



## LAB DEMONSTRATION COMPUTED TOMOGRAPHY USING DESKCAT™

Lab Manual: 0

## Introduction

This lab demonstration explores the physics and technology of Computed Tomography (CT) and guides the student and instructor through the process of using DeskCAT™ to scan, reconstruct and display CT images of a test object.

The procedures described are suitable for students to use in a *laboratory setting* or for an instructor to use in a *classroom setting*. Comments and questions are included to provide guidance in crafting a student lab report and to prompt discussion in the classroom.

This lab demonstration is different from subsequent student lab exercises in that it is non-quantitative. In contrast, Lab 0 focuses on instilling an understanding of the physics and technology of CT and provides an opportunity to learn about the operation of DeskCAT™.

## Educational Objectives

- To learn how 2D projection images are created
- To learn how 3D CT images are created from 2D projections
- To gain experience with common display modes for 2D and 3D images
- To understand the operation of the DeskCAT™ Optical CT scanner, including both hardware and software features

## Why Learn This?

Students are likely to come in contact with CT scanners as part of a medical diagnostic procedure at some time in their life. Professionally, they may also make use of the rich 3D information produced by CT scanners (physicians, scientists or engineers) or become scanner operators (imaging technologists, medical physicists). In each case, an understanding of the imaging process and results of CT scanning will be highly beneficial.

## Overview

### Medical Imaging

Medical imaging is routinely used in diagnosis, treatment planning and surgical guidance. One of the most common imaging techniques, radiography, uses X-rays to create a two-dimensional (2D) projection image of a patient. A 3D CT image can then be created through the mathematical reconstruction of a series of 2D projection images. There are also many non-medical uses of computed tomography and X-ray imaging in industry (inspection for impurities), security (airport scanners) and research (animal scanners).

### DeskCAT™

DeskCAT™ is an optical CT scanner. It operates on the same physical principles as a medical CT scanner except that it uses light instead of X-rays. Optical CT is ideal for education because it is safe and allows the scanner to be intuitive, accessible and interactive.

## Method and Discussion

### In this lab you will:

1. Acquire 2D projection images of a Mouse phantom
2. Acquire and reconstruct 3D CT images of a Mouse phantom
3. Use different display modes to explore 3D CT images of a Mouse phantom

Note: In the following procedures, discussion points and questions are included to enhance understanding and to provide guidance for preparing a laboratory report. Optional activities are also included to supplement the educational objectives. Some of the materials required for the optional activities are not supplied with the scanner but may be readily available in an educational setting.

### Lab Materials:

- Mouse phantom
- 2L Water (preferably distilled)
- DeskCAT™ Multi-slice Optical CT Scanner
- DeskCAT™ Quick Start Guide
- DeskCAT™ User's Guide
- Optional – phantoms and Lab manuals for subsequent labs
- Optional – laser pointer
- Optional – digital camera, phone camera or web cam
- Optional – clear plastic ruler 6" (15 cm)



### Preparation

In a *classroom setting*, the instructor should setup the scanner prior to demonstration.

In a *laboratory setting* the instructor must decide whether to: setup the DeskCAT™ scanner and software (steps 1 - 10 below) prior to the laboratory period **OR** require the student to setup the scanner and software during the laboratory period in preparation for later laboratory exercises.

Note: The following steps are similar to the Quick Start Guide and subsequent lab exercises. Refer to the DeskCAT™ User's Guide for further information on specific features of the scanner and software.

## Setup DeskCAT™ Scanner

1. Place the DeskCAT™ scanner on a flat, sturdy work surface such as a table or lab bench adjacent to the computer that will be used to control it.
2. Connect two USB cables from Scanner to computer running the DeskCAT™ software. The USB cable with the mini-connector provides power to the Camera. The green power LED beside the camera USB connector will light up when power is applied.
3. Connect power cable with barrel connector to top of Rotary Stage. Connect Auxiliary Power cable (3.5 mm stereo audio cable) between Rotary Stage and main Scanner body to power LEDs. Plug in the power adapter to power source.
- ~~4. Remove Rotary Stage and add water to the aquarium as required. Capacity is approximately 2 liters. Fill through the fill ports or the large opening with the stage removed. Fill slowly to avoid introducing bubbles into the aquarium, which could interfere with imaging and introduce errors into the data.~~

## Start & Setup DeskCAT™ Software

5. Click on DeskCAT™ icon to start program. The Open Project dialog box appears.
6. Create a new project, or select an existing one. Click **Open** to continue.
- ~~7. 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.~~
8. Adjust the camera setting to achieve maximum brightness without saturating the image. Select **Scanner → Camera Settings**. Adjust **Frame Rate/Shutter Speed** until only a few red pixels are visible in the Camera Video. Red pixels indicate saturation.

