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Simultaneous Neutron and X-ray Tomography for Materials Research

J.M. LaManna[1*], M.C. Daugherty[1,2], Y. Kim[1,3], D.S. Hussey[1], E. Baltic[1] and D.L. Jacobson[1]

[1] National Institute of Standards and Technology, Gaithersburg, MD, USA.
[2] Department of Chemical & Biomolecular Engineering, University of Maryland, College Park, MD, USA.
[3] Department of Chemistry & Biochemistry, University of Maryland, College Park, MD, USA.
* Corresponding author: Jacob.LaManna@nist.gov

Neutrons and X-rays are both penetrating probes to determine internal structure of materials. Neutrons interact with the atomic nucleus whereas X-rays interact with the electron cloud. The differences in interaction between the two modalities creates different sensitivities for different materials with neutrons being strongly sensitive to light isotopes such as hydrogen and lithium and X-rays being more sensitive to higher atomic number elements as shown in Figure 1(a). Correlative studies have been performed to leverage the complementarity of these two modalities. The difficulty that can arise when combining neutrons and X-rays is the length of time that can occur between scans, most often at different facilities. Obtaining scans that are separated in time can make it difficult to correlate the two scans if the sample is evolving in time or undergoing a stochastic process. To alleviate this issue and to fully leverage the complementarity of the two modalities, the National Institute of Standards and Technology developed the Neutron and X-ray Tomography system (NIST-NeXT) for truly simultaneous neutron and X-ray tomography. The NIST-NeXT system was commissioned in 2015 and has since operated under the NIST Center for Neutron Research facility user program. Simultaneous capture of the two modes is made possible by orienting a microfocus X-ray generated perpendicular to a reactor sourced thermal neutron beam. The sample sits at the intersection of the two beams so that it can be viewed simultaneously as shown in Figure 1(b). The 90° offset of the beams is corrected digitally via rigid volume registration after the 3D volumes are reconstructed.

The NIST team has developed a workflow to handle the tomography reconstruction, volume registration, and volume segmentation based on mutual information from the neutron and X-ray volumes. Volume registration corrects the 90° offset between the beams along with any translational or rotational misalignments. Segmentation is improved by fusing the datasets together into a bivariate histogram. The two-dimensional histogram and the contrast differences between the two modalities help to differentiate the peaks by allowing them to separate in two dimensions. This can allow superior peak discrimination over standard 1D histogram segmentation on a single modality. The bivariate histogram segmentation tool allows the user to draw polygons over the histogram to select peaks and regions of interest as shown in Figure 2(a). These polygons are then used to tag the fused volume and produce a colorized image stack and binary volumes for each tag, Figure 2(b) and (c). The tool can provide rapid segmentations with as little as 10 minutes of active user time to produce the polygon map. This talk will give an overview of the NIST-NeXT system, describe the workflow for fusing and segmenting the neutron and X-ray datasets, give some present challenges and research directions for improving registration and segmentation, and give several example studies ranging from electrochemical systems to geology.

