

# Denoising and Contrast Enhancement in MRI for Improved Medical Diagnosis

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**Abstract**—Diagnostic tools such as Magnetic Resonance Imaging (MRI) provide clear images of organs and tissues inside the body. Using a computer, a large magnet, and radio waves, MRI scans help doctors diagnose diseases and devise treatment plans for patients. Sometimes, these image scans can be distorted due to noise, especially from Gaussian and salt-and-pepper noise. This report aims to enhance the quality of MRI scans through image processing techniques, including classical spatial filters (i.e. average, Gaussian and spatial filters), NORDIC (NOise reduction with DIstribution Corrected), and DAMF (Different Applied Median Filter). With datasets obtained from online sources like Kaggle, a sample MRI image is denoised using the techniques mentioned. Other methods, such as histogram equalization, are also explored to observe the various image intensity levels in MRI scans. By making a visual comparison, performing a histogram analysis and averaging brightness/contrast measurements, the effectiveness of the methods is assessed, demonstrating the possibility of clear and accurate MRI images during diagnosis. The following link provides access to the source code that is associated with the technical and experimental aspects of our report: <https://github.com/icejan/MRI-Processing>.

**Keywords**—Average filters, DAMF, Gaussian filters, Histogram equalization, Image Processing, NORDIC, Magnetic Resonance Imaging, Salt and Pepper noise, Spatial filters.

## I. INTRODUCTION

### A. Background

An MRI (Magnetic Resonance Imaging) scan is a non-invasive medical diagnostic test that produces clear images of the organs inside the body using a large magnet, a computer, and radio waves [1]. It may be used for various reasons such as disease detection, diagnosis and treatment monitoring. It uses advanced technology to observe how the protons in the water inside our tissues change their direction as they rotate [1].

Using a very strong magnet, MRI machines make the protons in the body line up in one direction. When a radio frequency current is passed through the patient, the protons are pushed out of position. Once the frequency current is turned off, the protons return to their original positions and release energy. The MRI sensors then pick up the released energy. Depending on the type of tissue, how fast the protons realign and how much energy they give off will vary [1]. These differences help the doctors distinguish between the tissues.

The entire process is done by placing the patient inside a large magnet. The patient must remain still at all times to obtain

a clear image. In some cases, contrast agents that contain Gadolinium may be given to the patient before or during the MRI procedure to increase the speed at which the protons realign with the magnetic field. Faster realignment of protons produces a brighter image [1].

MRI scans are used to visualize soft tissues and internal structures within the body [1]. They help see the brain, muscles, ligaments, nerves, tendons and spinal cord distinctly compared to other diagnostic models (i.e. X-rays and Computer Tomography (CT) scans). In practical situations, MRIs are used to detect health defects such as tumours in the brain [1].

In terms of its risks, MRIs produce powerful magnetic fields, which can be detrimental for patients with metal implants, such as pacemakers and defibrillators, or pregnant women who are in their first trimester [6]. Since the field is so strong, it is recommended that vulnerable patients avoid MRI scans for those medical reasons [6].

### B. Purpose and scope

MRI images can be difficult to view due to noise sources such as Gaussian, salt and pepper, and thermal noise. We aim to reduce these noises using denoising algorithms such as [2] NORDIC (Noise reduction with Distribution Corrected), and [4] DAMF (Different applied median filter). We will be using low pass filters such as average and Gaussian filters to denoise the images. We will use histogram equalization [5] to enhance the low-intensity pixels in MRI images to ensure hidden tissues are clearer in the images for accurate interpretation during diagnosis.

For testing, we will use a dataset from Kaggle [8] that contains various MRI images with different human tissues. First, we will add different noise levels to the images as well as lower their intensity levels that match raw MRI images. We will then apply various image enhancement algorithms and models to denoise and enhance the contrast levels in the images. Lastly, to verify the efficacy of our methods, we will be using quantitative metrics such as Visual Comparison, Pixel Difference, histogram analysis and average brightness/contrast measurement.