## Calibrate Scanner

9. Under **Calibration → Geometry Calibration** select **Auto-Cal** and accept the values.  
\*Calibration must be done with NO phantom loaded.

## Obtain New Reference Image

10. Click on **New Reference Image** button on Side Panel to capture a single reference image. The captured reference image will be saved by the system for use in image reconstruction.

Note: Reference images are used to compensate for light source inhomogeneities.

The DeskCAT™ scanner and software are now ready to scan.

## Phantoms

Prior to acquiring images with DeskCAT™ it is helpful to observe and understand some physical properties of the test objects which are about to be scanned. These test objects are commonly known as phantoms.

The phantoms used with DeskCAT™ are made of clear silicone with the addition of colored dyes. They are translucent to light in the same way that patients are translucent to X-rays. Alternative materials for phantoms are water (used in Lab Exercise # 2) and clear gelatin. DeskCAT™ is provided with multiple phantoms which have been designed to enable the different experiments described in the subsequent lab exercises.

In general, phantoms are test objects with known properties which, when imaged, provide information about how an imaging system performs. In medical imaging, different kinds of phantoms are used for quality assurance to ensure that an imaging system is performing as expected or within tolerances.

11. Observe the Mouse phantom – hold it up in room light – hold it up in a dark room in front of a bright white screen – shine the light from a laser pointer through it – what optical effects do you observe? Hint – some optical effects to consider are reflection, refraction, scattering, absorption, and color.

X-rays are higher energy photons than light. Do X-rays interact with matter the same way that light does? What are the differences and similarities?

12. Optional – acquire a few close-up digital photos of the Mouse phantom from different directions. Make sure that you have one image from the front of the mouse and at least one image from an oblique angle. Save these photos for use later in this demonstration and in your lab report.



13. Optional – observe other DeskCAT™ phantoms, how are they different from the Mouse phantom? ~~Can you relate the differences in the phantoms to the educational goals of the subsequent labs?~~



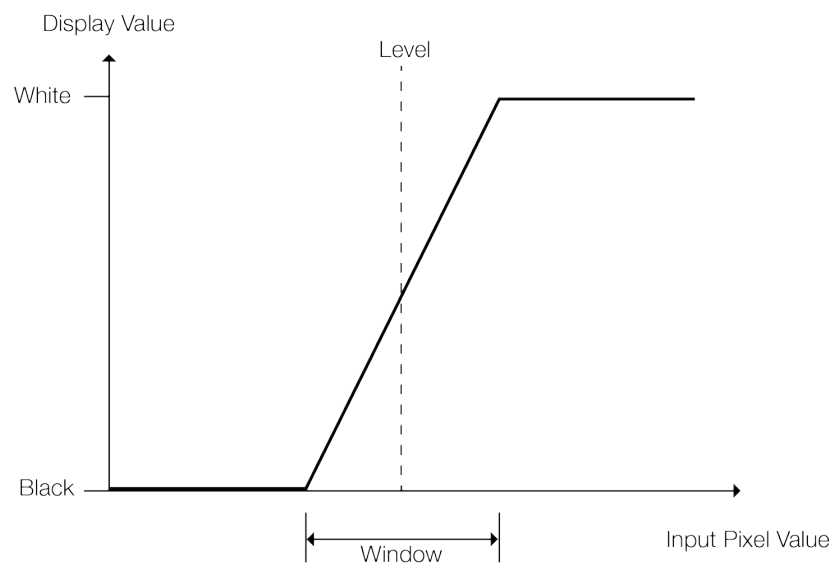
## Projection Image

14. Load the Mouse phantom into the scanner by attaching the phantom 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. As the phantom is lowered into the scanner you will see the image of the Mouse phantom appear in the Camera Video window. Maximize the Camera Video window.

