STUDENT EXERCISE

SPATIAL RESOLUTION AND MODULATION TRANSFER FUNCTION
LAB MANUAL: 3

Introduction

This lab exercise introduces the concepts of spatial resolution and modulation transfer function and guides the student through an experiment to investigate these characteristics using the DeskCAT™ scanner.

Educational Objectives

- To understand the concept of spatial resolution and how it can be assessed both qualitatively and quantitatively
- To learn the line pair technique for measuring the Modulation Transfer Function of a CT scanner.

Why learn this?

It is important to understand and assess the inherent limitations of an imaging system. For example, astronomers need to know the smallest size of celestial bodies that can be reliably observed using their telescopes, diagnostic radiologists need to know the size of the smallest tumor detectable, and cell biologists need to know the size of the smallest cell organelle that can be visualized using their microscopes. The line pair technique is commonly used to measure spatial resolution in many different imaging systems.

Overview

The ability of an imaging system to resolve small objects is described by its spatial resolution. The spatial resolution of an imaging system can be assessed qualitatively through visualization of small objects of known size or quantitatively by measuring the modulation of the system as a function of spatial frequency.
Spatial frequency is often defined in units of line pairs per unit length. A line pair is a white line next to a black line, where the difference between the brightness of the two lines is within the dynamic range (range of maximum brightness to maximum darkness) of the imaging system. The spatial frequency of the line pairs is increased as the line pairs shrink and crowd each other, making them harder to distinguish as shown in Figure 1 below.
You will learn a technique to assess spatial resolution of an imaging system by imaging a line pair test object. Comparing the resolution of projection images to CT images allows you to assess the change in resolution due to the reconstruction process.

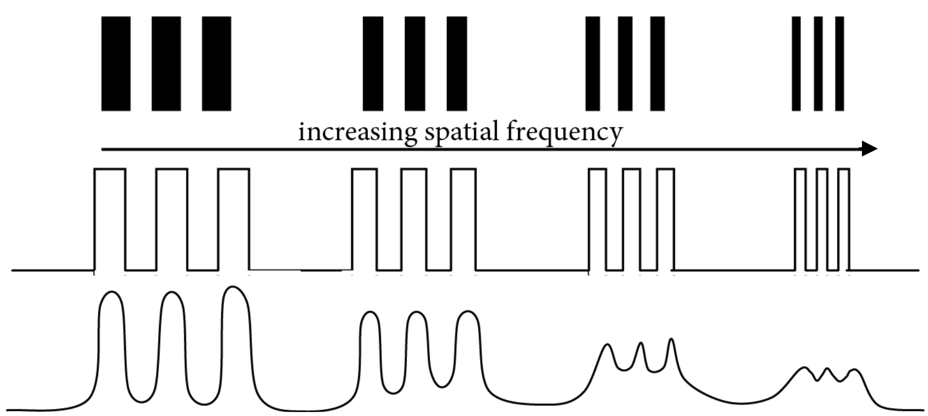


Figure 1: A line pair pattern (top), an ideal line profile through the pattern with no image degradation (middle), and with image degradation (bottom).

The modulation at each line-pair frequency can be defined as a function of the brightness of the line pairs (as displayed by the imaging system), using Equation 1 below:

Modulation(f) = (max. brightness – min. brightness) / (max. brightness + min. brightness) [1]

Where (f) denotes the spatial frequency.
As the spatial frequency increases, the modulation is reduced until the line pairs are no longer distinguishable.
The Modulation Transfer Function (MTF) is a plot of the relative modulation as a function of spatial frequency. The MTF is generally normalized such that the maximum modulation is given a value of 1.0

MTF(f) = Modulation(f)/Modulation (0) [2]

Where Modulation (0) is the maximum modulation of the system.

Method

In this lab, you will:

1. Calculate the Modulation Transfer Function by scanning a Line Pair phantom.
2. Plot the relative modulation as a function of spatial frequency (line pairs/mm).
3. Compare the MTFs using different filter and resolution settings.

Lab Materials:

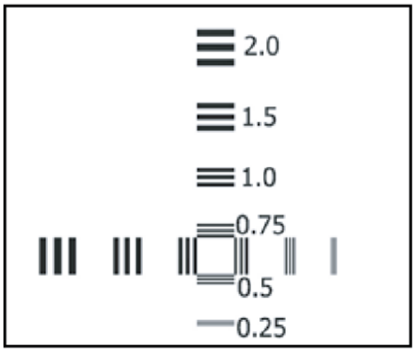
- Line Pair phantom (shown at right)
- DeskCAT™ Multi-slice Optical CT Scanner

Project Set up and Scanner Calibration

1. Setup and connect the DeskCAT™ scanner.
2. Start the DeskCAT™ software and create a new project.
3. 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.
4. Under **Reconstruction → Reconstruction Options**, select **Hamming Filter**.
5. Under **Calibration → Geometry Calibration** select **Auto-Cal** and accept the values. *Calibration must be done with NO phantom loaded.

