Photon-Counting Detector Calibration with Pulse Pile-up Correction using Transmission Measurements of a Step-Wedge Phantom

E. Y. Sidky [1], E.R. Paul [1], J.-P. Phillips [1], T. Gilat Schmidt [2] and X. Pan[1]
1 University of Chicago, Chicago, Illinois
2 Marquette University, Milwaukee, Wisconsin

JULY 12–16 2020 VIRTUAL
JOINT AAPM | COMP MEETING
EASTERN TIME [GMT-4]

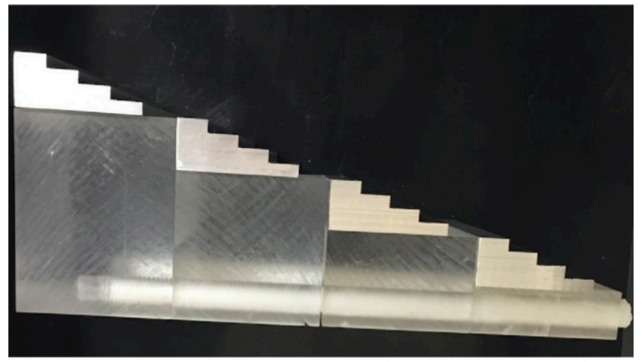
INTRODUCTION

The work aims to determine the spectral response of photon counting detectors (PCDs) from transmission measurements of a phantom of known dimension and composition. Previously, this methodology has been developed for low-flux transmission data, where the non-linear intensity response of the PCD is not a factor. We extend the methodology to measurements with higher photon flux.

