# A Noise Preserving Sharpening Filter for CT Image Enhancement

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**Goal:** To sharpen X-ray CT images while maintaining the desired texture

## Challenges

- Noise-resolution trade-off
  - ↑ resolution ⇔ ↑ noise
- CT images are noisy
  - \+ ↓ patients' radiation exposure

## Peek into literature

*State-of-the-art*

Convolutional Neural Networks

*How to get training pairs?*

Ground truth (GT) :
noise-free high-resolution image

Input: Blurred ground truth

*Trends to tackle noise*

Noise in training pairs

| | No-Noise Sharpener | Denoising Sharpener |
|---|---|---|
| Input | Low | High |
| Ground truth | Low | Low |
| Function | Sharpening | Sharpening + Denoising |

Substantially increases noise and artifacts for noisy input

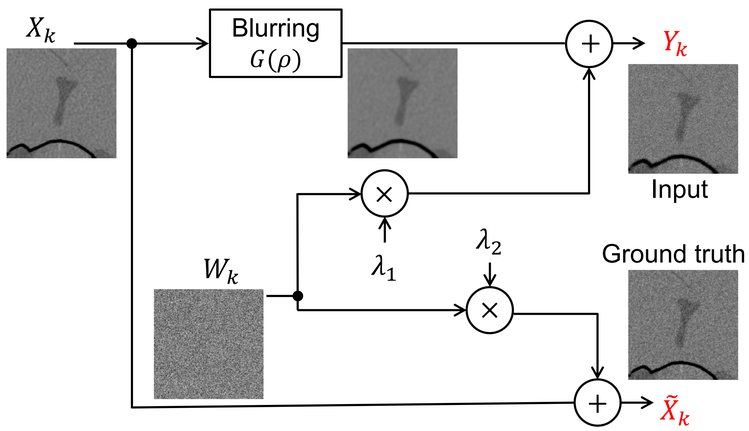
Sharpened images lack *radiologists-preferred* texture

## Our solution

*Noise Preserving Sharpening Filter (NPSF)*

- Generates training pairs, $(Y_k,\ \tilde{X}_k)$, that both account for noise in the input image

*NPSF Training Pairs*




*How to decide $\lambda_1$ and $\lambda_2$?*

$$\lambda_1 = \alpha\sqrt{\frac{\sigma^2_{input}}{\sigma^2_w}}$$

$\alpha = 1$ → noise std in the training input matches the noise std anticipated in the application

$$\lambda_2 = \beta\lambda_1$$

$\beta$ is tuned to meet the noise preserving condition

$X_k$: noise-free high-resolution sample

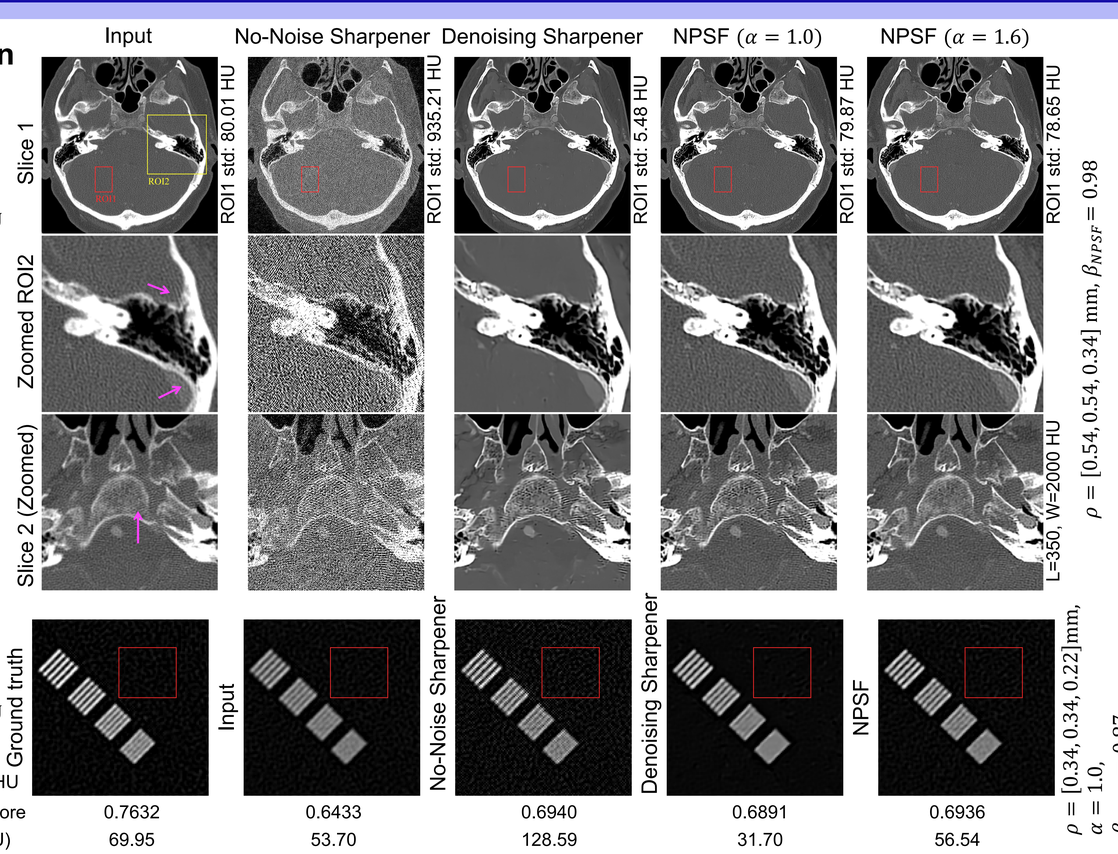
$W_k$: noise sample with desirable texture and variance $\sigma_w^2$