## Alignment Tab

15. Select **Scanner → Motor Control**. Drag the Motor Control window to a location that does not obstruct your view of the Mouse phantom. Use the Motor Control interface to rotate the Mouse Phantom.
16. Right click in the Camera Video window to gain experience with the **Zoom** and **Window/Level** controls.

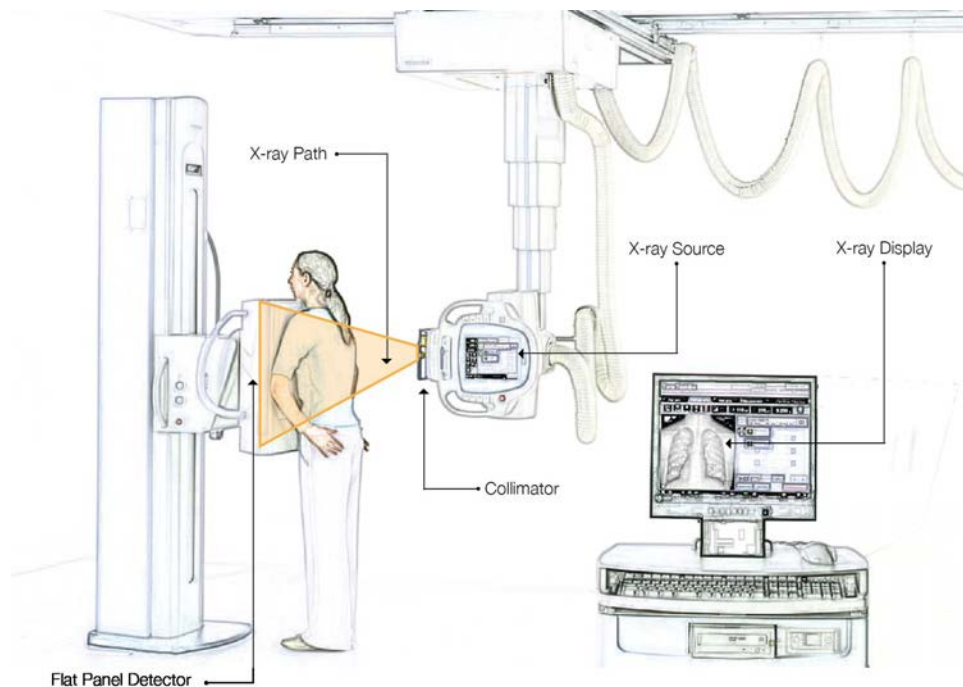
“Window” and “Level” are related to image brightness and contrast adjustment. Display contrast can be increased or decreased by making the window narrower or wider. Likewise, display brightness can be increased or decreased by adjusting the level (Figure 3).



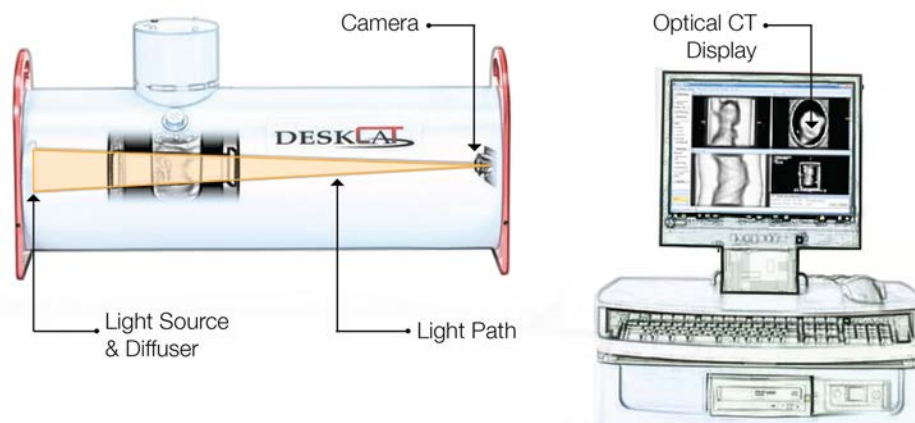
*Figure 3: A graphical representation of how “window” and “level” are used to adjust display contrast and brightness.*

The image that is displayed in the Camera Video window is an optical 2D projection image. It is the equivalent of an X-ray 2D projection image in medical imaging. A projection image is formed when a photon beam traveling from source to detector is attenuated by an object. The numerical value of each pixel in the image is the brightness of the source dimmed by attenuation values on the line through the phantom between the source and the detector.

