called Gaussian distribution. It is also known as the noise which has a Gaussian amplitude distribution. A Gaussian distribution is given by the normal distribution equation. The Gaussian is a continuous, symmetric distribution whose density is given as follows with a variate x and mean and variance σ^2

$$p(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma^2}\right)^2} \quad (2)$$

2.3 Salt-and-pepper noise

An image which includes salt-and-pepper noise will have bright regions containing dark pixels and dark regions comprising of bright pixels [4]. This kind of reverse noise can be due to dead pixels, errors in analog-to-digital conversion, bit errors in transmission, etc. This can be eliminated in large part by using dark frame subtraction and by altering around the dark/bright pixels.

3. NOISE REMOVAL METHODS

3.1 Linear smoothing or Mean filter

Mean or linear filtering works with a pixel by reducing the amount of intensity variation between one pixel and the next. Each pixel value in an image is replaced by taking the mean (`average') value of all its neighbors, including itself.[6,7] Such filtering eliminates those pixel values which are dissimilar or unrepresentative of the surrounding pixels. Let Sxv represent the set of co-ordinates in a rectangular subimage window of size a X b, with the pixel at the center being denoted by (x, y).This filtering process computes the average value of the affected image g(x, y) in the rectangular area defined by Sxy. The value of the restored image at any point (x, y) is simply the arithmetic mean computed using the pixels in the region defined by S. In other words.

$$f(x,y) = \frac{1}{mn} \sum_{(s,t)\in S_{x,y}} g(s,t) \quad (3)$$

3.2 Median filter

This is a nonlinear method used on MRI brain images to remove noise. It is a widely used method to preserve edges. It is particularly effective at removing salt and pepper noise. Median filter works in the same manner as the mean filter by moving through the image pixel by pixel, but replacing each value with the median value of its neighbouring pixels. All the pixel values from the pattern of neighbours is sorted into numerical order, and then the pixel being considered is replaced with median pixel value from the neighbouring pixel values already sorted. Median filter is much more effective in removing noise without reducing the sharpness of the image.

$$f(x,y) = median_{(u,v)\in Kxy} \{g(u,v)\} \quad (4)$$

where Kxy corresponds to the coordinate sets centered at point (x,y), within a rectangular sub image window, and median represents the median value of the window.

3.3 Midpoint filter

In this filter, each pixel value is replaced with the average of highest pixel and the lowest pixel (with respect to intensity) within a specified window size. The operation of this filter can be expressed as:

$$f(x,y) = \frac{1}{2}\left[\max_{(u,v)\in Sxy}\{g(u,v)\} + \min_{(u,v)\in Sxy}\{gu,v)\}\right] \quad (5)$$

where Sxy represents the set of coordinates in a rectangular sub image window, centered at point (x,y), also max and min represents the maximum and minimum value of the window respectively.

4. PROPOSED WORK

A new technique is proposed that combines both linear and nonlinear filters. Median filter and mean filter values are used to calculate and determine a more precise value of each pixel of the noisy image. The median filter runs through the pixels entry by entry, using the median of the neigbouring entries to replace each entry. This also depends on the number of entries as in if a window has an odd number of entries, then the median calculated in a simple manner: all the entries in the window are sorted numerically and the middle value is used. When the number of entries is even, the number of possible values of the median is multiple. Thus median filter is a robust filter. Median filter can remove the imprint of input noise values with drastically large magnitudes and this is a major benefit over liner filters. As a result of this, median filters find use in image processing, as well as in signal processing and time series processing as smoothers. (As against linear filters which are susceptible to this type of noise and the output may be degraded severely by even by a small fraction of abnormal noise values). For other random noises, that are not so bright or so dark, this existing median filter output is not so accurate. The proposed method is in the next sections.

4.1 Median value calculation

Median filter works by moving through the image pixel by pixel and using the median value of the neighbouring pixels to replace each value. Any odd sized rectangular sub image window or a mask of 3x3 is considered and all the pixel values in the neighbouring pattern is sorted into numerical order, and then the pixel being considered is replaced with the median pixel value. The existing median filtering method will be used to find the median value.

$$\text{Median} = median_{(u,v)\in Sxy} \{g(u,v)\} \quad (6)$$

where Sxy represents the set of coordinates in a rectangular sub image window, entered at point (x,y), and median represents the median value of the window.

4.2 Average value calculation

Average value is calculated by using each pixel in the sub image window Sxy and the median value calculated from the previous section. From this method, the neighbourhood pixels can be utilized to the maximum extent. This is calculated in the following way

$$Averagevalue_i = average_{(u,v)\in Sxy} \{g_i(u,v), Median\} \quad (7)$$

where, Sxy is the sub image window and g(u,v) is each pixel of the sub image window. For example, if the size of sub window is 3x4, there are total 12 average values.

4.3 Center pixel value calculation

This value is calculated by applying arithmetic mean filtering or taking the average of the average i.e. all the average values of the sub image window are used to calculate a more accurate value to replace each individual pixel of the original noisy image. It is calculated as shown below.

$$\text{Center pixel value} = \frac{\sum_{i=1}^{N} Averagevalue_i}{N} \quad (8)$$

where N is the product of the ROW (M) and COLUMN (N) of the rectangular sub image window of size M X N, centered at point (x, y) which is the value to be replaced.

