Simulating and Reconstructing X-Ray CT Projections

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Abstract

I have chosen to simulate x-ray transmission through a digital phantom, using energy dependent attenuation to generate sinograms that I then reconstruct using simple back projection. I used NIST data to model bone and soft tissue with energy dependent attenuation coefficients.

1 Introduction

Computed tomography scans are a form of medical imagery that uses X-rays to create images of the body. CT scans reconstruct cross sectional images of the body from multiple projections of X-ray attenuation through an object. In this project, I go through a large amount of the process of X-ray imaging: from simulating the incident X-rays using the python software toolkit spekpy, to simulating the x-ray attenuation and forming a spectogram, which I then use simple back projection to reconstruct the X-ray image.

2 Methods

2.1 Background Physics

2.1.1 X-ray generation

X-rays are produced when high kinetic energy electrons are accelerated towards a positive anode in a x-ray tube. Tungsten is a common choice for the anode (due to its high melting point and high atomic number). Electrons come close to nuclei of the target, causing a deceleration and change in direction, converting kinetic energy into a spectrum of electromagnetic radiation. Incident electrons can ionise the material, removing an electron from the anode. As the electron orbit vacancy gets filled by a orbital shell electron in a further out shell a photon is emitted. As orbital energies and their differences are unique in atoms, this leads to what we call "characteristic radiation". [1]

Figure 1 shows a diagram of a X-ray tube. [2]

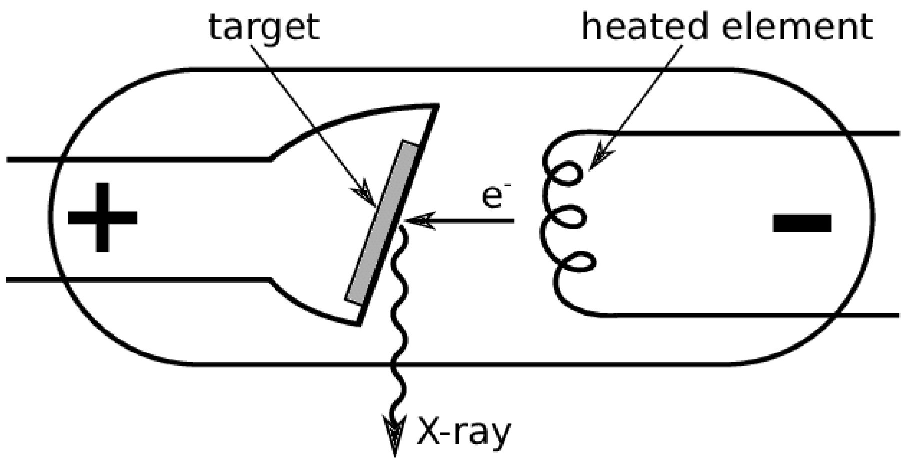

Figure 1: A X-ray tube

2.1.2 Attenuation of X-rays

As X-rays pass through matter, they are attenuated according to the Beer-Lambert law:

$$I(E) = I_0 \cdot e^{-\mu(E)x} \tag{1}$$

Where:

- I = transmitted intensity of radiation after passing through the material
- I_0 : Initial intensity
- μ : Linear attenuation coefficient
- x : Thickness of material

I have included μ to be energy dependent as this is what is observed in experiments, and allows us to look for an interesting phenomenon known as beam hardening. I calculate μ using:

$$\mu(E) = \left(\frac{\mu}{\rho}\right) \cdot \rho \tag{2}$$

using mass attenuation data from NIST and known material densities.

References

[1] D. Tafti and C. V. Maani., "Physics, x-ray production," 2023. Accessed: 2025-06-06.

[2] J. Mason, *Quantitative cone-beam computed tomography reconstruction for radiotherapy planning*. PhD thesis, 11 2018.