Report

CS 736 – Medical Image Computing

Assignment 2

Instructor: Dr. Suyash Awate

By,

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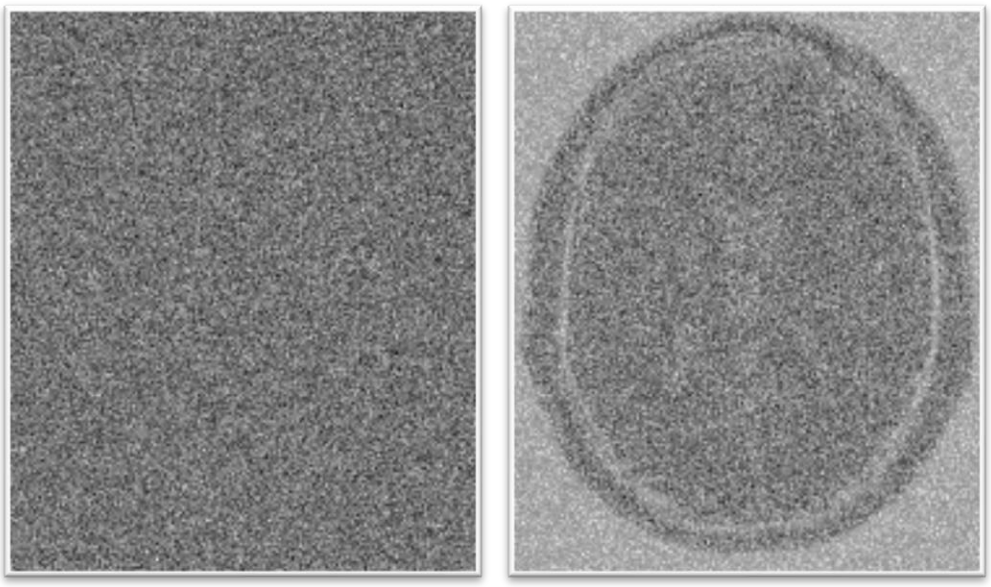
Notes

1. The code is written in Python 3.6. The following libraries are used and hence are necessary for the code to work seamlessly:
    a. matplotlib
    b. numpy
    c. os
    d. pillow
    e. scipy
    f. cv2
    g. h5py
2. We perform serial updates on the image instead of parallel updates.
3. The range of image intensities is $[0, 1]$.
4. For denoising, we've applied the algorithm for 5 times.
5. For hyper-parameter optimization, we take steps of 0.1 in the range of $[0, 1]$ and find the minimum.
6. The results (images) are saved in "results" folder, in case, the images in the report aren't up to the desired resolution.

Observations

1. We observe that the noise model is not additive Gaussian. We verified based on the following experiment. Take the noisy image (Y), assumed to be denoised by additive Gaussian noise $\mathcal{N}(0, \sigma^2)$ on noiseless image (X). That is, $Y = X + \mathcal{N}(0, \sigma^2)$. Hence if we subtract noisy image from the noiseless image, we should get a pure gaussian distribution $\mathcal{N}(0, \sigma^2)$. An example is given below. Given, such a case, the $Y - X$ looks like pure noise, like the image on the left below.



But, in our case, when we subtract the noisy image from noiseless image, we get the image on the right. Hence, this shows that variance of the noise is dependent on the

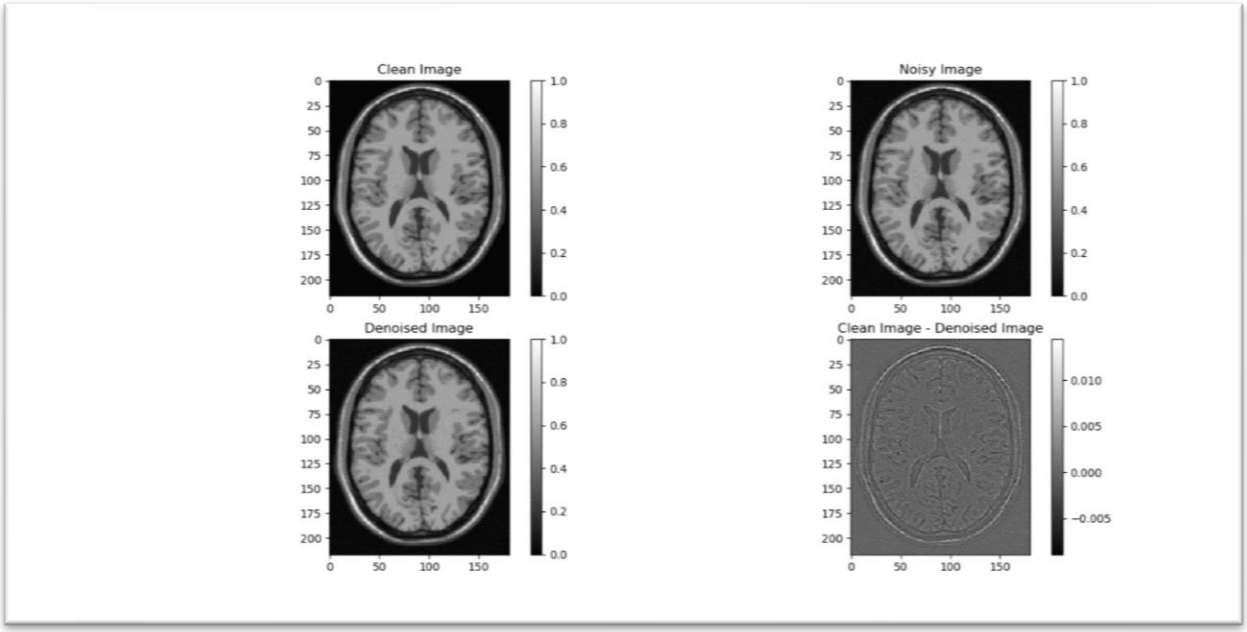
intensity of the image and hence, it couldn't be additive Gaussian noise. The noise could not be additive Gaussian.