## II. TECHNICAL

### A. Noise Modeling

In our denoising experiment, salt and pepper noise and gaussian noise are added to an MRI image from the dataset using *imnoise()* on MATLAB [3]. *Imnoise()* begins by assigning each pixel a random probability value in range (0,1) using the standard uniform distribution probability model.

At noise density  $d=0.05$  for salt and pepper noise, pixels with probability value between 0 and  $d/2$  are set to 0. Pixels with probability value between  $d/2$  and  $d$  are set to the maximum value of the image data type. Pixels with probability value between  $d$  to 1 are unchanged. The number of pixels set to 0 or 1 can be calculated as:

$$d * \frac{\text{numel}(I)}{2} \quad (1)$$

Where  $d$  is the noise density,  $\text{numel}(I)$  is the total number of pixels in the image. Figure 1 below displays an example of an MRI image that has been applied with salt and pepper noise at noise density=0.05.

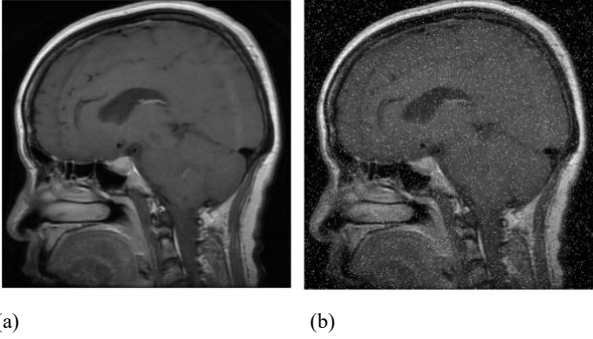


Fig. 1. MRI Image applied with salt and pepper noise. (a) original MRI Image. (b) MRI image with salt and pepper noise.

The scaled gaussian noise can be calculated with variance,  $v=0.05$ , as

$$n = \sqrt{v} = \sqrt{0.01} = 0.1 \quad (2)$$

The pixel random probability value can be multiplied with the scaled gaussian noise  $n$ , then added to the pixel intensity. This algorithm will slightly increase or decrease each pixel's intensity. Figure 2 below displays an example of an MRI image that has been applied with gaussian noise at variance=0.01.

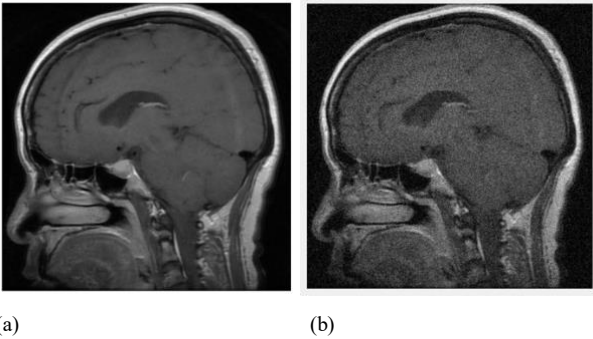


Fig. 2. MRI Image applied with gaussian noise. (a) original MRI Image. (b) MRI image with gaussian noise.

### B. Denoising Techniques

#### 1) Classical Spatial Filters

The filters are created using the *fspecial()* function in MATLAB to create average and gaussian filters. The *imfilter()* functions applies the average filter on an image by performing a 2D correlation between the input image and an averaging matrix. The filter matrix is slid across the input image for each pixel at position  $(m,n)$ . It computes the weighted sum of neighboring input pixel  $(x,y)$  as

$$P(x,y) = \sum_{s=-a}^a \sum_{t=-b}^b w(s,t) f(x+s, y+t) \quad (3)$$

where  $s$  and  $t$  are integer shifts over the pixel neighborhood.  $w(s,t)$  is the filter weight at position  $(s,t)$ . This smooths the image by replacing each pixel with the local mean, reducing noise while blurring edges.

The average filter on MATLAB is created with *fspecial()* to generate a matrix of size  $M \times N$  has equal weights summing to 1:

$$h(x,y) = \frac{1}{MN} \quad (4)$$

Where  $M$  and  $N$  is the filter size.

The gaussian filter matrix is created using *fspecial()* function on MATLAB computed as:

$$h(x,y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}} \quad (5)$$

Where  $\sigma$  is the standard deviation that controls the resulting blurriness.

