Polychromatic Maximum Likelihood Reconstruction for Talbot-Lau X-ray Tomography

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Introduction

Polychromatic artifacts in Talbot-Lau tomography due to energy dependence of

- **Material:** Attenuation coefficient $\mu(E)$, refractive decrement $\delta(E)$ [1], and scatter coefficient $\sigma(E)$ [2]
- **Talbot-Lau interferometer:** Spectrum $\mathrm{N}_0(E)$, spectral visibility $V_0(E)$ and energy dependent reference phase $\phi_0(E)$

Clinical application requires beam hardening correction

Materials and Methods

- Goal**:** Simultaneous reconstruction [3] of attenuation, phase and scatter coefficients **inherently** removing polychromatic artifacts
- Estimate phase-stepping data (Fig. 1) seen by pixel i at G_2 stepping position s

$$N_{i,s} = \int \mathrm{d}E \;\; N_i(E) \cdot (1 + V_i(E) \cdot \cos\phi_{i,s}(E))$$

with

$$N_i(E) = N_i^0(E) \cdot T_i(E)$$
$$V_i(E) = V_i^0(E) \cdot D_i(E)$$
$$\phi_{i,s}(E) = \phi_i^0(E) + \phi_s + \Delta\phi_i(E)$$

- Reference images $\mathrm{N}_i^0(E)$, $\phi_i^0(E)$, and $V_i^0(E)$ obtained using wave propagation simulation (Fig. 2)
- Attenuation $T_i(E)$, differential phase $\Delta\phi_i(E)$, and dark-field $\mathrm{D_i}(E)$ at energy E given by

$$T_i(E) = \exp\left(-\textstyle\sum_j M_{ij} \cdot \mu_j(E)\right)$$
$$D_i(E) = \exp\left(-\textstyle\sum_j M_{ij} \cdot \sigma_j(E)\right)$$
$$\Delta\phi_i(E) = \textstyle\sum_j M_{ij}^{\delta} \cdot \delta_j(E)$$

- System matrix elements M_{ij} and M_{ij}^{δ} calculated by integration over footprint of Kaiser-Bessel function (Fig. 3)
- $\mu(E)$, $\delta(E)$, and $\sigma(E)$ extrapolated using a physical model
- Minimization of negative log-likelihood

$$l(\theta \mid \mathbf{N}) = \textstyle\sum_{i,s} -N_{i,s} \cdot \ln(\overline{N}_{i,s}) + \overline{N}_{i,s}$$

Results and Discussion

- Synthetic CT data affected by polychromatic effects generated from well-defined phantom using proposed forward model (Fig. 4)
- Reconstruction removes polychromatic artifacts (Fig. 5)
- Slow convergence of phase-image

Conclusions

- Reconstruction method for Polychromatic Talbot-Lau imaging
- Experiments with synthetic phantom show strong artifact reduction
- Efficient optimization method for phase-image required
- Further experiments with real data in progress

