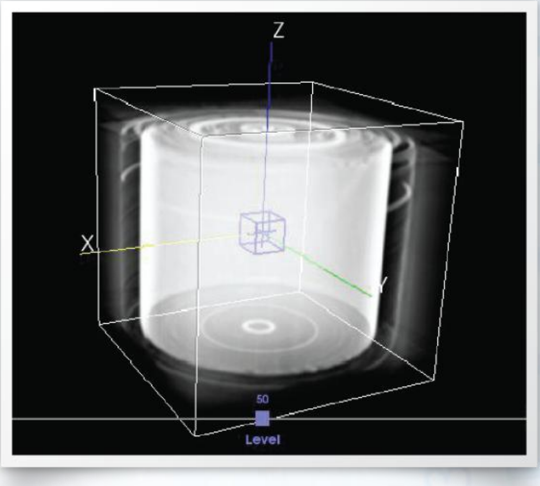

STUDENT EXERCISE

SYSTEM LINEARITY
LAB MANUAL: 2

Introduction

In this lab exercise, the student will investigate the linearity of the DeskCAT™ scanner by making measurements of attenuation.

Educational Objectives

- To learn about the relationship between optical density, transmission and attenuation coefficients in CT imaging
- To understand linearity, as it applies to CT imaging

Why Learn This

Characterizing the linearity of an imaging system identifies the range of attenuation values that can be accurately reproduced. Measuring linearity will help the student understand an important limitation in the use of an imaging system.

Overview

In optical CT, as in x-ray CT, a beam of photons traverses the object being scanned and measurements of the transmission are made at multiple angles. These projections of photon transmission can be used to reconstruct the internal geometry of the scanned object.
Transmission is defined as:

$$\frac{N}{N_o} = e^{-\mu x} \qquad [1]$$

Where N/N_o is the ratio of transmitted photons to incident photons through an object of length x and attenuation coefficient μ. The attenuation coefficient has units of inverse length. Figure 1 below gives a graphical representation of the variables in equation [1] for the attenuation of a photon beam by a homogeneous body with attenuation coefficient μ and length x.

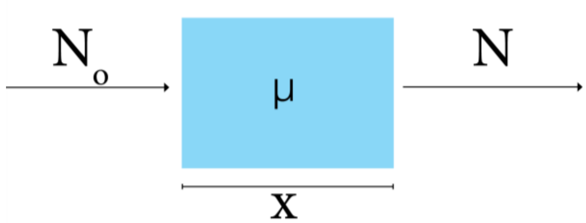

Figure 1: Beam attenuated by homogeneous body with attenuation coefficient μ and length x

The CT reconstruction algorithm calculates the attenuation coefficient (μ) as a function of 3D position from measured transmission values.

In x-ray CT imaging the attenuation coefficient is commonly called the linear attenuation coefficient. This use of the word linear could be confusing as we investigate the linearity of the response of the imaging system. For simplicity, this lab will refer to µ as the attenuation coefficient.

Linearity and Scanners

An important characteristic of a measurement device is that its response to a change in stimulus is linearly proportional to that change. A system with this property is said to have linearity and thus can be relied on to produce accurate results.

The linearity of a CT scanner can be tested by scanning phantoms with a variety of known µ values and plotting the results of the measured µ vs. known µ on a graph.
In this lab, the DeskCAT™ scanner will be tested for linearity using a series of water phantoms. Figure 2 below is a graphical representation of linearity, with examples of a linear and a non-linear system.

