An Approach to Characterizing Spatial Aspects of Image System Blur

Jesse Adams[1], Kevin Joyce[2], Daniel Champion[1], Eric Machorro[3], Malena Español[4], Michael Brennan[5], Eric Clarkson[6], Jessica Pillow[1,6], Ryan Coffee[7], Marylesa Howard[1], Arnulfo Gonzalez[1], Sean Breckling[1], Margaret Lund[1]

[1]Nevada National Security Site, [2]Lawrence Livermore National Laboratory, [3]Pacific Northwest National Laboratory, [4]Arizona State University, [5]Massachusetts Institute of Technology, [6]University of Arizona, [7]SLAC National Accelerator Laboratory

Abstract

In imaging applications, such as X-ray radiography, the experimental system setup and data capture process introduce system blur and distortion. In images taken with thick scintillators, a spatially-varying system blur is observed, requiring a non-standard approach to blur and distortion estimation and removal. We demonstrate an approach to estimation of local point spread functions using checkerboard radiographs collected at the Naval Research Laboratory (NRL) and extend that into a map defining the kernel over the camera field of view.

Thick Scintillators

In high energy X-ray radiography, X-rays are pulsed from a source and travel through a scene. X-rays that are not attenuated by objects in the scene are absorbed by a scintillator, and re-emitted as visible light. An imaging system then captures this light to produce the output image, as depicted in Figure 1.

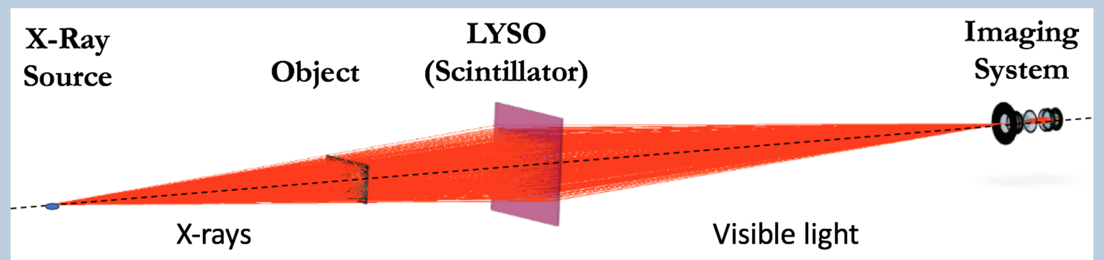

Figure 1: Imaging system schematic

X-rays from the source are emitted as a cone beam. The photons produced via scintillation can occur at any point along the X-ray trajectory through the scintillator. The X-ray path has a larger extent farther from the center of the X-ray source as depicted in Figure 2, which results in blur that varies spatially.

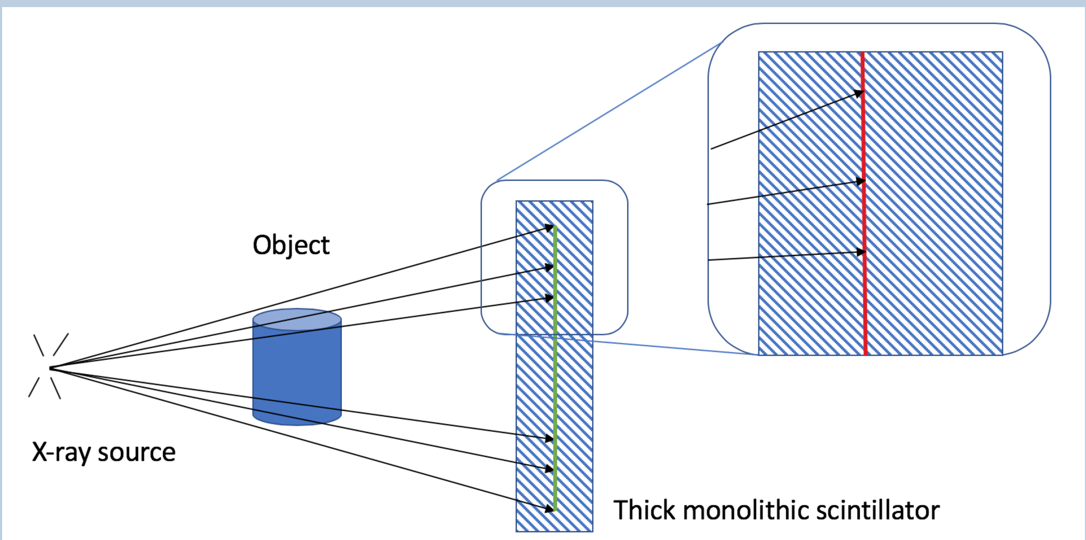

Figure 2: X-ray path through a thick scintillator

Checkerboard Data

A checkerboard target can be used as a calibration object for quantifying blur in X-ray radiography. This image was captured with a a 20mm thick Lutetium-yttrium oxyorthosilicate (LYSO) scintillator at NRL.

