Lab 1:

IBEHS 4D03 | W25

The overall goals of this lab are to assess image quality and to get a basic understanding of line-of-sight planar imaging and how this is extended to tomographic imaging.

PART 1: Spatial Resolution and Modulation Transfer Function

1.1 Introduction

The ability of an imaging system to resolve small objects is described by its spatial resolution. The spatial resolution (line pairs per mm: LP/mm) can be assessed qualitatively through the visualization of small objects of known size or quantitatively by measuring the modulation transfer function. Figure 1 shows a line pair phantom, the ideal image intensity profile, and an example system intensity profile, showing blurring and reduced contrast in the system output.

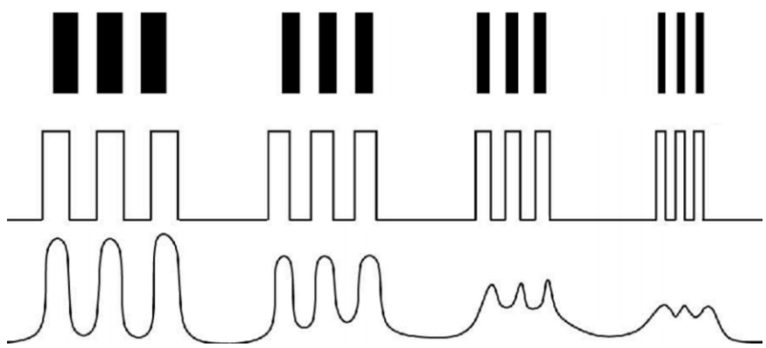

Figure 1: (A) Phantom lines; (B) Ideal image intensity profile; (C) Example system intensity profile

The modulation at each line pair frequency can be defined as a function of the brightness of the output line pairs, using equation (1.1) below, 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, usually normalized to the maximum modulation, Mod(0), as shown in equation (1.2):

$$Mod(f) = \frac{I_{MAX} - I_{MIN}}{I_{MAX} + I_{MIN}} \tag{1.1}$$

$$MTF(f) = \frac{Mod(f)}{Mod(0)} \tag{1.2}$$

NOTE: This lab was designed by Aravintahn Jegatheesan, using exerpts from the DeskCAT manual

1.2 Goals

- Calculate the Modulation Transfer Function (MTF) of the DeskCAT system by scanning a Line Pair Phantom.
- Plot the relative MTF vs. spatial frequency.
- Compare the MTFs using different filter and resolution settings.

1.3 Method

System Setup + Calibration

1. Start the DeskCAT software. Create a new project. Do not load the phantom yet. Make sure the chamber is clear and dry of any water. Water will be added to the aquarium later at the start of Part 2 in this lab.
2. Adjust camera settings Scanner > Camera Settings > Frame Rate / Shutter Speed until a few red pixels appear in the Camera Video Window.
3. Select Reconstruction > Reconstruction Options > Hamming Filter.
4. Select Calibration > Geometry Calibration > Auto-Cal.

Phantom Setup

5. Acquire a reference image: select New Reference Image (Do not load the phantom yet).
6. Load the Line Pair Phantom into the scanner.
7. Rotate the phantom (Scanner > Motor Control) so it is exactly flat to the camera. (Hint: rotate the phantom so only the edge is visible, then select Set Current Position as Home, then Move To 90 or 270).

2D Acquisition

8. Open the Projection Viewer. Select Enable Snapshot, then Take Snapshot.
9. Select the Line Profile tool. Draw a line which intersects the line pairs (Figure 2). Right click on the Line Profile: Export Data as CSV file (LP 2D Profile). Close the tool.