In the image of the phantom, the brain and intestines of the mouse are darker than the rest of the mouse. This is because these objects have higher optical densities and therefore attenuate more light. In a medical radiograph bones attenuate more X-rays than surrounding tissues because bones are more dense. However, when you look at bones in a skeleton they appear white. What is the difference between the density of the Mouse's brain in an optical projection image and bones in an X-ray projection image? What is the difference between the interaction of light with the phantom and X-rays with tissues in a patient?



*Figure 4a: Shows the clinical setup for acquiring a chest radiograph. The flat panel acquires the projection image.*



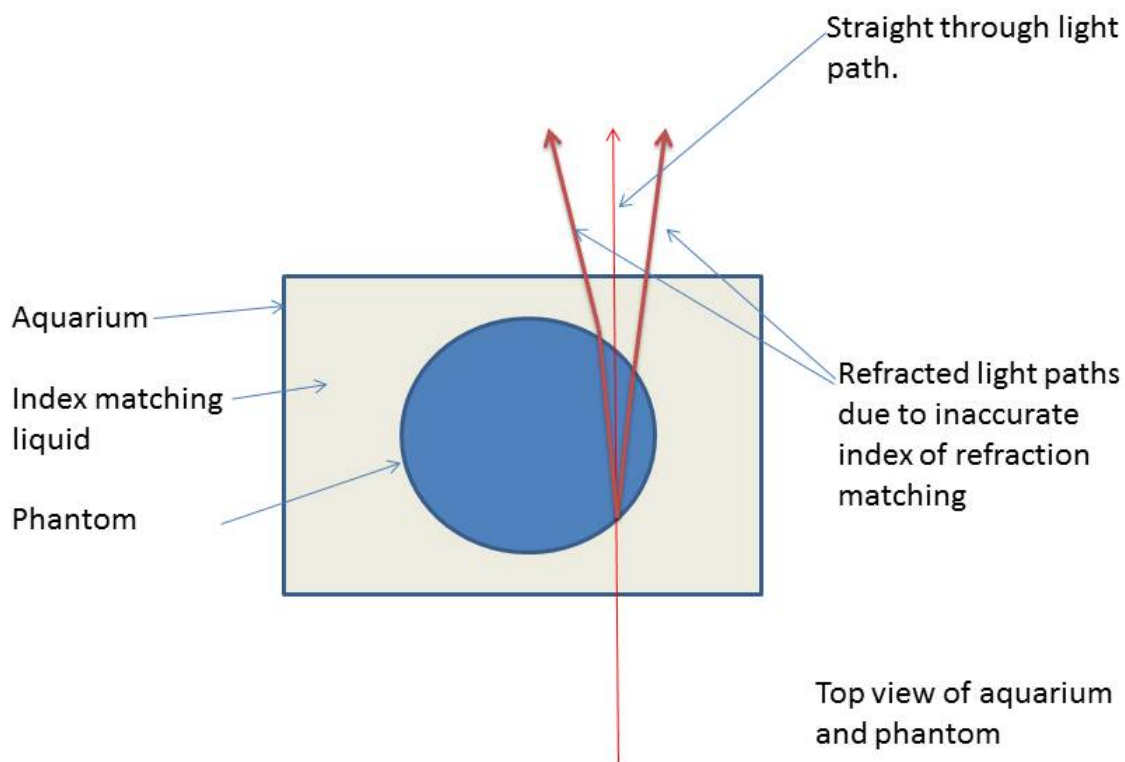
*Figure 4b: Shows the equivalent setup for the DeskCAT™ Optical CT Scanner.*

17. While viewing the phantom in the Camera Video window, do you see evidence of the optical effects that you observed in step **11** (before placing the phantom in the scanner)?

Figure 5 is a schematic showing a top view of the aquarium with a phantom and refracted light paths through the aquarium. The water in the aquarium is used to reduce the effect of refraction.

Figure 6 shows a projection image where some of the water has been removed from the aquarium. What evidence of refraction do you see in this image?

Is refractive index matching necessary in X-ray imaging?