#### 2) DAMF

The Different Applied Median Filter (DAMF) is a contemporary denoising method used to remove salt and pepper noise in common MRI images [4]. The filter is robust enough to apply as a median, non-linear filter, but appears sharper while preserving the entire image form [4] [7]. Even with different density levels of low, moderate and high, the DAMF algorithm is the most effective and successful when compared to other techniques used to remove salt and pepper noise [7].

Using MATLAB, a special function is designed for the DAMF algorithm, which is stored in the DAMF.m file. This algorithm takes a matrix size of any row ( $m$ ) by column ( $n$ ), and processes each pixel,  $a_{ij}$ , individually. From this, a binary mask is created to account for any refined or corrupted pixels using intensity levels ranging from 0 to 255 [7]. For the refined pixels, the value is contained. For the corrupted pixels, however, the median of adjacent pixels is computed to restore their values in a  $3 \times 3$  matrix [7]. This algorithm continuously checks if any pixel is acceptable, and expands to other matrix sizes until the maximum size of the original image is reached [7]. Once the cycle is done, it presents the final refined image.

For algorithms like DAMF, image quality metrics are used to assess the denoising results. For this report, only one metric equation will be illustrated, which is the Peak Signal to Noise Ratio (PSNR) [7]. It includes the Mean Square Error (MSE) for images  $X=[x_{ij}]_{m \times n}$  and  $Y=[y_{ij}]_{m \times n}$  as shown below [7].

$$PSNR = 10 \log \left( \frac{255^2}{MSE} \right) \quad (6)$$

where

$$MSE = \frac{1}{mn} \sum_{i=1}^m \sum_{j=1}^n (x_{ij} - y_{ij})^2 \quad (7)$$

### 3) NORDIC

NORDIC is an advanced denoising technique which is specifically designed and developed for MRI data. It forces the statistical properties of noise and low-rank modelling to suppress the noise while preserving the anatomical structures. From past research, it has been observed that NORDIC performs well in high-resolution MRI applications [2].

Since NORDIC is designed for raw MRI k space, a PCA based low rank denoising method was implemented to demonstrate the core principles of the NORDIC style noise suppression on the 2D MRI images. In this approach, the MRI image is reshaped into a 2D matrix and singular value decomposition (SVD) is performed:

$$X = USV^T \quad (8)$$

Here, U and V are orthogonal matrices and S is the diagonal matrix which contains singular values. Denoising is then obtained by retaining only the top k singular values and their corresponding vectors:

$$X_{denoised} = U_k S_k V_k^T \quad (9)$$

By retaining only the top principal components, the noise-dominated components are suppressed and the essential anatomical structures are preserved. In our MATLAB implementation, this corresponds to retaining the first 30 principal components (k=30) which helps us to reconstruct our denoised image. This procedure displays a NORDIC style demonstration without directly processing the k space data.

### C. Contrast Enhancement (Histogram Equalization)

Histogram Equalization is applied after the denoising process to enhance the contrast of MRI images by the redistribution of the pixel intensities across the available dynamic range. Since the MRI scans often consist of low intensity regions and subtle tissue variations, this technique helps to improve the visibility of the anatomical structures and their boundaries. This results in more accurate clinical interpretation and analysis [5].

Mathematically, histogram equalization maps the original pixel intensities k to new values sk using the cumulative distribution function(CDF):

$$s_k = (L - 1) \sum_{j=0}^k \frac{n_j}{N}, \quad k = 0, 1, \dots, (L - 1) \quad (10)$$

Where, L is the number of intensity levels, nj is the number of pixels with intensity j and N is the total number of pixels.

In the MATLAB implementation, the denoised MRI image is passed through the *histeq()* function, which automatically redistributes the intensity values to produce a more uniform histogram. Quantitative measures such as

calculating the mean intensity values and average pixel differences before and after the enhancement were calculated to assess the improvement in the image contrast. This combination of denoising the image followed by the histogram equalization ensures that both noise suppression and the enhanced tissue visibility in MRI images.

