Medical Imaging Project: Fan-beam tomographic image reconstruction

Course: Medical Imaging

MSc, Biomedical Engineering

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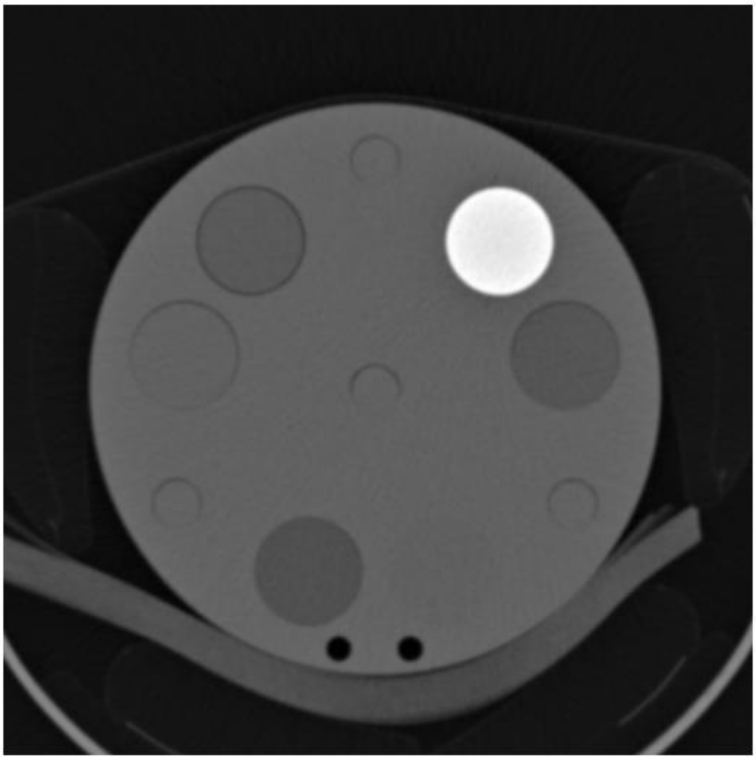
Introduction

The aim of this project is to get familiar with the CT image reconstruction procedure and understand better how some key-parameters affect Filtered Back-Projection image reconstruction in X-ray computed tomography. The focus of the project is the effect of different reconstruction kernels and different cut off frequencies in those filters.

Our work was done for the image of a phantom taken with a tube voltage of 90kV, which was name “Image1_90kV”. We utilized the matlab scripts that we were given from our instructor and expanded on those too carry out the analysis of the reconstructed images. The code starts with loading and showing the image we will work on and the continues to perform the Filtered Back-Projection and calculate background noise, Contrast to Noise Ratio (CNR) and Edge Spread Function (ESF) for specific Regions of Interest (ROIs). At the end of the report conclusions on the effect of different combinations of filters are reached and presented through answering the questions asked in the Project announcement.

Original image:



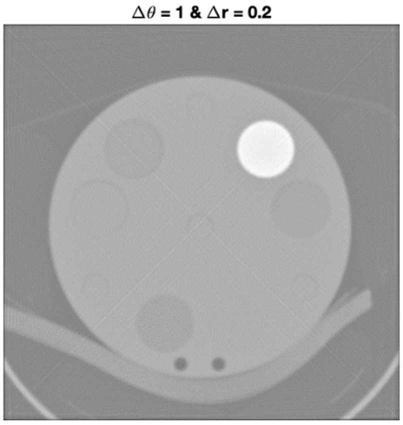
Qualitative Analysis

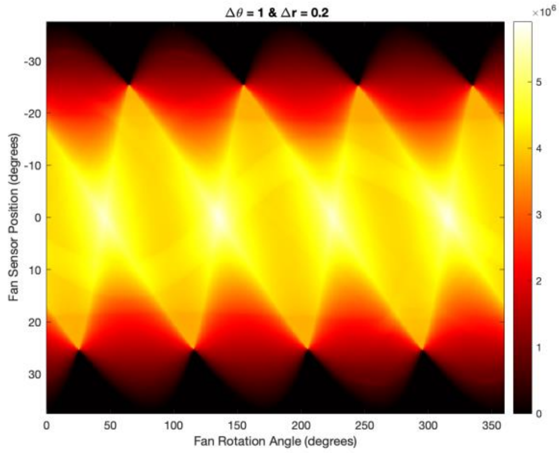
1. **The effect of Δr and Δθ in the sinogram and the reconstructed image**

We run the matlab code to create the corresponding sinogram and reconstructed axial slice for every combination of the following parameters Δr and Δθ: sensor spacing Δr: 0.8°, 0.5° and 0.2° and rotation increment Δθ: 3,2 & 1, corresponding to 120°, 180° and 360° angular sampling. The results are taken with consecutive runs of the code with changes in the corresponding parameters. The observed difference, as expected is that for larger steps in sensor spacing and rotation increment the reconstructed images are less sharp and resolution can drop significantly.

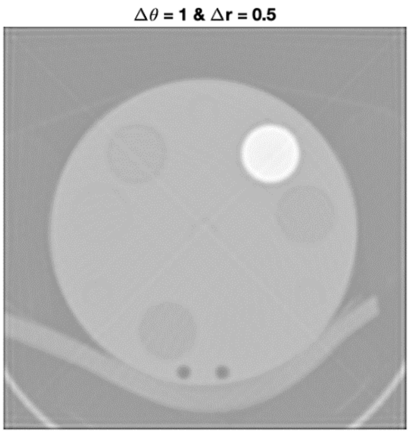
The images and sinograms are shown below:

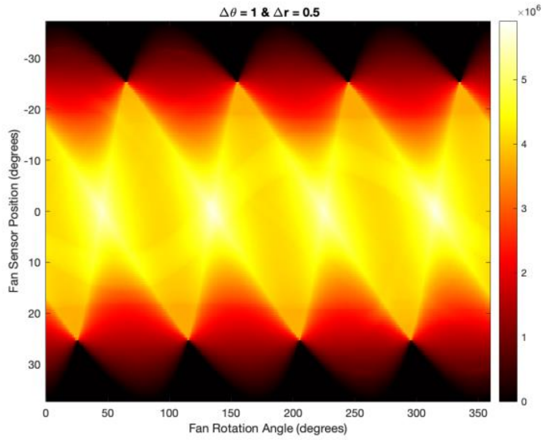
✓ Δθ = 1, Δr = 0.2:



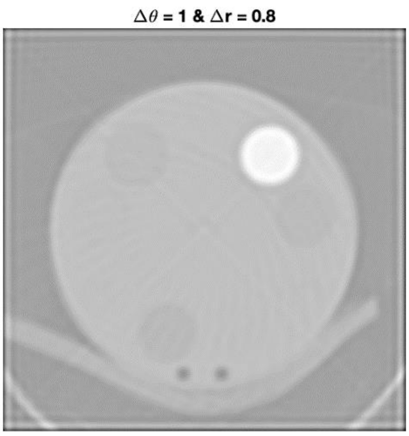


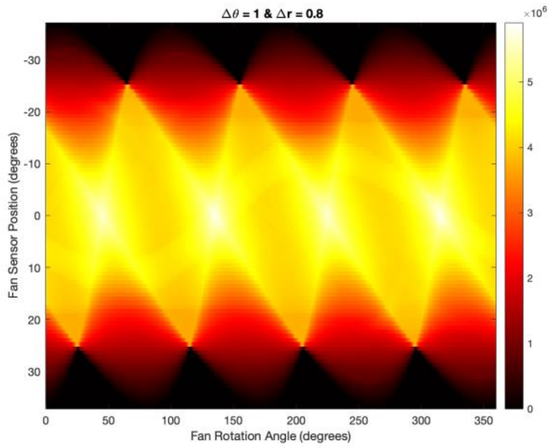
✓ Δθ = 1, Δr = 0.5:



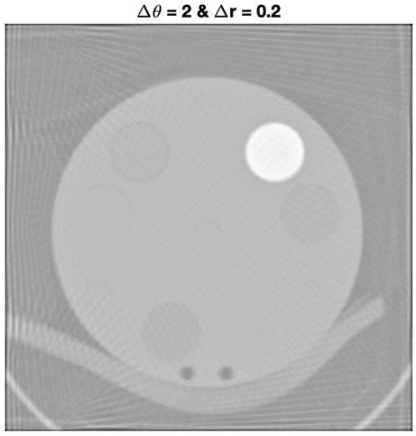


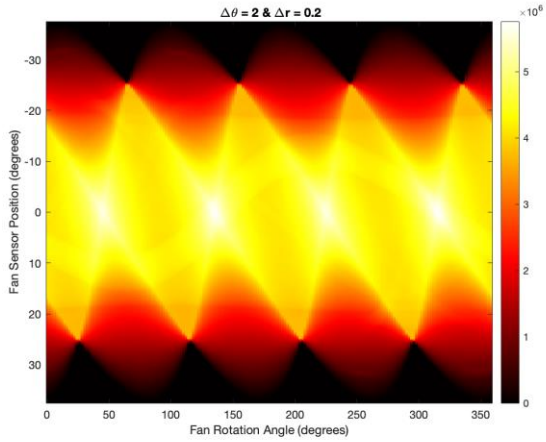
✓ Δθ = 1, Δr = 0.8:



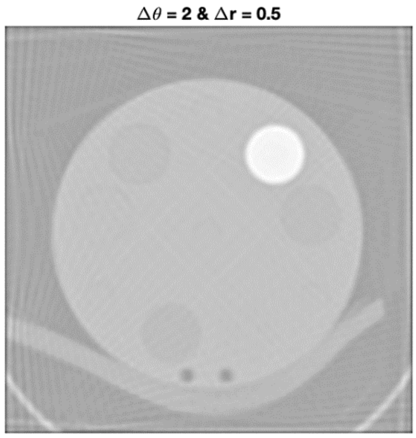


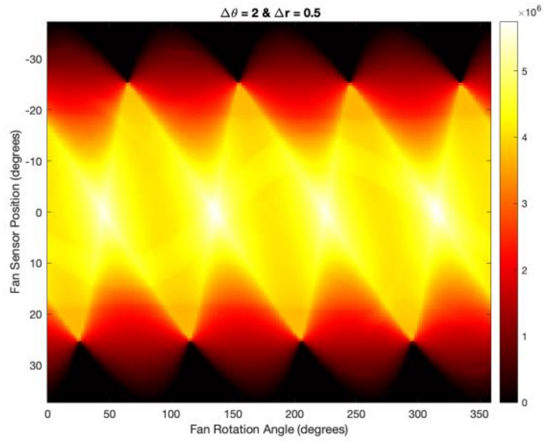
✓ Δθ = 2, Δr = 0.2:



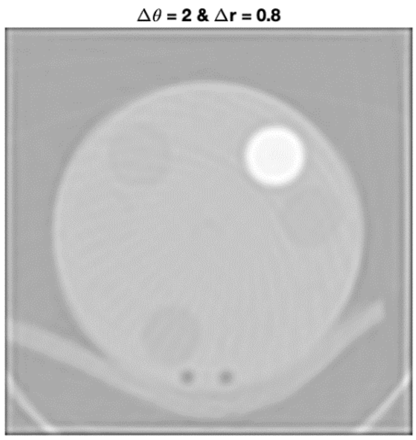


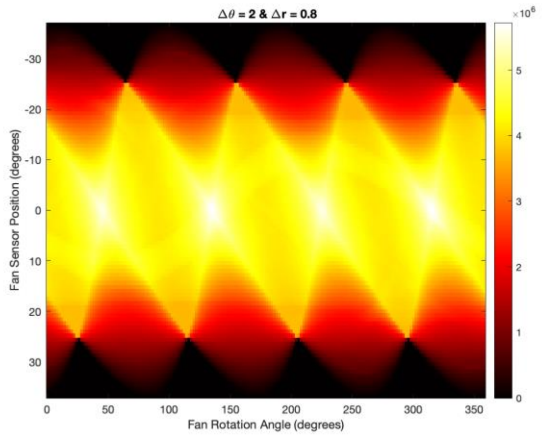
✓ Δθ = 2, Δr = 0.5:



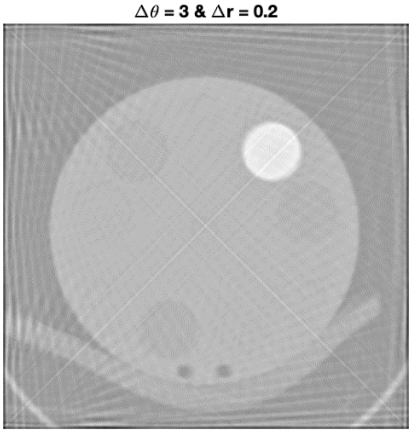


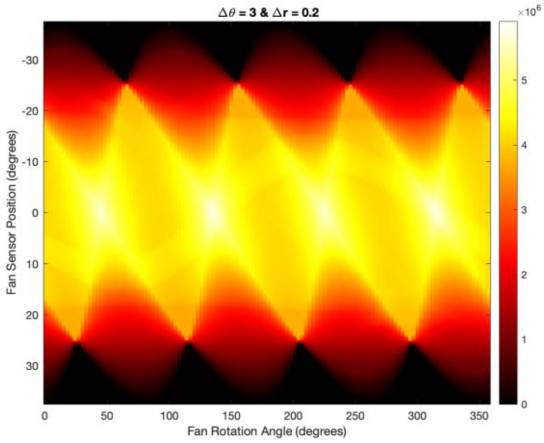
✓ Δθ = 2, Δr = 0.8:



