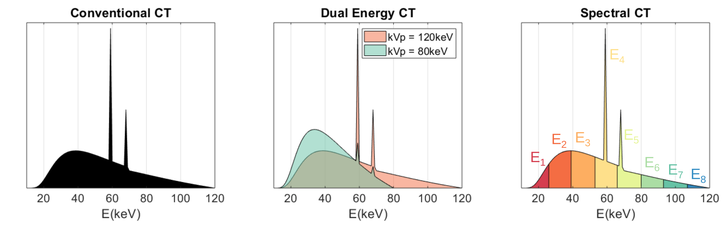
Material Characterization using Spectral X-ray CT

Matteo Busi†‡, Aditya K. Mohan†, Alex A. Dooraghi†, Kyle M. Champley†, Harry E. Martz†, Ulrik L. Olsen‡
†Lawrence Livermore National Laboratory
‡DTU Physics - Technical University of Denmark

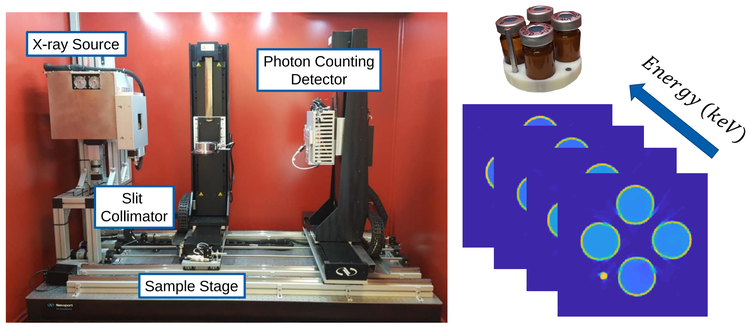
Abstract

We propose a new method for material characterization using spectral X-ray computed tomography (SCT). SCT takes advantage of the recently developed photon counting detectors, which are able to measure in a single shot the energy distribution of the incoming radiation.
The measured linear attenuation coefficient (LAC) of the sample is decomposed into the material features of electron density, ρ_e, and the effective atomic number, Z_{eff}.
While achieving accuracy comparable to traditional dual-energy computed tomography [1], which is carried by consecutive acquisitions, this method allows for a simultaneous collection of multiple energies. In addition, it allows for detection of absorption edges of elements with high atomic number Z.

SPECTRAL X-RAY CT PROVIDE ENERGY RESOLVED FEATURES



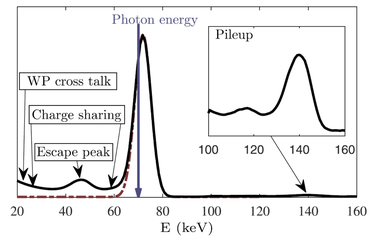
Techniques comparison. Left: In conventional CT, the detected polychromatic beam is integrated over the whole spectrum. Middle: In dual energy CT, data acquired using two spectra is analyzed for improved material characterization.
Right: In Spectral CT, the polychromatic nature of the X-ray beam is included in the analysis using energy resolving photon counting detectors.



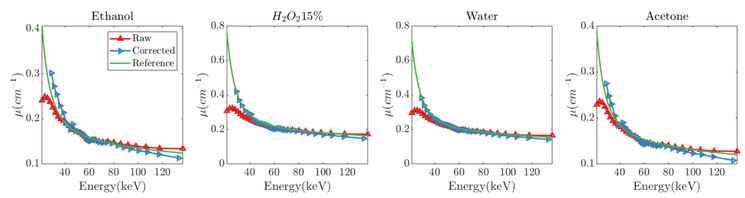
Spectral CT Method. Left: instrumental setup, including a X-ray source, a sample stage and a photon counting detector Multix-ME100 [2], capable of binning the incoming radiation into 128 energy bins of width 1.1 keV. The data can be rebinned into fewer energy bins. Right: the sample investigated, composed of a copper bar and four bottles filled with ethanol, H_2O_2 (15%), water and acetone. Four energy resolved reconstructions.

SPECTRAL DISTORTIONS CORRECTION ALGORITHM

Photon counting detectors suffer from interactions that distort the accurate detection of the energy of the incoming photons. These result, in the recorded attenuation, as a dampening of the spectra in the low energy range and increment in the high energy domain. We apply a flux dependent correction algorithm presented by Dreier et al. [3].