*Figure 5: Illustrates the effect of refraction along a light path. The refractive index of the matching liquid will determine which path the light follows. For example, an accurate refractive index matching liquid will result in light following the straight path through the phantom.*



*Figure 6: A projection image of a Mouse phantom in a half filled aquarium. Water is a better refractive index match to the phantom than air. Therefore, the effects of refraction are more evident above the water level.*

18. The source light in the scanner can be switched between red and green. What color are you using? Why is the image in the Camera Video window shown in grey scale? In X-ray imaging, what is the equivalent of changing color? Switch back to the original light color in the scanner before continuing.

## Perform Data Scan

19. In the Side Panel select **200** projection images.
20. Click **Data Scan** on the Side Panel to perform scan.
  - 200 projection images are acquired and saved (in the project folder) as the phantom is rotated through 360 degrees.
  - An image of the center slice sinogram appears as the scan progresses.

Note: During a scan with DeskCAT™ the phantom is rotated. Mechanically this is simpler and easier than rotating the source and detector. In contrast, a medical CT scanner rotates the source and detector because it is not practical to rotate patients.

## Review Scan

21. Select the **High (0.5mm) Voxel Resolution** radio button in the Side Panel.
22. Open the Projection Viewer by clicking on the **Projection Viewer** button in the Side Panel. In the Main Tab at the bottom of the Projection Viewer window you can use the radio buttons to show the **Reference ( $I_0$ )**, **Data ( $I$ )**,  **$I_0/I$**  (ratio of the reference image to data image for each pixel), and  **$\ln(I_0/I)$**  (natural logarithm of the ratio) images.

Note: The importance of these calculated images is beyond the scope of this document. However, it should be noted that a CT image is reconstructed using the  $\ln(I_0/I)$  images at the selected resolution.

It is possible to change the selected resolution from **Low (2mm)** to **Very High (0.25 mm)** by closing the Projection Viewer, selecting a different resolution and then reopening the Projection Viewer. It is possible to show the full image resolution by selecting the **Full Image** checkbox in the Projection Viewer window.

The projection images can be stepped through manually, or viewed through playback using the

**Play**  and **Pause**  controls.

**Zoom** and **Window/Level** values of the projection images can be manipulated by right clicking on the image and selecting the appropriate tool.

- ~~23. Optional — Once you have gained experience using these controls please select a projection image that shows a front view of the mouse. Compare this image to the front view of the mouse acquired with your digital camera earlier in the lab. DeskCAT™ uses a greyscale digital camera. Why is the DeskCAT™ projection image different from your digital camera image? Hint: consider the path of light from source to detector. Is it possible to find a projection image in DeskCAT™ that is from the same direction as the oblique image taken earlier with your digital camera?~~

~~Note: In a CT scanner the object being scanned is between the source and the detector. In DeskCAT™, the light photons converge from a large area diffuse source through the object being scanned and into the small aperture of the camera. In a cone beam X-ray CT scanner, the X-ray photons diverge from a small source through the object being scanned and onto a large area detector. In each case the geometry is a rectangular cone, allowing the same reconstruction algorithm to be used despite having reverse photon directions.~~

