IBEHS 4D04: Introduction to Medical Imaging

Lab 1 & 2

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Due: February 15th, 2024

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Lab 1

Question 1

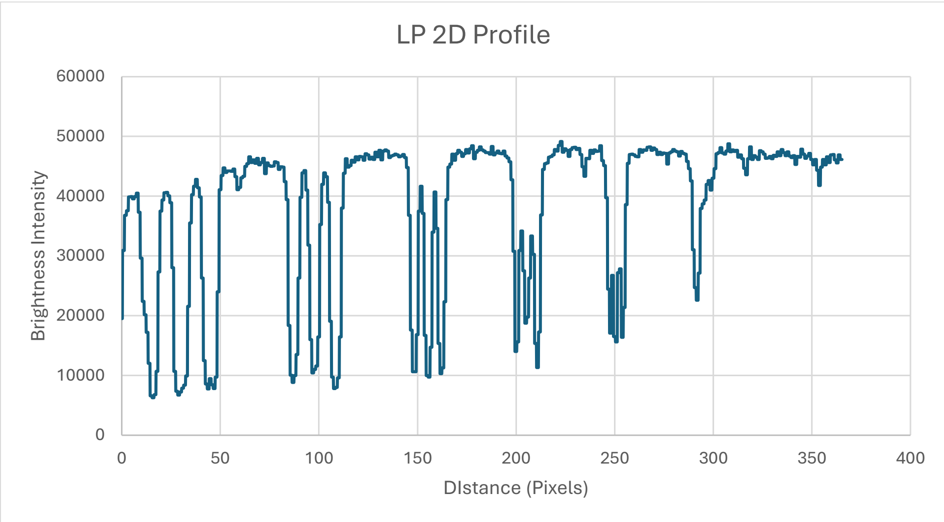

Figure 1: System Intensity Profile for LP 2D Profile

Table 1: Modulation Data for LP 2D Profile

Spatial Frequency (LP/mm)	Size (mm)	Maximum	Minimum	Modulation
0.50	2.00	42816	6592	0.7332
0.67	1.50	43904	7808	0.6980
1.00	1.00	41664	9984	0.6134
1.33	1.75	34176	11328	0.50211
2.00	0.50	27200	16384	0.24816
4.00	0.25	27136	22592	0.09138

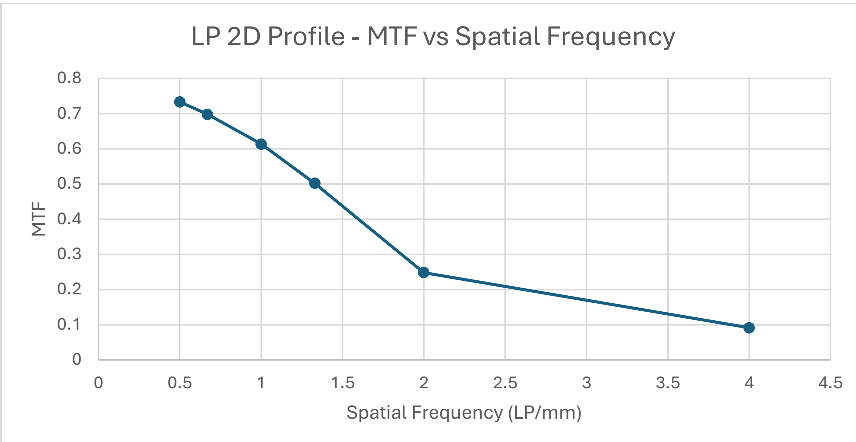

Figure 2: MTF of the LP 2D Profile vs Spatial Frequency

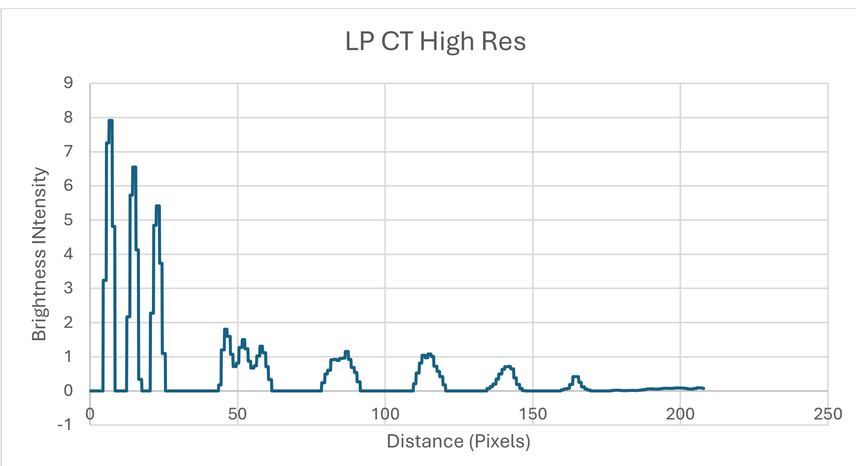

Figure 3: Unfiltered CT High Resolution for Line Phantom

Table 2: Modulation Data for LP CT High Resolution Profile

Spatial Frequency (LP/mm)	Size (mm)	Maximum	Minimum	Modulation
0.50	2.00	7.9914	0	0.7332
0.67	1.50	1.8048	0	0.6980
1.00	1.00	1.1531	0	0.6134
1.33	1.75	1.0797	0	0.50211
2.00	0.50	0.7184	0	0.24816
4.00	0.25	0.41635	0	0.09138