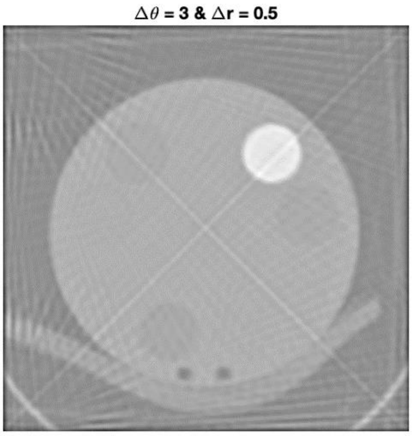


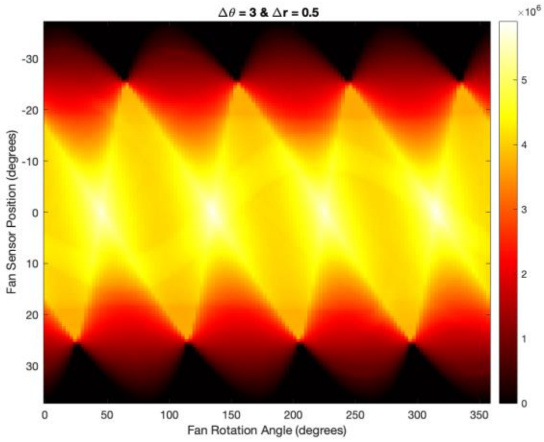
✓ $\Delta\theta = 3$, $\Delta r = 0.2$:



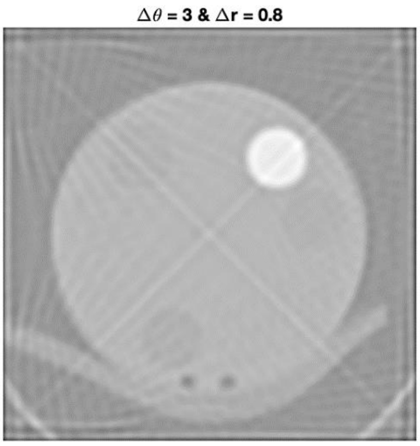


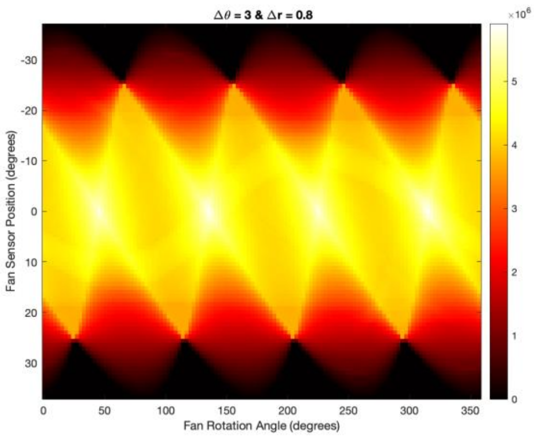
✓ $\Delta\theta = 3$, $\Delta r = 0.5$:





✓ $\Delta\theta = 3$, $\Delta r = 0.8$:

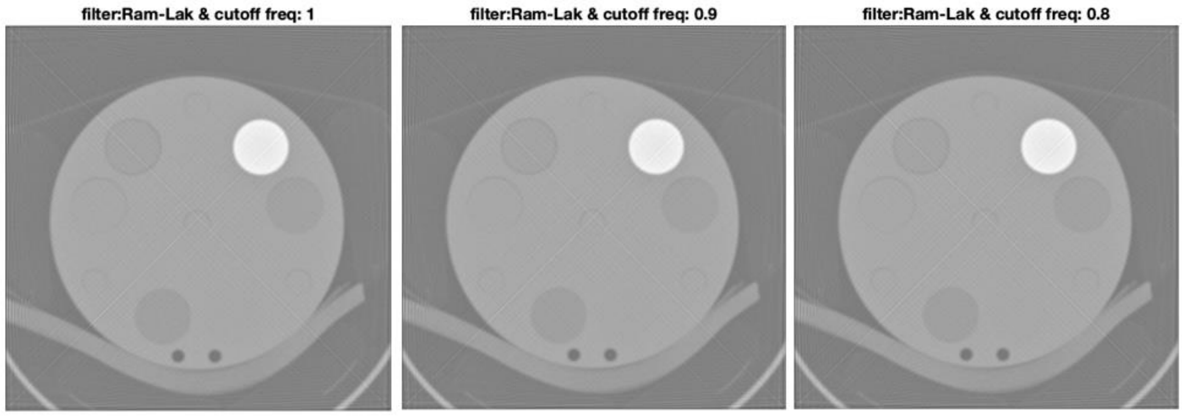




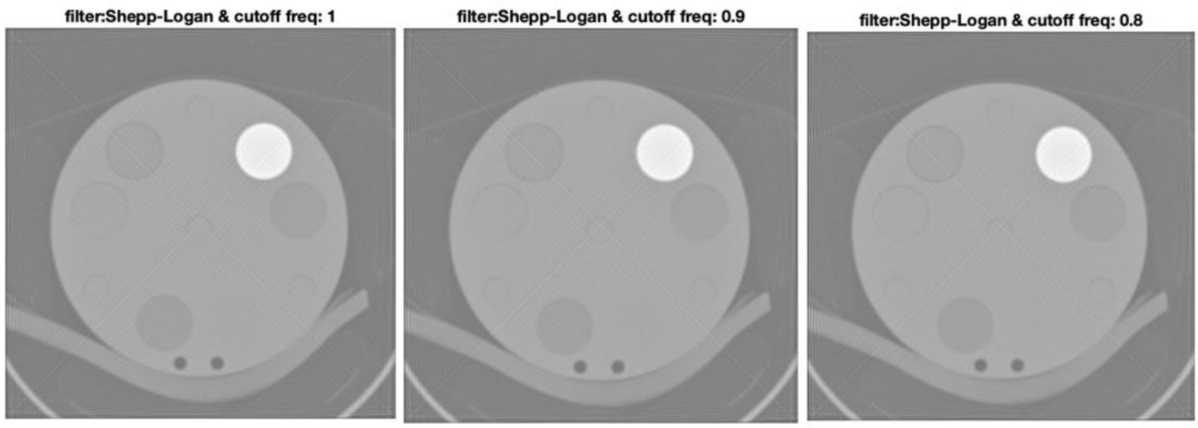
2. The effect of different reconstruction filters and cut-off frequencies

To experiment with different filtering, the values for Δr and $\Delta\theta$ had to be chosen. As observed on the previous paragraph, the combination for better resolution is the one with the lower values $\Delta r = 0.2$ and $\Delta\theta = 1$. The three filters examined are Ram-Lak, Shepp-Logan and Hamming. They were used with cut-off frequency scaling of 100%, 90% and 80% and cubic interpolation. The percentage represents the ratio of the cut-off frequency to the max frequency.

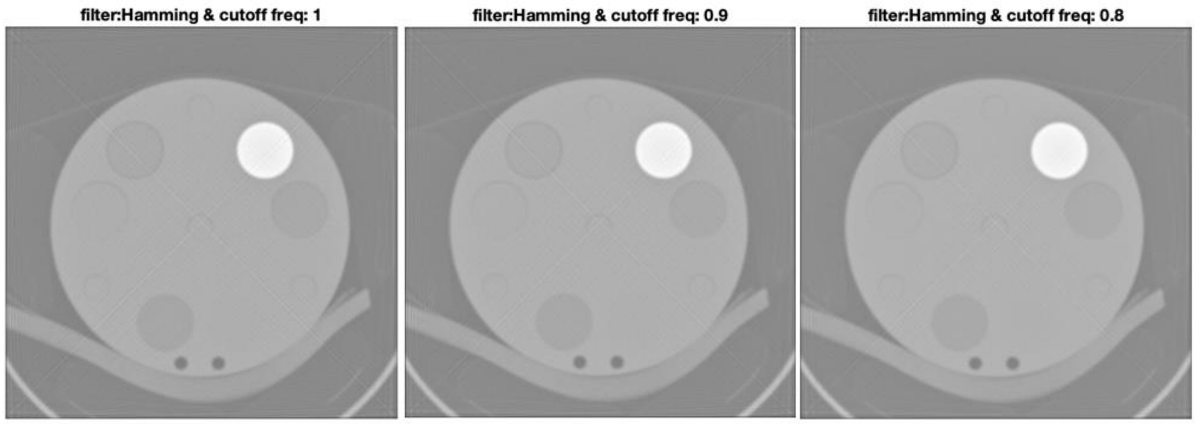
- **Filter: Ram-Lak, frequency scaling:100%, 90% & 80%**



- **Filter: Shepp-Logan, frequency scaling:100%, 90% & 80%**



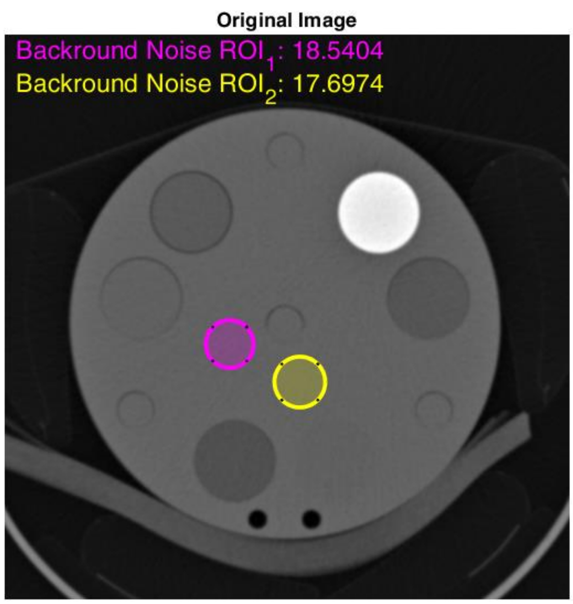
- Filter: Hamming, frequency scaling:100%, 90% & 80%



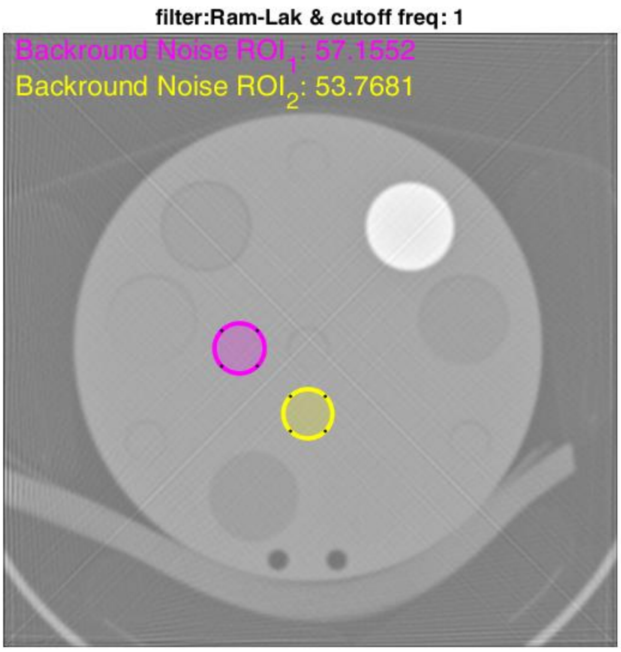
Quantitative Assessment of Image Quality in Reconstructed Images

Background noise

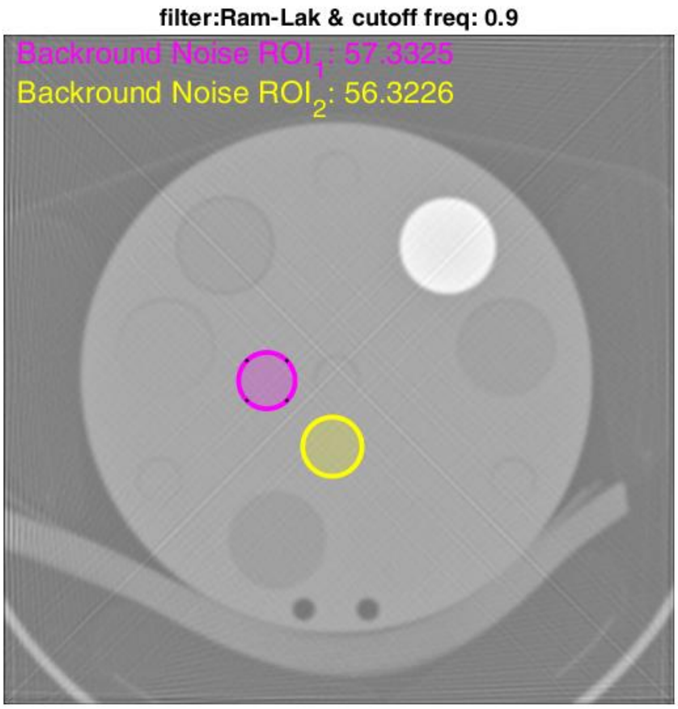
Noise is calculated in areas of the image which are macroscopically homogeneous. So, for our work we considered two circular ROIs in the grey background area. The noise is calculated as the standard deviation of the intensity of the pixels in the ROI. We performed the background noise calculation for the original image and then for each of the nine reconstructed images using different filters. The results can be seen in the colour coded text on the images. We must note that for the current version of matlab we utilized the drawcircle function instead of the proposed functions. The same stands for the next step concerning CNR.



