Using Machine Learning to Improve the Image Quality of Low-Dose Photon-Counting Computed Tomography

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INTRODUCTION

- Computed Tomography (CT) scans produce 3D X-ray images
- Conventional CT integrates detected X-ray energy
- Photon-counting CT (PCCT) detects and counts individual photons, providing energy-specific image information [1]

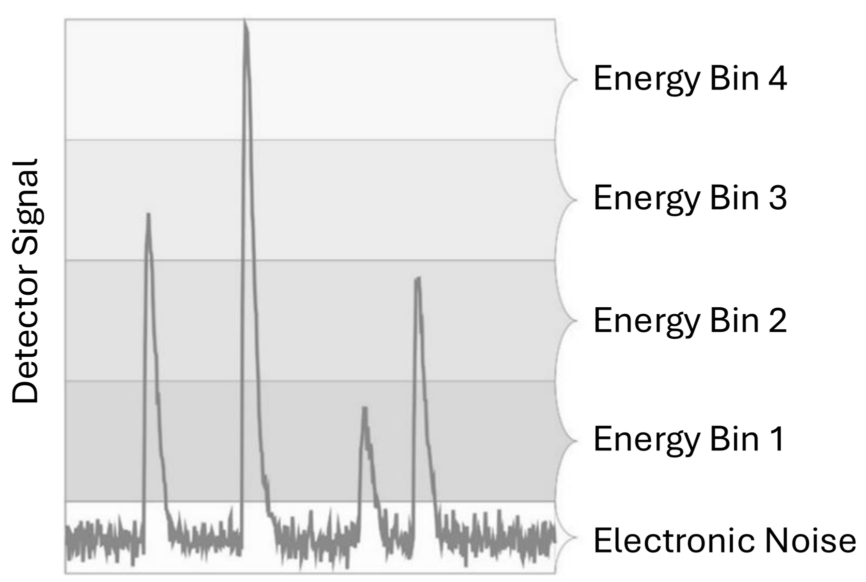

Figure 1. Example of a detector signal in which the pulse height is proportional to the energy of the detected photon.

- A single CT scan can deliver several times the average yearly background radiation dose [2]
- Reducing acquisition angles lowers radiation dose but also lowers image quality
- Machine learning has demonstrated strong performance in image denoising [3]

OBJECTIVE: Assess whether machine learning can produce high-quality images from low-dose PCCT and whether its energy-specific data improves performance compared to conventional CT.