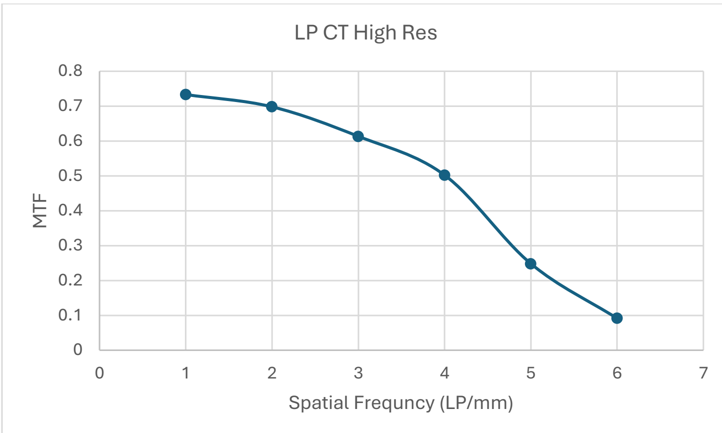

Figure 4: MTF of the LP CT High Resolution Profile vs Spatial Frequency

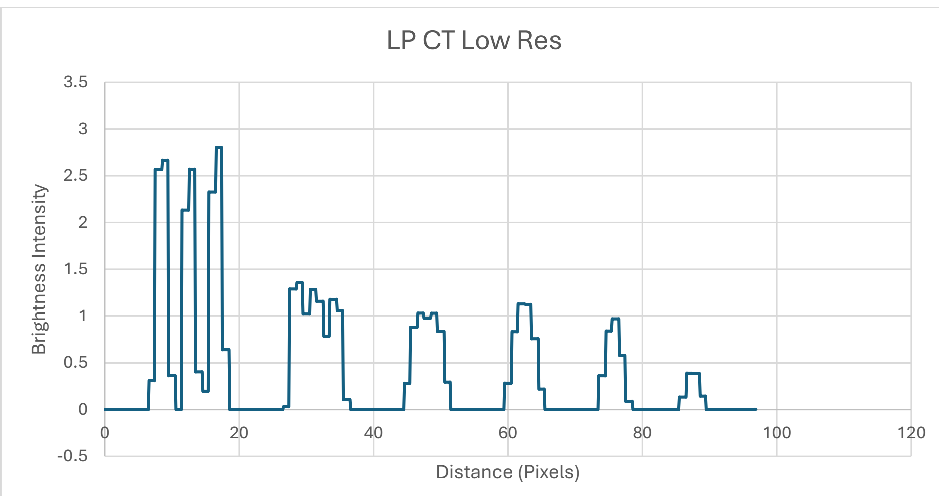

Figure 5: Unfiltered CT Low Resolution Line Profile for Line Phantom

Table 3: Modulation Data for LP CT Low Resolution Profile

Spatial Frequency (LP/mm)	Size (mm)	Maximum	Minimum	Modulation
0.50	2.00	2.8022	0	1
0.67	1.50	1.3582	0.783	0.268634
1.00	1.00	1.0332	0.97668	0.028121
1.33	1.75	1.1309	1.1251	0.002571
2.00	0.50	0.9683	0.839	0.071543
4.00	0.25	0.3886	0.3847	0.005043

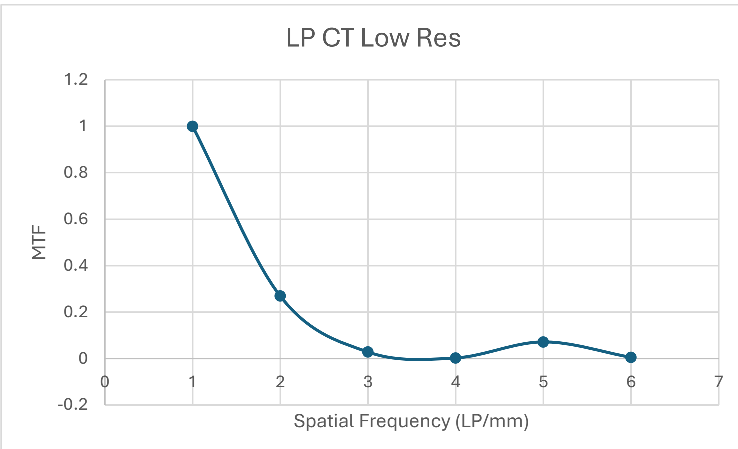

Figure 6: MTF for CT Low Res vs Spatial Frequency

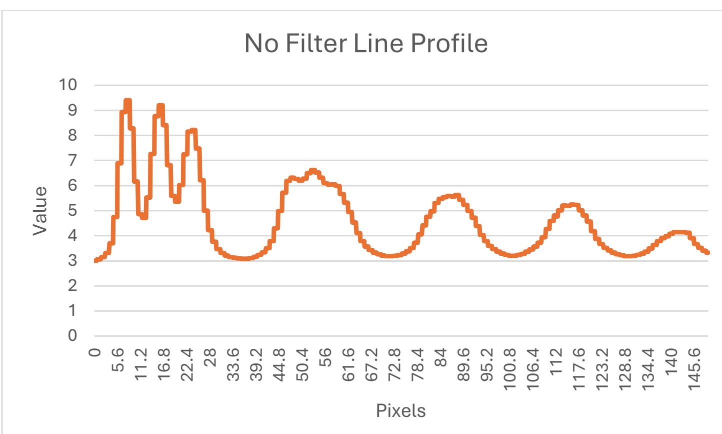

Figure 7: No Filter Line Profile for Line Phantom

Table 4: Modulation Data for No Filter Profile

Spatial Frequency (LP/mm)	Size (mm)	Maximum	Minimum	Modulation	MTF
0.50	2.00	9.403989689	4.708913125	0.332679721	1
0.67	1.50	6.616994423	3.18572209	0.350032802	1.052161526
1.00	1.00	5.619397838	3.196830315	0.274785031	0.785026514
1.33	1.75	5.239769366	3.187281139	0.243559502	0.886363794
2.00	0.50	4.148824712	3.322138892	0.110653172	0.454316793
4.00	0.25	None	None	None	0