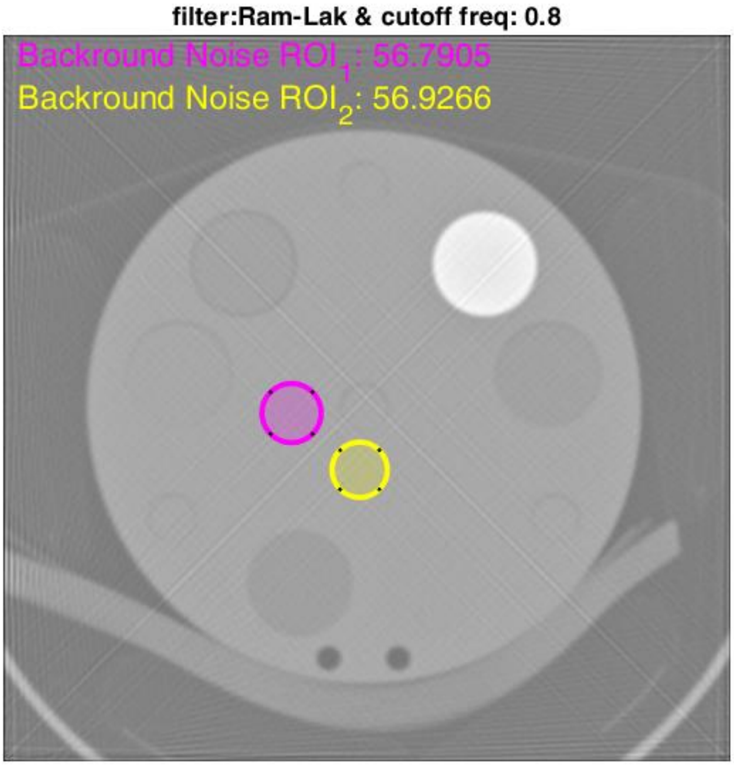
• Filter: Ram-Lak / cut-off frequency:1



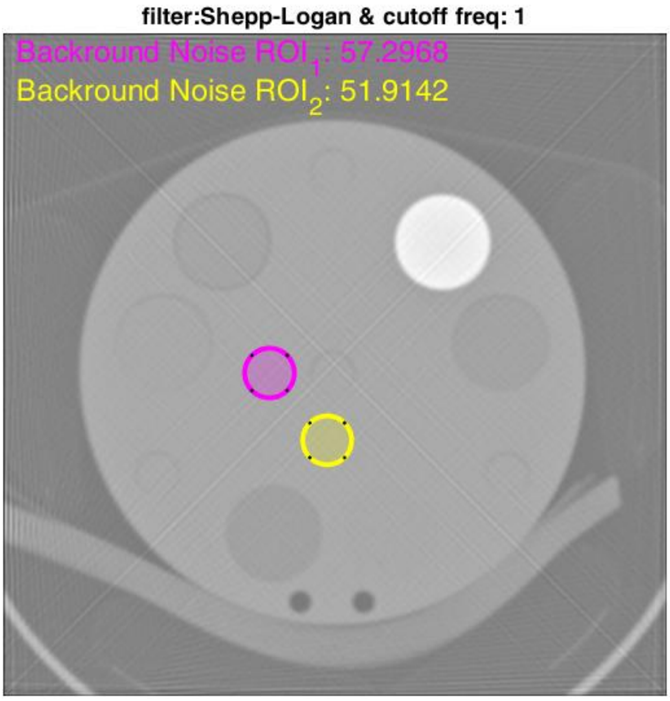
• Filter: Ram-Lak / cut-off frequency:0.9



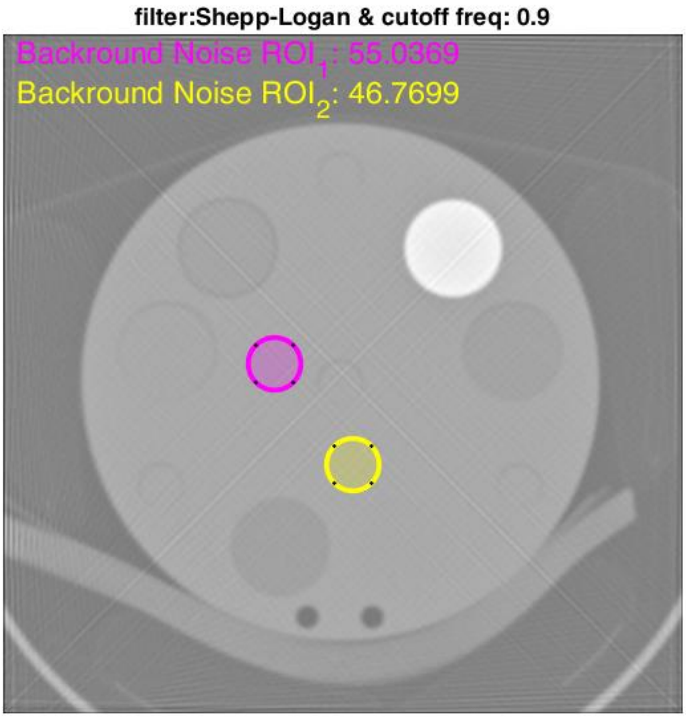
• Filter: Ram-Lak / cut-off frequency:0.8



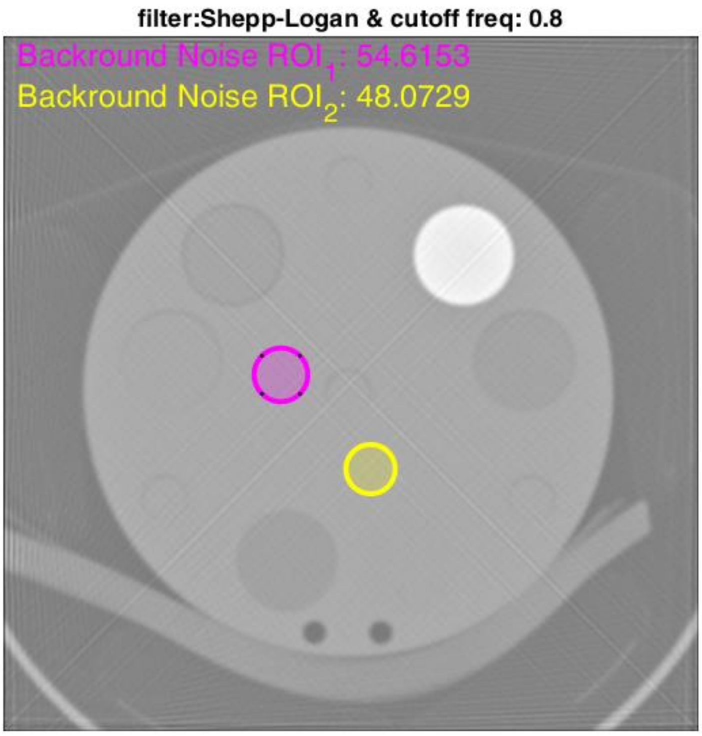
• Filter: Shepp-Logan / cut-off frequency:1



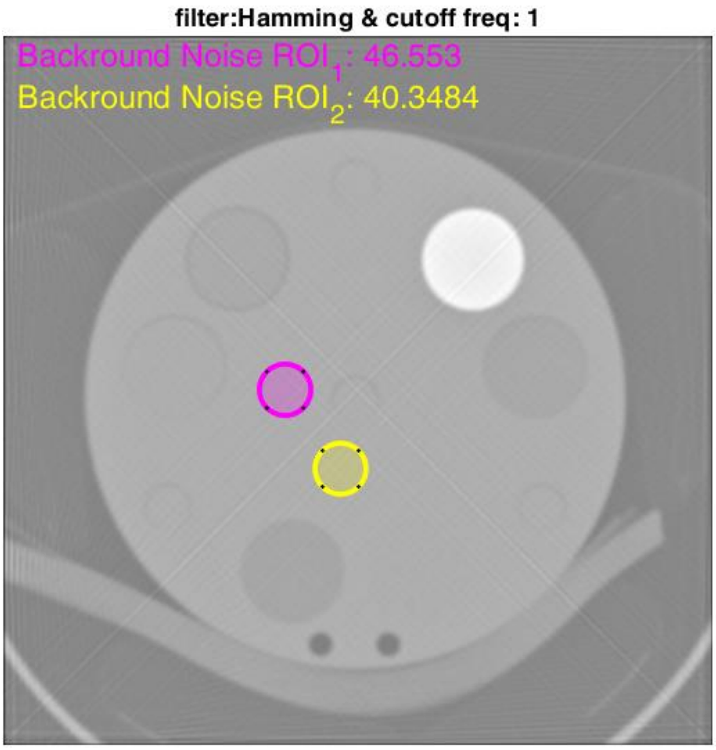
• Filter: Shepp-Logan / cut-off frequency:0.9



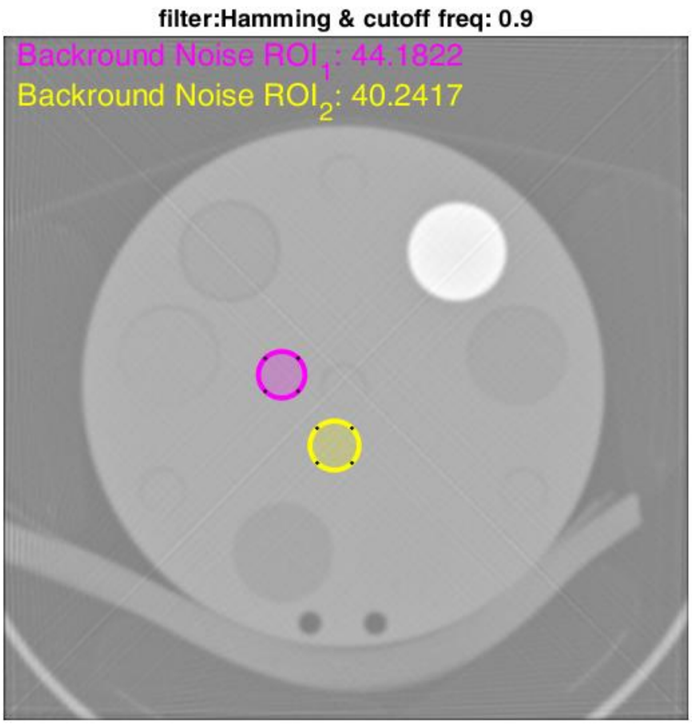
• Filter: Shepp-Logan / cut-off frequency:0.8



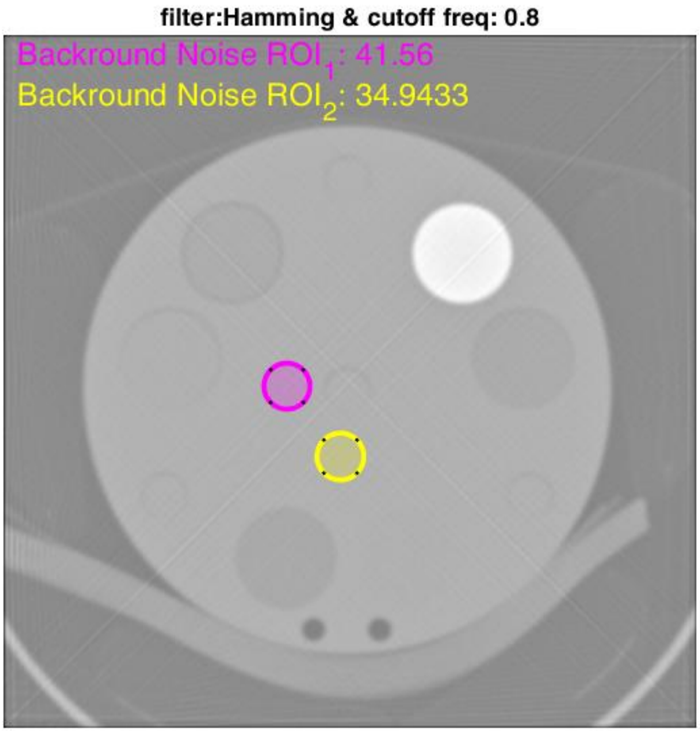
• Filter: Hamming / cut-off frequency:1



• Filter: Hamming / cut-off frequency:0.9

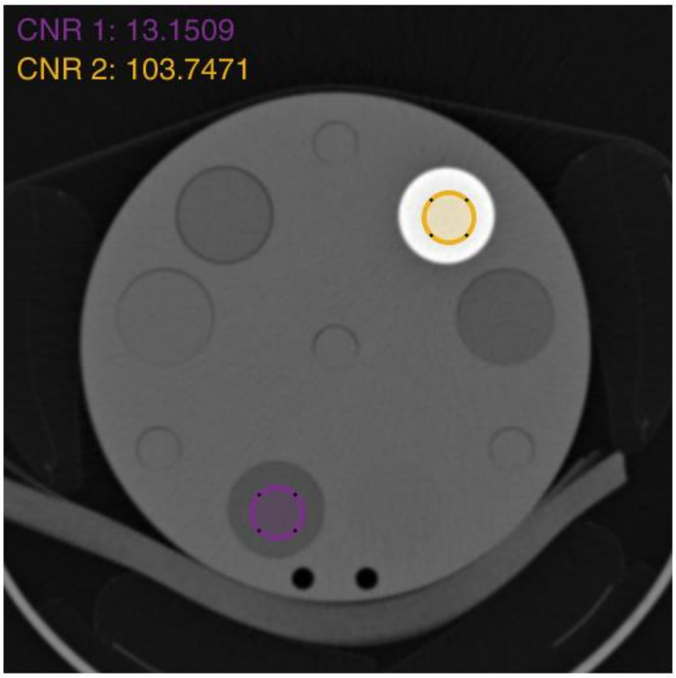


• **Filter: Hamming / cut-off frequency:0.8**



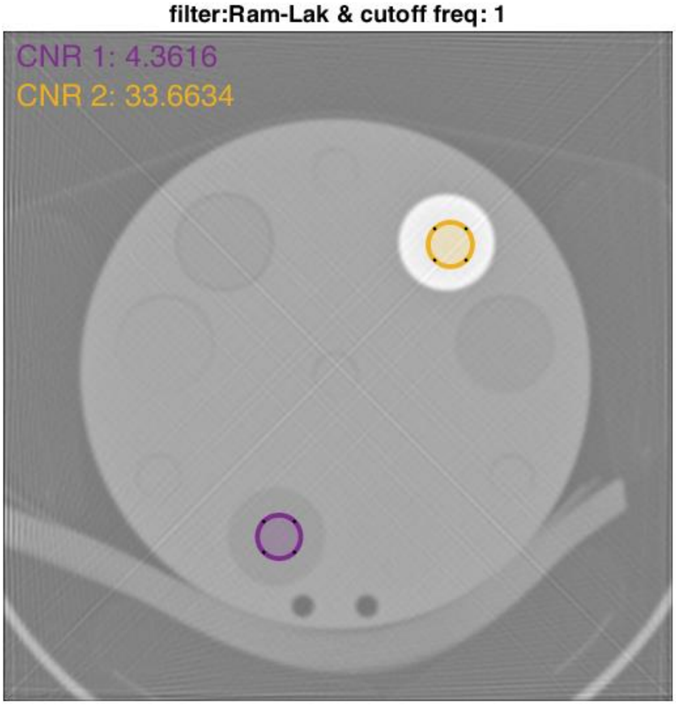
CNR (Contrast to Noise Ratio)