Prior: Quadratic

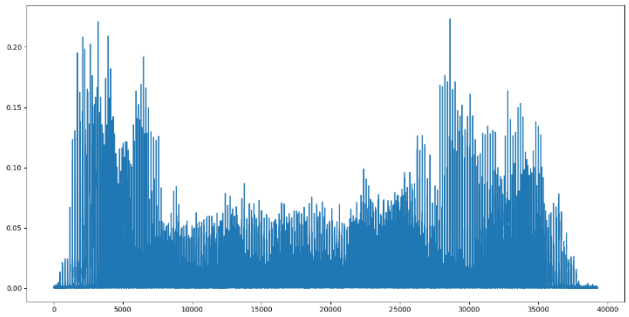
Noise Level: Low

Assumed variance: 4×10^{-4}

a. The Relative Root Mean Square Error (RRMSE) between the denoised image and noiseless image is 0.049.
b. Optimal Parameters
    i. Beta (β): 0.8
    ii. For $\beta' = 0.8 \times \beta$, RRMSE: 0.049
    iii. For $\beta' = 1.2 \times \beta$, RRMSE: 0.049
    The difference was insignificant ($< 10^{-4}$)
c. Denoised Image
    i. Top Left: Noiseless Image
    ii. Top Right: Noisy Image
    iii. Bottom Left: Denoised Image
    iv. Bottom Right: Difference between Denoised and Noiseless Image



d. Plot of objective function vs iteration
This is after updating every pixel, 1 run