DATA ACQUISITION

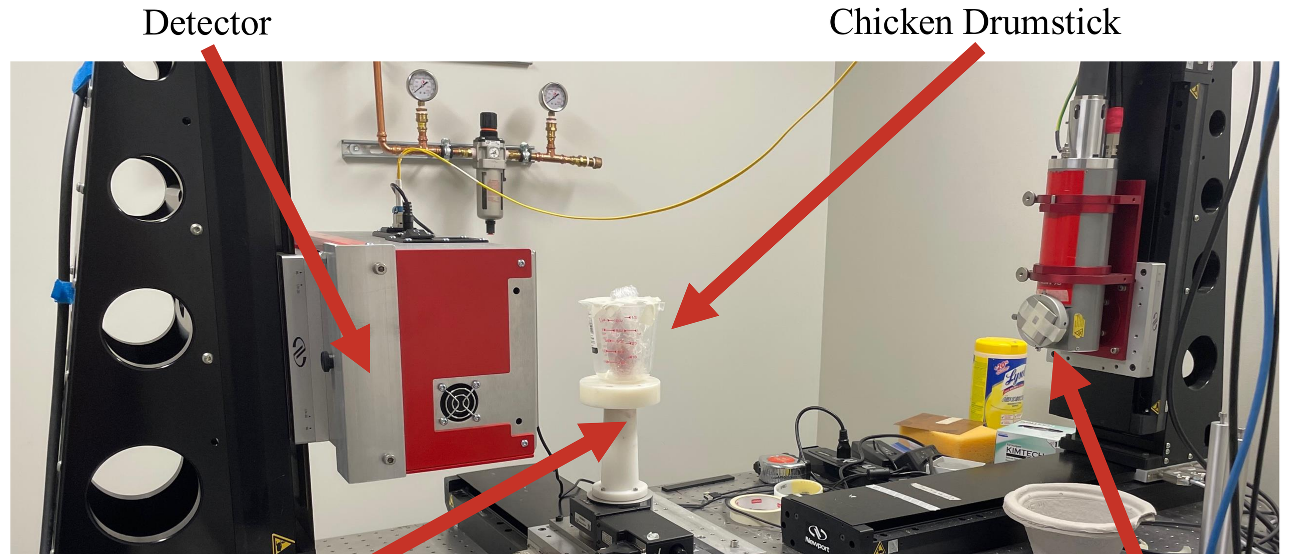

Figure 2. Experimental setup.

- 12 chicken drumsticks scanned twice, totaling 1,728 images
- 360 total acquisition angles
- Photon-counting detector: CZT, 330µm pixels
- X-ray beam: 120kVp, 1mA tube current
- Energy thresholds: 25, 33, 41, 50, 59, and 68keV

METHODS

- Images reconstructed in Python using TIGRE package
- Low-dose images created by using every 4th acquisition angle (90 angles total)
- Train/Validation/Test images: 1,224/240/264
- Two input types: summed energy bins (~Conventional CT), individual energy bins (~PCCT)