Effects yielding distortions in the energy distribution of the individual photons.



Reference and measured LAC's of the four materials using raw and corrected data.

DETERMINE MATERIAL FEATURES

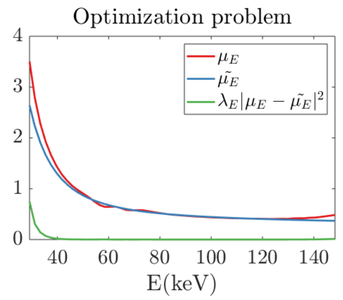
The decomposition method aims to map the measured LAC, μ_E, into the material features, ρ_e and Z_{eff}, where $E = 1,2,3,\dots,N_E$ and N_E is the number of energy bins used. We express the theoretical LAC, as:

$$\widetilde{\mu_E}(\rho_e, Z_{eff}) = \rho_e \sigma_e(Z_{eff}, E),$$

where σ_e is the total electronic X-ray cross section, retrieved by a cubic interpolation of reference tabulated values, into the input energy range. Then, the material features are found by an optimization of:

$$\underset{\{\rho_e, Z_{eff}\}}{\operatorname{argmin}} \sum_{E=1}^{N_E} \lambda_E \left|\mu_E - \rho_e \sigma_e(Z_{eff}, E)\right|^2$$

Therein, λ_E represent the energy weights, which adjust the confidence given to each of the individual energy bins. In this work, they are set to one over the standard deviation of the measured LAC's.



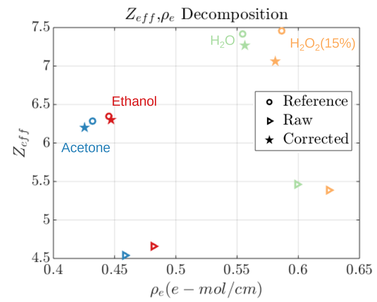
RESULTS

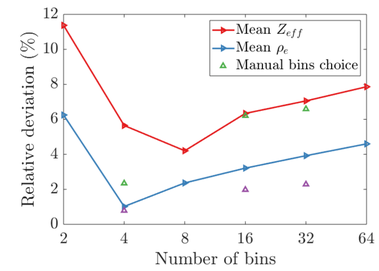
We report here the result obtained by rebinning the datasets into 4 energy bins. The first energy bin was manually truncated as it displayed severe metal artifacts from the copper bar.

Feature	Ethanol	H_2O_2	Water	Acetone
Z_{eff}^{true}	6.35±0.01	7.46±0.02	7.42±0.01	6.28±0.01
$Z_{eff}^{measure}$	6.30	7.06	7.26	6.20
$Z_{eff}^{relative}$	0.79%	5.36%	2.16%	1.27%
ρ_e^{true}	0.445±0.003	0.586±0.004	0.554±0.002	0.432±0.003
$\rho_e^{measure}$	0.447	0.581	0.556	0.425
$\rho_e^{relative}$	0.45%	0.85%	0.36%	1.62%

Reference and experimental estimates of material features, rebinning into four energy bins.

Since the ground-truth values of ρ_e and Z_{eff} of the materials are known, the accuracy is taken as the absolute relative percent difference between the feature measurements and the ground-truth.





Mean Z_{eff} and ρ_e relative deviation of the four materials as a function of the number of energy bins.

CONCLUSIONS

We have presented a method for material characterization using SCT, that achieves accuracy below 2% and 6% in the estimation of ρ_e and Z_{eff} respectively. We show that an automated optimal choice of the number of energy bins is not trivial and depends on the sample feature.

ACKNOWLEDGMENTS

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[2] Gorecki, A., et al. "Comparing performances of a CdTe X-ray spectroscopic detector and an X-ray dual-energy sandwich detector." *Journal of Instrumentation* 8.11 (2013): P11011.
[3] Dreier, E. S., Kehres, J., Khalil, M., Busi, M., Gu, Y., Feidenhans, R., & Olsen, U. L. (2018). Spectral correction algorithm for multispectral CdTe X-ray detectors. *Optical Engineering*, *57*(5), 054117

*Author contact: mbusi@fysik.dtu.dk

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