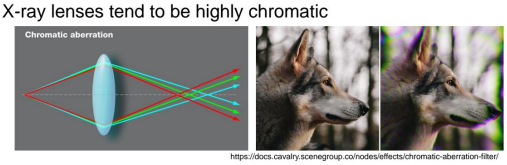
Forward Modeling Chromatic Aberration and Depth of Field in Transmission X-ray Microscopy

Zane Taylor
Stanford University, EE367, Winter 2024

Motivation

Transmission X-ray Microscopy (TXM) is a powerful technique for operando studies of dynamical systems, including laser powder bed fusion (LPBF) metal additive manufacturing.

X-ray lenses tend to be highly chromatic

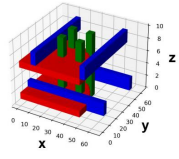


https://docs.cavalry.scenegroup.co/nodes/effects/chromatic-aberration-filter/

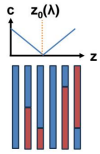
Goal: Implement a simple method to predict image formation

- Chromatic Aberration
- Depth of Field Blurring

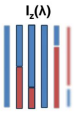
Present Technique



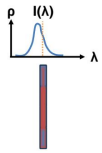
3D Sample Structure



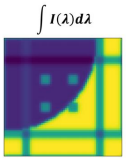
Calculate 3D PSF



Blur Image in Each Slice



Monochromatic Image

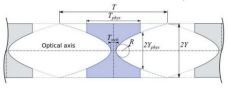


Integrate Over Spectrum

- This work is computationally cheap & tied to the physics of x-ray lenses
  Defocus blur is computed for each energy independently and then the effect is summed, giving the contribution of each energy
- Related work calculates the chromatic PSF of the lens independent of defocusing
- Wave-optics simulations such as multi-slice models are a more intensive alternative

Related Work

Simons [1] derived the performance of compound refractive lenses (CRLs) used in TXM as well as the chromatic PSF, but this PSF is not energy resolving.

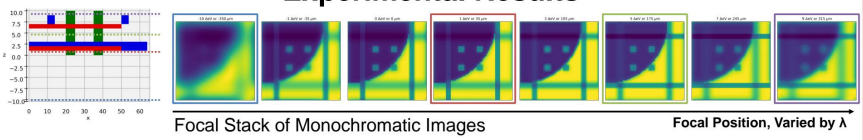


In x-ray imaging, the chromatic aberrations are almost always minimized by beam monochromation with little further consideration. The optical community models combined defocus- and chromatic aberration in more detail [2].

References

[1] Simons et al.,"Simulating and optimizing compound refractive lens-based X-ray microscopes", J. Synch. Rad., 2016
[2] Strasburger et al., "Blur Unblurred – A Mini Tutorial", i-Perception, 2018

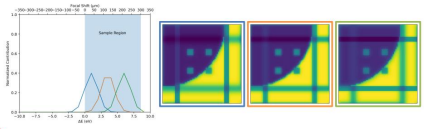
Experimental Results

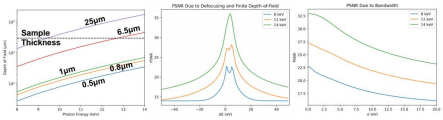


Focal Stack of Monochromatic Images

Focal Position, Varied by λ

Integrated Image with
Finite Bandwidth & Depth-of-Field Blurring





Higher energies → Lower Magnification
→ Larger DoF → Less Blurring → Higher PSNR