The 2 objects we chose can be seen in the images with the corresponding ROIs. The first one is a relatively dark object that we can approximate as being polyethylene or some other polymer. The second bright white object can be interpreted as bone tissue. The CNR is calculated as the difference of the mean intensities of the object and the background divided by the noise, which was explained on the previous paragraph. Our decision was to use as noise for every image the mean value of the 2 background noise ROIs calculated for the previous task. On the following images we can see the ROIs selected for the 2 objects for the original image and then for each of the nine reconstructed images as

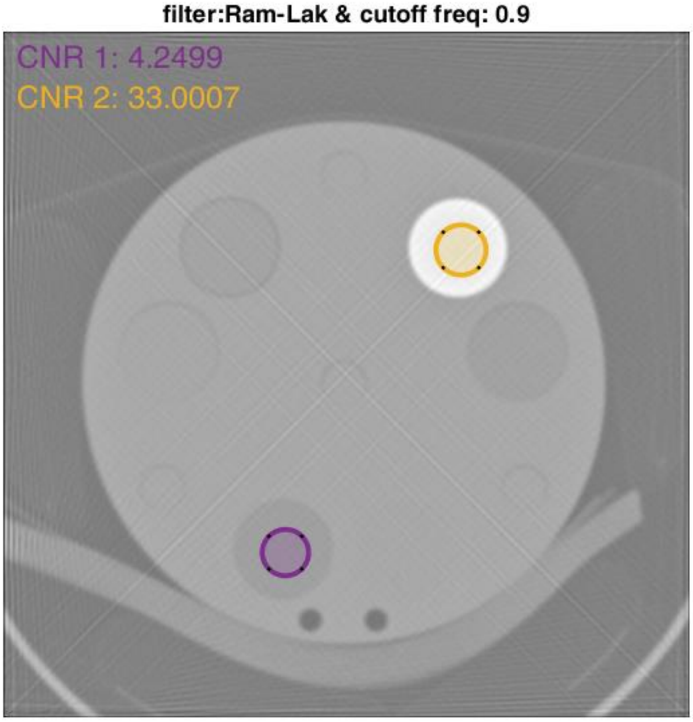


well as the CNR values. As expected, we observe much higher CNR values for the brighter 2nd object.

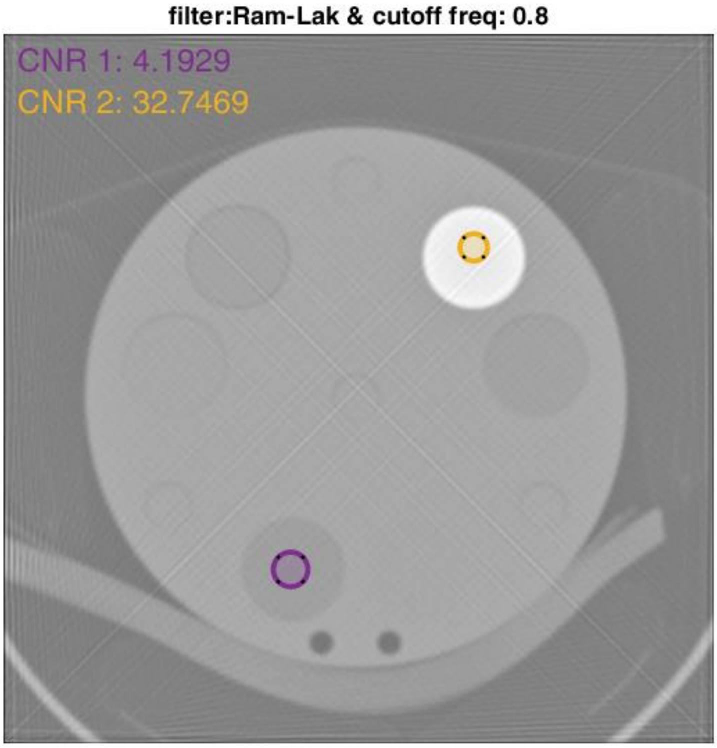
• **Filter: Ram-Lak / cut-off frequency:1**



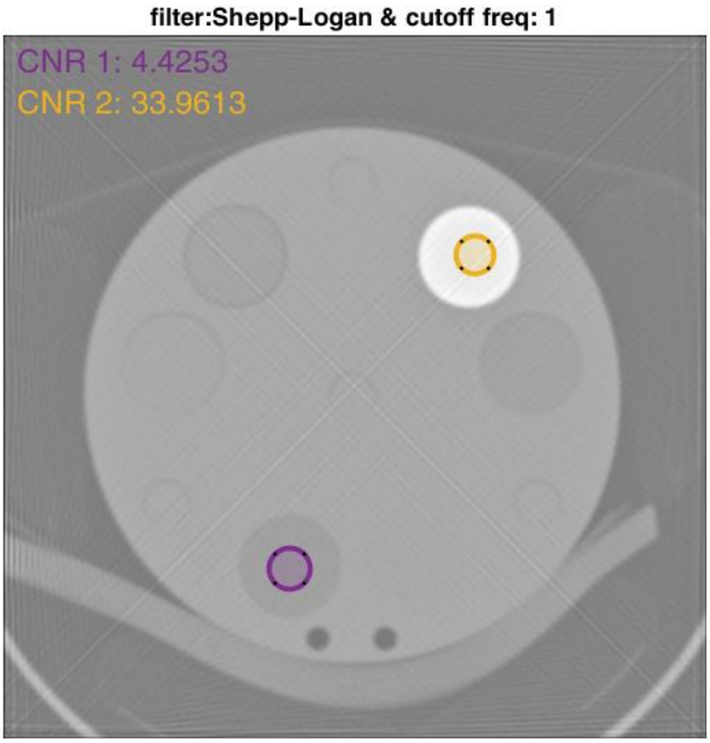
• **Filter: Ram-Lak / cut-off frequency:0.9**



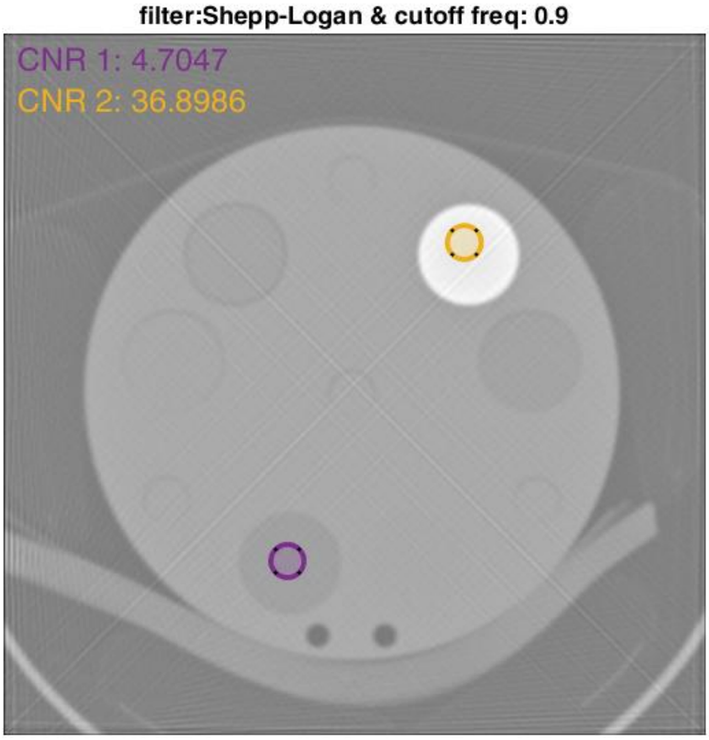
• Filter: Ram-Lak / cut-off frequency:0.8



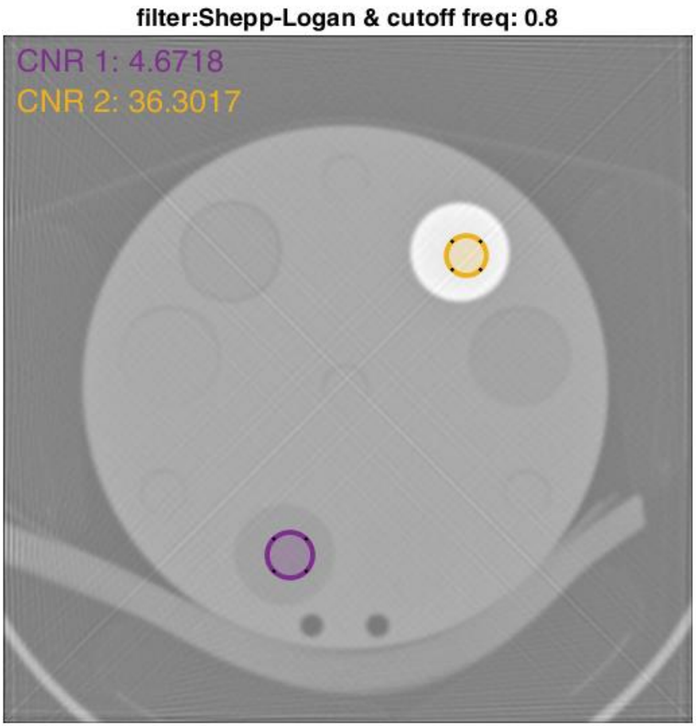
• Filter: Shepp-Logan / cut-off frequency:1



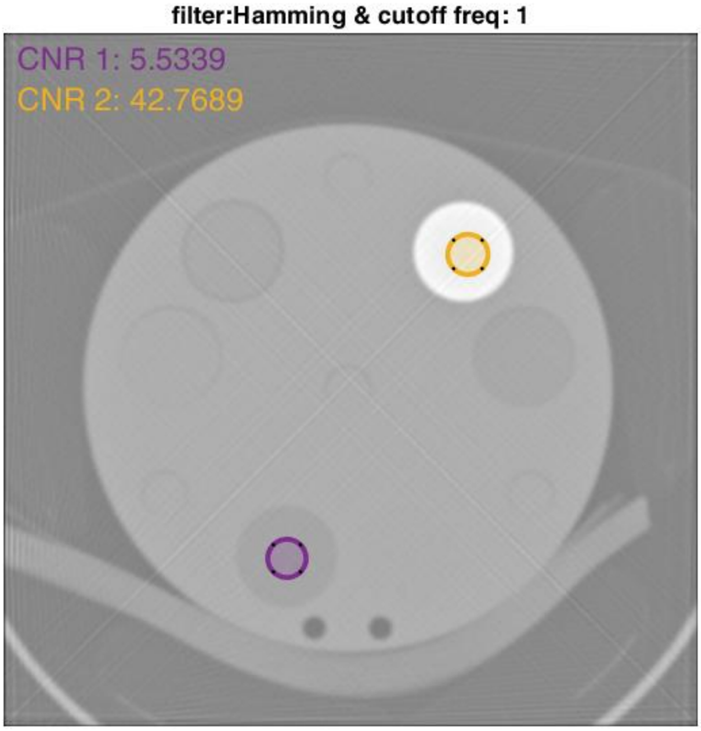
• Filter: Shepp-Logan / cut-off frequency:0.9



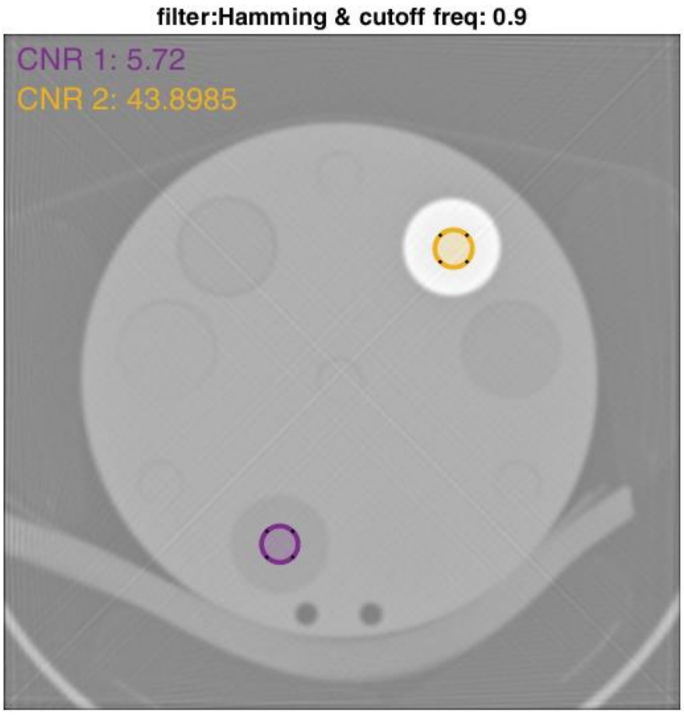
• Filter: Shepp-Logan / cut-off frequency:0.8