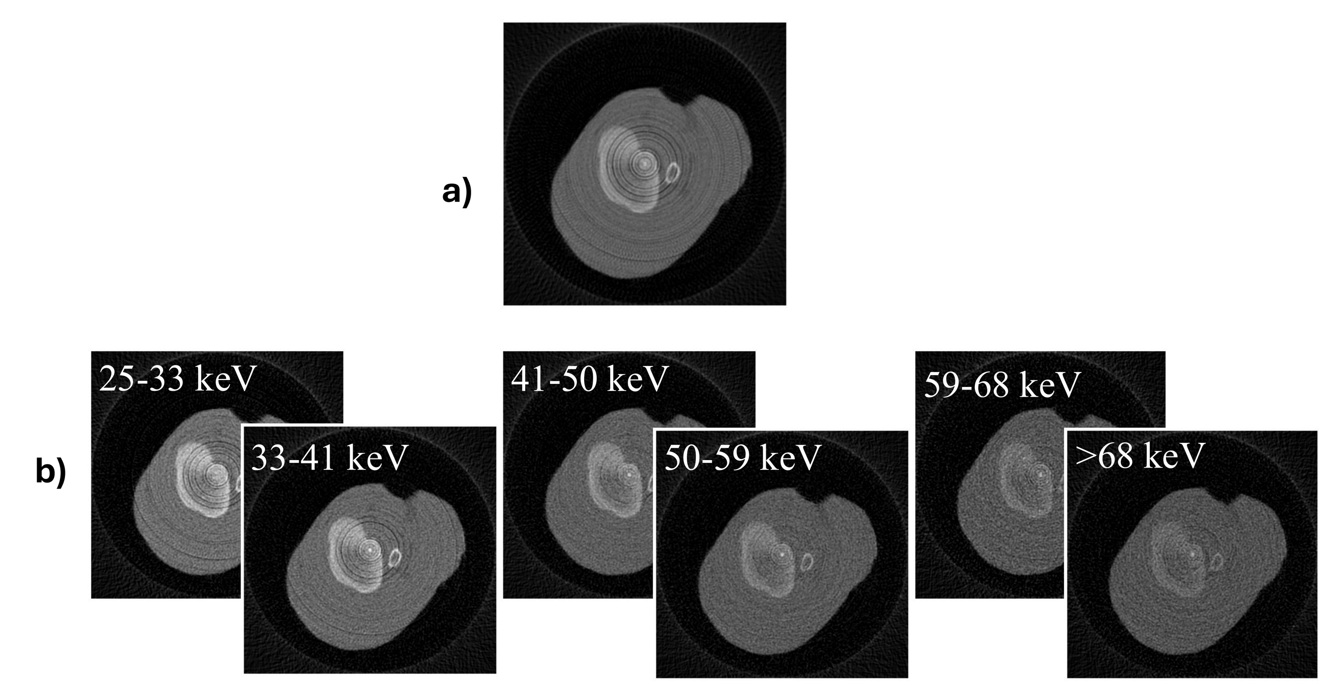

Figure 3. a) Image reconstructed for total summed energy bins using 360 angles. b) Image reconstructed for each individual energy bin using 360 angles.