## III. EXPERIMENTAL ANALYSIS

### A. Classical Spatial Filters

An average filter of size 6x6 is created on MATLAB to be used for denoising images corrupted by noise. This filter will attempt to remove the salt and pepper noise at noise density, d=0.05 and the gaussian noise at variance, v=0.01. The process is shown below in Figure 3 and Figure 4.

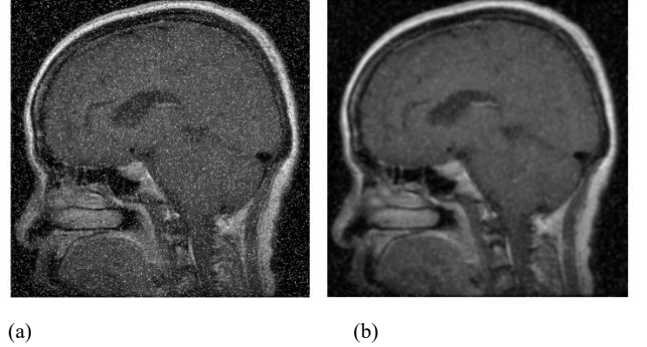


Fig. 3. Denoising the salt and pepper noise in an MRI Image using an average filter. (a) MRI Image corrupted by salt and pepper noise at d=0.05. (b) The denoised MRI image after its been applied with an average filter.

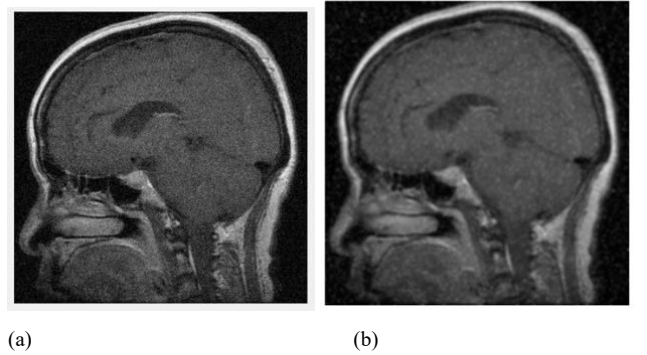


Fig. 4. Denoising the gaussian noise in an MRI Image using an average filter. (a) MRI Image corrupted by gaussian noise with variance, v=0.05. (b) The denoised MRI image after its been applied with an average filter.

A gaussian filter of size 5x5 with variance v=1 is created on MATLAB to be used for denoising images corrupted by noise. This filter will attempt to remove the salt and pepper noise at noise density, d=0.05 and the gaussian noise at variance, v=0.01. The process is shown below in Figure 5 and Figure 6.

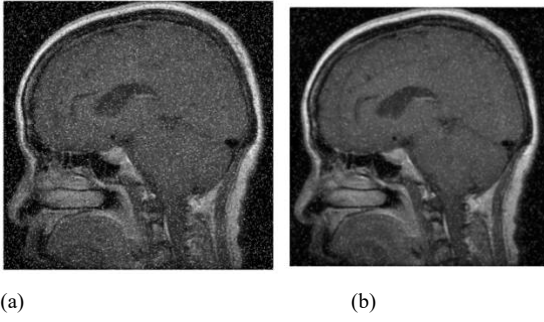


Fig. 5. Denoising the salt and pepper noise in an MRI Image using a gaussian filter. (a) MRI Image corrupted by salt and pepper noise at  $d=0.05$ . (b) The denoised MRI image after its been applied with an gaussian filter.

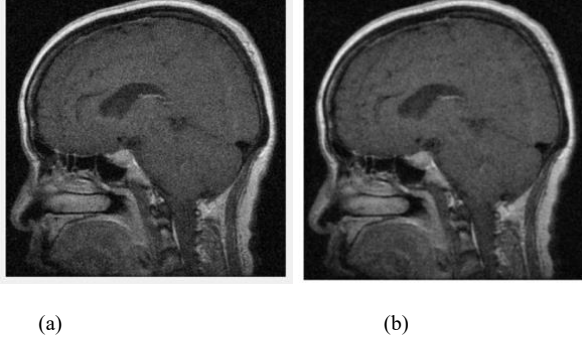


Fig. 6. Denoising the gaussian noise in an MRI Image using a gaussian filter. (a) MRI Image corrupted by gaussian noise with variance,  $v=0.05$ . (b) The denoised MRI image after its been applied with a gaussian filter.