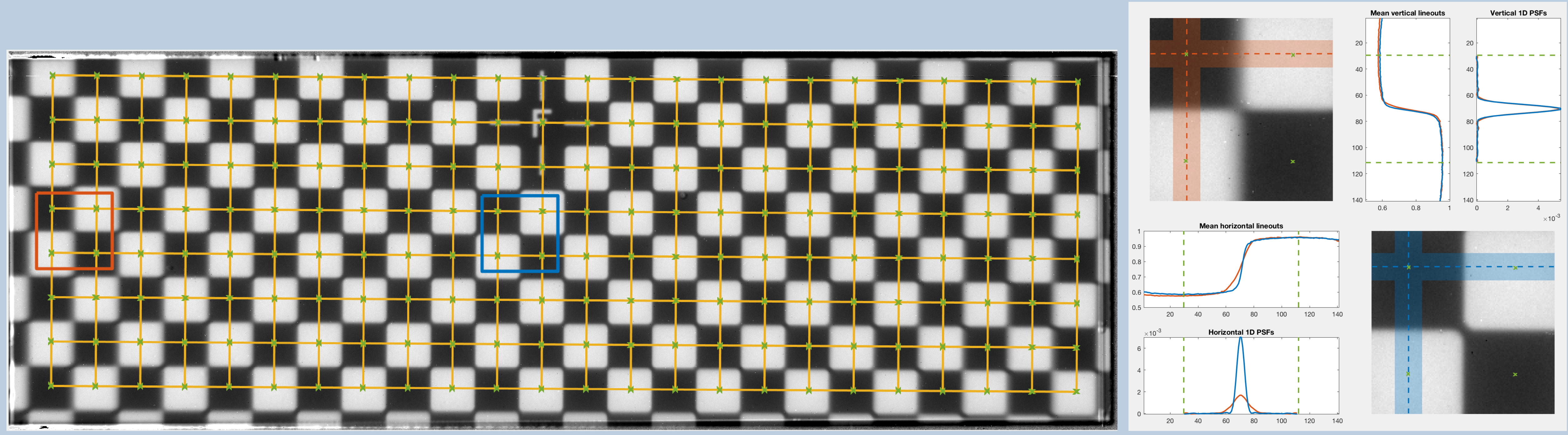

Figure 3: On the left, a radiograph of a tungsten checkerboard is overlaid with the center of each square, and positions for calculated PSFs. Specific portions are marked in red and blue. On the right, these portions are zoomed, and the mean vertical and horizontal edges are plotted, along with the resultant PSFs, calculated as in [1].

Spatially Varying Point Spread Functions

Given the two grids of horizontal and vertical PSFs, an approximation for a PSF at any point in the grid can be produced via a partition of unity (POU) between successive PSFs across the image.

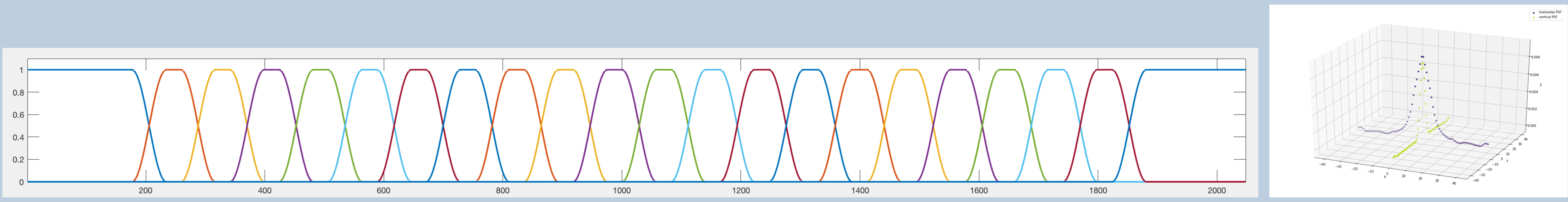

Figure 4: The set of horizontal POU functions used to interpolate a PSF between known points (left); an example pair of vertical and horizontal PSFs for a specific point (right)

It is expected that the PSFs are correlated to the center of the cone beam, so the horizontal and vertical cross sections are not along the primary axes of the PSF. Using a Gaussian approximation and forcing the covariance based on the position of the PSF, it is possible to get a regularized Gaussian fit of a 2D PSF that attempts to match the horizontal and vertical PSFs at that point.