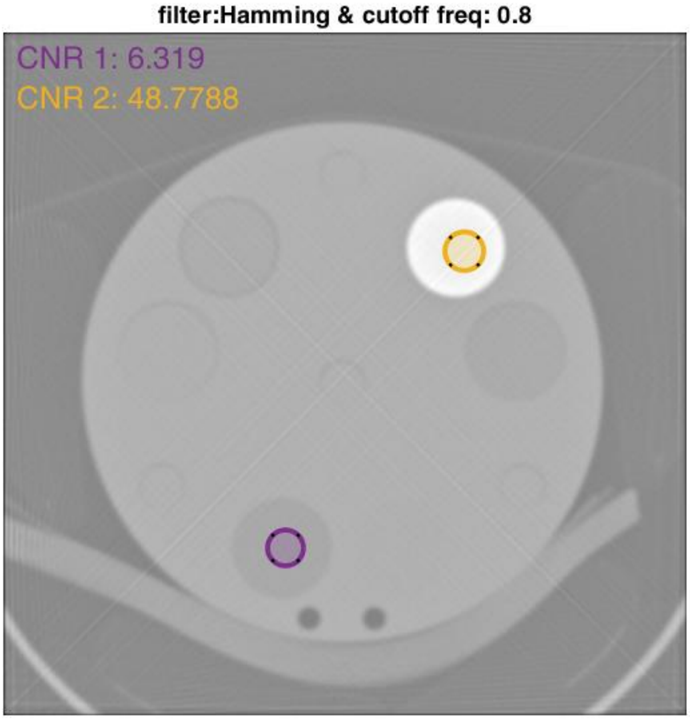
• Filter: Hamming / cut-off frequency:1



• Filter: Hamming / cut-off frequency:0.9

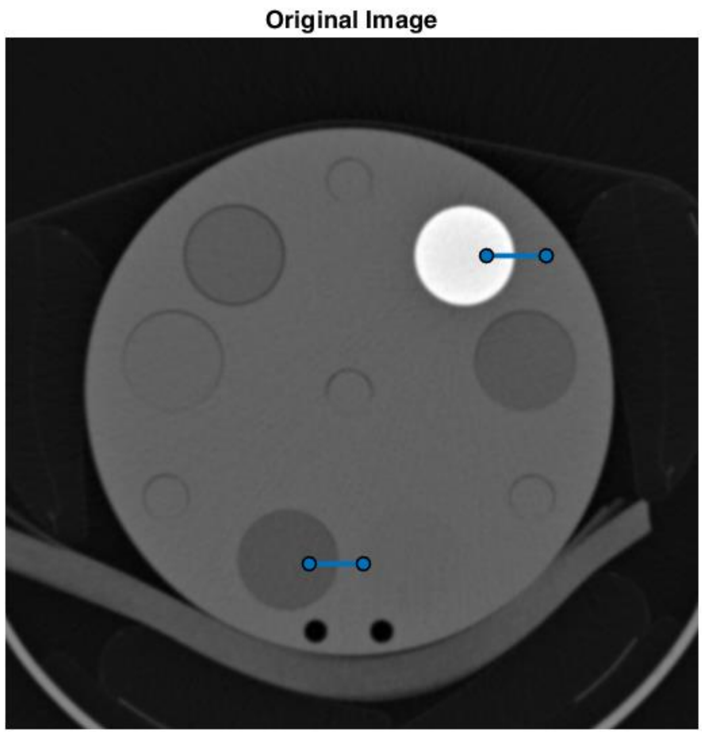


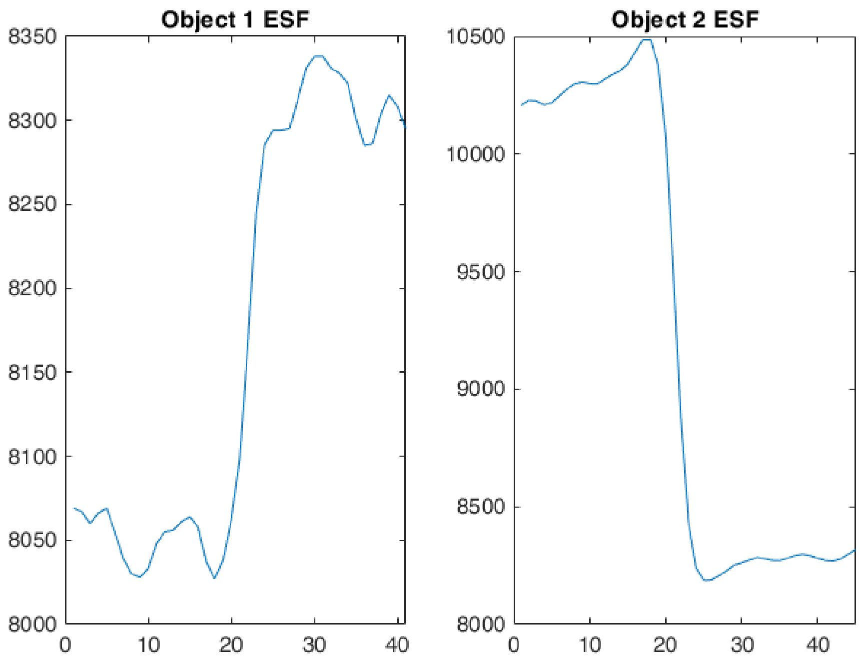
• Filter: Hamming / cut-off frequency:0.8



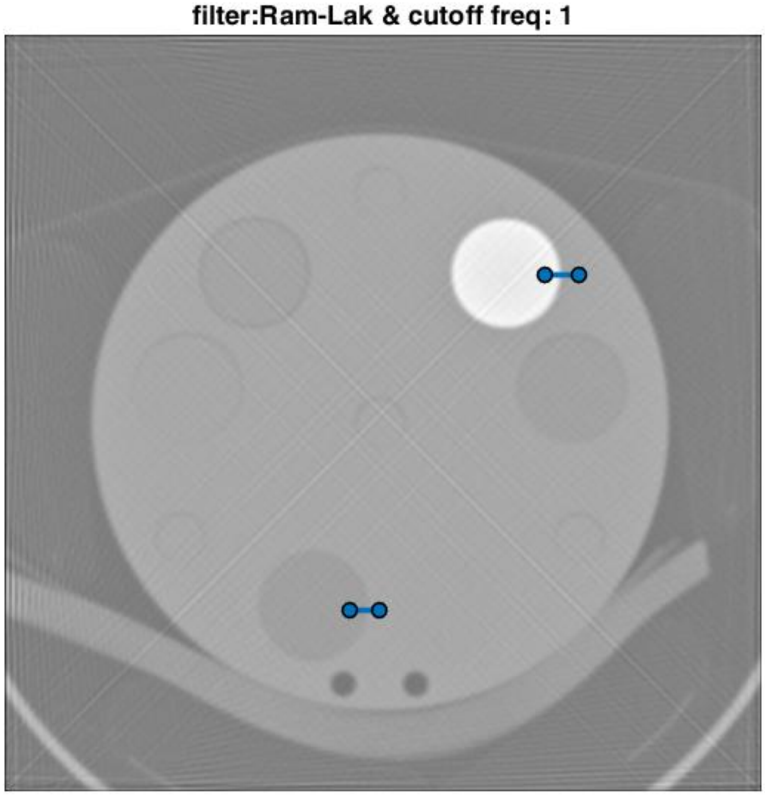
Edge Spread Function (ESF)

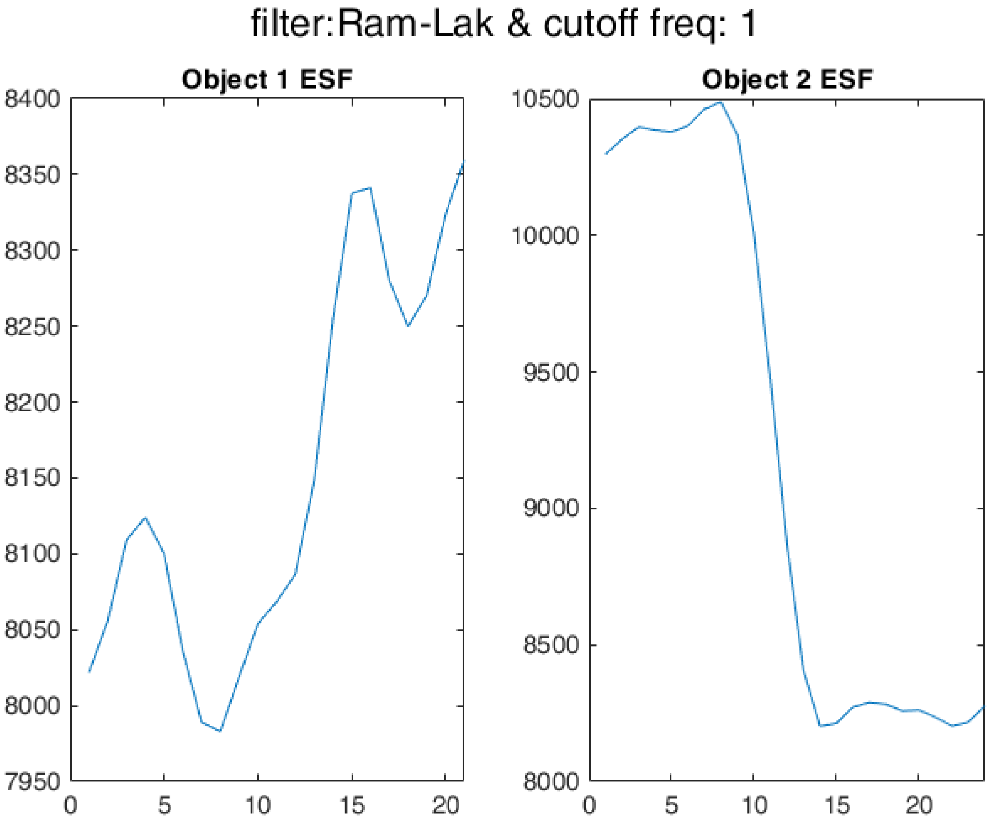
To estimate the ESF or else the blur, we utilized the drawline function. We performed the analysis on the same objects as before. We took the profile of two horizontal line segments exiting the object and we plotted the result to visualize the transition from the object material to the background material. To measure the edge width, we obtained from the graph the number of pixels from the beginning of the transitional line to the end. As the bright object offers better contrast and a more discrete transition, we can observe in the plots how cleaner the edge is with a bigger difference between the intensity levels on either side.


Original Image

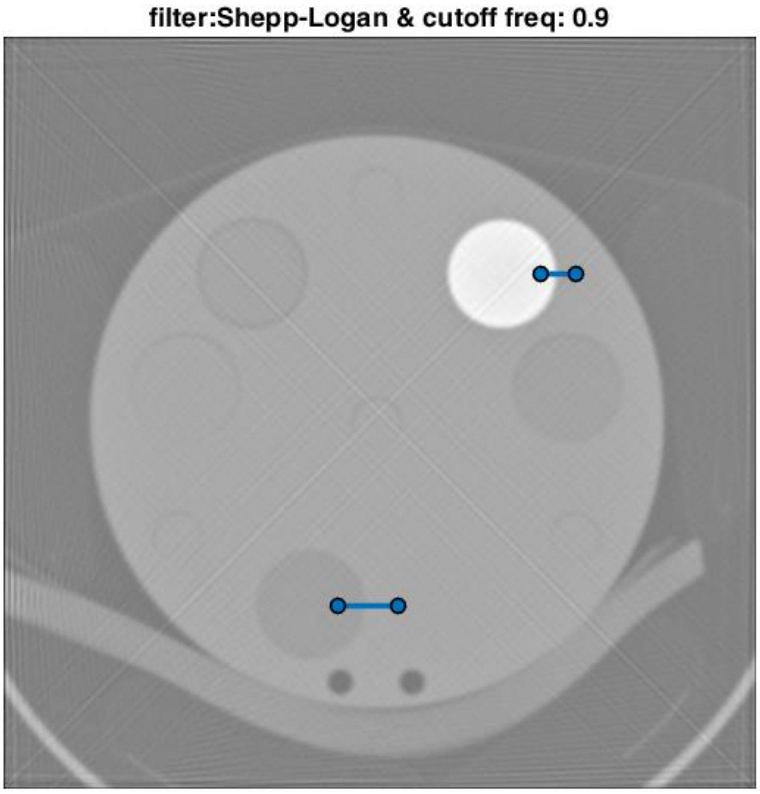

Object 1 ESF
8350
8300
8250
8200
8150
8100
8050
8000
0
10
20
30
40
Object 2 ESF
10500
10000
9500
9000
8500
8000
0
10
20
30
40

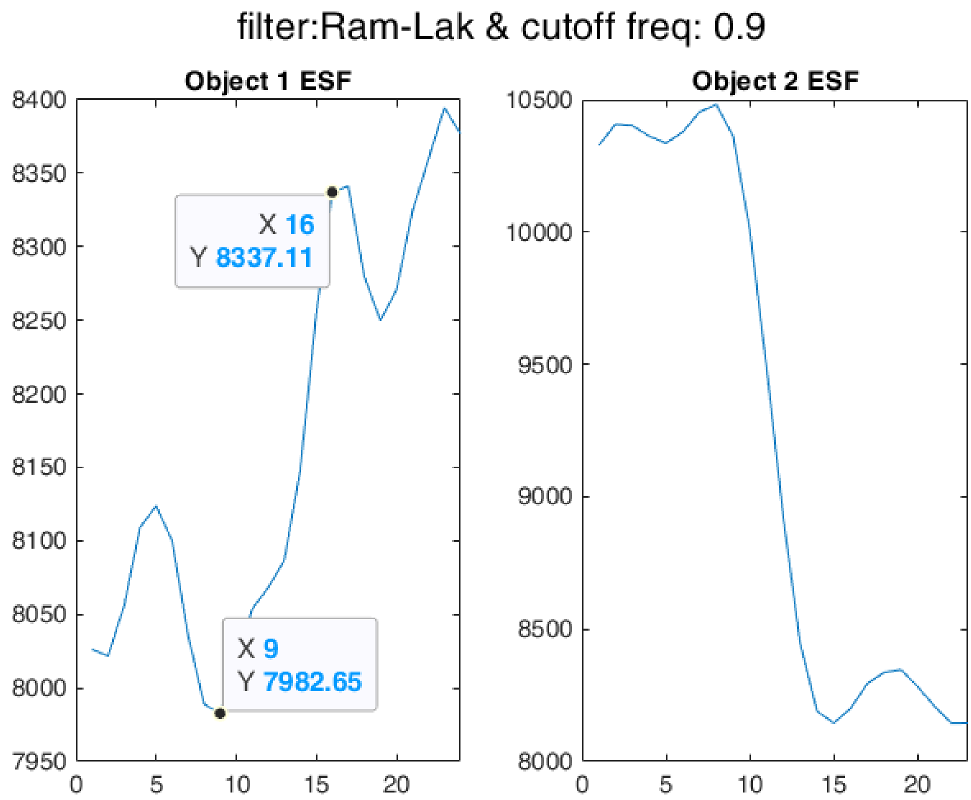
• Filter: Ram-Lak / frequency scaling:100%