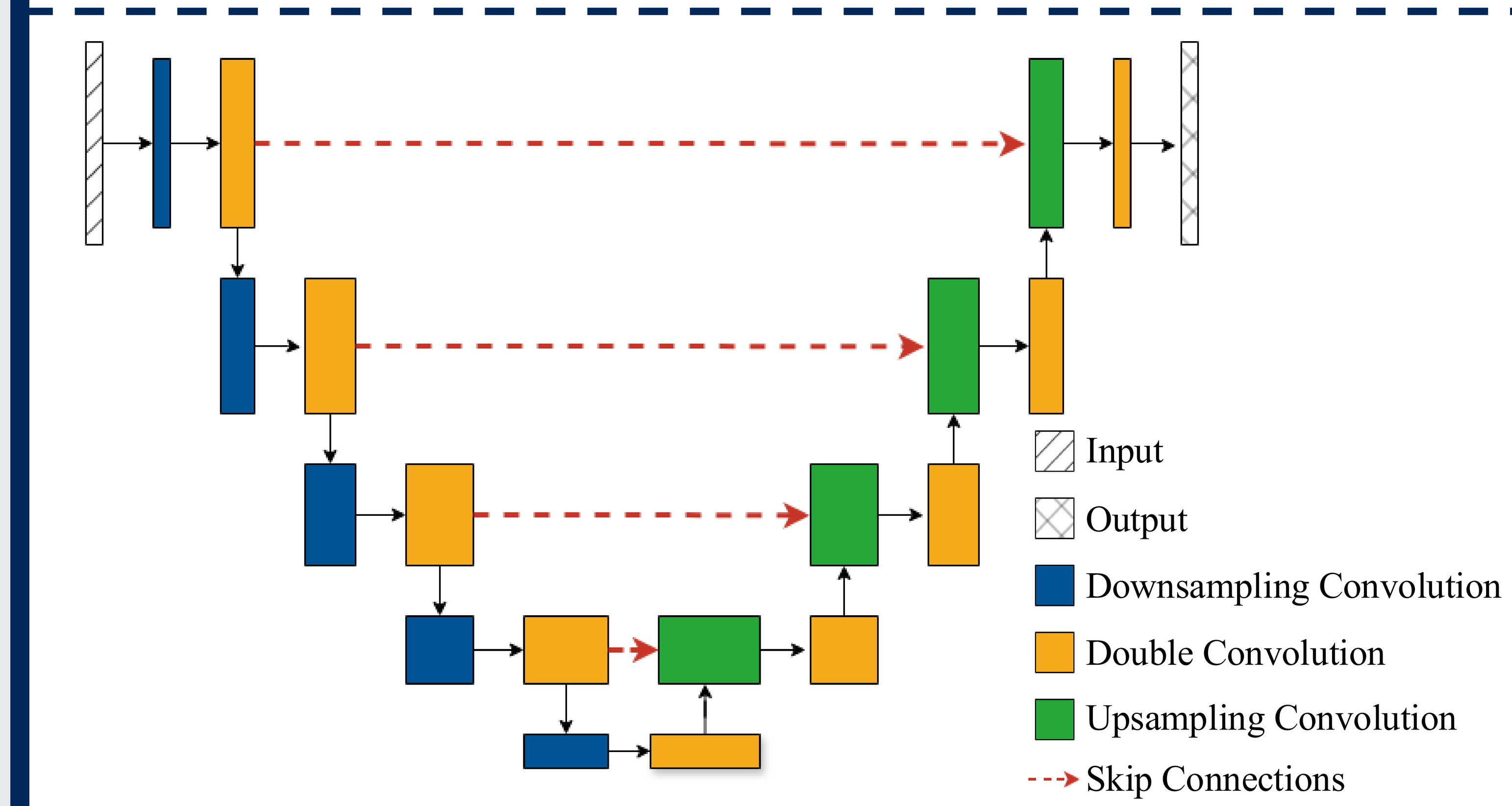

Figure 4. U-Net model architecture.

- Training: Combined Loss, batch size 8, Adam optimizer, NVIDIA Tesla T4 GPU
- Loss: $\mathbb{L}(x,y) = 0.85 \cdot \left(1 - SSIM(x,y)\right) + 0.15 \cdot MAE(x,y)$

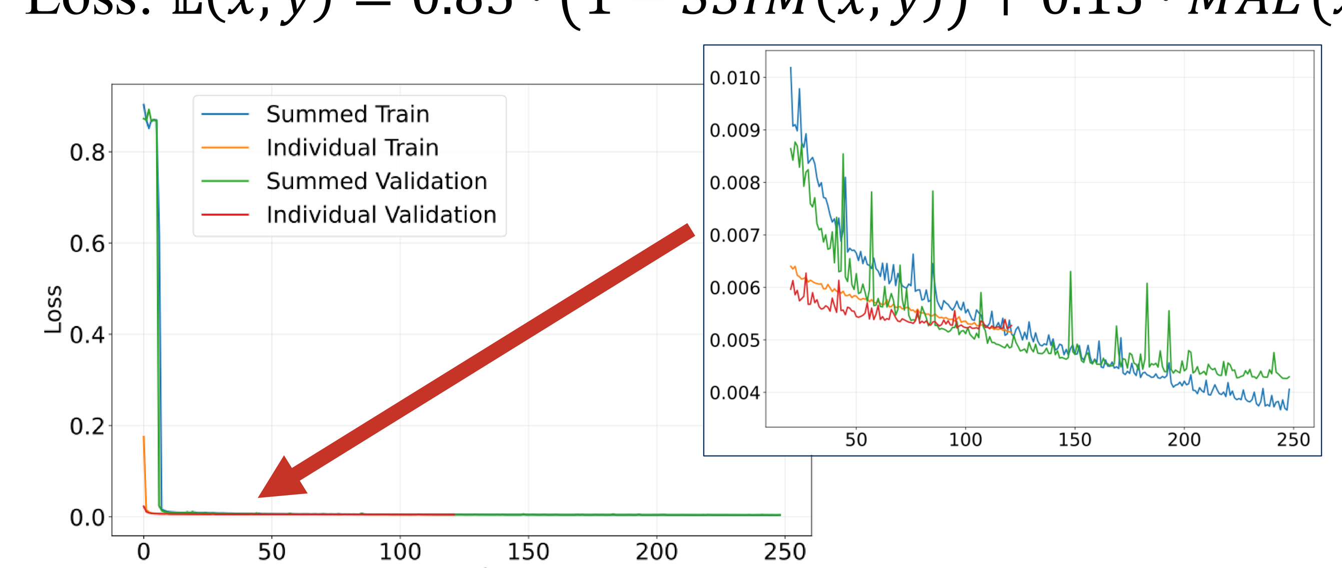

Figure 5. Training curves for individual and summed energy bins datasets.