5. METHODOLOGY FOR OUTPUT IMAGE ANALYSIS

The final output image's quality and performance is measured using different statistical parameters. The quality of enhancement of the denoised image and its performance is evaluated using (PSNR) peak signal-to-noise ratio, (SNR) signal-to-noise ratio (SNR) and (RMSE) root mean square error. Signal-to-noise ratio (SNR) is defined as the ratio of signal to noise strength or the ratio of the mean value of the signal to the standard deviation of the noise.. Mean square error(MSE) is the average difference of the pixels throughout the image or the average of the square of the error between two images. The peak signal to noise ratio (PSNR) is the ratio between the maximum possible power of a signal and the power of distorting noise that affects the quality of its representation. A higher PSNR normally indicates that the reconstruction is of better quality.

For two MxN digital images P and Q the mean square error (MSE) which shows the average of the pixels throughout an image is calculated as follows

$$\text{MSE} = \frac{1}{MN}\sum_{i=0}^{M-1}\sum_{j=0}^{N-1}\left(P(i,j) - Q(i,j)\right)^2$$

and the RMSE is $\sqrt{MSE}$

$$\text{PSNR} = 10\log_{10}\left(\frac{(W-1)^2}{MSE}\right) = 20\log_{10}\left(\frac{W-1}{MSE}\right)$$

where W is the number of maximum possible intensity levels (for 8 bit image, L=256) in an image.

6. EXPERIMENTAL ANALYSIS AND RESULTS

MRI human brain images are taken as the test images for this proposed method. Rician noise is usually present in human brain MRI scans. The size of the test image for this proposed work is 256x256 as shown in Figure 1 which is a noisy MRI image. The proposed noise removal method is applied on the noisy image and the results are shown in Figure 2.

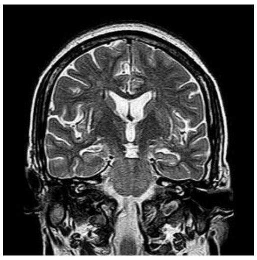

Fig 1: Original noisy MRI image of human brain

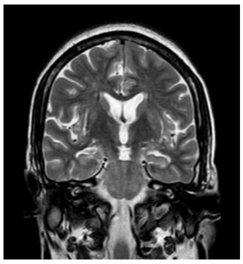

Fig 2: MRI image after removing noise using proposed method

Figure 2 shows that the Rician noise is removed to a major extent. The experimental result is also compared with images processed using the mean, median and midpoint filters. Figure 3 and Figure 4 show the comparision of the proposed method and the mean method. The normal mean method blurs the output image as can be seen in Figure 4. The proposed method makes the image more sharper.

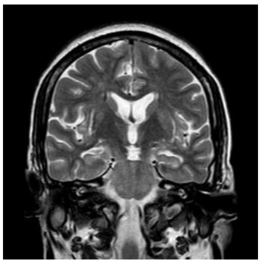

Fig 3: MRI image after removing noise using proposed method

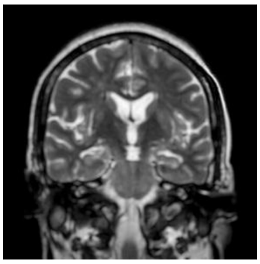

Fig 4: MRI image after removing noise using mean filter

The proposed method is also tested on MRI Spinal cord images. The test MRI spinal cord image shown in Figure 5 contains salt and pepper noise. Figure 6 is the output after removing the noise using the proposed method.

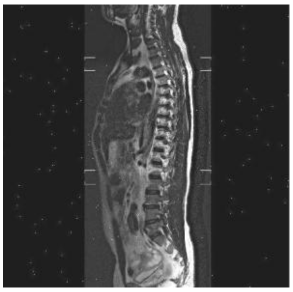

Fig 5: Noisy MRI image of Human spinal cord

Fig 6: MRI image after removing noise using proposed method

For the output image performance evaluation PSNR, SNR and RMSE values are used. Higher values of SNR and PSNR and lower values of RMSE indicate that the enhancement method is better and useful. The results of mean, median and midpoint filters are compared with the proposed method and the Table 1 shows the results.

From the results shown in Table 1, it can be noticed that the proposed method gave better enhancement than the methods based on mean, median and midpoint filtering. The best result in terms of SNR is given by the mean method but the output image tends to get blurred in this method. The output image looks sharper in the proposed method.

Table 1. Results of comparsion of different filtering methods with the proposed filtering method

Image type	Method used	SNR (dB)	PSNR (dB)	RMSE
MRI brain image	Mean filter	3.81	43.43	442.67
	Median filter	3.68	43.64	435.48
	Midpoint filter	3.62	42.17	512.25
	Proposed filtering method	3.81	43.67	428.00
Spinal cord image	Mean filter	5.52	19.43	26.32
	Median filter	5.24	19.75	26.09
	Midpoint filter	4.28	19.25	27.32
	Proposed filtering method	5.53	19.82	25.79

7. CONCLUSION

This paper presents a technique where both median and mean filtering are combined to remove noise from medical images. This proposed method has been compared with mean, median and midpoint filters using numerical parameters like PSNR, SNR and RMSE and the results have been compared and analyzed with the standard pattern of noises. It has been shown that this proposed approach retains the structural details of the medical image and yet clearing out much of the noise present in the image. This experimental approach will improve the accuracy of MRI images for easy diagnosis.

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