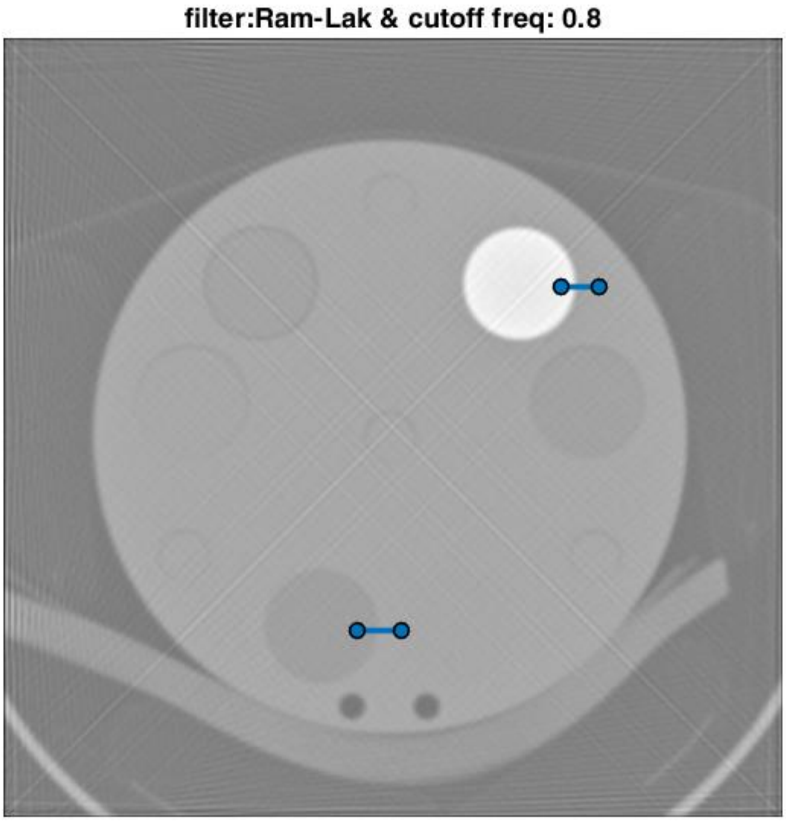


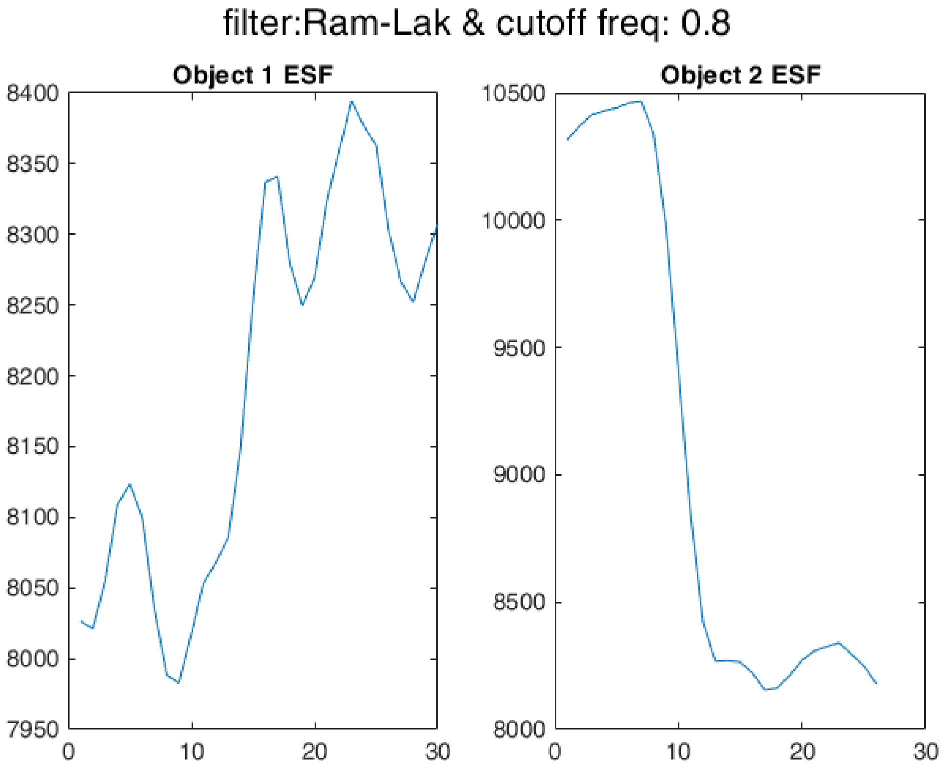
• Filter: Ram-Lak / frequency scaling:90%



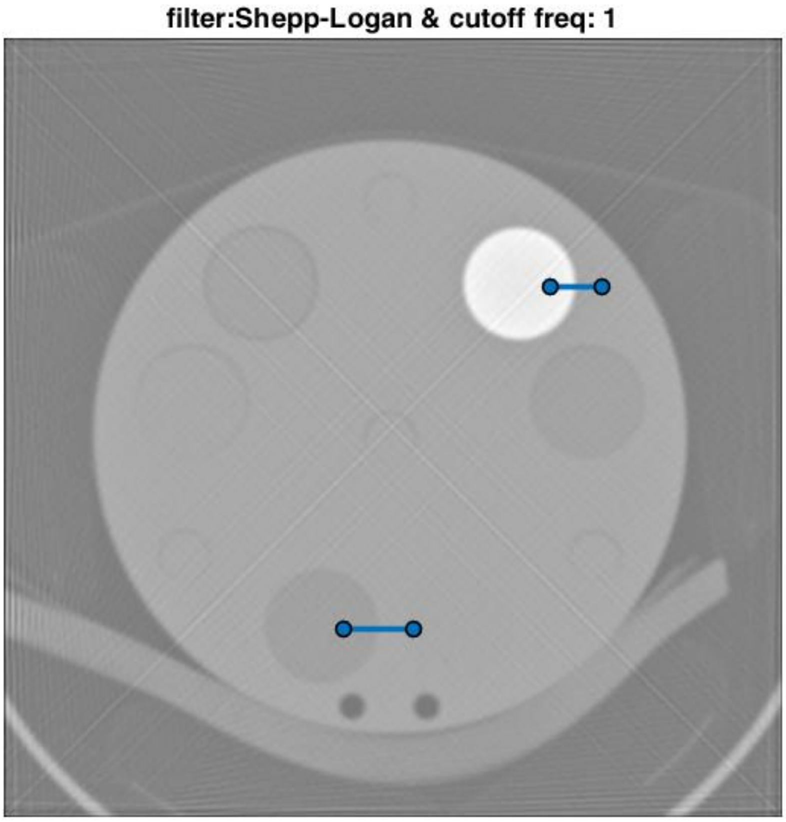


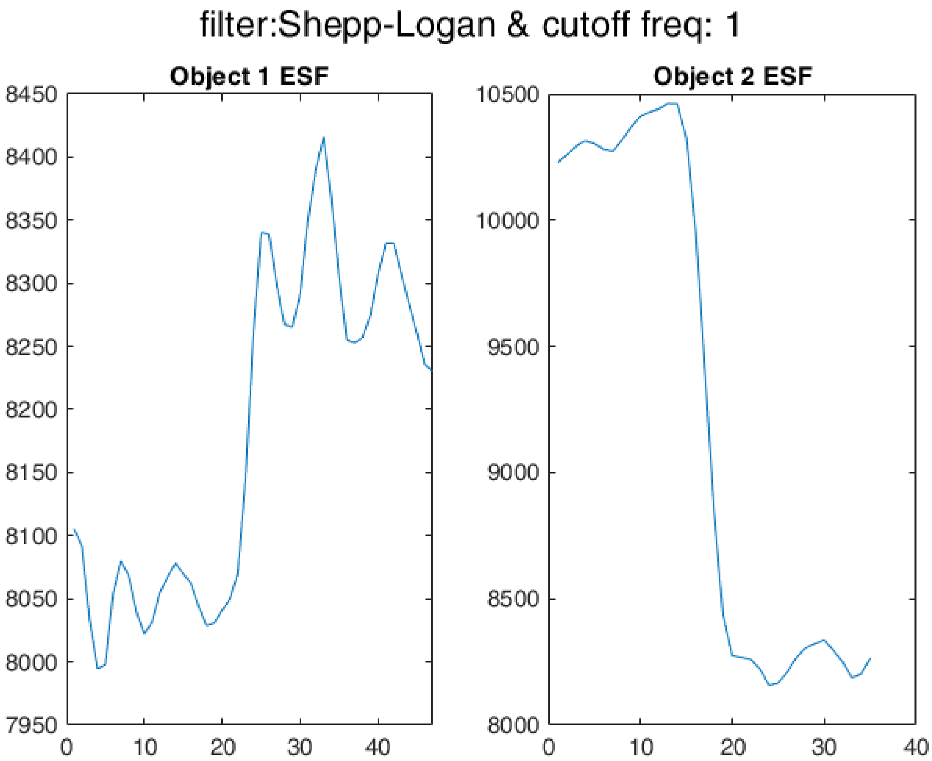
• Filter: Ram-Lak / frequency scaling:80%



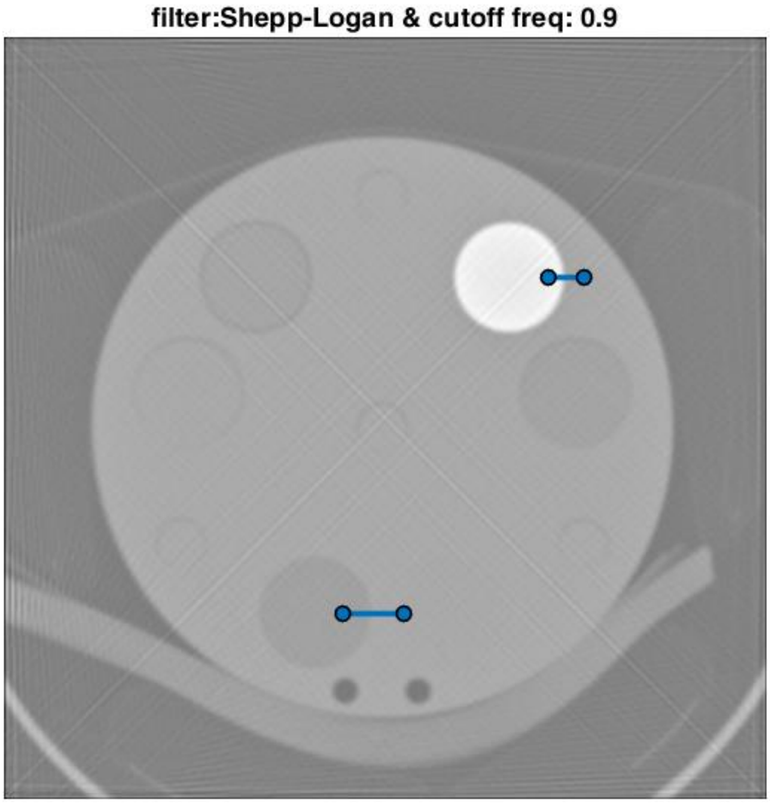


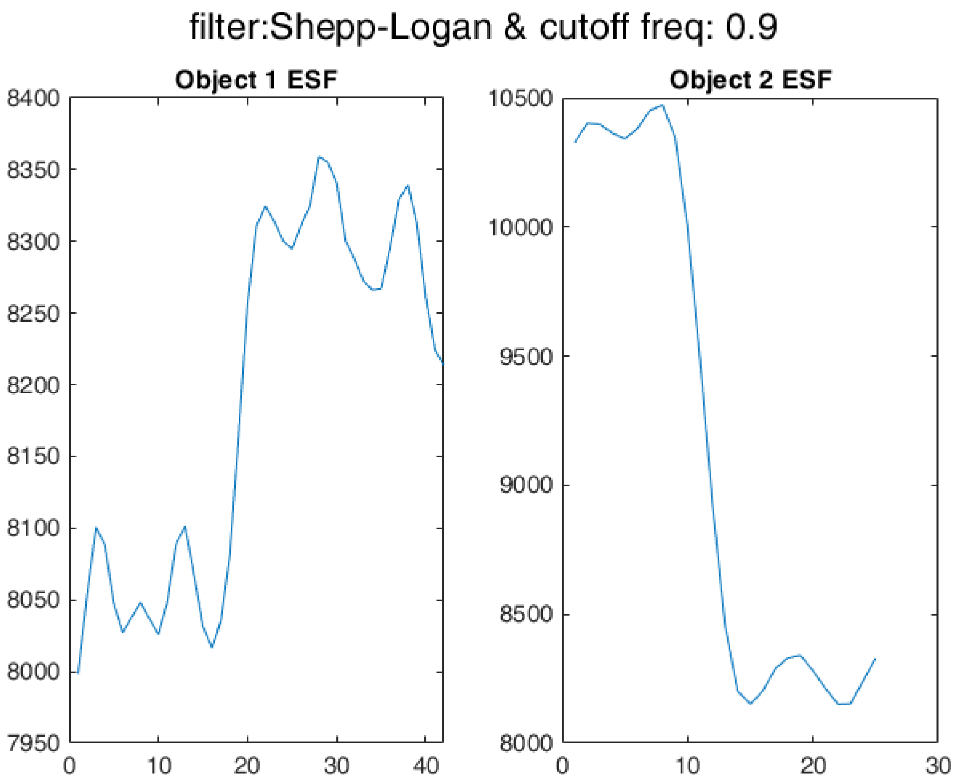
• Filter: Shepp-Logan / frequency scaling:100%



