Guided Noise Reduction for Spectral CT with Energy-Selective Photon Counting Detectors

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Introduction

- **Spectral CT** facilitates the **quantitative measurement** of **material properties** in X-ray CT.
- Popular diagnostic applications are bone removal, measurement of blood volume in the lung or quantification of contrast agent concentrations (e.g., in the myocardium).
- Spectral CT data can be acquired using **energy-selective photon counting detectors** [1]. The energy-selective detectors assign incoming photons to energy bins (Fig. 1).
- However, especially bins covering only the low energy portion of the spectrum energy distribution are **corrupted by noise**. Therefore noise reduction is required to obtain appropriate image quality at clinically acceptable dose levels.

Materials and Methods

- We apply **joint bilateral filtering** (JBF) [2] for computationally fast edge preserving noise reduction in projection space and in image space after FBP reconstruction.
- The JBF is a variant of the bilateral filter, where the edge preservation is controlled by a **guidance image**:

$$I'(\mathbf{x}) = \frac{\sum_{\mathbf{o}\in\mathcal{N}_\mathbf{x}} I(\mathbf{x}+\mathbf{o})\mathcal{W}(\mathbf{x},\mathbf{o})}{\sum_{\mathbf{o}\in\mathcal{N}_\mathbf{x}} \mathcal{W}(\mathbf{x},\mathbf{o})}$$

I Input image; I' Filtered image; I^G Guidance image; $\mathcal{N}_\mathbf{x}$ Spatial neighborhood

$$\mathcal{W}(\mathbf{x},\mathbf{o}) = \mathcal{G}_{\sigma^S}(\mathbf{x}-\mathbf{o}) \cdot \mathcal{G}_{\sigma^R}\left(I^G(\mathbf{x}) - I^G(\mathbf{x}+\mathbf{o})\right)$$

Spatial and range closeness weighting

$$\mathcal{G}_\sigma(\mathbf{z}) = \exp\left(-0.5 \cdot \|\mathbf{z}\|_2^2 / \sigma^2\right)$$

Gauss kernel

- To exploit the complete spectral information for the edge preservation, the guidance image is formed by the **sum over all spectral bins**.

$$I^G(\mathbf{x}) = \sum_{b=1}^{B} I_b(\mathbf{x})$$

In projection space an equally weighted sum is used, which inherently includes an uncertainty weighting as the signal-to-noise ratio is proportional to the number of measured photons.

$$f^G(\mathbf{y}) = \sum_{b=1}^{B} \frac{f_b(\mathbf{y})}{\sigma_b^2}$$

In image space the reconstructed bins are combined by an inverse variance weighting.

- For evaluation we simulated a static instance of the human heart using the **CONRAD** framework [3] (Fig. 2).

Results and Discussion

- Fig. 3 shows that combined JBF in projection and image space could **restore low-contrast heart chambers** in the very noisy bin 1.
- Tab. 1 shows that JBF does **not significantly increase structural similarity** between bins. Thus only **little cross-talk** between the channels is introduced.

Conclusions

- We created a **joint bilateral filter** for **energy-selective detectors** with encouraging first results.
- The SNR was improved from 3.3 to 72.3, while a low rRMSE is preserved and only little cross-talk between the channels is introduced.