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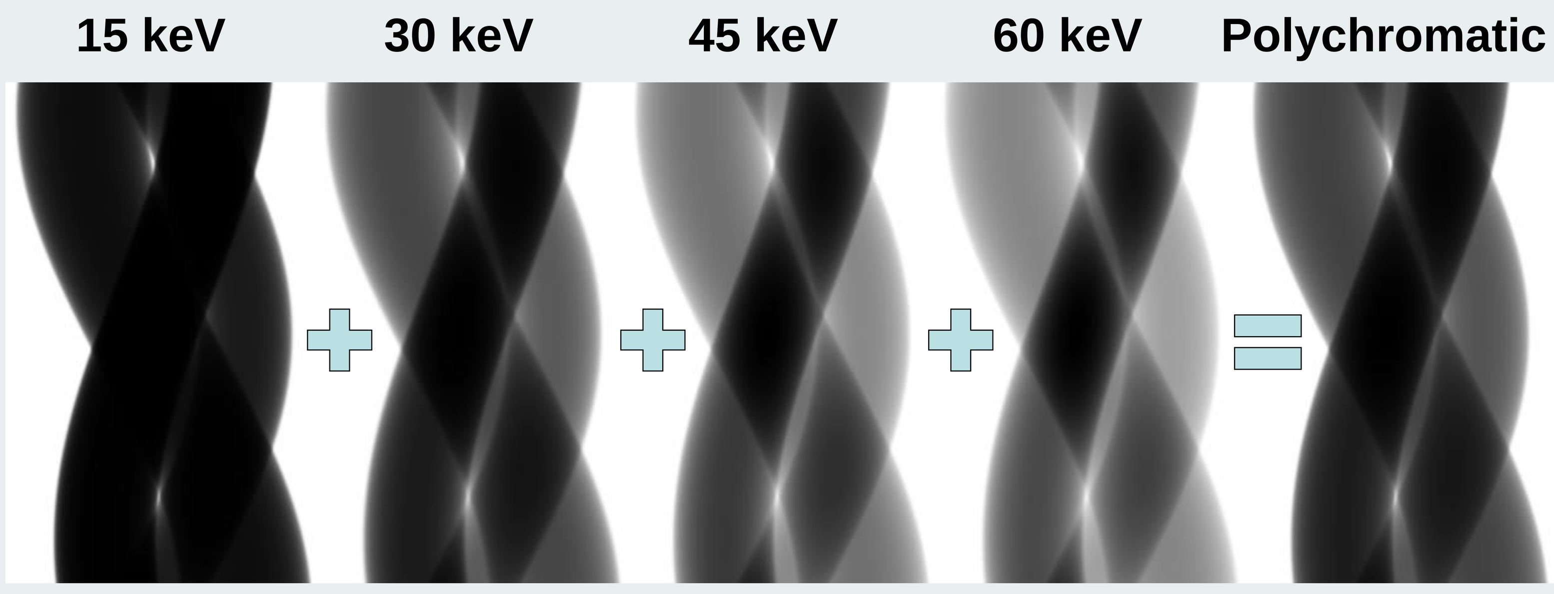


Figure 1: Superposition of mutually independent forward projections for phase-stepping data (here shown for phase step 0) at different energies result in the expected phase-stepping data in a polychromatic setup.

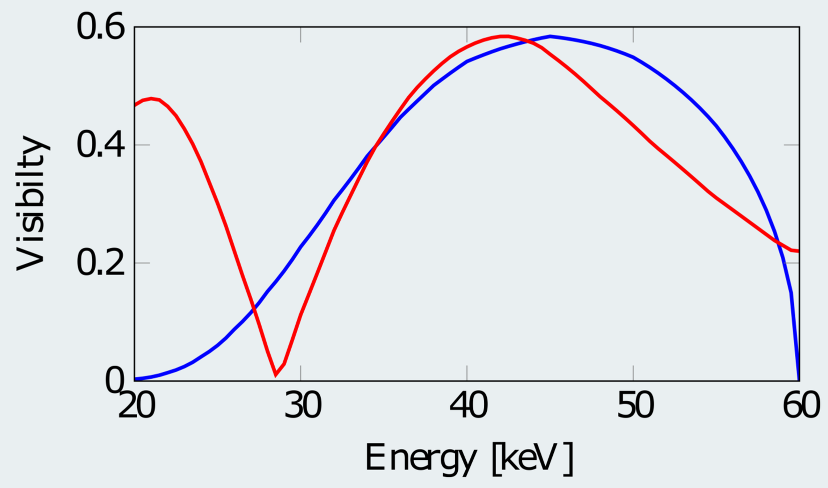


Figure 2: Spectral visibility and X-ray spectrum for the interferometer used in the evaluation.