Phantom Geometry

Figure 2 is a diagram of the line pair pattern as printed on a plastic transparency in the Line Pair phantom. The pattern is labeled with the width of each line in mm. The chart in Figure 2 shows the corresponding spatial frequency in line pairs per mm (lp/mm).



Size (mm)	Spatial Frequency (lp/mm)
2.0	0.5
1.5	0.67
1.0	1.0
0.75	1.3
0.5	2
0.25	4

Figure 2: Schematic of the Line Pair pattern

Calculate Modulation Transfer Function (MTF) for a Projection Image

6. Acquire a reference image by selecting **New Reference Image**.*Reference image must be acquired with NO phantom loaded
7. Select **320** projections for the scan from the Side Panel.
8. Load the Line Pair 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.
9. Using the **Scanner → Motor Control** function, rotate the phantom while observing it in the Camera Video window (upper left window).

Figure 3: Edge of Line Pair transparency in Camera Video window

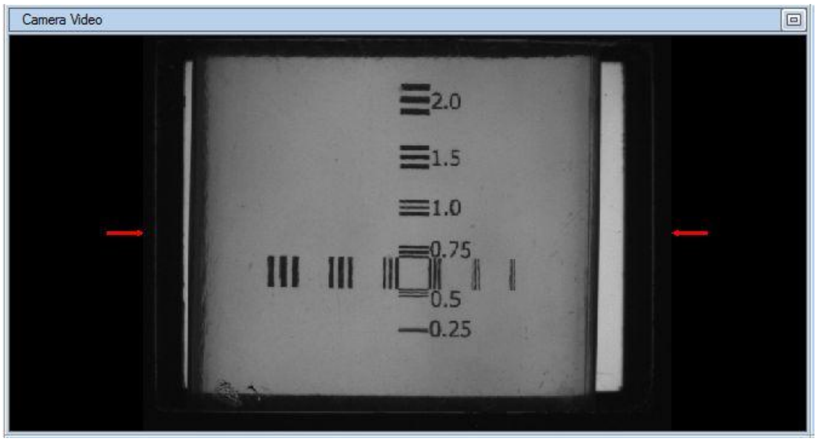


Figure 4: Line Pair pattern, Camera Video

10. Rotate the phantom until the edge of the Line Pair transparency is visible, as shown in Figure 3. Select **Set Current Position As Home**.
11. Select **Move To 90 or 270** to rotate the Line Pair pattern to appear as shown in Figure 4.
12. Open the Projection Viewer window by clicking **Projection Viewer** on the toolbar on the left of the screen.
13. Select **Enable Snapshot**. Acquire snapshot by selecting **Take Snapshot.**
14. Select the **Line Profile** tool (from the bottom tab) and draw a line profile (click and drag mouse) that intersects the lines pairs, as shown by the red line in Figure 5.

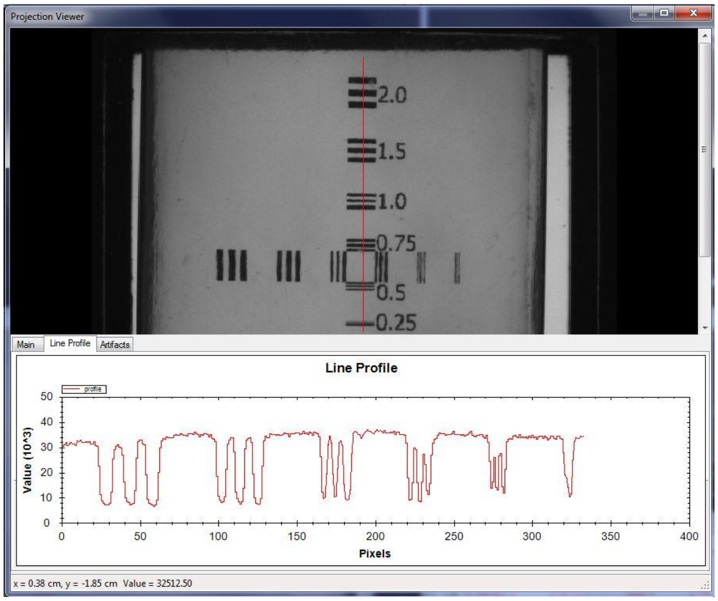


Figure 5: Line Profile, Projection Viewer

15. Observe the minimum and maximum peaks of the line profile as it intersects each of the groups of line pairs. Record your results in a table like the one below:

Spatial Frequency	Maximum	Minimum	Modulation
0.5			
0.67			
1.0			
1.3			
2			
4			

16. Using these measurements, calculate the modulation of each spatial frequency using equation [1] and make a plot of the MTF versus spatial frequency.