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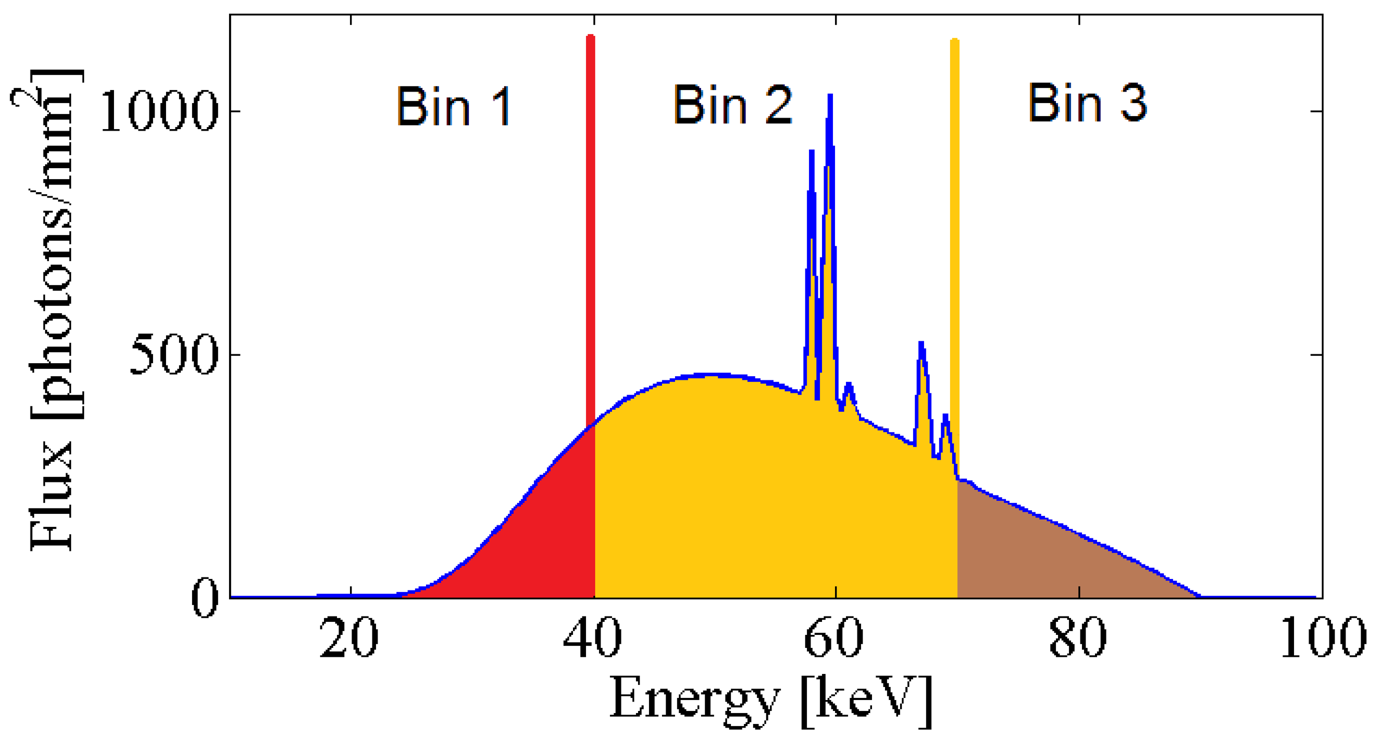
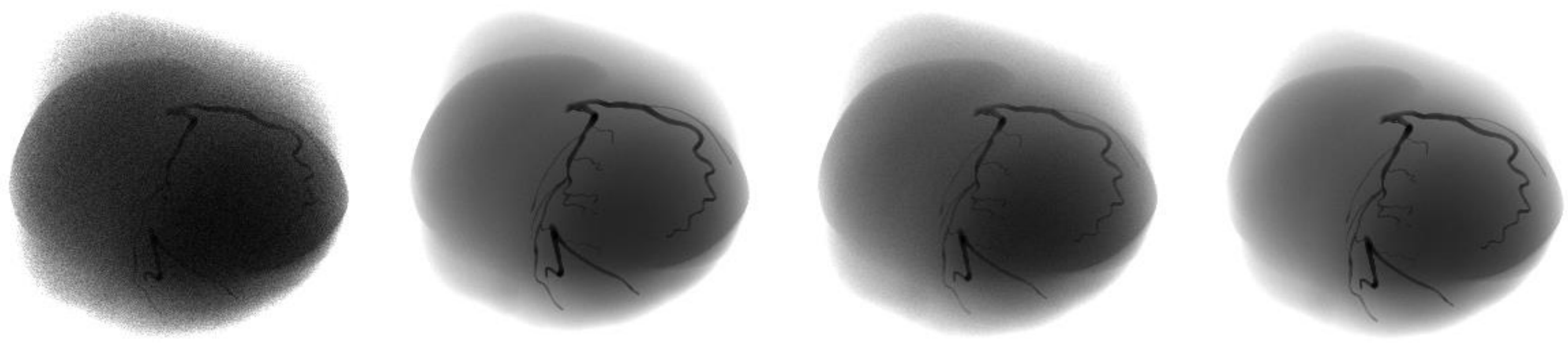


Fig. 1: Binning of an X-ray spectrum into 3 bins.

Simulation of a static human heart:

Phantom description: The heart chambers consist of water (1.06 g/cm³), heart muscle (1.05 g/cm³) and coronary arteries filled with Iopromide (1.40 g/cm³). Poisson noise was simulated assuming I0_1 = 948, I0_2 = 28982, and I0_3 = 10103 arriving photons per mm² at the corresponding detector bins in the un-attenuated case. We simulated 495 projections over an angular range of 200 degrees.



(a) Bin 1 (b) Bin 2 (c) Bin 3 (d) Guidance image

Fig 2: Energy-selective projection images and guidance image.