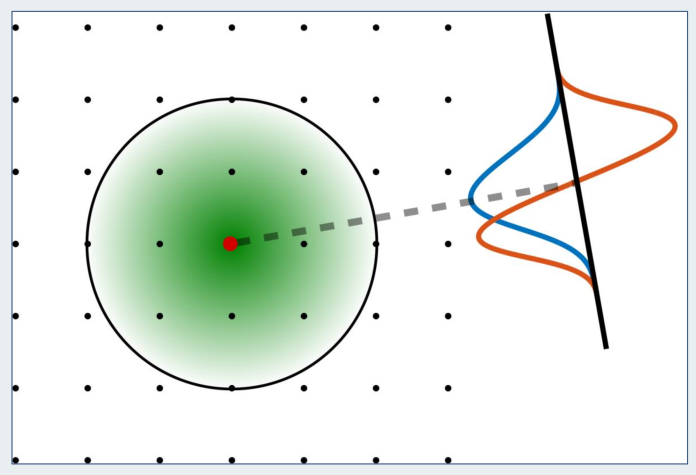


Figure 3: (Differential) footprint of Kaiser-Bessel function.

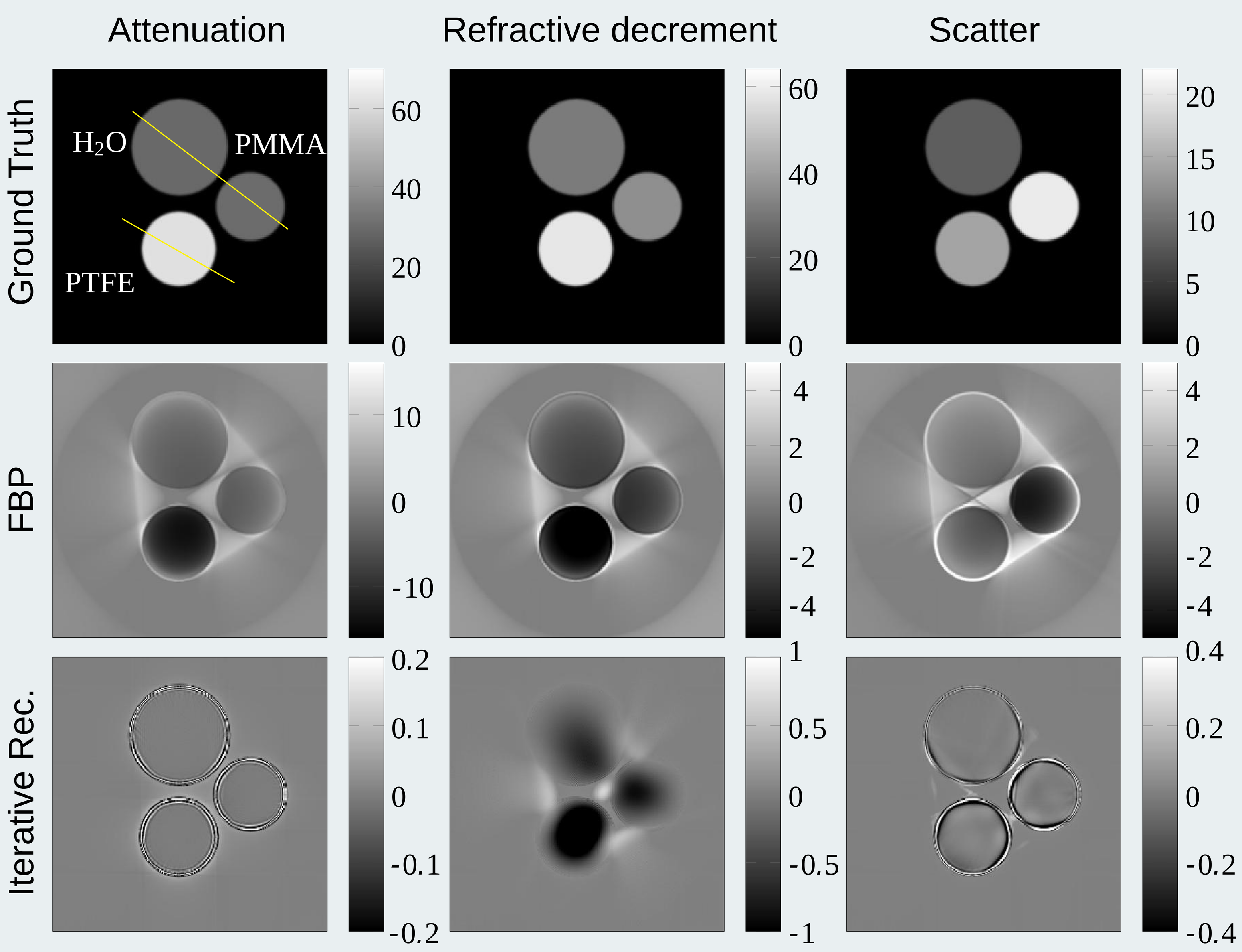
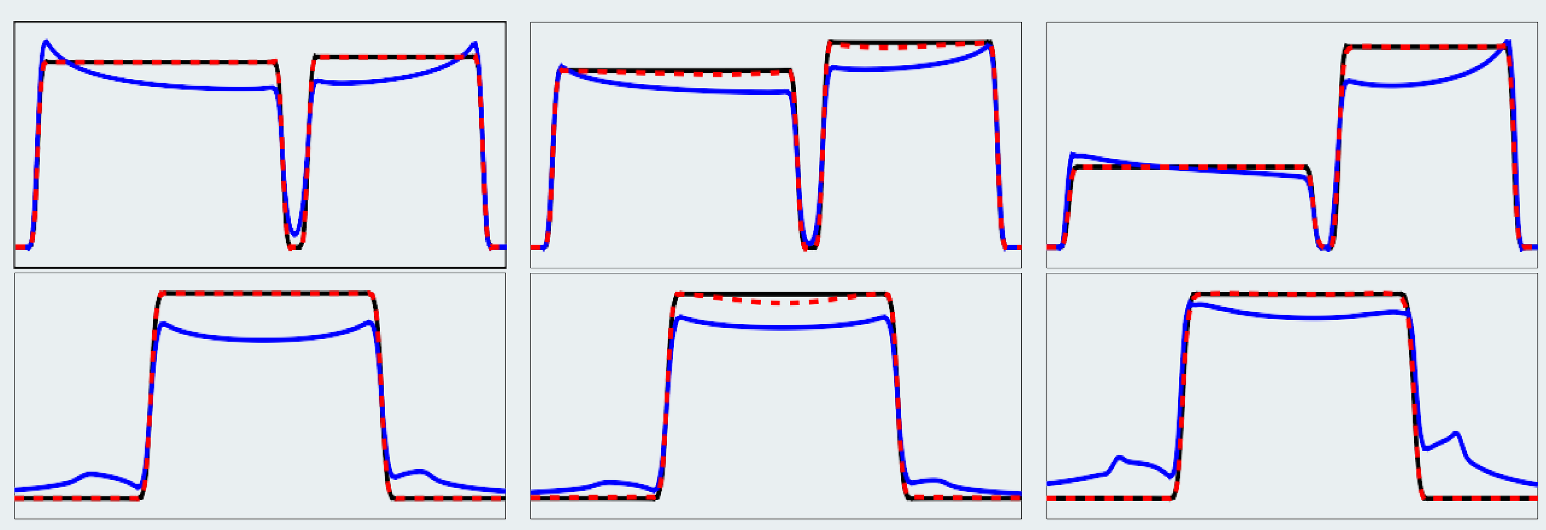


Figure 4: First row: ground truth data. Second row: reconstruction error using filtered backprojection. Third row: reconstruction error with proposed iterative method and polychromatic forward model.



(a) Attenuation (b) Refractive decrement (c) Scatter

Figure 5: Two cross-sections through the reconstructed data as visualized in Fig. 4. Black: Phantom ground truth, Blue: Filtered Backprojection, Red (dashed): Proposed reconstruction method. For all images, the iteratively reconstruction and ground truth are in high agreement.

References

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[3] A. Ritter *et al.*: "Simultaneous maximum-likelihood reconstruction for x-ray grating based phasecontrast tomography avoiding intermediate phase retrieval," arXiv:1307.7912, Jul. 2013.