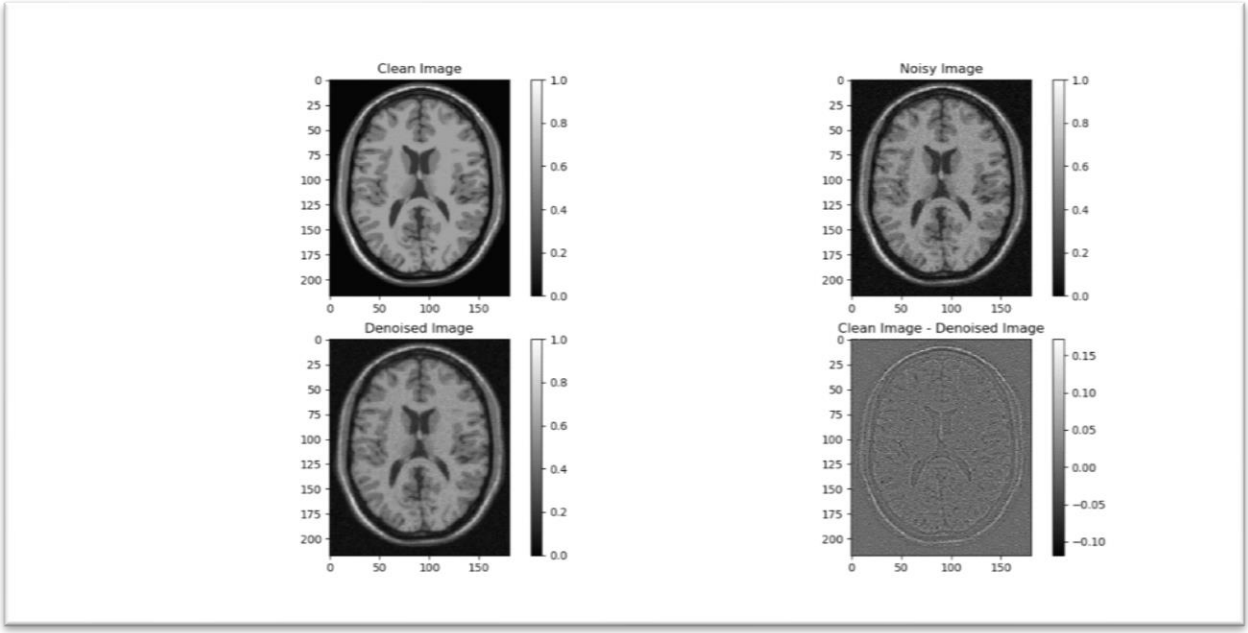


Noise Level: Medium

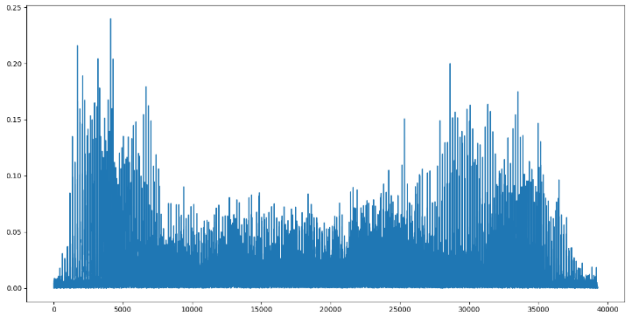
Assumed variance: 6×10^{-4}

a. The Relative Root Mean Square Error (RRMSE) between the denoised image and noiseless image is 0.114.
b. Optimal Parameters
    i. Beta (β): 0.8
    ii. For $\beta' = 0.8 \times \beta$, RRMSE: 0.114
    iii. For $\beta' = 1.2 \times \beta$, RRMSE: 0.119
    The difference was insignificant ($< 10^{-4}$)

c. Denoised Image
    i. Top Left: Noiseless Image
    ii. Top Right: Noisy Image
    iii. Bottom Left: Denoised Image
    iv. Bottom Right: Difference between Denoised and Noiseless Image



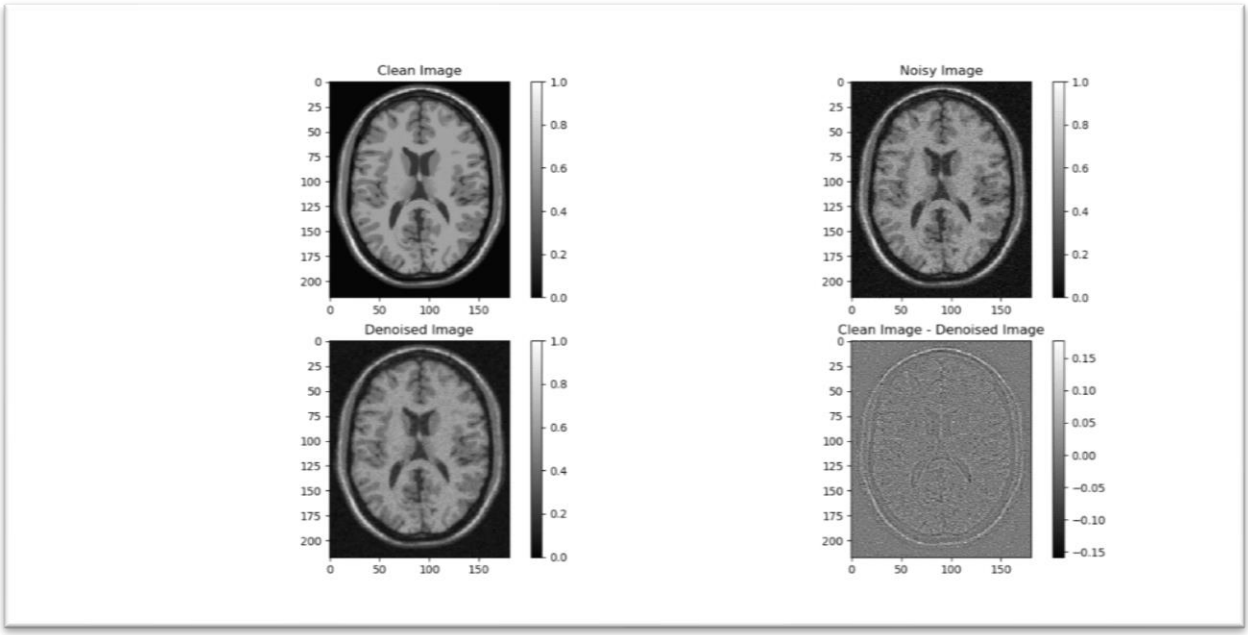
d. Plot of objective function vs iteration
This is after updating every pixel, 1 run



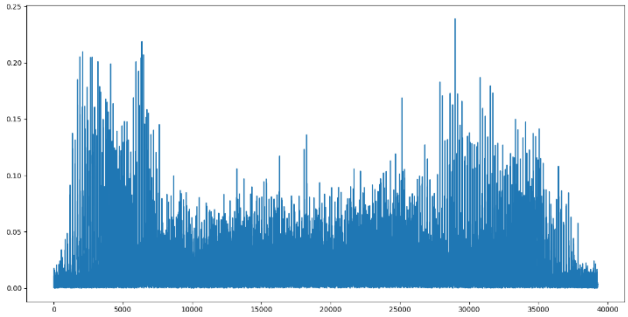
Noise Level: High

Assumed variance: 9×10^{-4}

a. The Relative Root Mean Square Error (RRMSE) between the denoised image and noiseless image is 0.122.
b. Optimal Parameters
    i. Beta (β): 0.9
    ii. For $\beta' = 0.8 \times \beta$, RRMSE: 0.123
    iii. For $\beta' = 1.2 \times \beta$, RRMSE: 0.131
c. Denoised Image
    i. Top Left: Noiseless Image
    ii. Top Right: Noisy Image
    iii. Bottom Left: Denoised Image
    iv. Bottom Right: Difference between Denoised and Noiseless Image



d. Plot of objective function vs iteration
This is after updating every pixel, 1 run