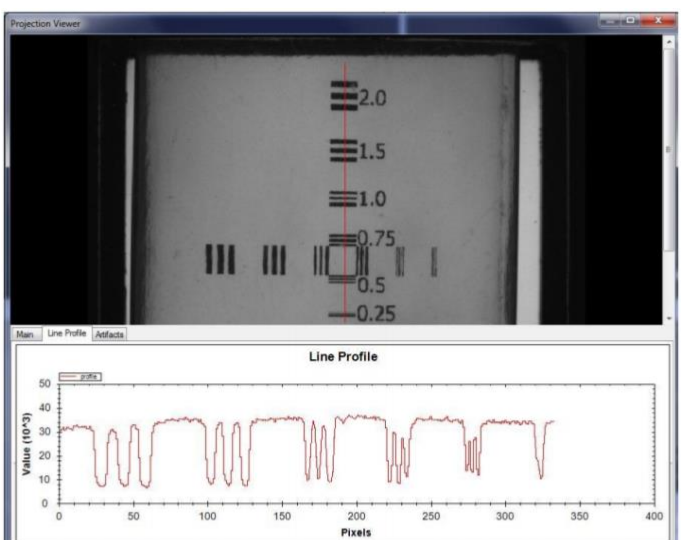

Figure 2: Line Profile through 2D snapshot.

CT Acquisition: Basic

10. Perform a Data Scan (320 Projections; Line Pair Phantom loaded).
11. Select Side Panel > Voxel Resolution: Very High. Perform a Reconstruction (this may take a few minutes).
12. Maximize the 3D viewer. Select Multiplanar Reformatting. Rotate the cube so the entire Line Pair pattern is visible (as close to flat as possible).
13. Use the Line Profile tool again (Figure 3) and Export Data as CSV file (LP CT High Res).

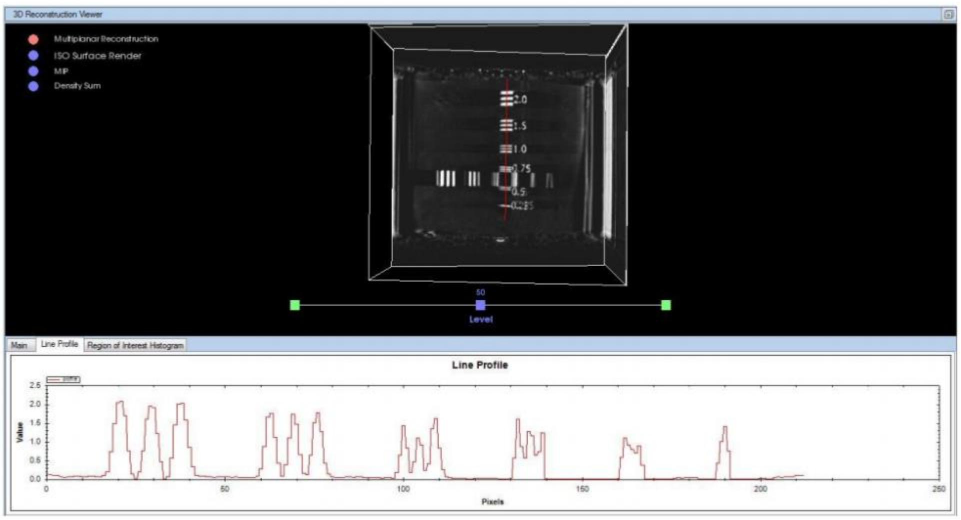

Figure 3: Line Profile through Line Pair Phantom in CT reconstruction.

CT Acquisition: Variations

14. Repeat steps 11 – 13 with Side Panel > Voxel Resolution: High (LP CT Low Res).
15. Repeat steps 11 – 13 after selecting: Reconstruction > Reconstruction Options > No Filter (LP CT #NoFilter).

1.3 Report Questions

Question #1: Results

Repeat Results (not Analysis) for: 1) LP 2D Profile; 2) LP CT High Res; 3) LP CT Low Res; 4) LP CT #NoFilter.

- Include raw Line Profile plots (from CSV), complete a table (e.g. Table 1), and plot MTF (Eqn. 1.2).

Table 1: Modulation Data Table

Spatial Frequency (LP/mm)	Size (mm)	Maximum	Minimum	Modulation
0.50	2.00			
0.67	1.50			
1.00	1.00			
1.33	1.75			
2.00	0.50			
4.00	0.25			

Question #2: Analysis

- Based on the curve, what happens to the clarity of the image as your features become smaller?
- At what spatial frequency does blurring begin to occur in each system?
- What happens as the CT voxel size is made larger? Why?
- What happens to the reconstructed image when the back-projection filter is turned off? Why?