The average filter performed better than the gaussian filter in removing the salt and pepper noise. The gaussian filter handles the salt and pepper white specs poorly as they are still visible in the MRI Image. Both the average and gaussian filters performed relatively well in removing the gaussian noise from the MRI Image. The gaussian filter performs slightly better than the average filter in keeping the details of the MRI image.

#### B. DAMF

When applying DAMF to MRI noisy images, such as the ones in Figure 7a and Figure 8a, the results are effective. Through our naked eye, it is clear that the DAMF image removed the pixelated salt and pepper spots and formed a sharper image for both low and high density levels of 10% and 60%. This demonstrates that the DAMF denoising technique is capable of keeping the MRI image intact regardless of the density level.

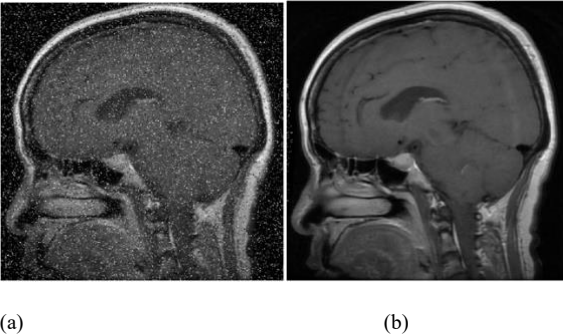


Fig. 7. (a) Noisy Salt and Pepper MRI Image at 10% Density Level. (b) DAMF Filtered MRI Image at 10% Density Level

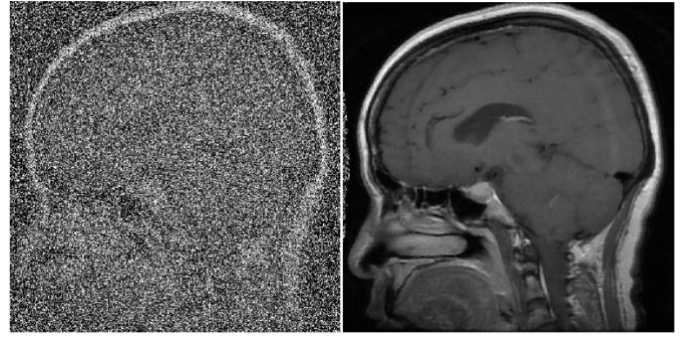


Fig. 8. (a) Noisy Salt and Pepper MRI Image at 60% Density Level. (b) DAMF Filtered MRI Image at 60% Density Level.

#### C. NORDIC

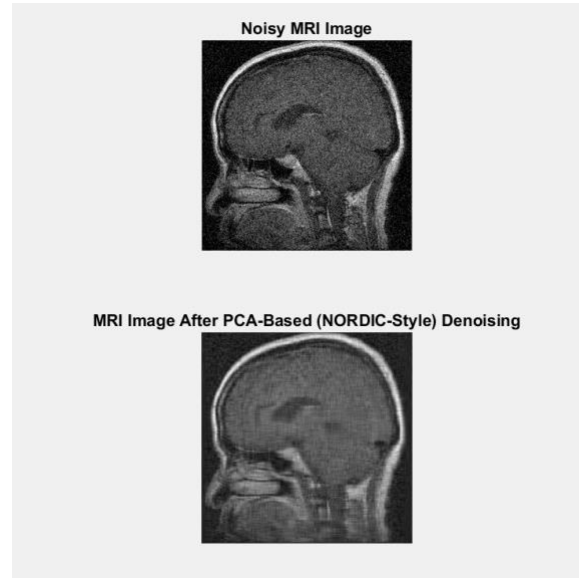


Fig. 9. Comparison of noisy image and image after NORDIC style denoising.

