Projection-based Denoising Method for Photon-Counting Energy-Resolving Detectors

Yanye Lu[1,5], Michael Manhart[1,3], Oliver Taubmann[1,4], Tobias Zobel[1], Qiao Yang[1], Jang-hwan Choi[2], Meng Wu[2], Arnd Doerer[3], Rebecca Fahrig[2], Qiushi Ren[5], Joachim Hornegger[1,4], Andreas Maier[1,4]

[1] *Pattern Recognition Lab, Department of Computer Science, Friedrich-Alexander University Erlangen-Nuremberg, Erlangen, Germany*
[2] *Department of Radiology, Stanford University, CA, USA*
[3] *Department of Neuroradiology, University Hospital Erlangen, Germany*
[4] *Erlangen Graduate School in Advanced Optical Technologies (SAOT), Friedrich-Alexander University Erlangen-Nuremberg, Erlangen, Germany*
[5] *Department of Biomedical Engineering, Peking University, Beijing, China*

FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG
TECHNISCHE FAKULTÄT

SAOT erlangen graduate school in advanced optical technologies

SIEMENS

Introduction

Polychromatic X-ray sources are commonly employed for medical Computed Tomography (CT). However, most of them are processed as mono-energetic CT measurements by conventional CT detectors which can not take advantage of the energy information in the X-ray beam.

Photon-counting detectors are able to detect each photon individually. In the energy-resolving case, we get more than a single measurement per pixel, as shown in Fig. 1.

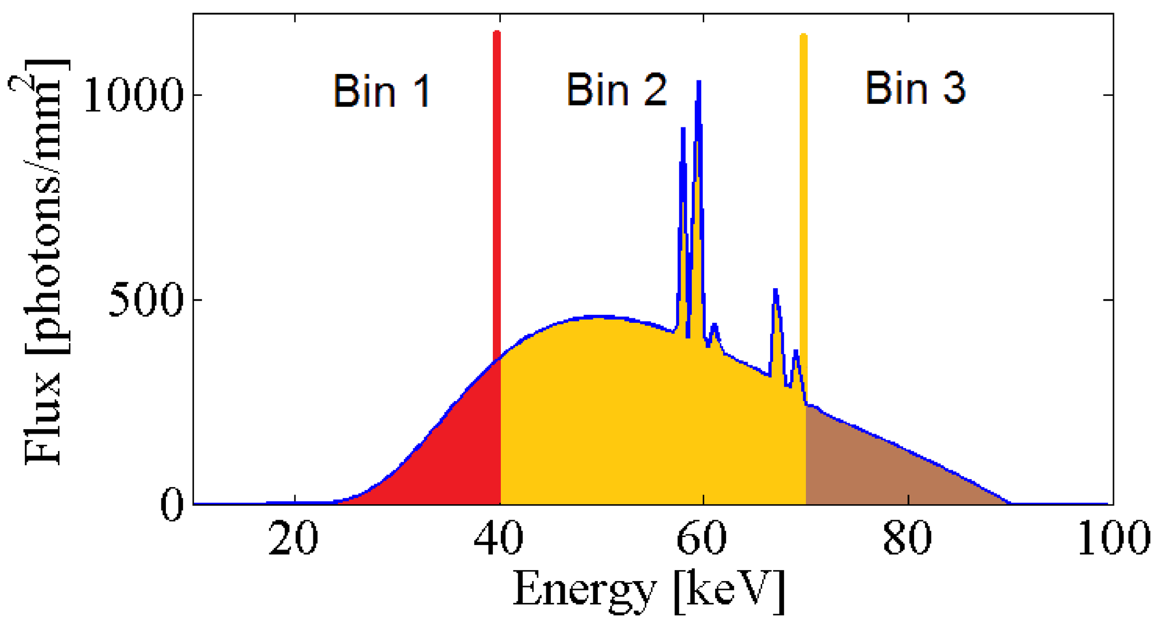

Fig. 1: Binning of a X-ray spectrum into 3 bins

It is worth mentioning that the noise from photon-counting energy-resolving detectors can be modeled by using Poisson statistics accurately and easily, which is a great advantage in projection based denoising processing. In this project, We presented a novel approach for noise reduction of energy-resolved projection images as well as simulated results.