PART 2: Edge Response, Point Spread Function & MTF

2.1 Introduction

The MTF of a system can also be resolved using Fourier analysis. For instance, the Point Spread Function (PSF) is defined as the response of the system to an Impulse Function input δ(x), as shown in equation (2.1), where x represents any point in real space. The MTF of the imaging system can then be calculated using the Fourier Transform of the PSF(x), as in equation (2.2):

$$PSF(x) = IM\,\{\,\delta(x)\,\} \tag{2.1}$$

$$MTF(\mathrm{f}) = \mathcal{F}\,\{\,PSF(x)\,\} \tag{2.2}$$

However, it is difficult to actually construct a phantom of a perfectly sharp single point. Another input function, the Step or Edge Function H(x) is more practically constructed, and can be used to determine the Edge Response Function (ERF), as shown in equation (2.3):

$$ERF(x) = IM\,\{\,H(x)\,\} \tag{2.3}$$

This is useful because the integral of the Impulse Function δ(x) is the Edge Function H(x). Therefore, if the ERF(x) of a system can be determined, the MTF can be calculated using the relationships above. These relationships are summarized graphically in Figure 4 Relationships between the Impulse Function, Edge Function, PSF, ERF, and the METF. The sketches are all in real coordinates except the MTF, which is plotted against spatial frequency.

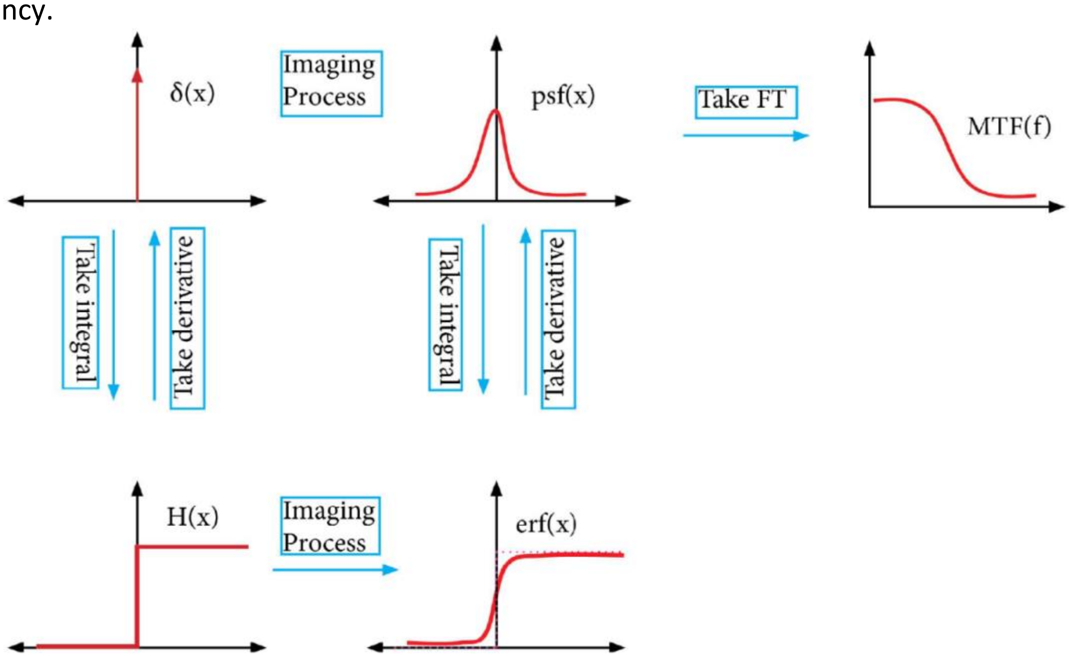

Figure 4 Relationships between the Impulse Function, Edge Function, PSF, ERF, and the METF. The sketches are all in real coordinates except the MTF, which is plotted against spatial frequency.

2.2 Goals

- Measure the MTF using the Edge Response technique.
- Determine if the DeskCAT system is shift invariant.
- Compare MTF curves under different imaging conditions.

