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RAPID 3D X-RAY PHASE CONTRAST IMAGING

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BASICS OF X-RAY CT

X-ray CT is a widely used non-destructive inspection technique, but to reconstruct a 3D image requires the acquisition of 100s to 1000s of images at different angles, which can take many hours and results in GBs of data

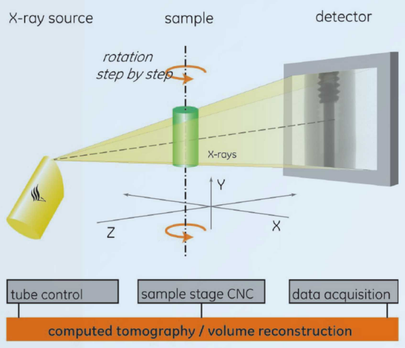


Figure reprinted from Introduction to Computed Tomography (p 16), by A. Cantatore and P. Müller, 2011, Kgs. Lyngby: DTU Mechanical Engineering.

$I = I_0 e^{-\mu x}$

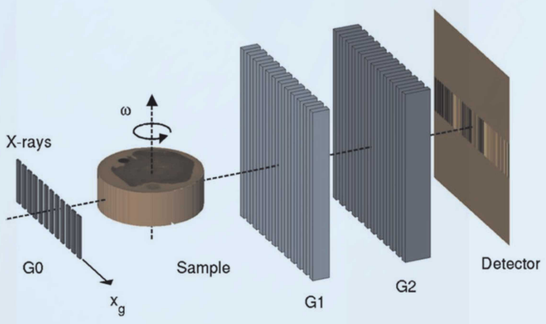
I = measured intensity
I_0 = incident intensity
μ = linear attenuation coefficient of the material
x = sample thickness

Image contrast depends on how well the material(s) absorb x-rays

X-RAY PHASE CONTRAST IMAGING

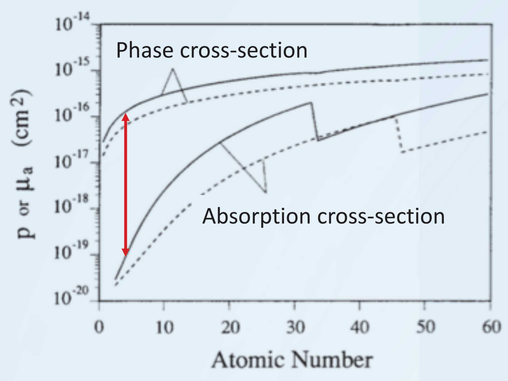
X-ray phase contrast imaging (XPCI) enables non-destructive imaging of low-density materials with up to three orders of magnitude greater sensitivity over conventional x-ray imaging

Talbot-Lau Interferometer



Interferometer refence: M. Nielsen, et. al., Phys Med Biol, 57, 5971, 2012.

Up to 3 orders of magnitude greater sensitivity in the phase signal

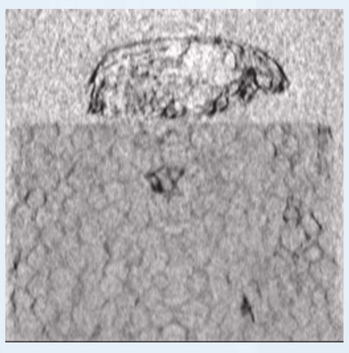


Plot adapted from: A. Momose and J. Fukuda, Med. Phys., 22, 375, 1995.

- Sandia built the world's largest field-of-view benchtop XPCI system; made possible by the unparalleled grating fabrication capability of MESA
- Requires 4-20x more image acquisitions than CT, increasing acquisition time and data volume by at least that factor (100+ GBs of data, 10s of hours)

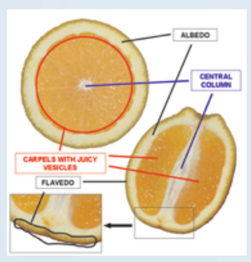
CONVENTIONAL X-RAY VS XPCI

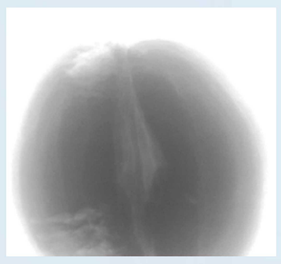
Conventional X-Ray



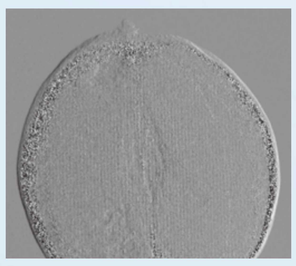
X-Ray Phase Contrast

XPCI ENABLES SENSITIVITY TO LOW-DENSITY MATERIALS

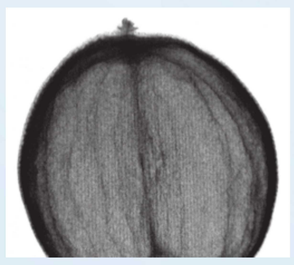




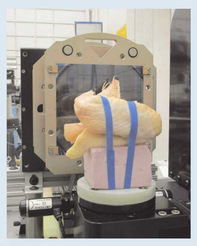
Absorbtion



Phase contrast



Dark Field



Absorbtion

Phase contrast

Dark Field

Combined

TOMOSYNTHESIS

Tomosynthesis enables 3D reconstruction with just 10s of images; saving significant time and reducing the data volume that needs to be managed