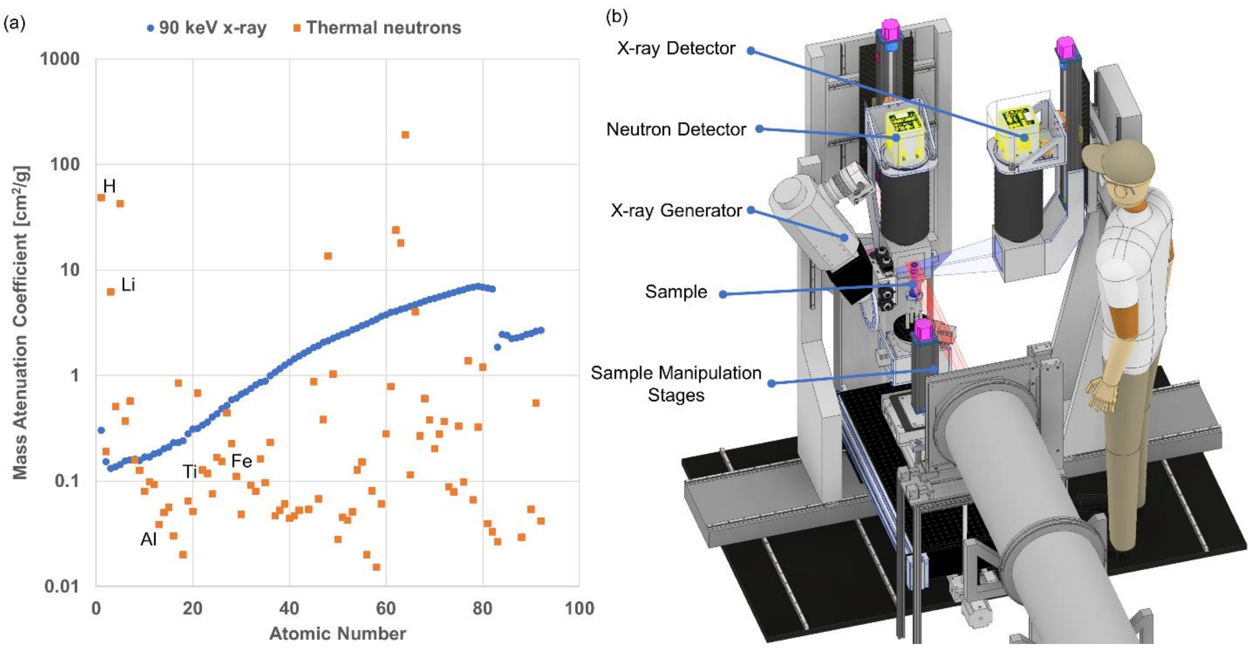

Figure 1. (a) Mass attenuation coefficient comparison between thermal neutrons and 90 keV X-rays with elements of interest highlighted. (b) Engineering model of the NIST-NeXT system.

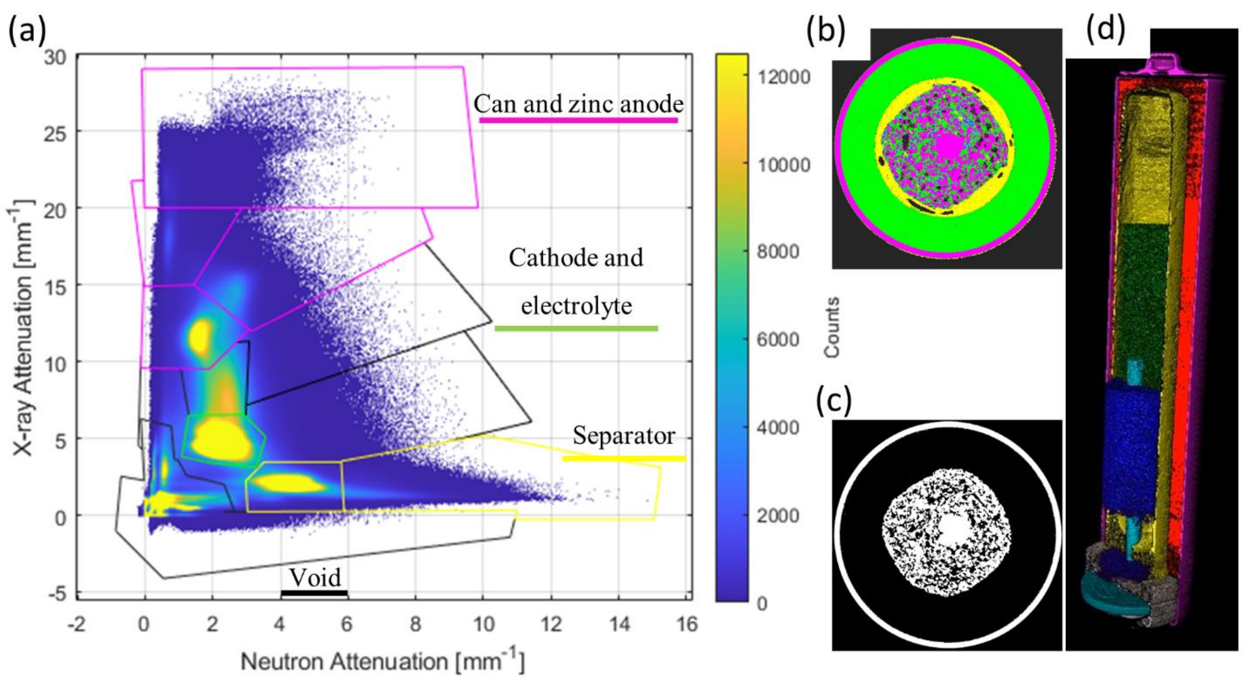

Figure 2. (a) Bivariate histogram plots neutron grayscale values versus X-ray grayscale values. Polygons are drawn around peaks and regions of interest in histogram. (b) Colorized output with colors matching corresponding polygons in histogram. (c) Binary output for can and zinc anode components. (d) fully segmented AAA alkaline battery based on bivariate histogram tool.

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