Material Characterization using Spectral X-ray CT

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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, \( \rho_e \), and the effective atomic number, \( Z_{\text{eff}} \).

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

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

\[
\mu_E(\rho_e, Z_{\text{eff}}) = \rho_e \sigma(E) Z_{\text{eff}}(E),
\]

where \( \sigma(E) \) 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:

\[
\arg\min_{\rho_e, Z_{\text{eff}}} \sum_{E=1}^{N_E} \lambda_E |\mu_E - \rho_e \sigma_e Z_{\text{eff}}(E)|^2
\]

Therein, \( \lambda_E \) 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.

Determine Material Features

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

CONCLUSIONS

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

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REFERENCES