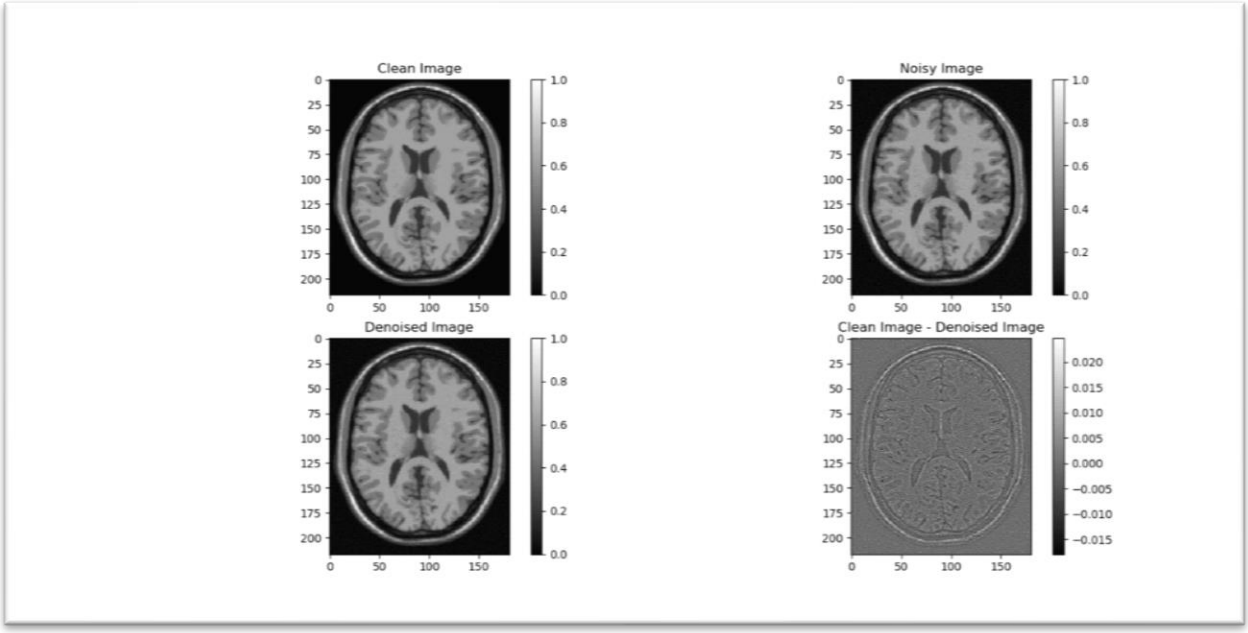


Prior: Discontinuity Adaptive

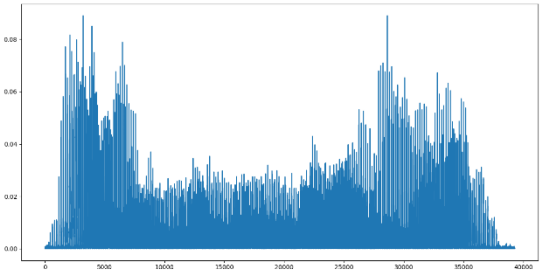
Noise Level: Low

Assumed variance: 4×10^{-4}

a. The Relative Root Mean Square Error (RRMSE) between the denoised image and noiseless image is 0.047.
b. Optimal Parameters
    i. (Beta, Gamma) (β, γ): $(0.8,\ 0.6)$
    ii. For $(\beta', \gamma) = (0.8 \times \beta, \gamma)$, RRMSE: 0.046
    iii. For $(\beta', \gamma) = (1.2 \times \beta, \gamma)$, RRMSE: 0.045
    iv. For $(\beta, \gamma') = (\beta, 0.8 \times \gamma)$, RRMSE: 0.045
    v. For $(\beta, \gamma') = (\beta, 1.2 \times \gamma)$, RRMSE: 0.046
c. Denoised Image
    i. Top Left: Noiseless Image
    ii. Top Right: Noisy Image
    iii. Bottom Left: Denoised Image
    iv. Bottom Right: Difference between Denoised and Noiseless Image