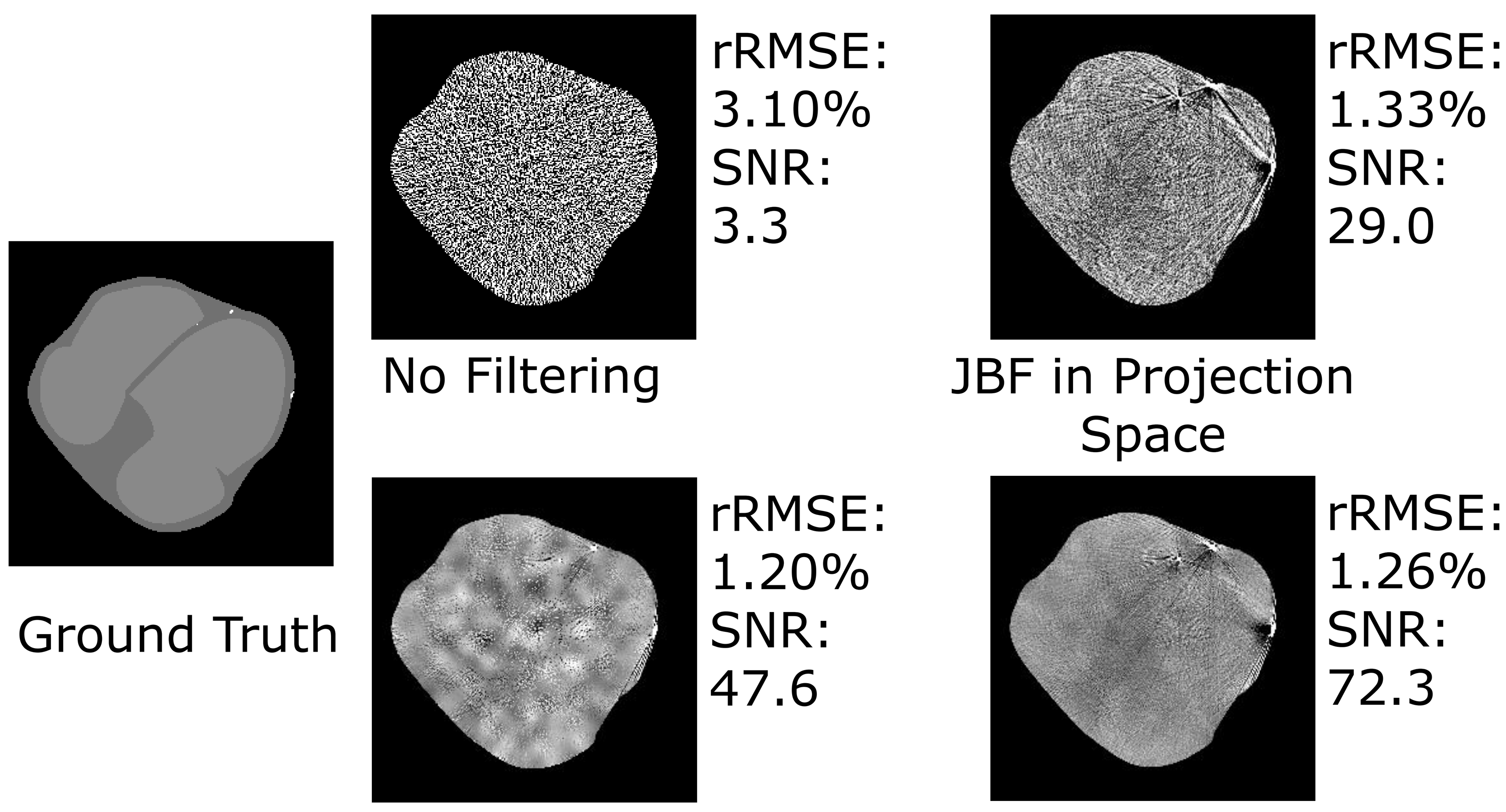


Fig 3: Comparison between the different filtering methods in the central slice of Bin 1 [10, 110 HU].

Image	GT Bin 1	GT Bin 2	GT Bin 3	Bin 2	Bin 3
Ground truth (GT) Bin 1	1.0 (1.0)	0.78 (0.97)	0.62 (0.99)	0.78 (0.97)	0.62 (0.99)
No Filtering Bin 1	0.95 (0.91)	0.67 (0.87)	0.52 (0.91)	0.69 (0.90)	0.56 (0.92)
JBF Bin 1	0.98 (0.98)	0.76 (0.95)	0.60 (0.98)	0.79 (0.99)	0.64 (0.99)
ID-JBF Bin 1	0.98 (0.98)	0.75 (0.95)	0.60 (0.98)	0.78 (0.98)	0.64 (0.99)
JBF + ID-JBF Bin 1	0.98 (0.98)	0.76 (0.65)	0.60 (0.98)	0.79 (0.99)	0.64 (0.99)

Tab 1: Structural similarity and linear correlation (in brackets) for the different filtering methods.

References

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