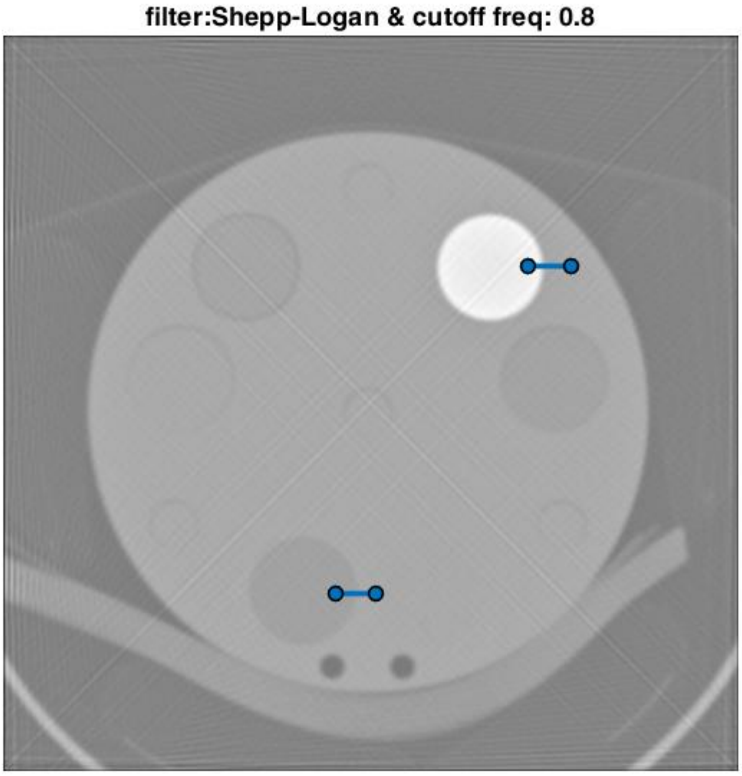


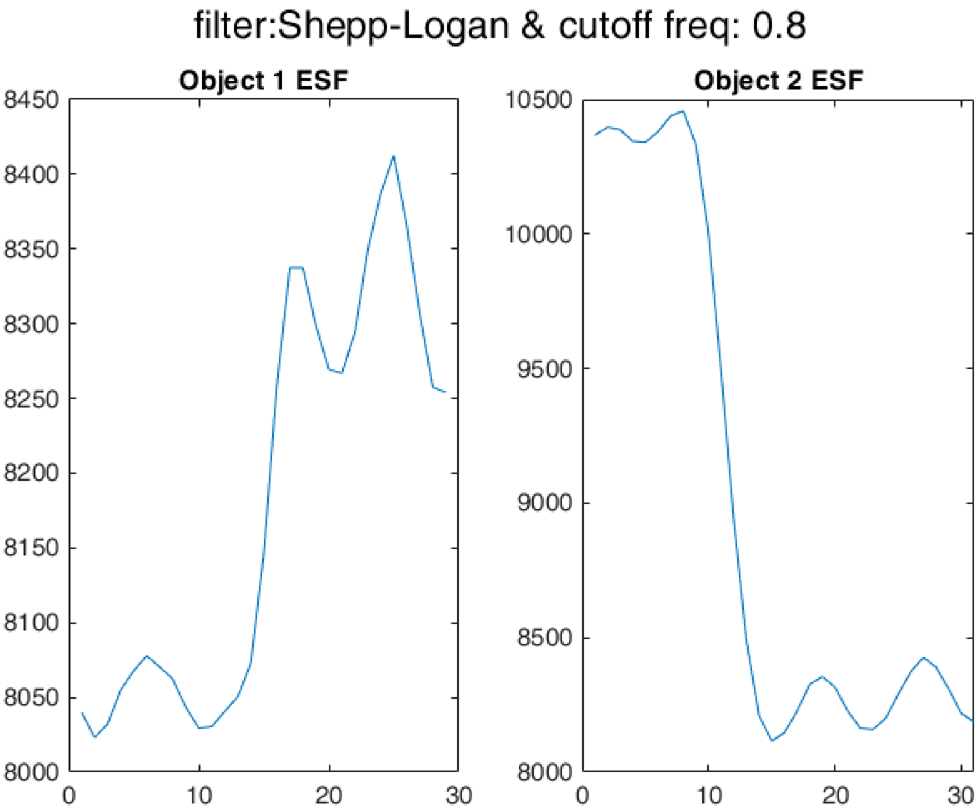
• Filter: Shepp-Logan / frequency scaling:90%



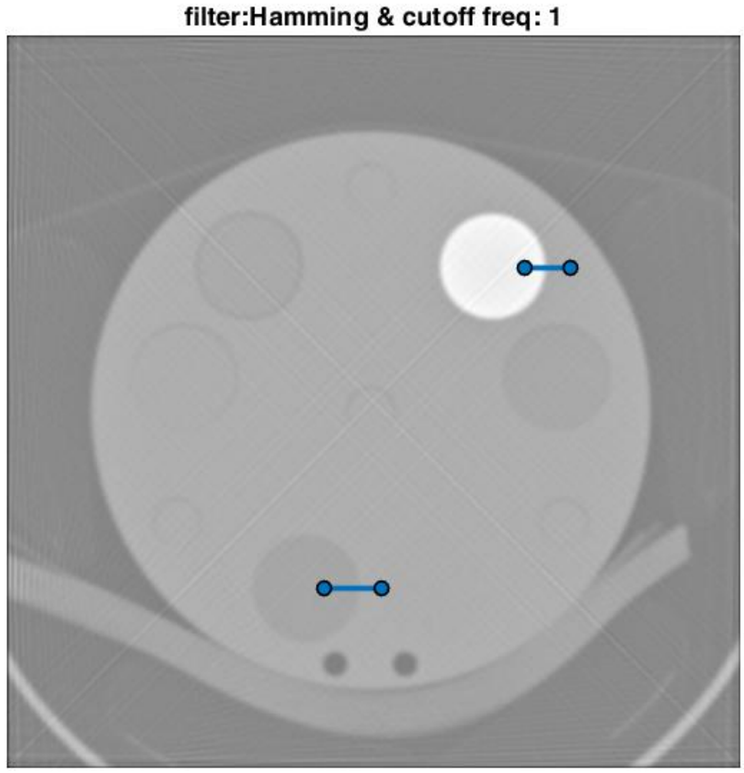


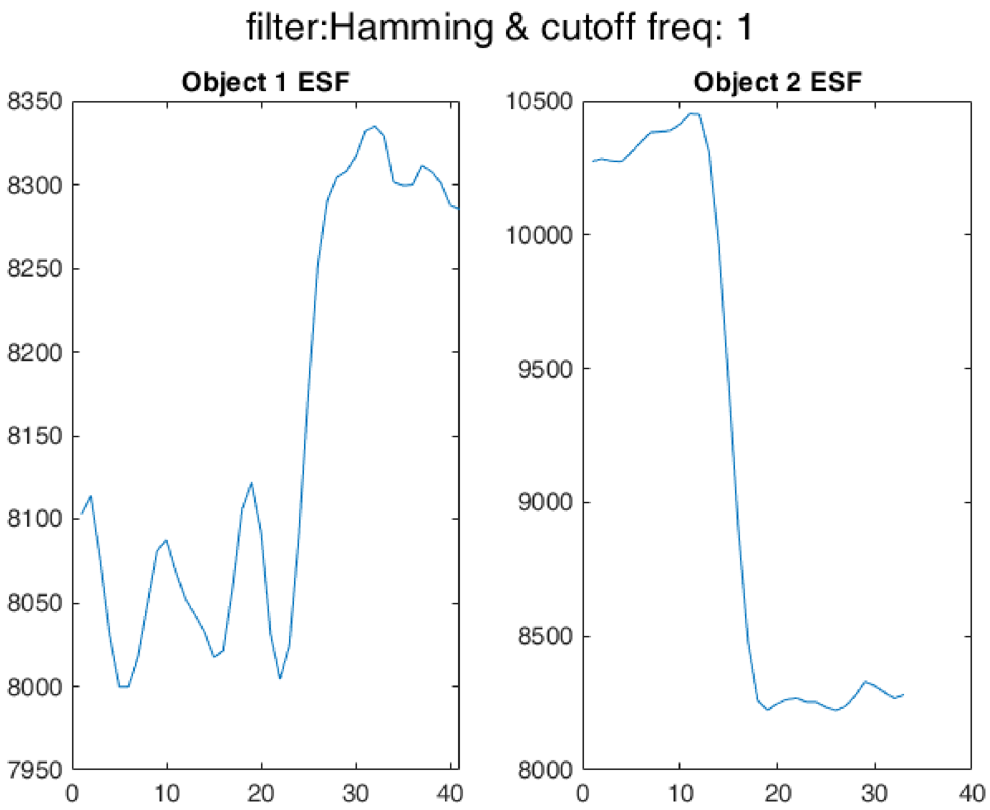
• Filter: Shepp-Logan / frequency scaling:80%



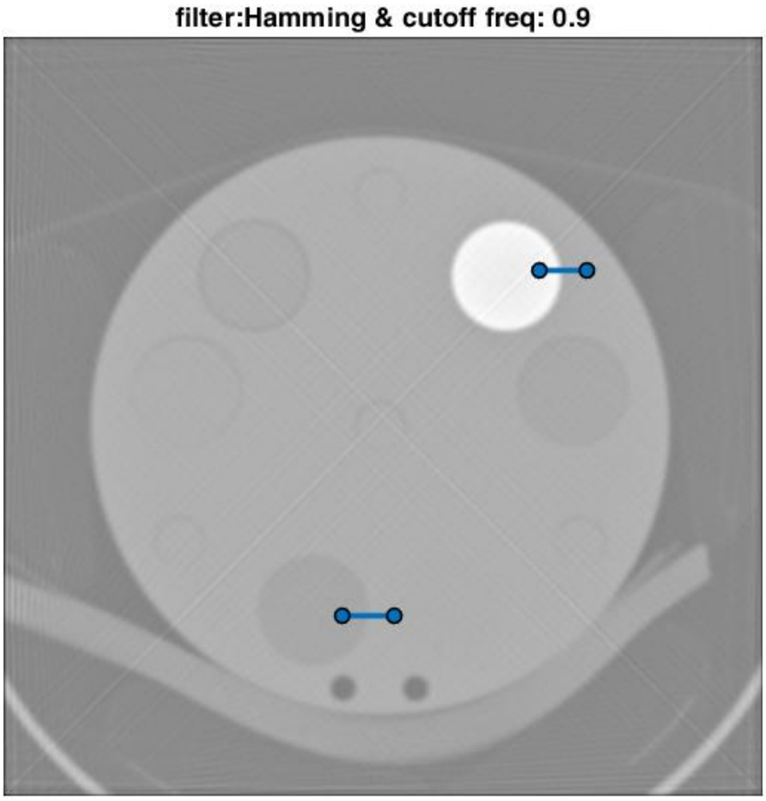


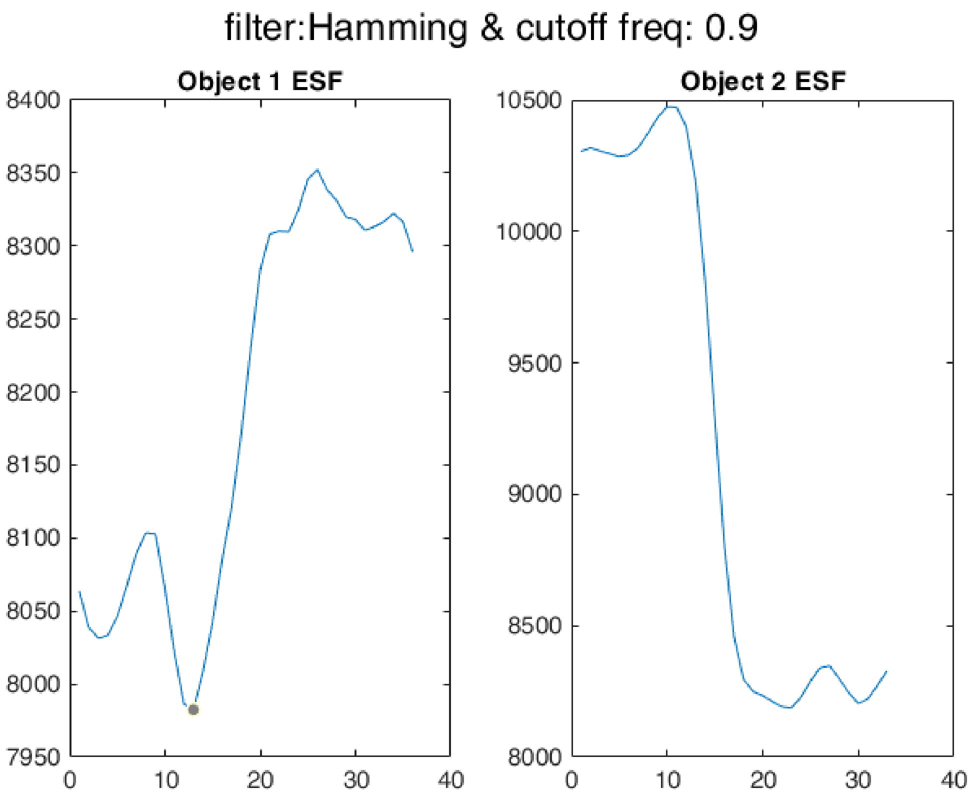
• Filter: Hamming / frequency scaling:100%