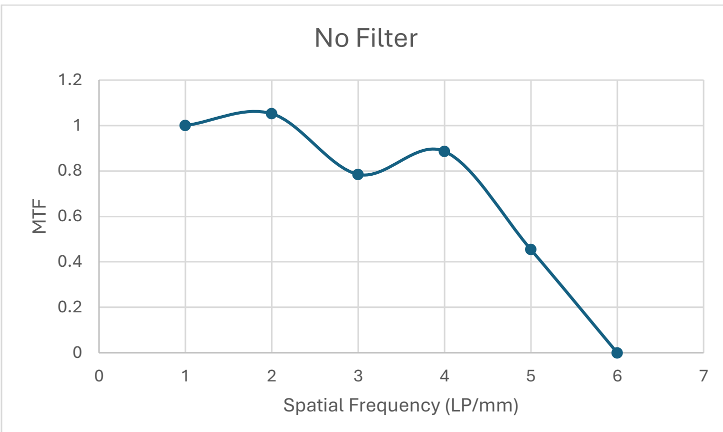

Figure 8: MTF for No Filter vs Spatial Frequency

Question 2

The features become smaller as the spatial frequency increases. As the spatial frequency increases, the percent contrast decreases. When the features become smaller, the lines on the phantom become closer together, and the CT has more difficulty distinguishing between the phantom lines and the surrounding background.

In each system, blurring should occur as soon as the contrast is below 1. For all our graphs, this occurs before the spatial frequency reaches 1. The differentiation can be due to noise or artifacts during the scan. Blurring also occurs when the features become really small, since the CT can no longer differentiate between the phantom lines and the background and therefore the peaks slowly disappear in the line profile.

When the CT voxel size increases, the spatial resolution decreases and the blurring of the image increases. Since a voxel can only represent one value of contrast at a time, if the voxel size increases, it just shows a larger area of the image. So, when the voxel size is decreased, a smaller area is shown with the same amount of contrast. When the voxel size is increased, a lot of the smaller details may be lost in image reconstruction.

When the back-projection filter is turned off, an offset can be seen in the intensity profile of the system. This is visible in the baseline of the no-filter system intensity profile since it is greater than 0. The offset is most likely caused by noise during the imaging, which is removed in the filtered graph, causing the baseline value to go back to 0.

Question 3

Center profiles, above center profiles, and below center profiles were merged separately to make meaningful comparisons and since maximum number of unique colors in MATLAB is 7.