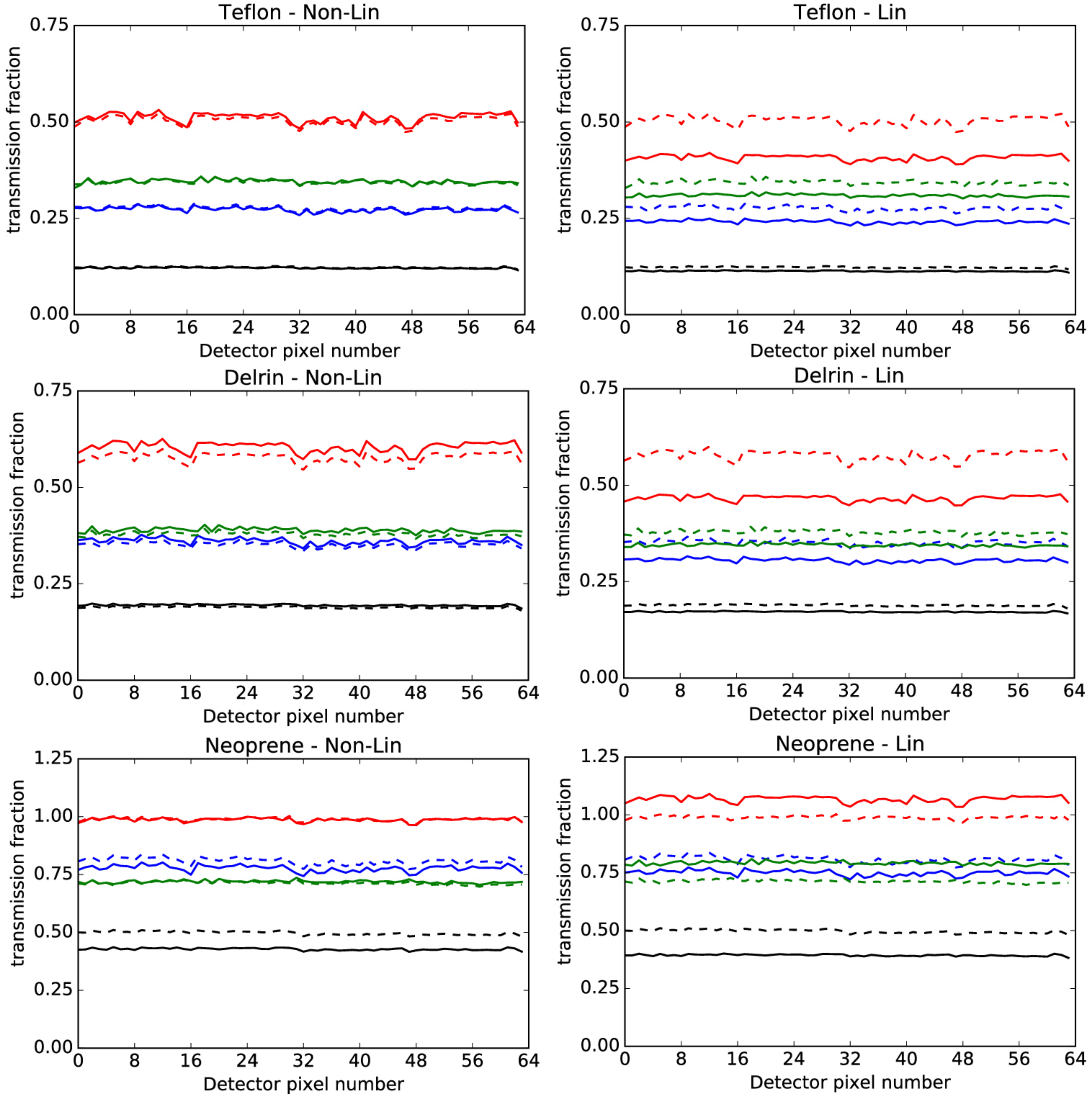
METHOD

Simultaneous spectrum and non-linear intensity response calibration is performed using transmission measurements of a step-wedge phantom with 25 known combinations of Aluminum and PMMA thicknesses. The transmission measurements are obtained with a DxRay PCD with 4 energy-windowed transmission measurements. The X-ray source is operated at an intensity so that the un-attenuated beam has a flux of 54% of the maximum PCD count rate of 1,000,000 photons per second. The PCD spectral sensitivity is arrived at by making a parametric model including the product of an initial source spectrum estimate, a PCD sensitivity model, and an exponential of a 10th-degree polynomial to allow the spectral sensitivity to adjust to the true response. Additionally, the ideal transmitted intensity is taken as an input to a cubic polynomial to account for non-linear effects such as detector pulse pile-up. The coefficients of the spectral exp-polynomial and the intensity cubic polynomial are determined by fitting the model to the Aluminum/PMMA step-wedge transmission data.

Step-wedge Phantom



RESULTS



Measured versus predicted X-ray transmission through known test materials. The predicted transmission is based on PCD calibration with non-linear (Right column) and linear (Left column) intensity response modeling, where the Dashed Curves represent measured X-ray transmission fractions for 64 pixels and 4 energy windows and the Solid Curves indicate the corresponding modeled transmission fractions based on the PCD calibration. The comparison between model and measurements is performed on transmission through slabs of three materials: one inch of Teflon (Top row), two inches of Delrin (Middle row), and one half inch of Neoprene (Bottom row). The color of the curves indicate the energy window of the PCD, where the photon discrimination thresholds are set to 22, 45, 55, and 65 keV, and the corresponding windows from lowest to highest are indicated by black, green, blue, and red.

CONCLUSIONS

The use of the non-linear intensity transformation as part of the PCD calibration at high-flux appears to capture the non-linearity due to pulse pile-up. The improvement with the non-linear transformation is particularly striking for the Teflon data where the predicted Teflon transmission is accurate to the percent level with this transformation included. For the higher Z materials Delrin and Neoprene the predicted transmission does not fit quite as well as the Teflon case, although it is clear that the non-linear modeling improves results over the case where it is not used. Future work will focus on improving the results for higher Z materials by testing different calibration materials and configurations.

ACKNOWLEDGEMENTS

This work is supported in part by NIH Grant Nos. R01-EB026282 and R01-EB023968. ERP is also supported by a University of Chicago Metcalf Award. The contents of this article are solely the responsibility of the authors and do not necessarily represent the official views of the National Institutes of Health.

REFERENCES

Sidky E. Y., Yu L., Pan X., Zou Y., and Vannier M. (2005), A robust method of x-ray source spectrum estimation from transmission measurements: Demonstrated on computer simulated, scatter-free transmission data. J. Appl. Phys., 97:124701.

Ha, W., Sidky, E.Y., Barber, R.F., Schmidt, T.G. and Pan, X. (2019), Estimating the spectrum in computed tomography via Kullback–Leibler divergence constrained optimization. Med. Phys., 46: 81-92.

CONTACT INFORMATION

For further questions please contact Emil Sidky at sidky@uchicago.edu