Calculate Modulation Transfer Function (MTF) for a CT Image

17. With the Line Pair phantom loaded, perform a **Data Scan** at **320** projections setting.
18. With the Voxel Size set to **Very High (0.25mm)**, perform a reconstruction. The reconstruction may take a few minutes.
19. Once the reconstruction is complete, maximize the 3D Viewer
20. Select Multiplanar Reformatting.

Navigating the 3D Image

- To rotate the cube containing the 3D image, 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 push/pull 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 plane check box in Main Tab at bottom of image window
- To turn on/off wireframe: select View Outline checkbox in Main Tab at bottom of image window
- To turn on/off axis labels: select View Axes checkbox in Main Tab at bottom of image window

Position Reconstructed CT slice for MTF analysis

21. Navigate the 3D image until the entire Line Pair pattern is visible as shown in Figure 6. The Line Pair pattern should not have a ‘gradient’ appearance as shown in Figure 7.

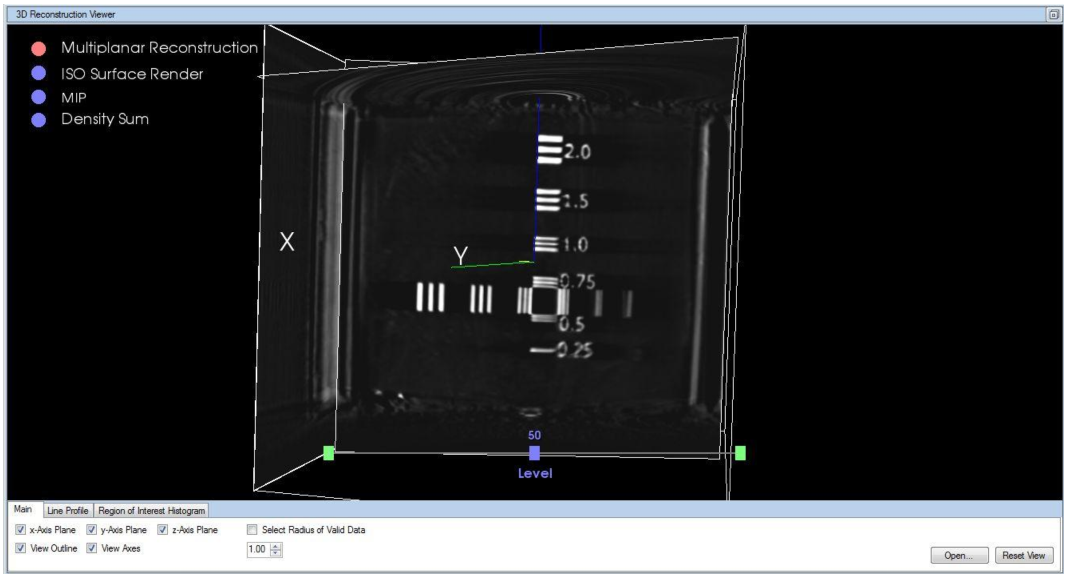


Figure 6: Line Pair pattern properly aligned in 3D image

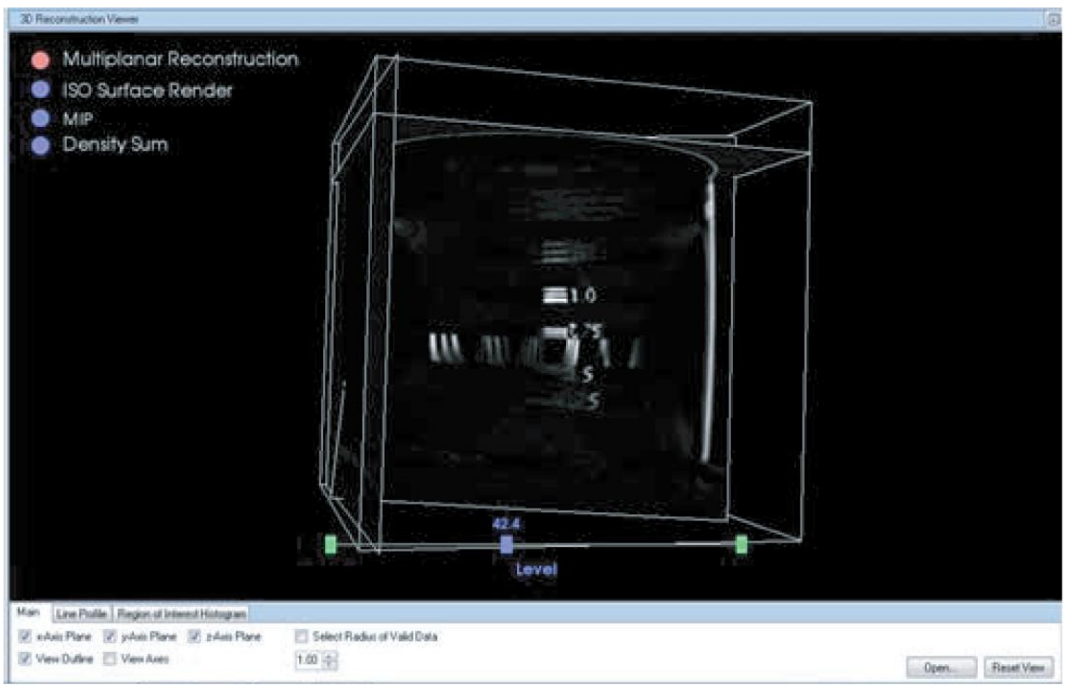


Figure 7: Gradient appearance on Line Pair pattern due to poorly aligned plane

Calculate MTF of Reconstructed CT Image

22. Select the **Line Profile** tool by clicking the appropriate tab along the bottom of the 3D Viewer window.