RESULTS

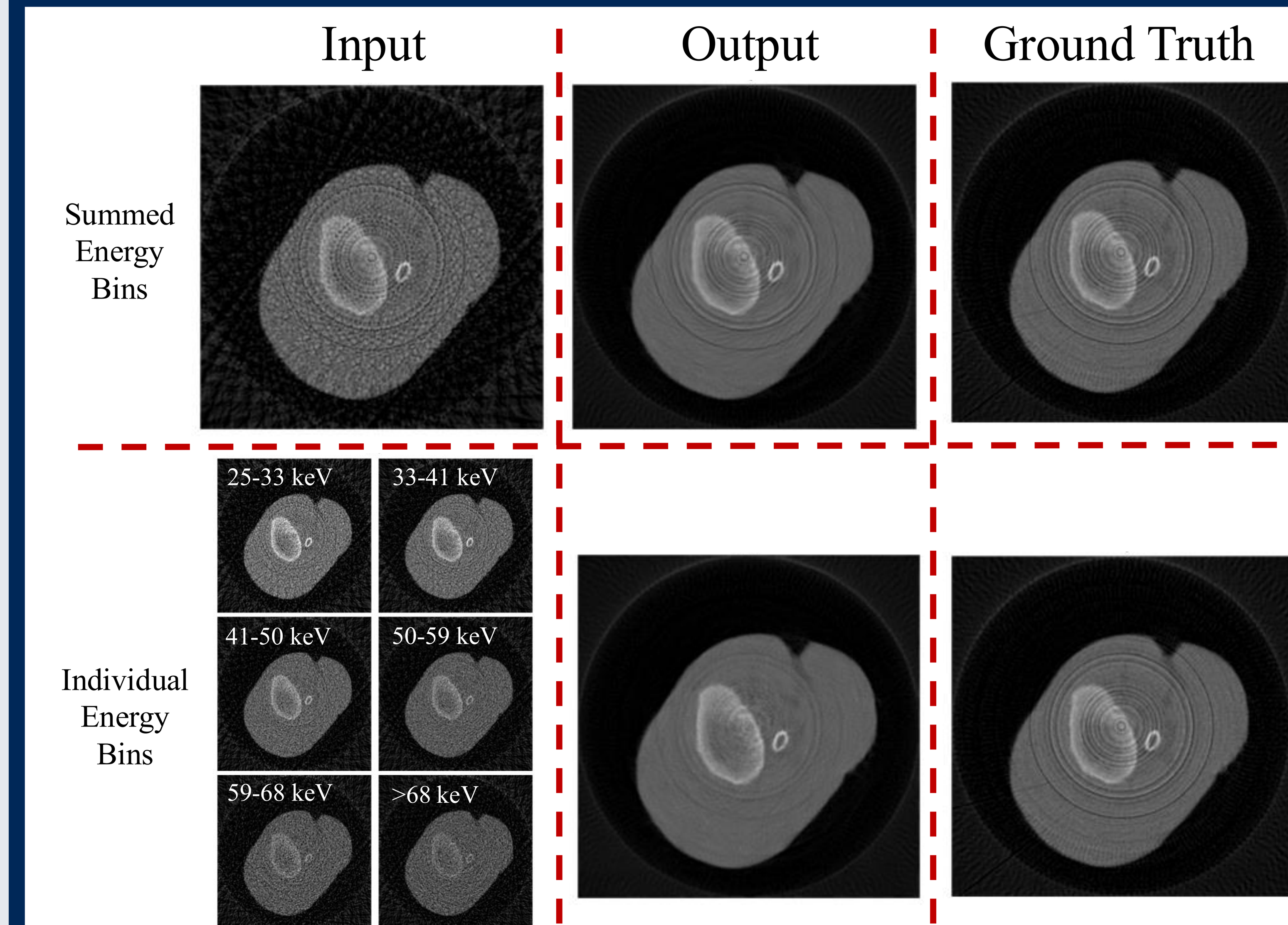

Figure 6. Comparison of model performance when trained on summed energy bins versus individual energy bins. All images are displayed with a linear attenuation coefficient scale of [0.00, 0.07] mm^{-1}.