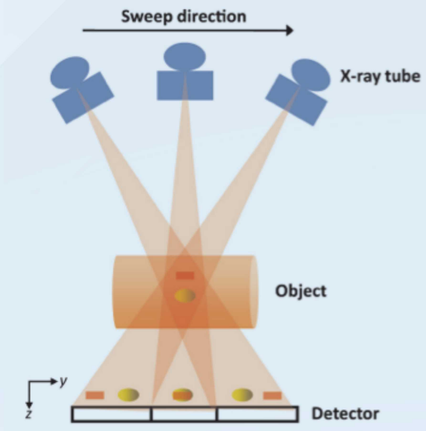


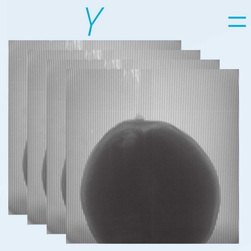
Figure adapted from: Arthroplasty: A comprehensive review (p166), by T. Gomi, 2016, IntechOpen.

- Projections are acquired as the x-ray source and detector are scanned
- Alternatively, the source and detector are fixed and the object is tilted and rotated
- Acquisition time reduced to < 1 hr and the volume of data that needs to be save, manipulated and transmitted is only 100 MBs- 1 GBs
- Fast acquisition enables broader use of a powerful non-destructive imaging capability

ITERATIVE RECONSTRUCTION

Iterative reconstruction allows the physics of an imaging system to be explicitly modeled, improving the fidelity of image reconstruction

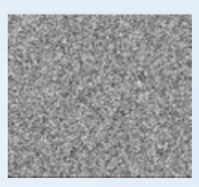
Y = *H* *X* + *W*



Measurements

System Model

Reconstruction



Measurement Noise

Research questions:

- How do we define, H, the system model, to accurately model the physics of all 3 XPCI image products?
- What is the best selection of a regularizer or prior model that retains important image details while removing noise and artifacts?
- What noise distribution best reflects measurement error?

MACHINE LEARNING

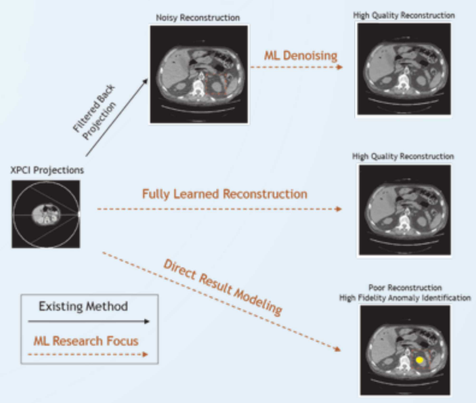
Deep learning algorithms have shown promise compared to traditional methods in reconstructing few-view CT scans

We will investigate 3 ML approaches:

- Data-driven denoising
- Fully learned reconstruction
- Direct result modeling

Research Questions:

- Can we develop similar techniques that work for XPCI?
- Are there specific ML approaches that yield faster collections?



IMPACT

When we are successful we will have:

- Made non-destructive **rapid 3D imaging** feasible for more applications
- Implemented the **world's first** compressive sensing XPCI system
- Expanded the non-destructive evaluation toolbox for **quick response diagnostics**
- **Advanced** the state-of-the art in physics-based models for XPCI
- **Reduced** the time to validate computational models with quick as-built geometry and material properties
- Developed the **first** machine learning algorithms for reconstruction of the three XPCI image products

Follow-On:

- Implementation at the Kansas City National Security Campus for reduced inspection times
- High speed dynamic testing with limited data for use in Explosive Ordinance Disposal (EOD) and Nuclear Incident Response Program (NIRP)
- Technology transfer to industry and field applications
- Transfer technology to medical applications for significant reduction in x-ray dose to patients

High throughput screening for critical defects with unprecedented sensitivity in low-density materials

- Sandia received a 2018 R&D 100 Award for work in XPCI
- 1 issued patent and 1 patent application for work related to the gratings

2018 R&D 100 WINNER

Sandia National Laboratories

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National Nuclear Security Administration