23. Repeat the measurements of maximum and minimum peaks as in step 15 and 16 above, and make a second plot of MTF vs. spatial frequency.

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24. Perform another reconstruction of the data using a **lower Voxel Resolution** and repeat the measurements in steps 15 and 16 and plot MTF vs. spatial frequency.

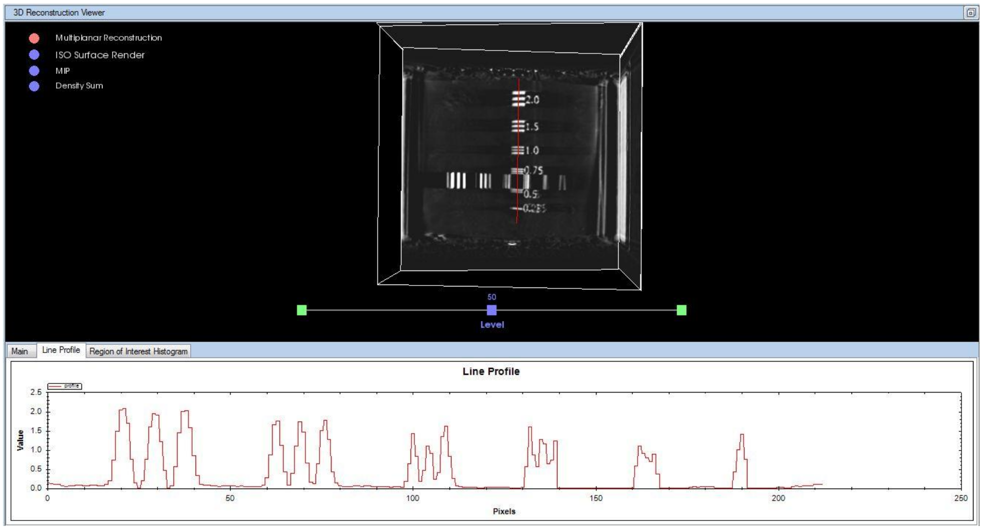

Figure 8: 3D image with line profile

25. Perform another reconstruction of the data without a backprojection filter selected. To turn off the backprojection filter, select **Reconstruction → Reconstruction Options → No Filter** prior to starting the reconstruction.
26. Repeat the measurements in step 15 and 16 and plot MTF vs. spatial frequency.

Discussion / Additional Questions

1. Based on your MTF curve, what happens to the clarity of your image as features become smaller? At what spatial frequency does blurring begin to occur?
2. What happens in this experiment as the voxel size is made larger? Why?
3. What happens to the reconstructed image when the backprojection filter is turned off?

Further Study

4. Why are filters used in backprojection reconstruction? Briefly describe common filters and their properties.
5. How is the spatial resolution of a CT image affected by the number of projection images acquired?