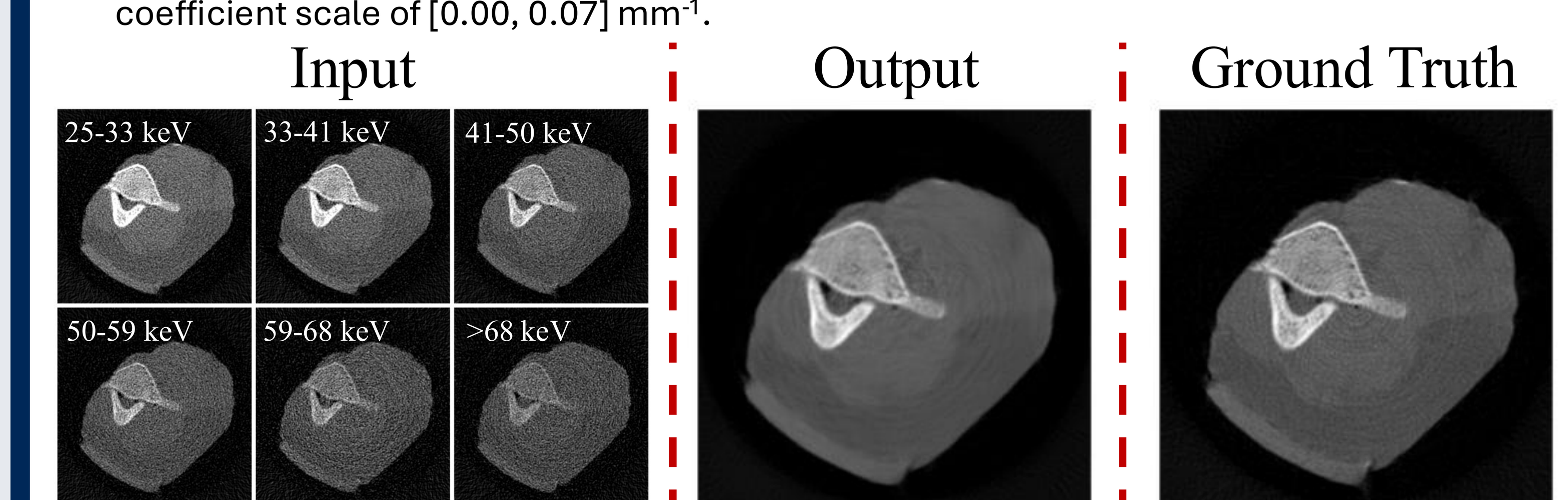

Figure 7. Performance of model, trained on chicken drumsticks, given pig tail data . All images are displayed with a linear attenuation coefficient scale of [0.00, 0.07] mm^{-1}.

CONCLUSIONS AND FUTURE WORK

- Machine learning enhances low-dose PCCT image quality
- The model trained on individual energy bins yields better output than the one trained on summed energy bins
- The model will be trained on pig tail PCCT data
- Further models such as cGAN and diffusion models will be tested

[1] M. J. Willemink, M. Persson, A. Pourmorteza, N. J. Pelc, and D. Fleischmann, “Photon-counting CT: Technical Principles and Clinical Prospects,” *Radiology*, vol. 289, no. 2, pp. 293–312, Nov. 2018, doi: https://doi.org/10.1148/radiol.2018172656.

[2] F. A. Mettler, W. Huda, T. T. Yoshizumi, and M. Mahesh, “Effective Doses in Radiology and Diagnostic Nuclear Medicine: A Catalog,” Radiology, vol. 248, no. 1, pp. 254–263, Jul. 2008, doi: https://doi.org/10.1148/radiol.2481071451.

[3] A. E. Ilesanmi and T. O. Ilesanmi, “Methods for image denoising using convolutional neural network: a review,” *Complex & Intelligent Systems*, Jun. 2021, doi: https://doi.org/10.1007/s40747-021-00428-4.

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