2.3 Methods

2.3.1 In-Lab Procedure

System Setup + Calibration

1. Keep the same "project" you started in Part 1 of the lab.
2. Fill the aquarium to the top of the window (approx. 2L). Ensure there are no bubbles in the field of view. If there are, use a syringe to 'blast' them away.
3. Set up the DeskCAT system again: adjust Shutter Speed for a few red pixels, Hamming filter, and Auto-Cal.
4. In the Calibration section, record the value of Horizontal Light Size (units: cm; you will need this later).

Phantom Setup

5. Load the Blank Silicone Phantom into the scanner.
6. Acquire a reference image: select New Reference Image.

Estimating ERF(x): Radiographic Mode

7. Load the Step Edge Phantom into the scanner.
8. Perform a Data Scan (320 Projections).
9. Select 'Projection Viewer' from the menu. Select the Data radio button. Select the Full Image checkbox. Scroll through the 320 projections and find the projection image showing the sharpest edge (perpendicular to the image). Use the Line Profile tool to draw a line which perpendicularly intersects the edge (Figure 5) and Export Data as CSV file (ERF 2D Profile).

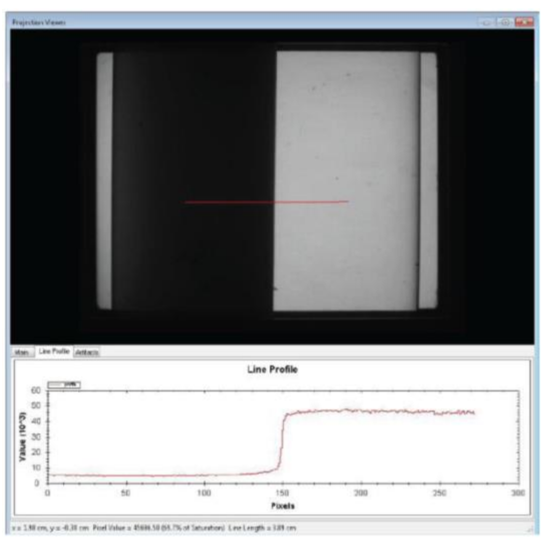

Figure 5: Line Profile through Step Edge Phantom single projection.

Estimating ERF(x): CT

10. Select Side Panel > Voxel Resolution: Very High. Perform a Reconstruction.
11. Maximize the Slice Reconstruction window. Scroll through the axial slices to the centre.
12. Use the Line Profile (right click) tool to draw a line on the central slice, perpendicular to the Step Edge, a few mm from the axis of rotation and equally distributed on either side of the edge (as in Figure 6). Export Data as CSV file (ERF CT High Res Centre).

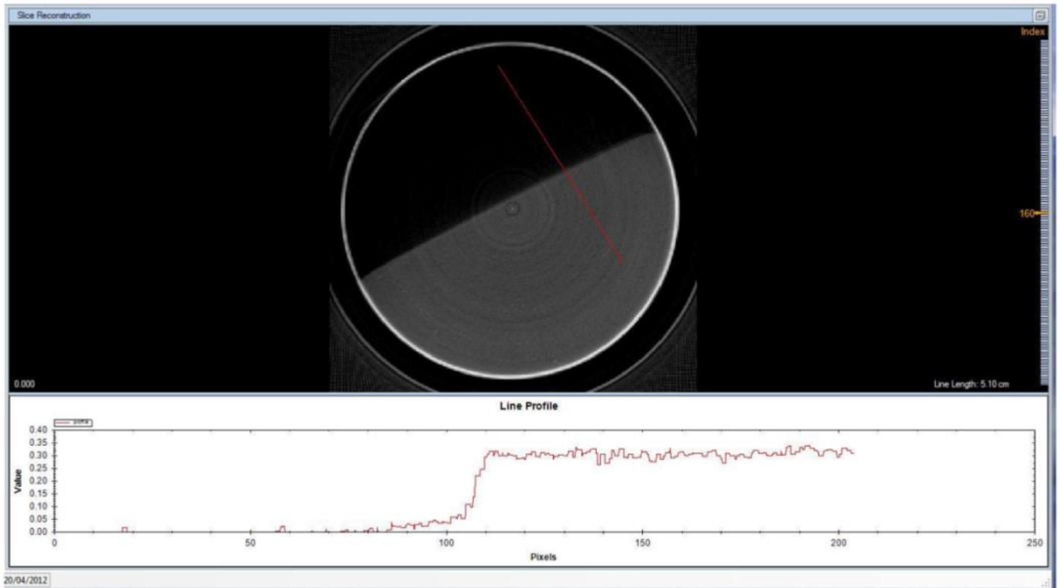

Figure 6: Line Profile through Step Edge Phantom in CT reconstruction.