Noise Reduction with Joint Bilateral Filtering

To obtain an image with distinct structures and reduced noise, we summate the photons of all energy-selective projection images I_b to recover the projection image I covering the full energy spectrum:

$$I = \sum_{b=1}^{B} I_b$$

We use I as a guidance image for a joint bilateral filter (JBF) [1] to compute energy-selective projection images I_b' with reduced noise but preserved structures:

$$I_b'(x,y) = \frac{1}{c(x,y)} \sum_{i,j} g_s(x,i,y,j)\, g_I(x,i,y,j) I_b(x,y)$$

$$c(x,y) = \sum_{i,j} g_s(x,i,y,j)\, g_I(x,i,y,j)$$

$$g_s(x,i,y,j) = e^{-\frac{(x-i)^2+(y-j)^2}{2\sigma_s}}$$

$$g_I(x,i,y,j) = e^{-\frac{(I(x,y)-I(i,j))^2}{2\sigma_I}}$$

Where $g_s(x,i,y,j)$ is the spatial kernel controlled by σ_s and $g_I(x,i,y,j)$ is the range kernel controlled by σ_I and the guidance image I.

The range kernel is configured such that a certain contrast difference D is preserved:

$$D = I_1 - I_2 = I^0 e^{-\mu^{bg} l^{bg}} - I^0 e^{-(\mu^{bg} l^{bg})-(\mu^{v} l^{v})} = I_1 z,$$

Where The X-ray absorption μ^{bg} and the path length l^{bg} correspond to the anatomic background, while μ^{v} and l^{v} define absorption and path length corresponding to a contrast agent filled vessel.

The parameter z is only dependent on the vessel size and material. Note that z can be conveniently computed as $z = 1 - \frac{I_2}{I_1}$. This leads to a contour adaptive definition of the bilateral filter with $\sigma_I = \bar{I}(x,y) \cdot z$, where $\bar{I}(x,y)$ is the mean value of the guidance image in a local neighborhood.

Experimental Setup and results

We simulated a set of fluoroscopic images using an append buffer based rendering procedure [2] using XCAT. An X-ray spectrum with the same half layer values as a commercially available C-arm system is used. Projection size was simulated with 620×480 pixels with a pixel size of 0.6 × 0.6 mm. The peak-voltage was set to 90 kV. We applied a time current product of 2.5 mAs, which is comparable to the dose setting per projection in a clinical 3D scan. The projection was centered around the heart to focus on the coronary arteries, which were filled with an iodine-based contrast medium (comparable to Ultravist 370). Energy-dependent X-ray absorption coefficients for elemental data and compounds such as bone were obtained from the NIST database. All methods were implemented in the CONRAD framework [3].