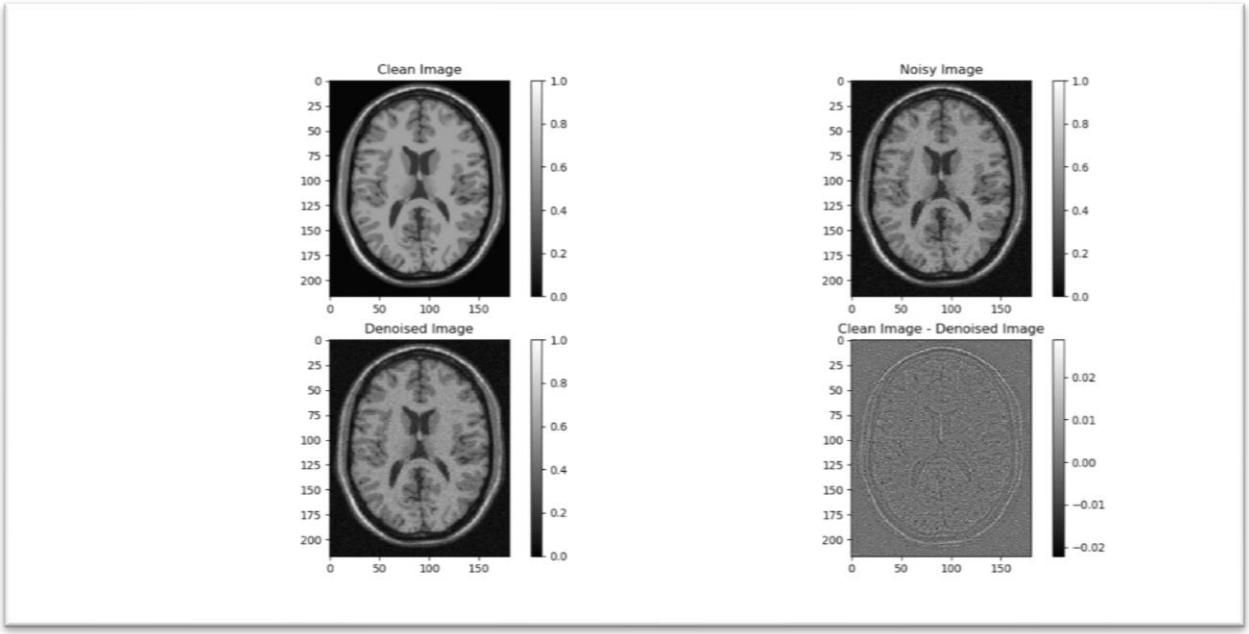
d. Plot of objective function vs iteration
This is after updating every pixel, 1 run



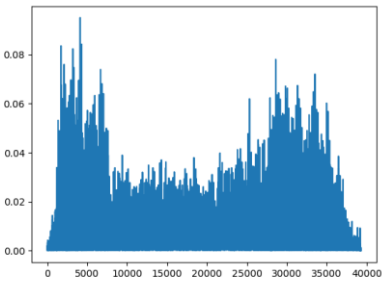
Noise Level: Medium

Assumed variance: 6×10^{-4}

a. The Relative Root Mean Square Error (RRMSE) between the denoised image and noiseless image is 0.118.
b. Optimal Parameters
    i. (Beta, Gamma) (β, γ): $(0.8,\ 0.6)$
    ii. For $(\beta', \gamma) = (0.8 \times \beta, \gamma)$, RRMSE: 0.124
    iii. For $(\beta', \gamma) = (1.2 \times \beta, \gamma)$, RRMSE: 0.116
    iv. For $(\beta, \gamma') = (\beta, 0.8 \times \gamma)$, RRMSE: 0.118
    v. For $(\beta, \gamma') = (\beta, 1.2 \times \gamma)$, RRMSE: 0.118
c. Denoised Image
    i. Top Left: Noiseless Image
    ii. Top Right: Noisy Image
    iii. Bottom Left: Denoised Image
    iv. Bottom Right: Difference between Denoised and Noiseless Image



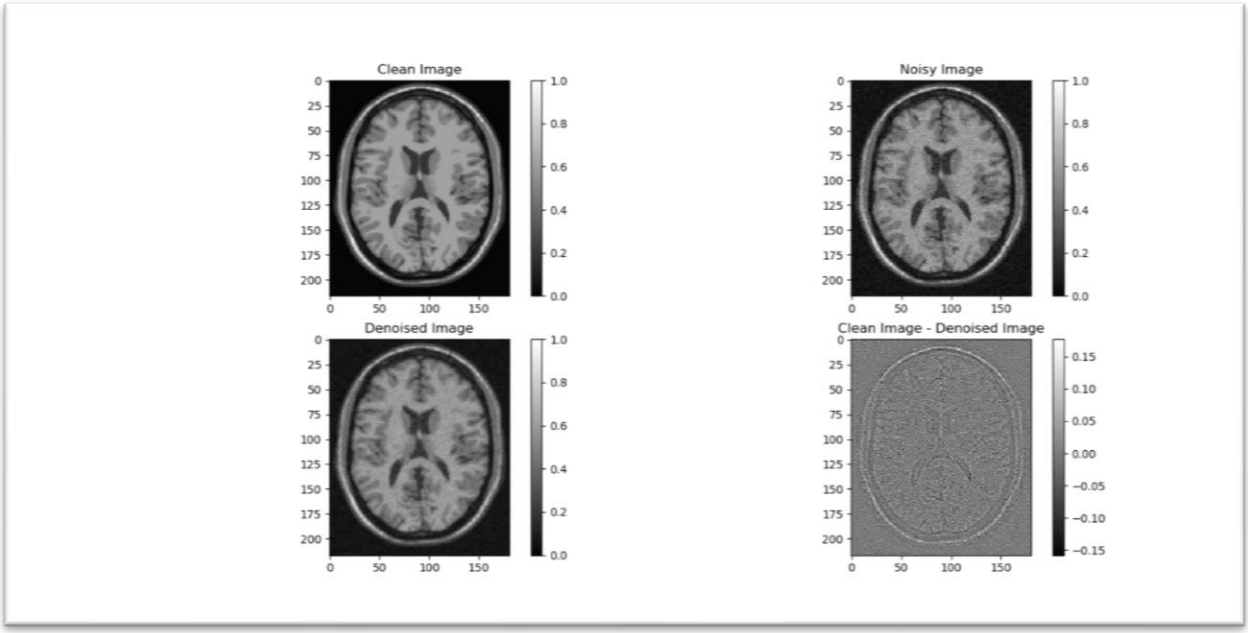
d. Plot of objective function vs iteration
This is after updating every pixel, 1 run