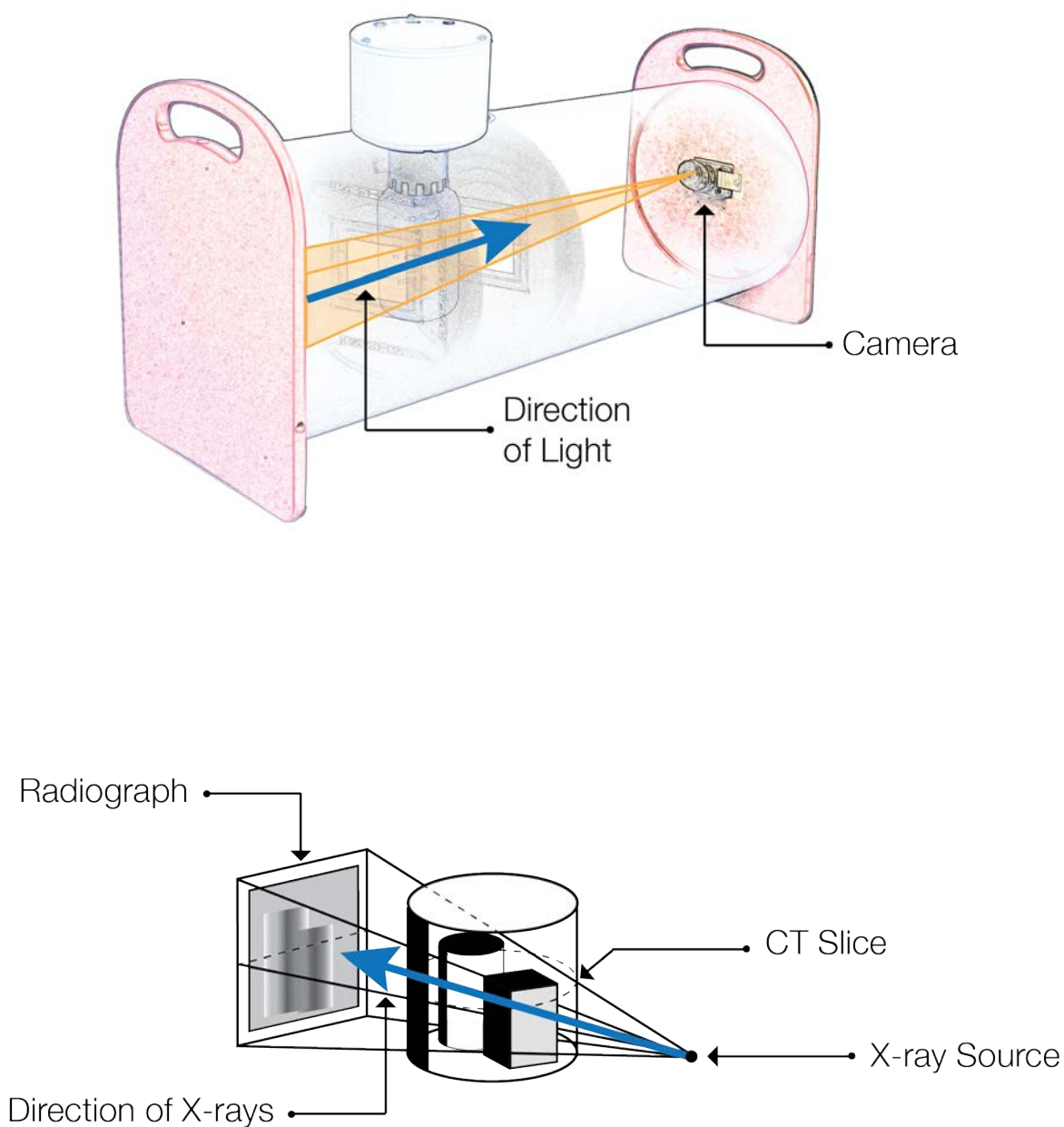


Figure 7: (a) DeskCAT™ scanner schematic showing light photons direction of travel (b) Schematic of a cone beam X-ray CT scanner, showing the X-ray photons direction of travel.

## Sinogram

During each scan a sinogram appears in the Center Slice Sinogram window. This image is created by stacking the central line of each projection image (identified by the red arrows in the Camera View window). The vertical axis of the sinogram represents the angle of rotation (projection number). Objects that do not rotate during a scan appear as vertical stripes in the sinogram display.

24. Save a screen shot of the sinogram image for your report.

Observe the sinogram – can you see any obvious or faint vertical lines? Where could the objects that cause such vertical lines be located in the scanner?

25. Optional – place an object such as a clear plastic ruler into the aquarium so that it can be seen next to the Mouse phantom. This object must be tall enough to intersect the central line in the projection image (Figure 8). Please note that this object will not rotate during the scan. Repeat the data scan, observe the sinogram and save a screen shot for your lab report. Identify the non-rotating object in the resulting sinogram. Remove the non-rotating object and repeat the data scan before continuing.