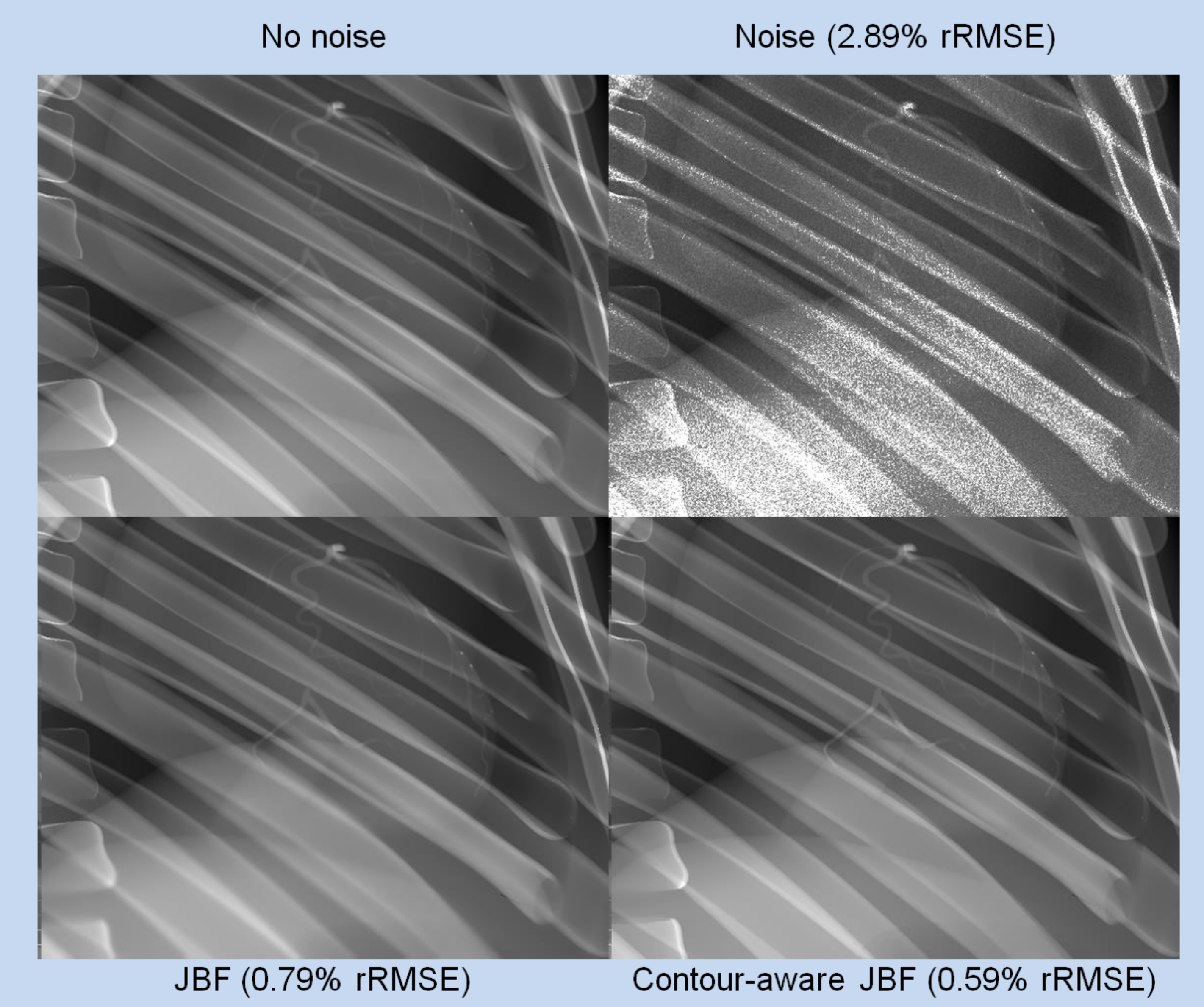

Fig. 2: Line integral images with and without noise (top row) and after restoration using JBF filtering (bottom row).

Figure 2 displays the simulated images of the first energy channel with and without noise. The relative root mean square error (rRMSE) that is normalized with the maximal intensity in the noise-free image is reduced from 2.89% to 0.59%. Note that the rRMSE was only evaluated at pixels that did not suffer from photon starvation (excessive white noise) in the noisy image, while all pixels were considered for the JBF denoised images.

Conclusions

We presented a novel approach for noise reduction of energy-resolved projection images. The idea of a contour-aware joint bilateral filtering to energy-resolving detectors is applied in this study, which could reduce noise but well preserve edges and structures. As shown in the result, denoising with JBF and contour-aware JBF is very successful, which could reduce noise by 80% while at the same time preserving edges and structures well. We will apply this method to realistic data in the future work and explore potential clinical applications.

References

[1] Petschnigg G, Szeliski R, Agrawala M, Cohen M, Hoppe H, Toyama K. Digital photography with flash and no-flash image pairs. ACM Transactions on Graphics (TOG). 2004;23(3):664{672.

[2] Maier A, Hofmann HG, Schwemmer C, Hornegger J, Keil A, Fahrig R. Fast simulation of X-ray projections of spline-based surfaces using an append buffer. Physics in Medicine and Biology. 2012 10;57(19):6193{6210.

[3] Maier A, Hofmann H, Berger M, Fischer P, Schwemmer C, Wu H, et al. CONRAD - A software framework for cone-beam imaging in radiology. Medical Physics. 2013;40(11):111914-1-8.

Contact
✉ yanye.lu@fau.de http://www5.cs.fau.de/~lu

The authors gratefully acknowledge funding by Siemens AG, Healthcare Sector and funding of the Medical Valley national leading edge cluster, Erlangen, Germany, diagnostic imaging network, sub-project BD 16, research grant nr. 13EX1212G.