

Denoising of Computed Tomography Scans

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Abstract

ADMM Denoising was computed with three priors (TV, NLM, and BM3D) for three types of CT images (brain, lungs, and abdomen). Three noise parameters were used for each of two noise types - Gaussian and Poisson. Results indicated that the PSNR values ranged between 20 dB and 30 dB, with PSNR increasing as iteration increased and residuals decreasing as the iteration number increased. In both cases, lower noise corresponded to a higher PSNR and lower residual.



Figure 1: CT Image of Lungs of 41-Year Old Patient who tested positive for COVID-19

Background

Computed Tomography (CT) is a method used to generate cross-sectional images of a patient’s body. Specifically, it uses X-Rays that are beamed at and rotated around the patient’s body to generate a cross-sectional “slice”. Slices can provide insight into disease or injury; in particular, CT imaging has proven effective at detecting tumors or lesions in the abdominal and thoracic regions.

Selected References

[1] “Computed Tomography (CT).” National Institute of Biomedical Imaging and Bioengineering, U.S. Department of Health and Human Services, www.nibib.nih.gov/science-education/science-topics/computed-tomography-ct.

[2] Modica, Michael J., et al. “The Obese Emergency Patient: Imaging Challenges and Solutions.” RadioGraphics, 4 May 2011, pubs.rsna.org/doi/full/10.1148/rg.313105138.

[3] Wang, Jing, et al. “An Experimental Study on the Noise Properties of x-Ray CT Sinogram Data in Radon Space.” Physics in Medicine and Biology, U.S. National Library of Medicine, 21 June 2008, www.ncbi.nlm.nih.gov/pmc/articles/PMC2579780/.

Methods

To solve the problem of image reconstruction, we chose the method of Alternating Direction Method of Multipliers (ADMM) on a Radon-Transformed image with injected noise.

$$\begin{aligned} &\underset{\{x\}}{\text{minimize}} \quad \underbrace{\frac{1}{2} \| \mathbf{Ax} - \mathbf{b} \|_2^2}_{f(x)} + \underbrace{\lambda \Gamma(\mathbf{z})}_{g(z)} \\ &\text{subject to} \quad \mathbf{Kx} - \mathbf{z} = 0 \end{aligned}$$

We use three priors to reconstruct the original image:

- Total Variation (TV) Prior
- Non-Local Means (NLM) prior
- Block Matching and 3D Filtering (BM3D) Prior.

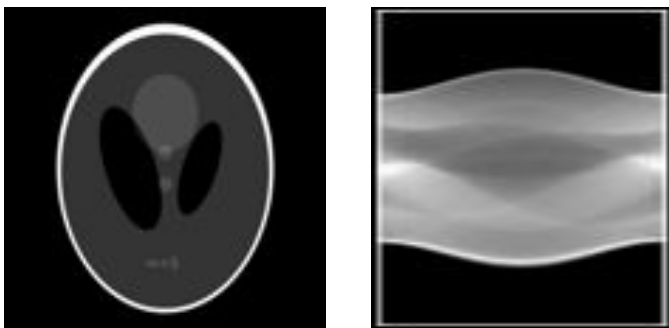


Figure 2. Schepp-Logan Image and Radon-Transformed CT Image

We used three types of CT images (brain, lungs, and abdomen), Poisson & Gaussian noise, and three noise levels. For Gaussian noise, we chose $\sigma = 3, 5$, and 7 . For Poisson noise, we chose $\lambda = 5, 10, 20$.