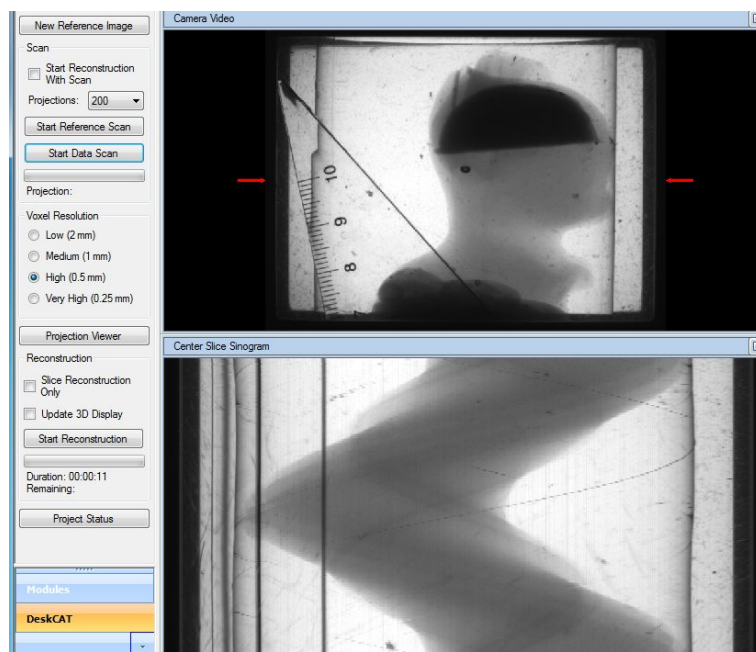


Figure 8: Shows a ruler placed inside the aquarium and the resultant center slice sinogram.

## Reconstruct and Display 2D and 3D CT Images

Note: For the purpose of discussion and questions, please know that you can repeat the scan as many times as you would like because there is no X-ray radiation dose to the phantom (or to the operator) and there is no X-ray tube to wear out.

26. On the Side Panel select the following:

- **Start Reconstruction With Scan**
- **High (0.5 mm) Voxel Resolution**
- **Update 3D Display**

27. From the menu bar, select **Reconstruction → Reconstruction Options** and select the **Hamming Filter**.

Filters are used to reduce high frequency noise in the reconstructed image. The selection of which filter to use during reconstruction is beyond the scope of this document.

28. Press **Start Data Scan** button on the Side Panel. During the scan:

- the Camera View window is updated as projection images are acquired
- the sinogram is created during the scan
- the 2D CT image in the Slice Reconstruction window is updated as each projection is acquired
- the 3D CT image in the 3D viewer window is updated as each projection is acquired

29. When the scan is complete click **Ok** to continue.

30. Once reconstruction is complete, reconstructed images can be viewed and manipulated in the Slice Reconstruction window or the 3D Viewer window.

Note: The reference image, calibration parameters, projection images and reconstructed CT images are saved in the project folder as they are generated. Select **Project Status** on the Side Panel at any time to review the project data which has been generated and saved.

Note: on a slower or less powerful computer it may be preferable to keep the scanning, reconstructing and 3D Display activities separate. This can be done by deselecting the **Start Reconstruction with Scan** and **Update 3D Display** buttons in the Side Panel.

Reconstruction can be started manually using the **Start Reconstruction** button in the Side Panel. Reconstructed images can be loaded using the **Open** button on the Main Tab of the 3D Viewer window. Selecting **Slice Reconstruction Only** allows you to observe the reconstruction of the center slice. **Slice Reconstruction Only** and **Update 3D Display** cannot be active at the same time.

### 2D CT Image

31. By observing the Slice Reconstruction window during a scan you will see how projection image data is back projected into a single slice. Repeat the scan until you understand qualitatively how the projection data is back projected and displayed. Following reconstruction, you can observe different 2D slices by clicking and dragging the arrow in the Slice Reconstruction window.

32. Explore the following commands in the Slice Reconstruction window:

- Right click in the window and manipulate the **Zoom** and **Window/Level** controls

- Right click and select the **Line Profile Tool**. Click and drag a line within the image to see a line profile
  - Right click within the Slice Reconstruction window and select the **Region Profile Tool**. Click and drag in the image to see a Region of Interest (ROI) Histogram. Right click again to change the ROI from a rectangle to a circle
  - Right click in the Line Profile or ROI Histogram window to display a menu of functions allowing you to save the image, save the data, or export the data in the window
33. Once you have become comfortable with the display and manipulation of 2D CT images you should save some screen shots for your laboratory report.