13. Repeat step 11 at ±40 slices from the centre slice (±10mm). You must re-draw the line each time. (ERF CT High Res Below, ERF CT High Res Above).
14. Repeat steps 9 – 13 with Side Panel > Voxel Resolution: High (ERF CT Low Res Centre).
15. Select Side Panel with 160 Projections. Then, perform another Data Scan.
16. Repeat steps 9 – 13 with Side Panel > Voxel Resolution: Very High (ERF CT High Res Subsample).

2.3.2 MATLAB Post Processing

The MATLAB code used to analyze the line profiles of the Step Edge Phantom was provided with this lab and are available on Avenue. You are encouraged to read the code to understand how line profiles are analyzed to calculate the ERF, PSF, and MTF curves. Analyze Lab 1 Part 2.2 CSV files by:

1. Run: `Analyze_Edge.m` for all line profiles:
    - Select the CSV file to analyze and identify the data as 2D Projection Profile or 3D CT Image Profile.
    - 2D: enter the value of Horizontal Light Size (Step 2).
    - 3D: select the voxel size.
    - Plots of ERF, PSF and MTF will appear for the selected profile (Figure 7).
2. Run `MergeAndPlot_Edges.m` to merge the data from each profile for each plot type.

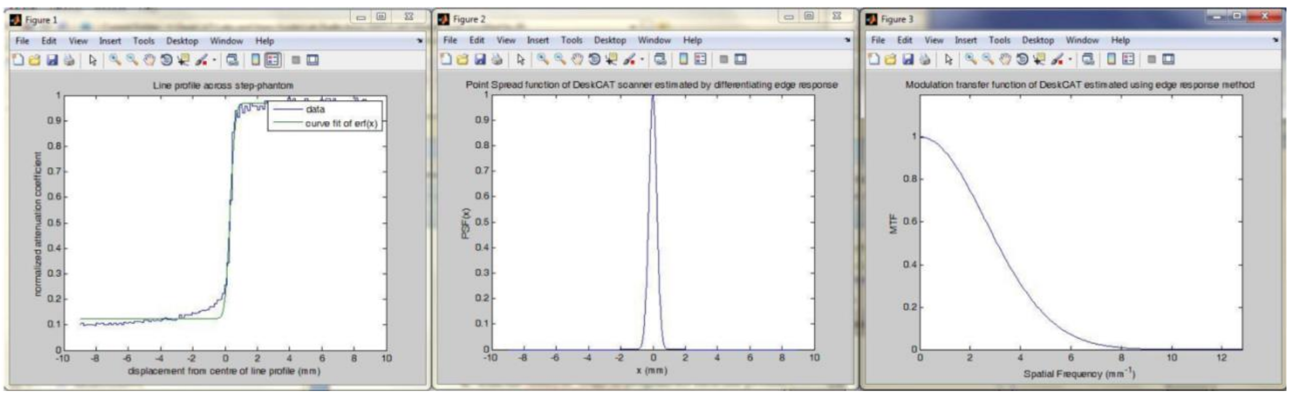

Figure 7: Example output from Analyze_Edge.m

2.4 Report Questions

Question #3: Analysis

- Include the merged ERF, PSF, and MTF plots.

Question #4: Analysis

- Describe the effects on the MTF of changing: the number of projections and construction resolution.
- Based on your results, is the DeskCAT scanner shift invariant?
- Do your MTFs from Parts 1 and 2 agree? Give reasons why they might differ. Which imaging experiment would you expect to provide a more accurate measurement of the maximum spatial frequency?

Mark Breakdown

Part 1:
Question 1: 6
Question 2: 4

Part 2:
Question 3: 6
Question 4: 6

Report Formatting:
Spelling, Grammar, Figures, Clarity, Formatting, Organization: 5

Total: 27