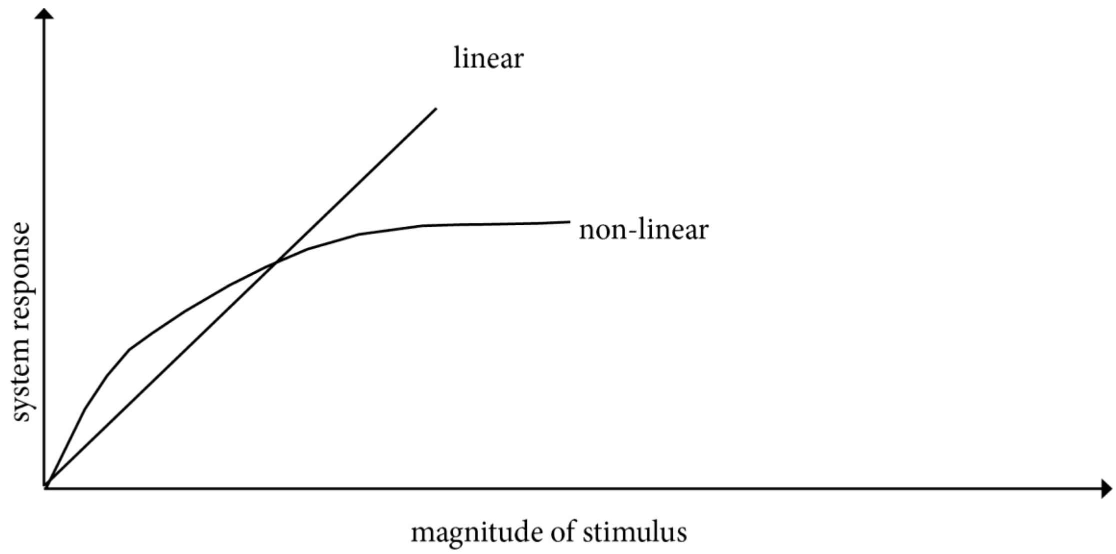

Figure 2: Stimulus/response curve of a linear and a non-linear system

Method

In this lab you will:

1. Measure the attenuation coefficient of a series of dye + water mixtures.
2. Compare measured attenuation coefficients using 2D and 3D imaging techniques to determine whether the scanner response is linear.

Lab Materials:

- Premixed solution of water & dye (food coloring), provided by lab instructor
- Water-filled jar
- 2L Water (preferably distilled)
- DeskCAT™ Multi-slice Optical CT Scanner

Project Set up and Scanner Calibration

1. Setup and connect the DeskCAT™ scanner.
2. Fill the aquarium with water to the top of the aquarium window. Capacity is approximately 2L. (Fill through the access ports or the large opening with the Rotary Stage removed).
3. Start the DeskCAT™ software and create a new project.
4. Inspect the Camera Video window (upper left), to see if there are any air bubbles in the field of view. *Air bubbles may interfere with the accuracy of your results. They can be removed by directing a stream of water from a syringe through either of the access ports. Alternatively, a short length of wire can be used as a poker to remove the bubbles.
5. Adjust the camera setting to achieve maximum brightness without saturating the image. Select **Scanner → Camera Settings**. Adjust **Frame Rate/Shutter Speed** until a few red pixels appear in the Camera Video window
6. Under **Reconstruction → Reconstruction Options**, select **Hamming Filter**.
7. Under **Calibration → Geometry Calibration** select **Auto-Cal** and accept the values. *Calibration must be done with NO phantom loaded.

Acquire Scans and Reconstruct Image

8. Load the Water-filled jar into the scanner by attaching the Water-filled jar to the Rotary Stage using the Jar Clamp and mounting the Rotary Stage onto the scanner. Ensure that the Rotary Stage is properly aligned using the alignment tab.
9. Select **320** projections for the scan from the Side Panel.
10. Acquire a reference scan using the **Start Reference Scan** button on the Side Panel. Note that reference images are a measure of the incident photons N_0 in equation 1.
11. Open the Projection Viewer window by clicking the **Projection Viewer** button on the Side Panel.
12. Select **Enable Snapshot**. Acquire snapshot by selecting **Take Snapshot**. Save the image for use later in this lab.
13. Remove the jar from the scanner and add 1 ml of dye+water solution to the jar. Secure the jar cap and shake the jar to mix the liquids. Load the jar into the scanner.
14. Acquire a data scan using the **Start Data Scan** button on the Side Panel.
15. Once the scan is complete, select the **High (0.5 mm) Voxel Resolution** option and press the **Start Reconstruction** button to perform a reconstruction.

Measure Attenuation Coefficient in 3D Image

Use the image in the 3D Viewer window (bottom right) to measure the linear attenuation coefficient of the liquid in the jar. The liquid in the jar is homogeneous, so a small region can be used to measure the attenuation coefficient. The following steps will be easier if you maximize the 3D Viewer window.