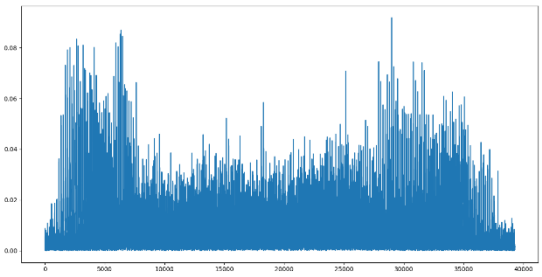
Noise Level: High

Assumed variance: 9×10^{-4}

a. The Relative Root Mean Square Error (RRMSE) between the denoised image and noiseless image is 0.135.
b. Optimal Parameters
    i. (Beta, Gamma) (β, γ): (0.8, 0.6)
    ii. For $(\beta', \gamma) = (0.8 \times \beta, \gamma)$, RRMSE: 0.14
    iii. For $(\beta', \gamma) = (1.2 \times \beta, \gamma)$, RRMSE: 0.132
    iv. For $(\beta, \gamma') = (\beta, 0.8 \times \gamma)$, RRMSE: 0.136
    v. For $(\beta, \gamma') = (\beta, 1.2 \times \gamma)$, RRMSE: 0.141
c. For $(\beta, \gamma') = (\beta, 1.2 \times \gamma)$, RRMSE: Denoised Image
    i. Top Left: Noiseless Image
    ii. Top Right: Noisy Image
    iii. Bottom Left: Denoised Image
    iv. Bottom Right: Difference between Denoised and Noiseless Image



d. Plot of objective function vs iteration
This is after updating every pixel, 1 run