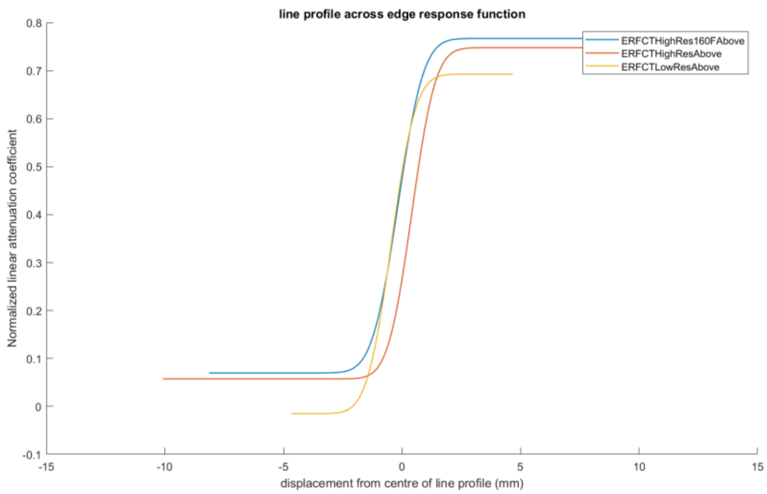

Figure 9: Line profile edge response of the upper layer slice

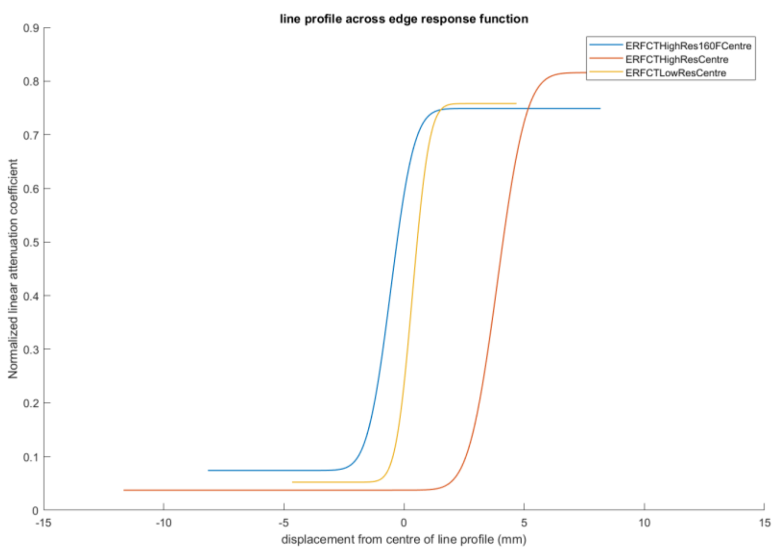

Figure 10: Line profile edge response of the center layer slice

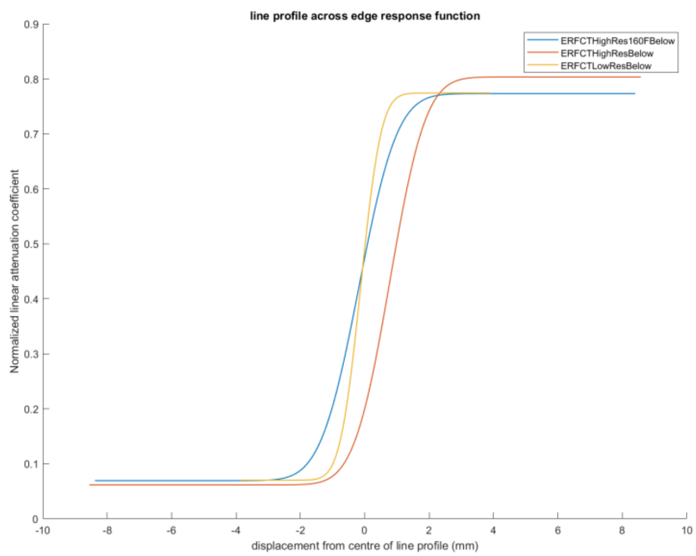

Figure 11: Line profile edge response of the lower layer slice

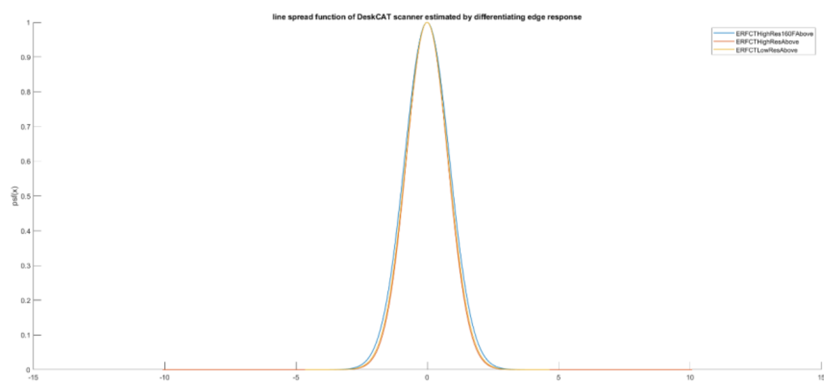

Figure 12: Line spread function of the upper layer slice

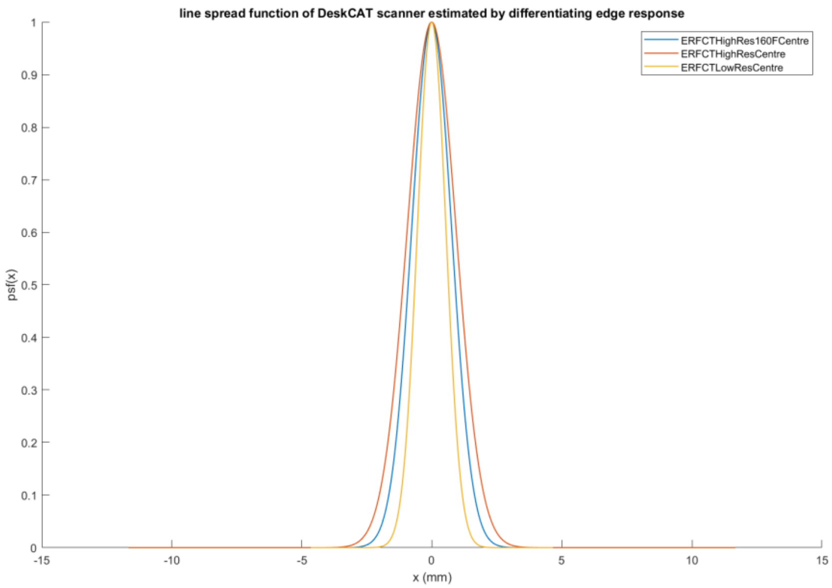

Figure 13: Line spread function of the center layer slice

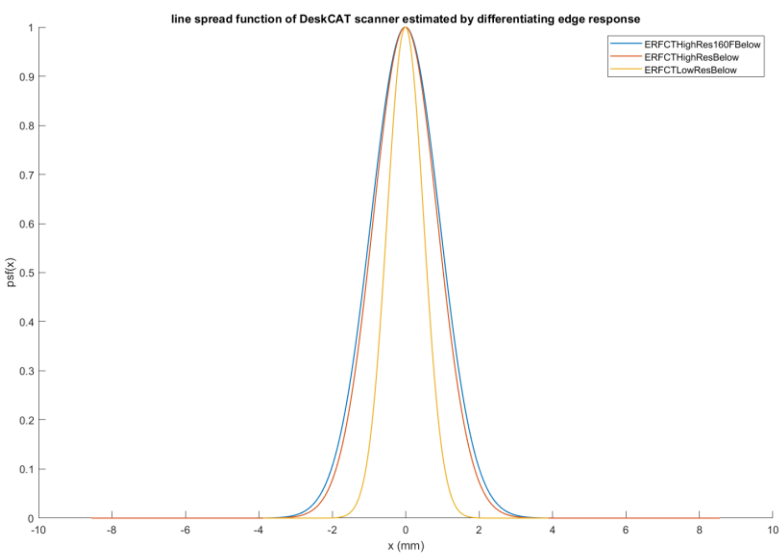

Figure 14: Line spread function of the lower layer slice

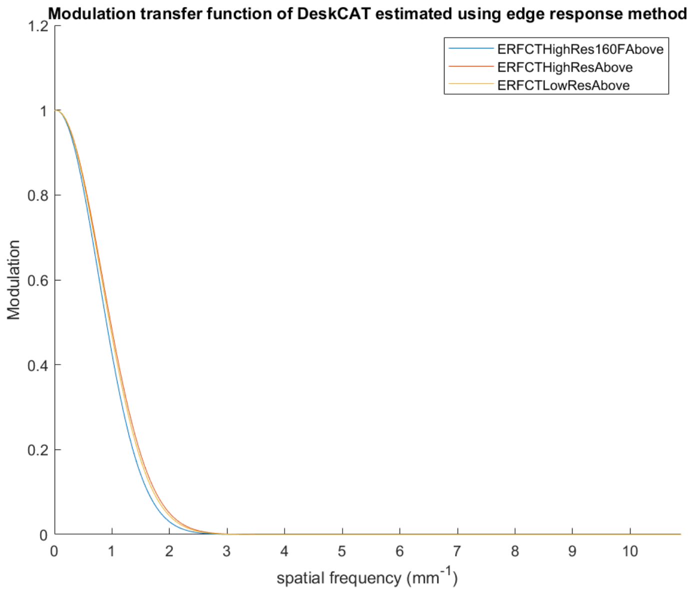

Figure 15: Modulation transfer function of the upper layer slice

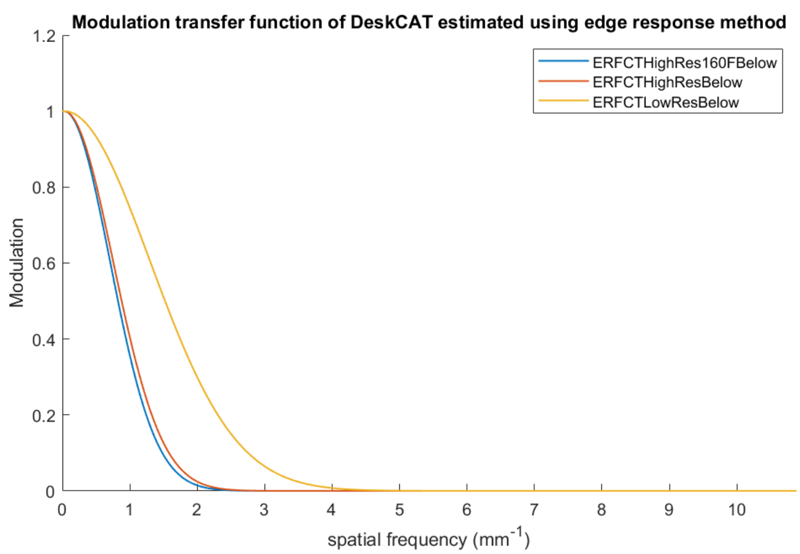

Figure 16: Modulation transfer function of the lower layer slice

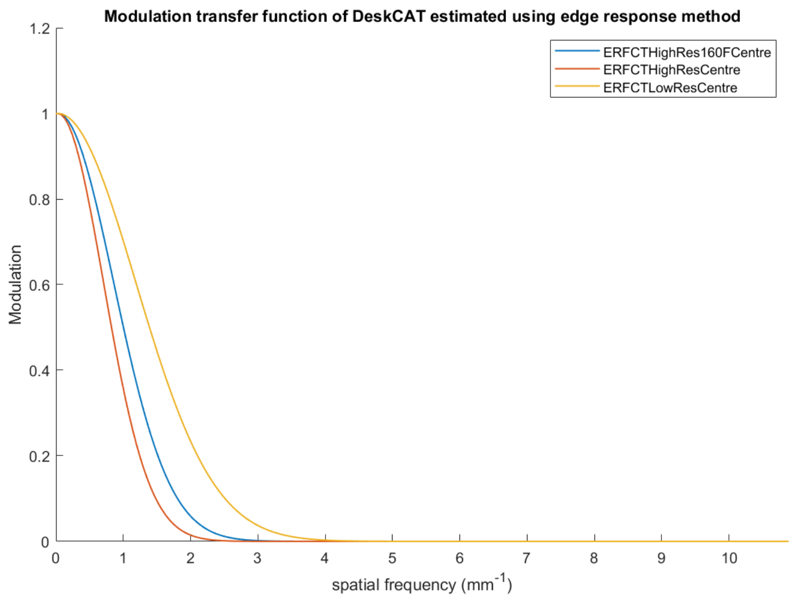

Figure 17: Modulation transfer function of the center layer slice

Question 4

The Modulation Transfer Function (MTF) describes the system's ability to translate the transmission of a spatial frequency into a visible image that accurately represents the features of the object. The spatial frequency refers to the patterns or structures that can be of varying sizes within an image. An ideal MTF would have a level of 1 at all spatial frequencies as when this occurs, the resulting point spread function (PSF) would be the ideal impulse function. However, this is not possible in reality so the best modulation transfer function that we could ask for is one having the highest value possible for as long as possible, and decaying to zero at a high spatial frequency.

The number of projections refers to the total number of 2D images that are taken of the object at a unique angle. As the number of projections increases, the number of images taken from unique angles does too. This allows for a better reconstruction of the 2D images into a 3D image when the reconstruction process is completed. It is expected that the MTF curves when there is a greater number of projections to be closer to an ideal curve. With our curves on figures 15-17 this phenomenon can be seen sometimes. In Figures 15 and 16, the plot of the MTF for the scan that took 160 projections did in fact drop off quicker and had a steeper slope than the scans that had 320 projections. This makes sense but for Figure 17 which looked at the MTF of the center layer slice, the high resolution scan had a steeper drop in the MTF than the scan with 160 projections. This doesn't align with what is expected and what is seen for the other slices.

Construction resolution refers to the sharpness of the reconstruction and is influenced by size of the voxels. Smaller voxels lead to a higher resolution and results in a sharper image with more detail in the images. It is expected that at lower resolutions (higher voxel sizes), there would be a steeper MTF which makes sense because that would lead to a wider point spread function and a more unsharp reconstruction. However, this is not what is seen in any of our plots because in Figures 15-17, the high resolution scan has a steeper slope for the MTF (when looking at the two plots with 320 projections). This is not expected as it should be the opposite.