16. Use the Region of Interest (ROI) Histogram feature to make measurements of the attenuation coefficient by selecting the **Region of Interest Histogram** tab on the 3D Viewer. The default ROI cube should be centered in the 3D image and have a size of 1 cm^3 (as shown in Figure 3). Reset the ROI if required. Use this size and position for all measurements.

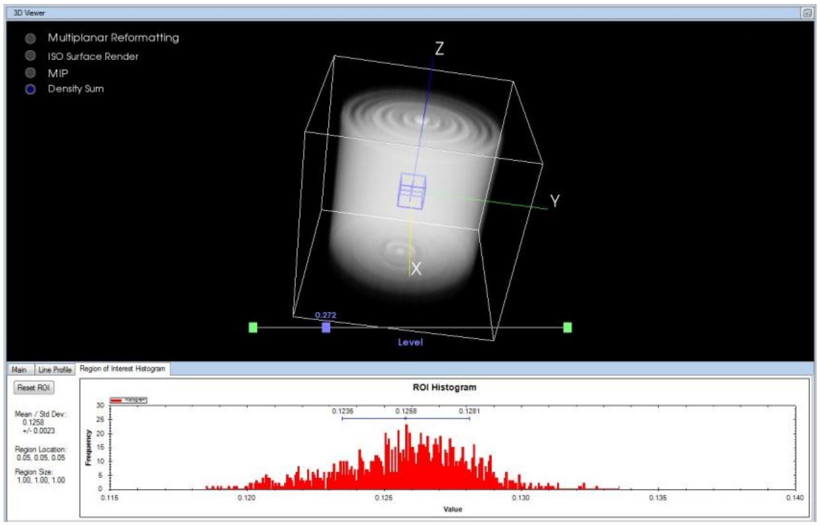

Figure 3: ROI and histogram display in 3D Viewer

17. Observe the histogram that appears below the 3D image. There should be a spread of values because of noise in the 3D image.
18. Record the mean (μ) and standard deviation in cm^{-1}.

Repeat Measurement for Darker Liquids

19. Remove the phantom and add another 1 ml of dye +water solution to the phantom. This will make the contents of the jar darker (increased attenuation coefficient).
20. Repeat steps 14 -18 above to measure the attenuation coefficient of the darker liquid. Each time you start a new data scan you will be warned that a data scan already exists. Select **Yes to Overwrite.**
21. Repeat this process by adding another 1 ml of dye+water solution to the jar and scanning, until you have recorded attenuation coefficient measurements for 1, 2, 3, 4, and 5 ml of dye+water solution.
22. Plot the recorded attenuation coefficient versus the amount of dye+water in the jar.

Measure Attenuation Coefficient in 2D Image

23. With the darkest liquid still in the scanner, open the Projection Viewer from the Side Panel.
24. Select **Enable Snapshot**. Acquire a snapshot by selecting **Take Snapshot**. Save the image.
25. Move the cursor to the middle of the snapshot. Observe the position of the cursor and greyscale pixel value shown along the bottom of the window (as seen in Figure 4). This greyscale value corresponds to the device's measured transmission at that location.

Figure 4: Measuring transmission values using Projection Viewer

26. Record the value and cursor location near the center of the jar by placing the cursor over a pixel in this region. This measurement corresponds to the attenuated transmission (N).
27. Load the image of the water only phantom taken in step 12 above.
28. Measure the greyscale value at the same cursor location as used in step 26 above. This measurement corresponds to the maximum transmission (N_o)
29. Use equation [1] to calculate the attenuation coefficient of the darkest liquid. The jar is 7.2 cm in diameter.

Discussion / Additional Questions

1. Based on your results, would you say that the DeskCAT™ scanner is linear? Why or why not? If not, what are possible causes of the non-linearity?
2. Does the attenuation coefficient measured in 2D match the value measured in 3D for the darkest liquid? If not, give reasons why.
3. What is a cupping artifact? Do you see a cupping artifact in any of your images? How are cupping artifacts related to linearity?

Further Study

4. In this experiment, dye was added to water to change optical density. How would you create a phantom to perform an equivalent experiment in x-ray CT?
5. What are Hounsfield units and how are they related to attenuation coefficients?
6. What is beam hardening in x-ray CT?