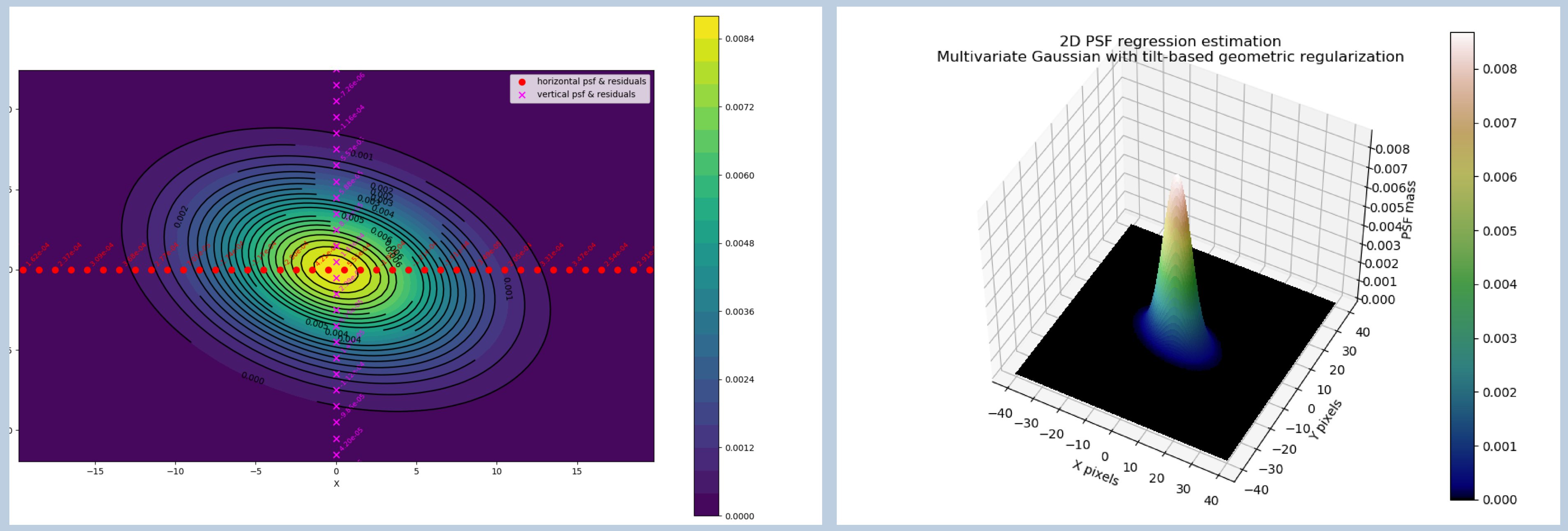

Figure 5: 2D PSF contour with vertical and horizontal residuals (left); Gaussian 2D PSF (right)

Conclusion

In many classical treatments, the blurring process is modeled as a convolution between the true image and a spatially invariant PSF.

$$b(s,t) := \mathcal{A}[u](s,t) = \int_{\Omega} u(x,y)a(s-x,t-y)\,dx\,dy$$

The tools under development here seek a higher fidelity, higher precision model that accounts for spatially varying blur that has been found experimentally [2].

Building on techniques that can model blur (as PSFs) but only in small regions across boundaries of high contrast [1], the team has developed the framework to piece together PSFs from those discrete points to form a smooth spatially varying blur kernel.

$$b(s,t) := \mathcal{A}[u](s,t) = \int_{\Omega} u(x,y)a(s,t,x,y)\,dx\,dy$$

Numerical simulations followed by direct comparisons with anticipated experiments are planned to calibrate the model and evaluate its performance with respect to deconvolution.

References

[1] K. T. Joyce, J. M. Bardsley, and A. Luttman. Point spread function estimation in X-ray imaging with partially collapsed Gibbs sampling. *SIAM Journal on Scientific Computing*, 40(3):B766–B787, 2018.

[2] A. Lin, M. A. Kupinski, X. Li, and L. R. Furenlid. Gpu-assisted generation of system matrices for high-resolution imaging systems. *IEEE*, 2018.

Acknowledgements

This work was done in part by by Mission Support and Test Services, LLC, under Contract No. DE-NA0003624 with the U.S. Department of Energy and supported by the Site-Directed Research and Development Program. DOE/NV/03624--0719
This research was performed in part at Pacific Northwest National Laboratory (PNNL) using PNNL Institutional Computing. Funding for this work was provided by the Nuclear Process Science Initiative (NPSI), a Laboratory Directed Research and Development Initiative at PNNL which is operated by the Battelle Memorial Institute for the US Department of Energy under Contract No DE-AC05-76RL0-1830.
Coffee is supported by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences under Contract No. DE-AC02-76SF00515 and FWP-100498 within the Accelerator and Detector Research program.
This work resulted from the Data Analysis for Nuclear Security Science Workshop 2020.