A shift invariant system is a system where the output experiences the same shift as the input when one is applied, and the same initial relationship between the input and the output is maintained. CT scans are typically shift invariant, so it is expected that the DeskCAT scanners which approximate CT scanners are also shift invariant. However, our scans don't seem to line up with this because the lower and center slices seem to be relatively similar but differ quite greatly from the upper slice. These deviations should not be observed but could be due to anything from the scanners not working as expected, to human error from our misuse. But, it's hard to diagnose a single source of error just with the data that we have.

Part 1 would give more accurate results since even if the pixels happened to line up perfectly with the edge, making it seem like a sharp transition, a trend can be derived from the many edges created by the multiple lines for every spatial frequency without having to rescan or reconstruct for Part 1. Part 2 on the other hand only has one edge, making it unreliable and prone to coincidence. Furthermore, unsharpness is hard to detect when there's only one transition, even for the human eye, as is the case for Part 2. Having many lines is not only a good representative of image details, but can also be seen as many trials in one scan and one reconstruction.

Lab 2

Question 1

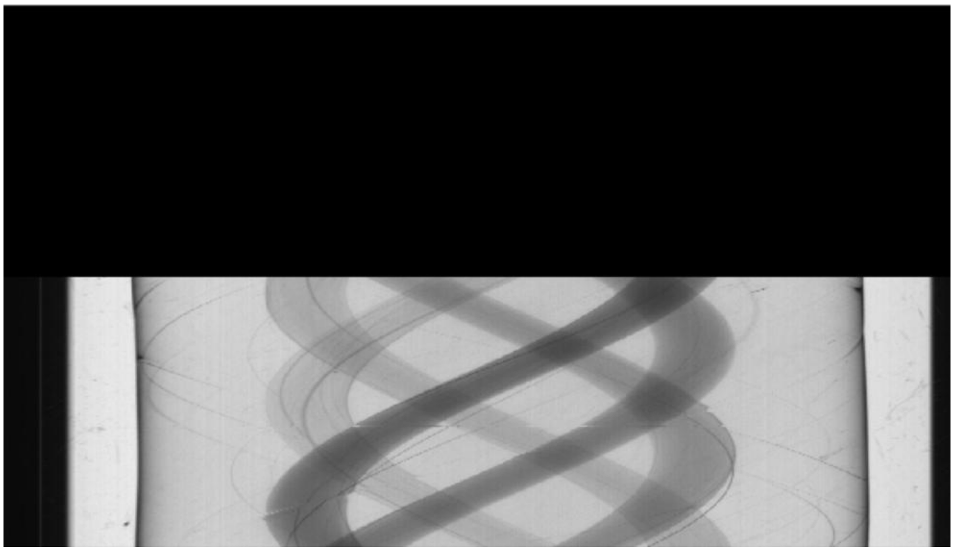

Figure 18: Center slice sinogram with 0-199 missing.

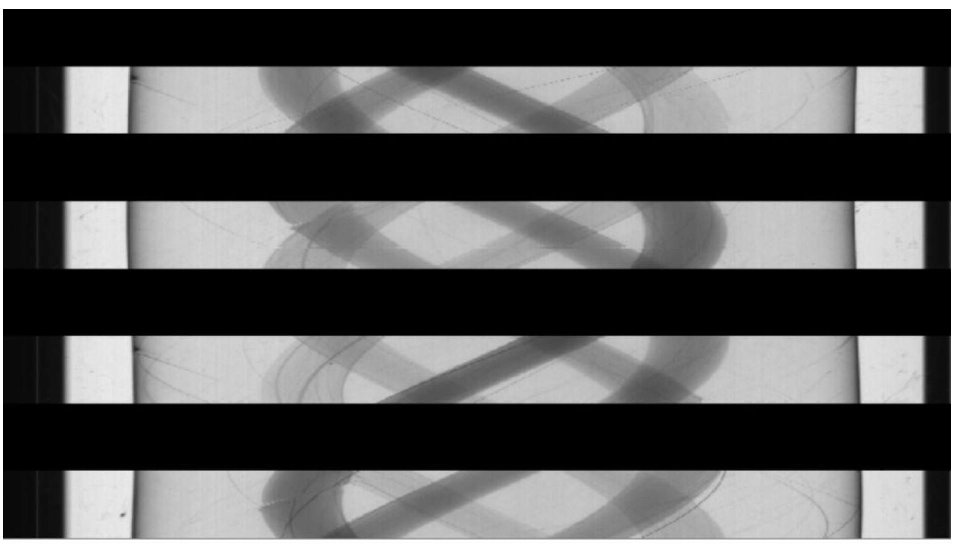

Figure 19: Center slice sinogram with every other 50 slices missing.

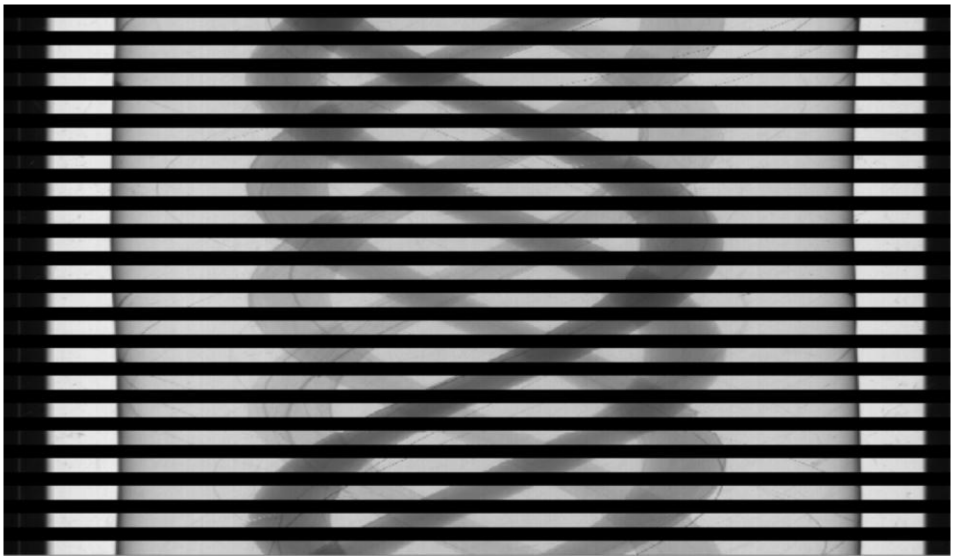

Figure 20: Center slice sinogram with every other 10 slices missing.