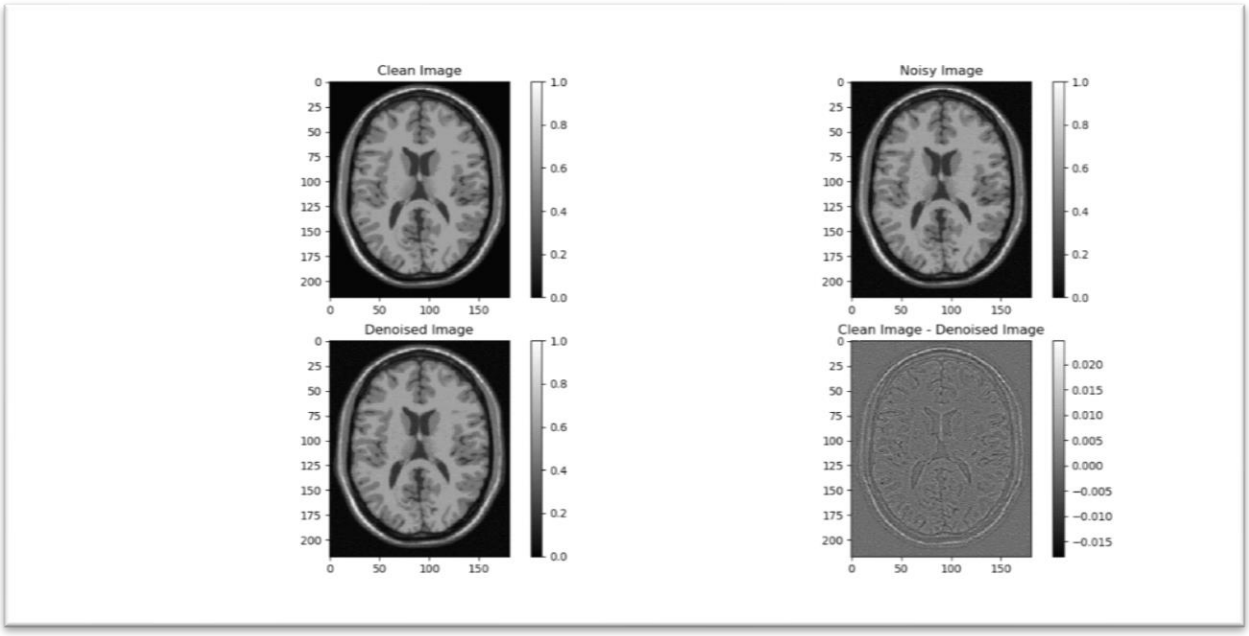


Prior: Discontinuity Adaptive Huber

Noise Level: Low

Assumed variance: 4×10^{-4}

a. The Relative Root Mean Square Error (RRMSE) between the denoised image and noiseless image is 0.046.
b. Optimal Parameters
    i. (Beta, Gamma) (β, γ): (0.8, 0.6)
    ii. For $(\beta', \gamma) = (0.8 \times \beta, \gamma)$, RRMSE: 0.051
    iii. For $(\beta', \gamma) = (1.2 \times \beta, \gamma)$, RRMSE: 0.046
    iv. For $(\beta, \gamma') = (\beta, 0.8 \times \gamma)$, RRMSE: 0.046
    v. For $(\beta, \gamma') = (\beta, 1.2 \times \gamma)$, RRMSE: 0.048
c. Denoised Image
    i. Top Left: Noiseless Image
    ii. Top Right: Noisy Image
    iii. Bottom Left: Denoised Image
    iv. Bottom Right: Difference between Denoised and Noiseless Image



d. Plot of objective function vs iteration
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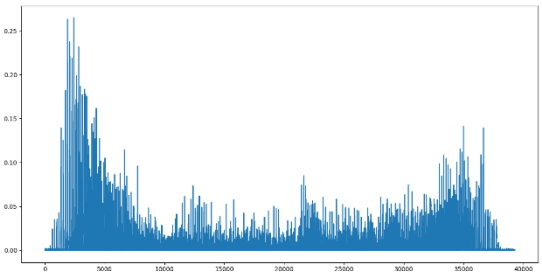

Noise Level: Medium

Assumed variance: 6×10^{-4}

a. The Relative Root Mean Square Error (RRMSE) between the denoised image and noiseless image is 0.118.
b. Optimal Parameters
    i. (Beta, Gamma) (β, γ): (0.8, 0.6)
    ii. For $(\beta', \gamma) = (0.8 \times \beta, \gamma)$, RRMSE: 0.121
    iii. For $(\beta', \gamma) = (1.2 \times \beta, \gamma)$, RRMSE: 0.117
    iv. For $(\beta, \gamma') = (\beta, 0.8 \times \gamma)$, RRMSE: 0.118
    v. For $(\beta, \gamma') = (\beta, 1.2 \times \gamma)$, RRMSE: 0.118
c. Denoised Image
    i. Top Left: Noiseless Image
    ii. Top Right: Noisy Image
    iii. Bottom Left: Denoised Image
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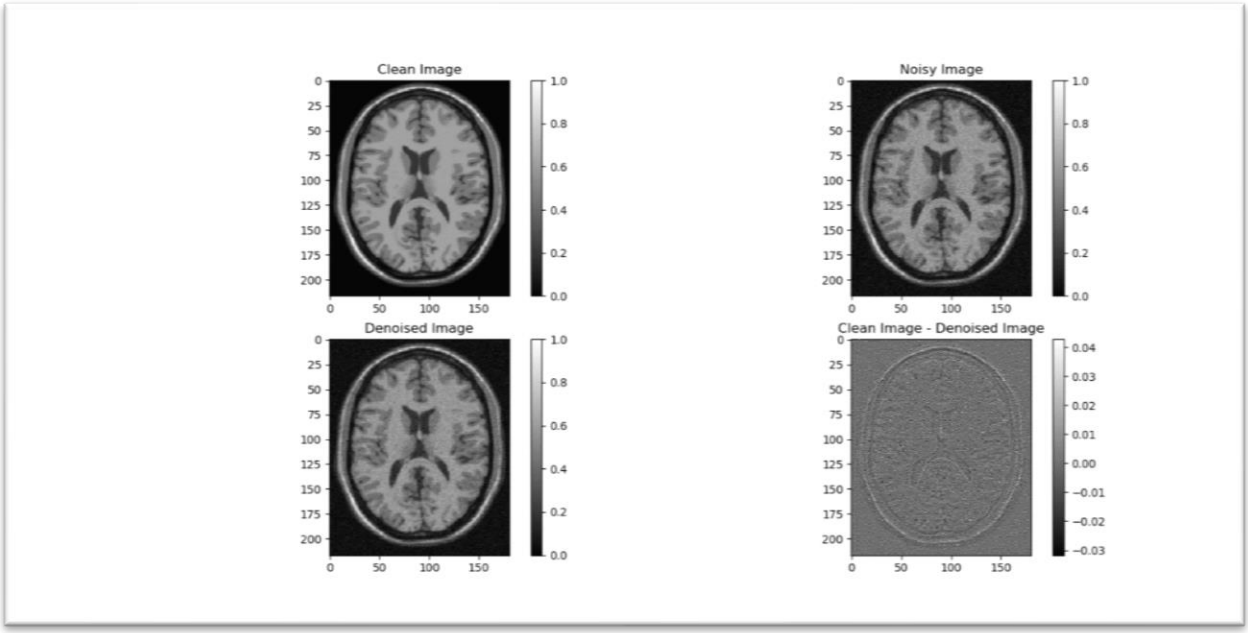