$G(\rho)$: Gaussian filter of standard deviation $\rho = [\rho_x, \rho_y, \rho_z]$

$\sigma^2_{input}$: noise variance of input anticipated in the application

## Evaluation

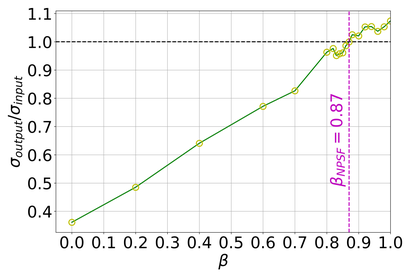
Test Data:
Exam 1 (Clinical),
$\sigma_{input} = 74.63$ HU




| | Ground truth | Input | No-Noise Sharpener | Denoising Sharpener | NPSF |
|---|---|---|---|---|---|
| Resolution score | 0.7632 | 0.6433 | 0.6940 | 0.6891 | 0.6936 |
| ROI std (HU) | 69.95 | 53.70 | 128.59 | 31.70 | 56.54 |

**Noise-resolution trade-off in the sharpened results is controlled by hyperparameters $\beta,\ \rho,\ \alpha$.**

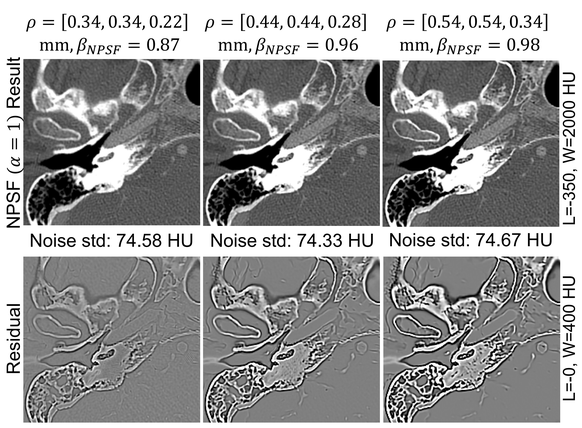
↓ β ⟹ ↓ noise



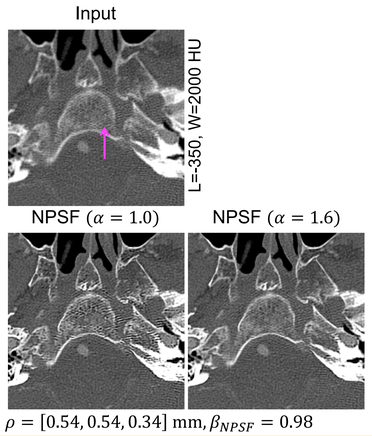

$\rho = [0.34, 0.34, 0.22], \alpha = 1.0$

Test Data: Exam 1, $\sigma_{input} = 74.63$ HU

↑ ρ ⟹ ↑ sharpness




↑ α ⟹ ↓ aliasing artifacts




**Conclusion:** We proposed NPSF that preserves noise texture and level in the input image while sharpening, and thereby

✓ Produces favorable texture in sharpened images ✓ Preferred by radiologist because of consistent noise levels ✓ Can be employed for any machine learning algorithm