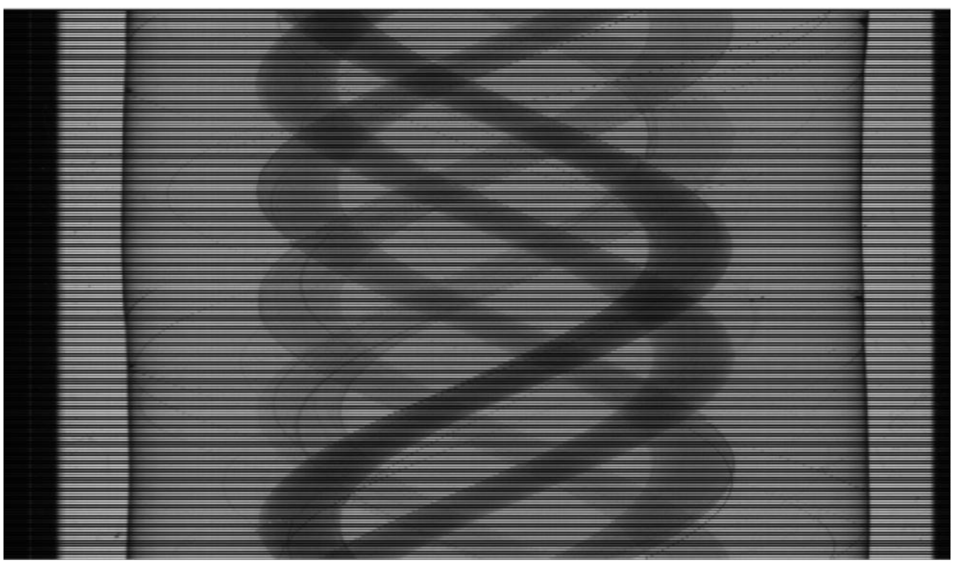

Figure 21: Center slice sinogram with every other slice missing.

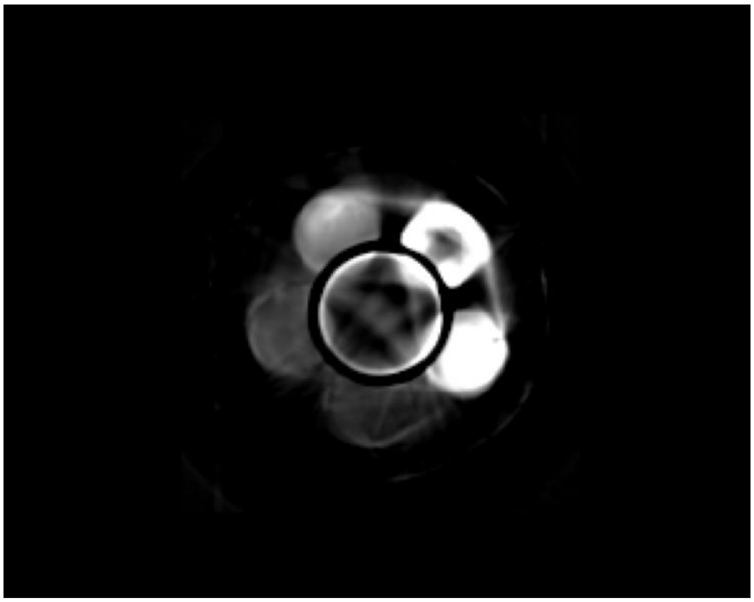

Figure 22: Bad pixel slice at top slice of reconstruction.

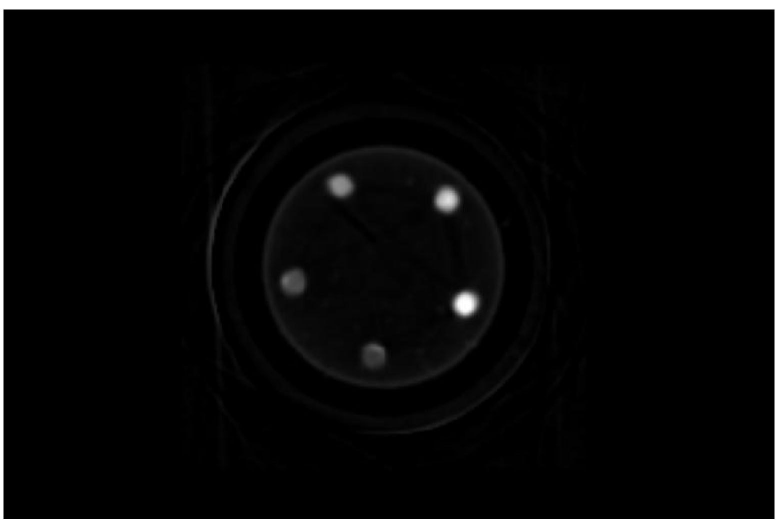

Figure 23: Bad pixel slice at middle slice number of reconstruction.


Figure 24: Bad pixel slice at low number of reconstruction.