From the image above, we can observe that the noisy MRI image displays significant intensity fluctuations due to the inherent MRI noise. After applying the NORDIC style denoising, we can observe that the image appears significantly smoother and has an improved structural continuity while preserving the tissue boundaries. In our implementation, retaining the top 30 principal components resulted in smoother images with enhanced anatomical continuity.

#### D. Contrast Enhancement (Histogram Equalization)

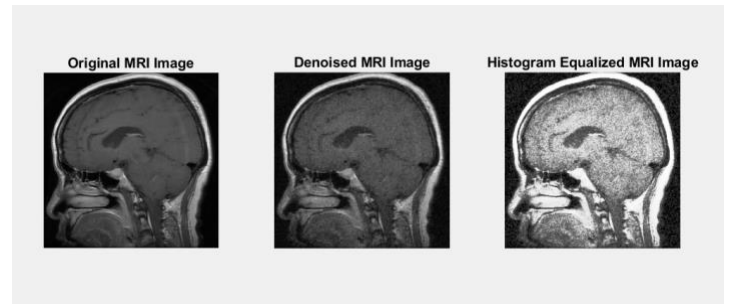


Fig. 10. Comparison of denoised image and image after histogram equalization.

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Mean Intensity Values:
Original Image: 0.2423
Denoised Image: 0.2496
Equalized Image: 0.5000

Average Pixel Difference:
Original vs Denoised: 0.0260
Original vs Equalized: 0.2583

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Fig. 11. Mean Intensity Values & Average Pixel Difference.

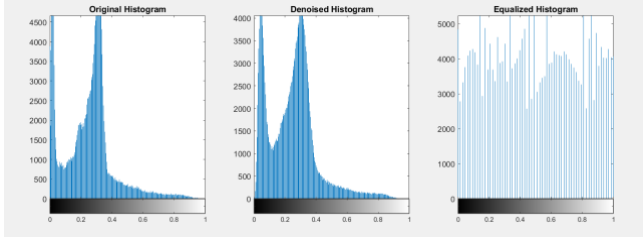


Fig. 12. Comparison of Histograms.

From the images above, we can see that the histogram of the original MRI image is concentrated within a very narrow intensity range. This indicates the low contrast and very limited visibility of the subtle tissue variations. After denoising we can observe that minor smoothing is observed due to the suppression of the noise but the overall intensity distribution remains very similar. Histogram equalization redistributes intensities of the pixels across a wider range which results in a more uniform histogram. This enhancement increases the contrast in low intensity regions and also improves the visual distinction of anatomical structures in the equalized image.

Quantitative evaluation included mean intensity values and average pixel differences before and after contrast enhancement. These metrics confirmed that the histogram equalization effectively enhances the contrast without introducing significant artifacts and makes subtle anatomical structures more distinguishable.

#### IV. CONCLUSION

In this report, various denoising and contrast enhancement techniques were examined to improve the visual quality of MRI images which are degraded by noise and low contrast. Classical spatial filters, DAMF and a NORDIC style PCA based approach were evaluated under controlled noise conditions and demonstrated that advanced and adaptive denoising techniques are more efficient at suppressing noise while preserving the critical anatomical structures. Experimental results displayed that DAMF performed particularly well for salt and pepper noise while the NORDIC style denoising provided smoother images. Furthermore, histogram equalization displayed significant enhancement in the contrast of low intensity MRI regions which improved the tissue visibility. Overall, this work highlighted the importance of combining appropriate denoising and enhancement techniques as a processing step in medical image analysis while providing a strong foundation for more accurate diagnosis and future automated MRI processing applications.

#### A. Team Contributions

Janice Zhu: Contributed to the implementation and analysis of noise modeling and classical denoising techniques. This included adding Gaussian and salt-and-pepper noise to MRI images and evaluating the effectiveness of various spatial filtering methods.

Najiba Imam: Implemented the Different Applied Median Filter (DAMF) and researched denoising algorithms.

Ayesha Irfana: Implemented the NORDIC style PCA based denoising approach and contrast enhancement using histogram equalization.

All Authors: Collaboratively developed the introduction, including background information and project scope, and jointly reviewed and revised the final manuscript.

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