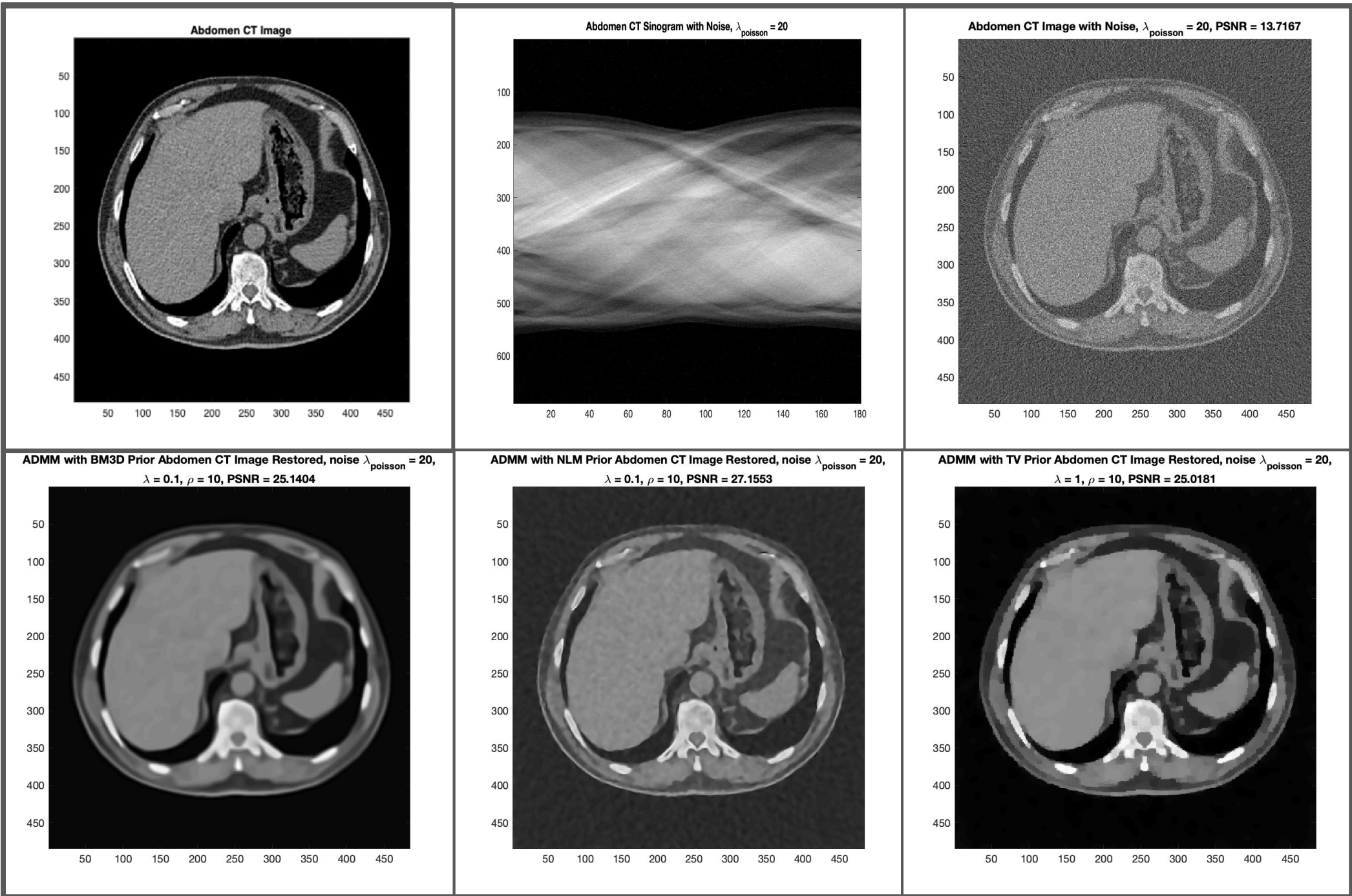
Conclusion

We were able to successfully denoise noisy CT images of the brain, lungs, and abdomen. PSNRs for all of the resulting images ranged between ~20 dB and ~30 dB. Of the three types of images, we found that we were able to denoise the lungs best. Additionally, the ADMM + NLM pairing performed best. It is expected that NLM performs better than TV; BM3D performed about as well as TV. Finally as expected, we found that PSNR increased as iteration increased and the residuals decreased as the iteration number increased. One critical finding is that NLM is the best technique for CT denoising, as the reconstructed image preserves the texture of the original image, enabling detection of lesions. With TV and BM3D reconstruction, the reconstructed image is more blocky, making it harder to detect irregularities.

Results

Figure 3. (Clockwise):

The original spatial image of the abdomen, the CT transformed sinogram of the abdomen with noise, the abdomen with injected noise transformed back to the spatial domain, ADMM + TV reconstruction, ADMM + NLM reconstruction, and ADMM + BM3D reconstruction



Abdomen CT Image (NLM)		
Noise Type	Noise Level	PSNR (dB)
G	$\sigma = 3$	27.9
G	$\sigma = 5$	26.8
G	$\sigma = 7$	24.4
P	$\lambda = 5$	28.2
P	$\lambda = 10$	27.9
P	$\lambda = 20$	27.2