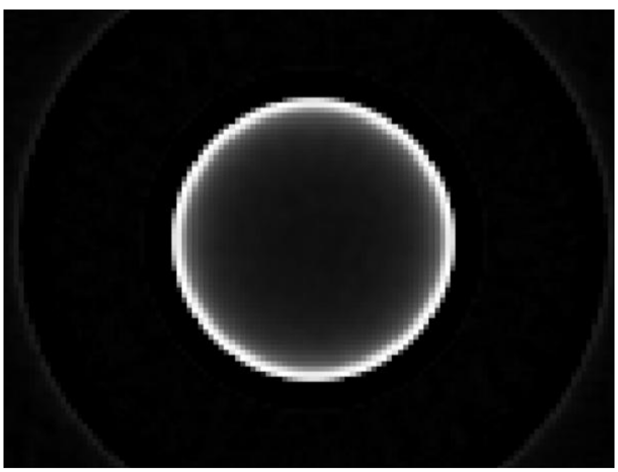
Figure 25: Bad pixel slice of a bad column.

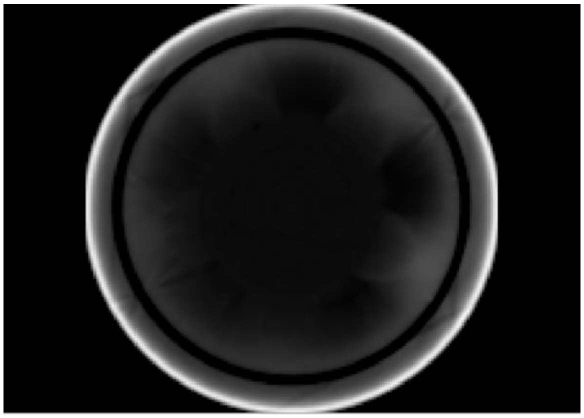

Figure 26: Bad pixel slice of a bad row.

Table 5: Attenuation Coefficient Data

Attenuation Coefficient	Original	Half	Blocks 50	Blocks 10	Every Other
Mean	0.7926	0	0.7394	0.7905	0.7911
SD	0.0128	0	0.0206	0.0128	0.0213

Question 2

No trend can be observed for the mean and standard deviation among the trials. However, all mean values for the latter 4 trials are lower than that of the original. All trials lack the same amount of data which causes the mean values to be in a similar range.

Using fewer projections results in aliasing due to under sampling of the image. Under sampling refers to using a sampling rate below the Nyquist frequency and it presents as thins streaks in the reconstructed image. Consequently, high frequency data isn't captured accurately, and the image appears unsharp. The scattering effect may also occur if the beams are highly attenuated which can cause more photons to be detected than expected. Figure 20 shows an example of the beam artifact due to fewer projections. The artifacts produced by aliasing after reconstructing the image are called Moire patterns [2] The reconstructed image lacks data from the true image making it an inaccurate representation of the truth. It was observed that the reconstructed images became more unsharp as more projections were removed and the original reconstruction with 400 projections was the sharpest.

Bad pixels occur when elements of the detector are defective or poorly calibrated. They produce a ring artifact in the reconstructed image consisting of sharp rings. Figure 25 shows an example of the ring artifact due to bad pixels. The spiral detector produces an erroneous reading at each angular position as the detector rotates about the patient which produces the artifact in a circular shape. Ring artifacts are centered about the center of the detector's rotation with a radius determined by the detector element. A larger radius will produce strong rings while a lower radius will produce weak rings [3].

The ring artifact can be misinterpreted as circular structures such as tumors during diagnosis. However, this artifact can be easily identified and can be rectified more easily because the artifact is identical across the image. Beam artifacts can obscure soft tissues making it difficult to identify structures and conduct an accurate diagnosis [1]. The unsharpness due to under sampling makes it difficult to distinguish between structures entirely. It's difficult to identify under sampling and the only solution is to take more projections. It's challenging to further process the image to obtain a better representation of the original when there is missing data. Therefore, the beam artifact due to taking fewer projections has a larger impact on diagnosis than the ring artifact.

Question 3

Finding N:
Looking at Emission Space B, average noise is 3230.2. Max brightness is 10740. N would then be 10740-3230.2=7509.8. The N value is calculated similarly for A and C:

Table 6: Finding N value (output emission) for each line profile

	A	B	C
Average noise	2620.4	3230.2	2682
Max value	10740	10740	5312
N	8119.6	7509.8	2630

Table 7: Finding ACF and N0

	A	**B**	**C**
$\sum \mu_i \Delta d_i$	1.681373635	0.144705453	1.012849165
$e^{\sum \mu_i \Delta d_i}$	5.372931351	1.155699112	2.75343484
$N_o = N * e^{\sum \mu_i \Delta d_i}$	43626.05989	8679.1	7241.550265

Question 4

Average emission brightness N0 is 23,235 with standard deviation 15,989. The values are all in the thousands range, but line profiles that had the most contrast gave a higher emission brightness value. Reasons why the source emission brightness values don't agree include the fact that More noise, particles, or bubbles causes the background to block some light, reducing the difference between the object and background and therefore reducing N in some line profiles This effect might also influence the attenuation coefficient $\boldsymbol{\mu}$, also giving a false value for N0 as a result of noise. Another reason is that when the object is darker or more transparent, as is the case with B and C, the difference between the light intensity through the object and from the background or noise will be less, leading to the same effect as source light having same intensity, especially since the N parameter doesn't use maximum emission brightness without subtracting the minimum brightness (average noise) from it.

References

[1] A. F. Alzain *et al.*, “Common computed tomography artifact: Source and avoidance,” *Egyptian Journal of Radiology and Nuclear Medicine*, vol. 52, no. 1, Jun. 2021. doi:10.1186/s43055-021-00530-0

[2] S. Artul, “Ring artefact in Multidetector CT,” *Case Reports*, vol. 2013, no. dec27 1, Dec. 2013. doi:10.1136/bcr-2013-201379

[3] “5. aliasing artifacts and noise in CT images,” *Principles of Computerized Tomographic Imaging*, pp. 177–201, Jan. 2001. doi:10.1137/1.9780898719277.ch5