## 3D CT image

By observing the 3D Viewer window during a reconstruction, you will see how projection image data is back projected into a 3D image (**Update 3D Display** must be selected). It may be helpful to maximize the 3D Viewer window and repeat the scan/reconstruction as you explore the 3D image using the different display modes.

## Navigating the 3D Image using Multiplanar Reformatting

Multiplanar Reformatting (MPR) is one of the most important display modes in medical imaging. MPR allows you to visualize 2D planes within a 3D image. Manipulating the 3D image within DeskCAT™ software is easy to do with a bit of practice. The image will not be damaged by experimenting with the display. You may use the **Reset View** button to return the image to its starting position.

The description below is a brief summary of the tools for manipulating the 3D image. Practice with each tool until you become comfortable with navigation.

- To rotate cube, left click outside of cube and drag
  - To pan, middle click outside of cube and drag
  - To zoom, right click outside of cube and drag up/down OR scroll mouse wheel
  - For point cursor (xyz coordinates and attenuation value): left click on plane
  - To move plane: middle click on plane and drag
  - To tilt plane: middle click on border of plane and drag
  - To adjust window: right click on plane and drag left/right
  - To adjust level: right click on plane and drag up/down
  - To turn on/off planes: select x, y or z axis plane check box in Main Tab at bottom of window
  - To turn on/off wireframe: select **View Outline** checkbox in Main Tab at bottom of window
  - To turn on/off axis labels: select **View Axes** checkbox in Main Tab at bottom of window
34. Manipulate the image of the Mouse phantom until the brain and intestines are visible. Save a screen shot of this image for your report.

## Navigating the 3D Image using ISO Surface Render

ISO Surface Render displays the surface of objects within a 3D image that have the same density (pixel value). The cube can be rotated and moved the same way as in MPR.

Note: In this and the following display modes it may be helpful to turn on the **Select Radius of Valid Data** button on the Main Tab at the bottom of the 3D Viewer window. Decreasing the value from 1.00, crops the image perimeter. Use this feature to remove the jar walls in the displayed image.

35. By adjusting the **ISO Value** you can display surfaces of different densities. Adjust the slider to show the surface of the mouse, the brain and/or the intestines. Save a screen shot of these images for your lab report.

## Navigating the 3D Image using Maximum Intensity Projection

Maximum Intensity Projection (MIP) is a reprojection display mode where lines are projected through the image – one line for each display pixel – and the brightest pixel on each line is shown on the display. This mode is commonly used because it is a fast algorithm that is easy to implement. The cube can be rotated and moved the same way as in MPR.

36. By observing and manipulating the MIP display during a scan/reconstruction (**Update 3D Display** must be selected), you will see how projection image data is back projected into a 3D CT image. Repeat this process until you understand qualitatively how the projection data is back projected and displayed.
37. By adjusting the **Intensity Slider** you can alter the MIP display. Save a screen shot for your lab report.

## Navigating the 3D Image using Density Sum

Density Sum is a more computationally intensive reprojection display mode than MIP. It produces an image that is similar to an acquired projection image from the scanner; however the 3D image can be viewed from any angle (including projection angles that are not possible in the scanner). In this technique, lines are projected through the image – one line for each display pixel – and the average pixel value along on each line is shown on the display. The cube can be rotated and moved the same way as in MPR.

38. By adjusting the **Level Slider**, you can alter the Density Sum display. Save a screen shot for your report.

## Culminating Activities

- ~~39. Optional – Once you have become comfortable with the display and manipulation of each display mode you should be able to display the phantom in the same orientation as in your digital photos. Save a screen shot of these images and match each of them with the appropriate digital photo in your report.~~
40. Optional – Line Profile and Region of Interest Histogram tabs are similar to the tools in the Slice Reconstruction window. Explore each tool, referring to the appropriate section of the User's Guide if necessary. Save screen shots for your report.
41. In your laboratory report describe, in a few paragraphs, how a 2D projection image is formed. Similarly, describe how a 3D CT image is formed.

## Further Study

DeskCAT™ is a cone beam CT scanner. What other geometries of scanners are there (e.g. multislice, helical)? Hint - sometimes these are called different generations of CT scanners.

How long does it take to scan and reconstruct an image using the DeskCAT™ scanner? How do the number of projections and the resolution of the 3D image affect the speed? What is the speed of medical CT scanners? In what medical applications would high speed be an advantage?