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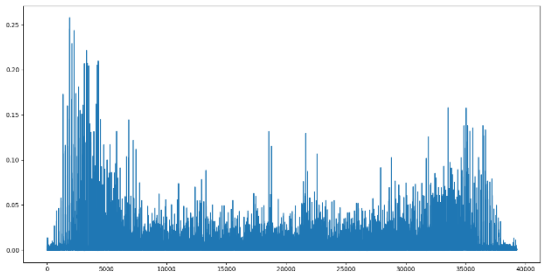
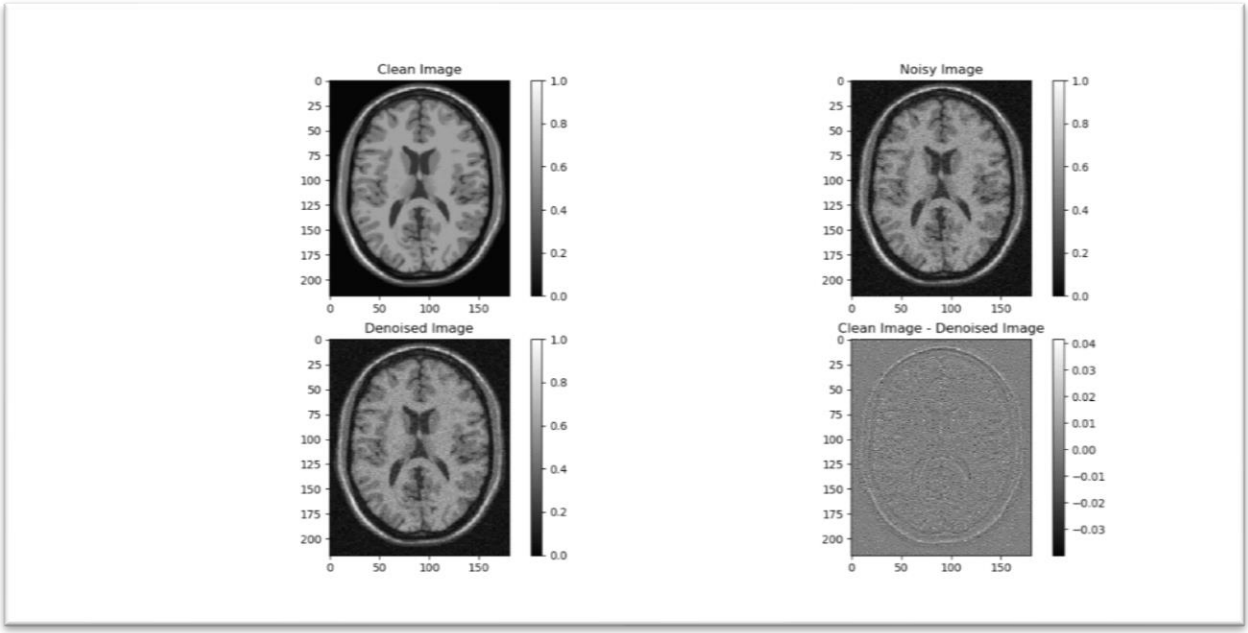


Noise Level: High

Assumed variance: 9×10^{-4}

a. The Relative Root Mean Square Error (RRMSE) between the denoised image and noiseless image is 0.132.
b. Optimal Parameters
    i. (Beta, Gamma) (β, γ): (0.8, 0.6)
    ii. For $(\beta', \gamma) = (0.8 \times \beta, \gamma)$, RRMSE: 0.138
    iii. For $(\beta', \gamma) = (1.2 \times \beta, \gamma)$, RRMSE: 0.132
    iv. For $(\beta, \gamma') = (\beta, 0.8 \times \gamma)$, RRMSE: 0.134
    v. For $(\beta, \gamma') = (\beta, 1.2 \times \gamma)$, RRMSE: 0.134
c. For $(\beta, \gamma') = (\beta, 1.2 \times \gamma)$, RRMSE: Denoised Image
    i. Top Left: Noiseless Image
    ii. Top Right: Noisy Image
    iii. Bottom Left: Denoised Image
    iv. Bottom Right: Difference between Denoised and Noiseless Image



d. Plot of objective function vs iteration
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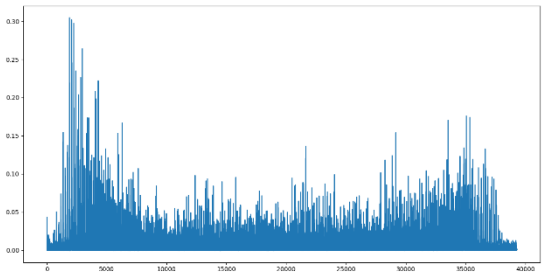
0.30
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