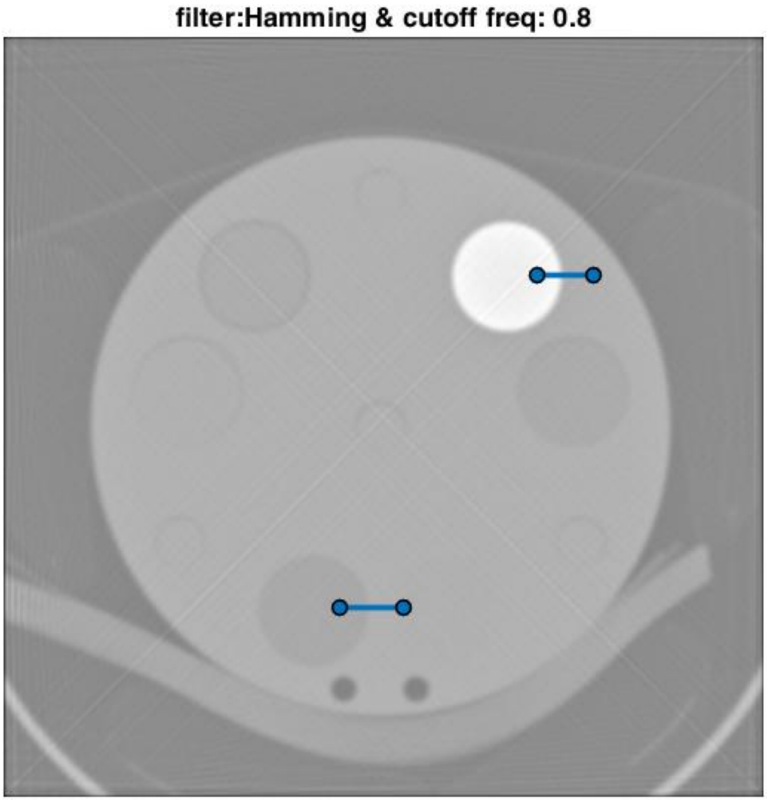


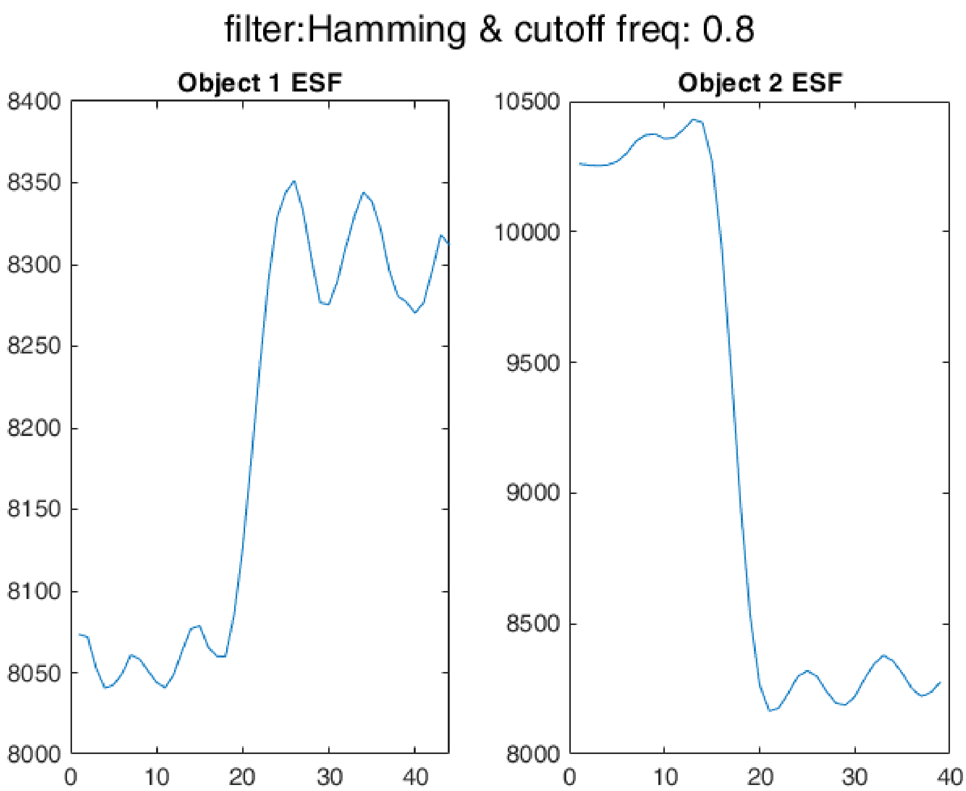
- Filter: Hamming / frequency scaling:90%





• Filter: Hamming / frequency scaling:80%





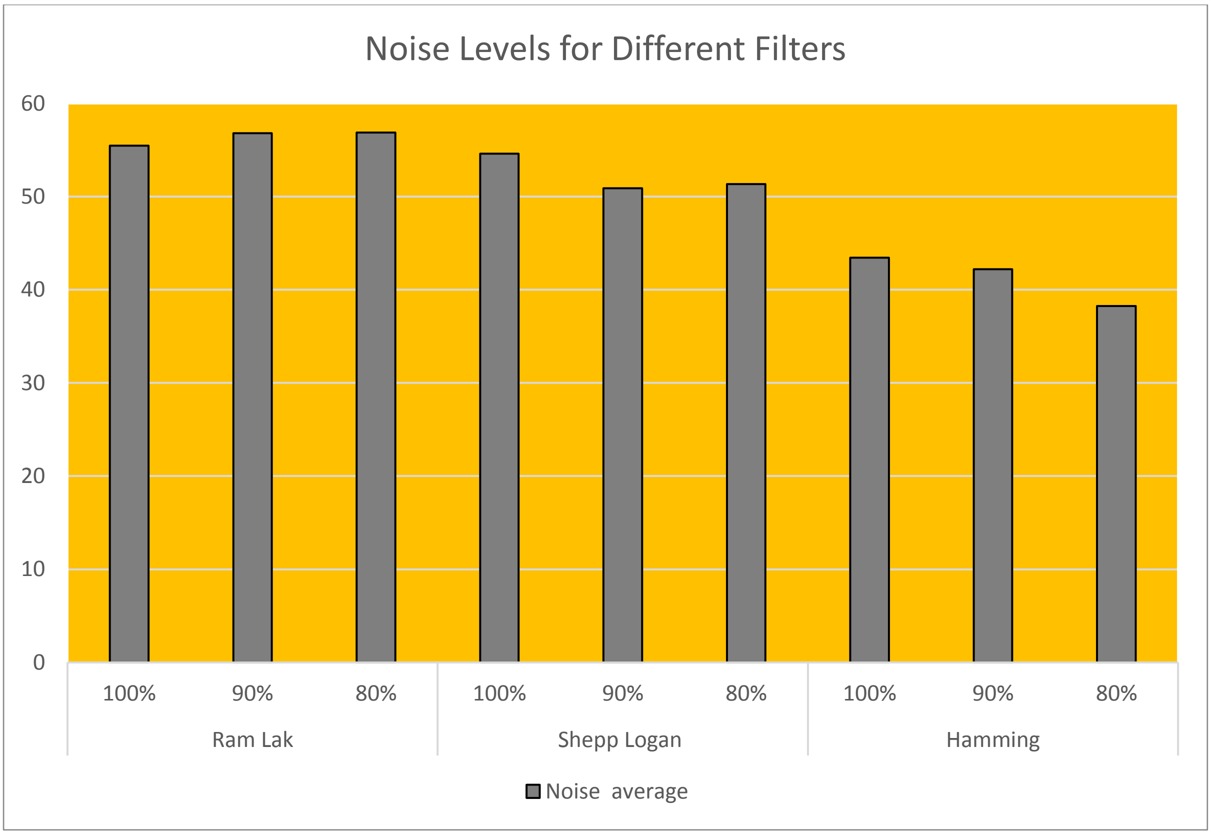
On the following table we present the results for the edge width from all the previous images. Object 2 has a smaller edge width in many cases, but the homogeneity of the objects allows for a small difference between the 2, even if object 1 has significantly less contrast. In some images we observe an increase in edge width, which is justified by the increased noise in those images. We also have to remember that as the intensity levels fluctuate in the homogenous regions because of the noise, it is expected to have an uncertainty on the actual edge width.

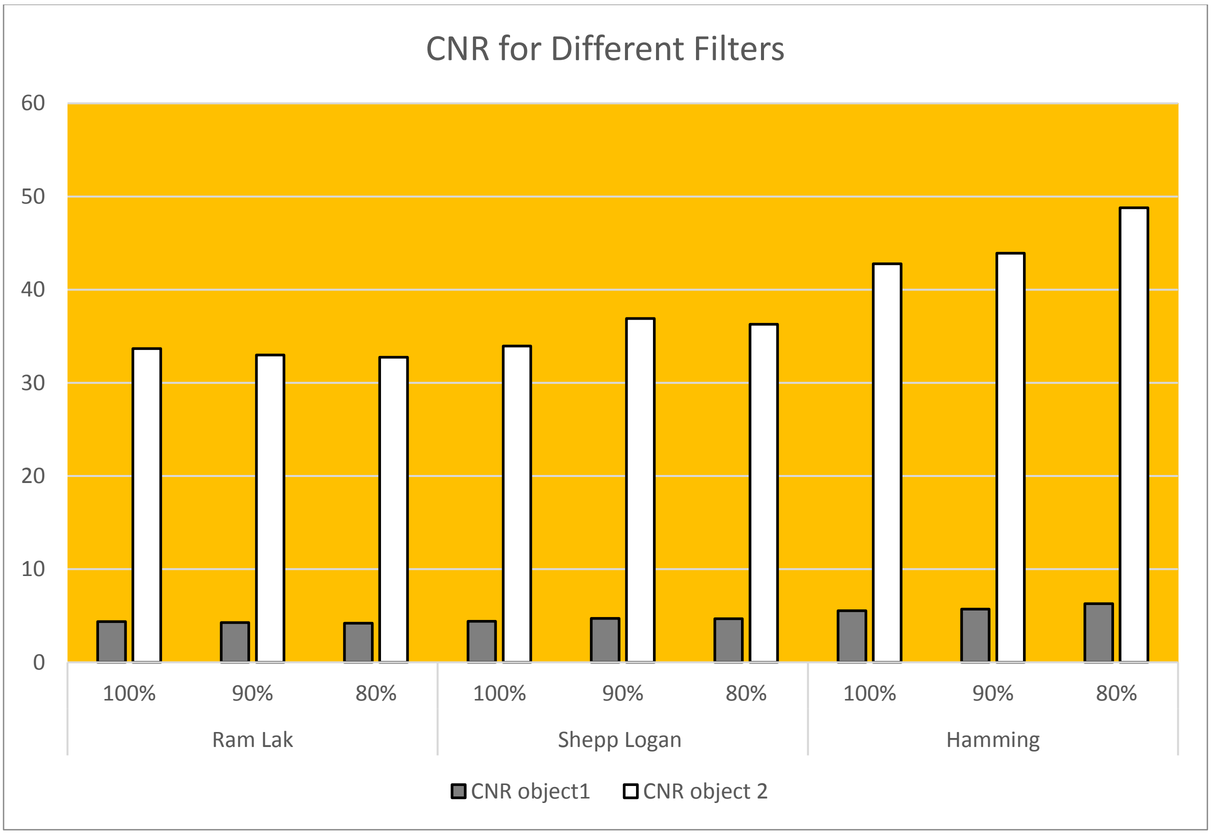
Filter	Cutoff Frequency	Edge Width object 1	Edge Width object 2
Original Image	-	12	7
Ram Lak	100%	7	6
	90%	7	7
	80%	7	6
Shepp Logan	100%	6	10
	90%	6	7
	80%	7	7
Hamming	100%	9	7
	90%	13	13
	80%	9	7

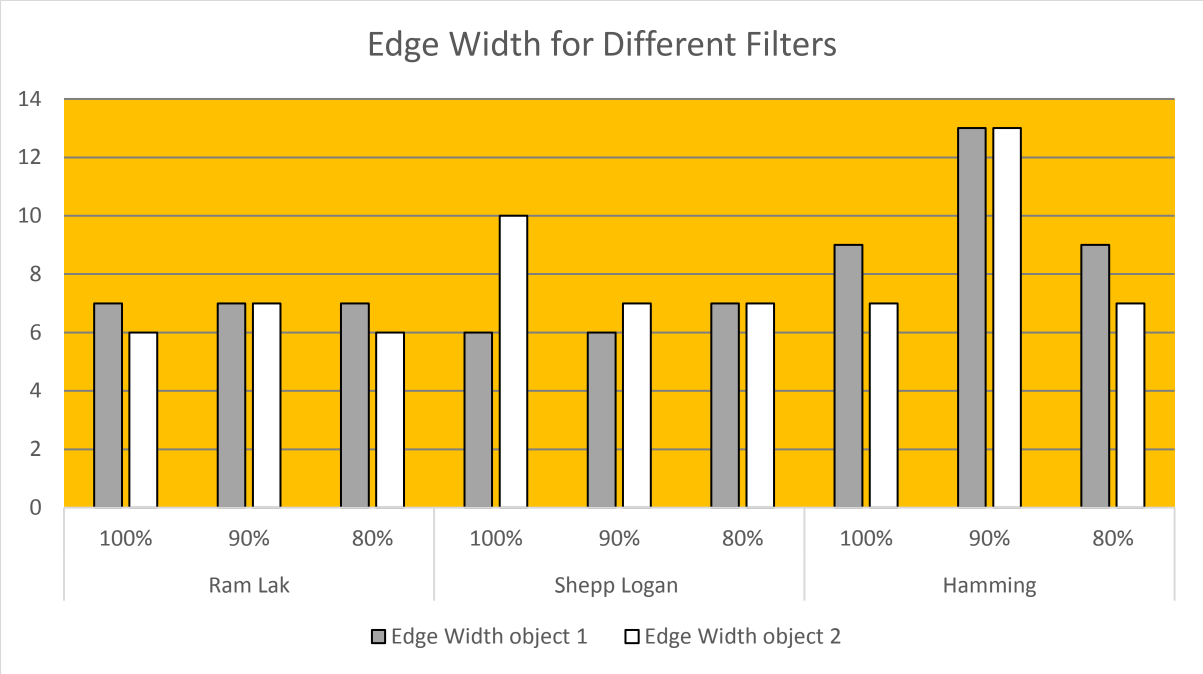
Questions

Question 1

As we mentioned previously, we opted for $\Delta r = 0.2$ and $\Delta\theta = 1$ as they offered the best resolution and the best reconstructed image. Comparing and observing our results and the reconstructed images created by each of the different reconstruction kernels we can reach some conclusions. For the same type of filter, as expected we achieve better results with a smaller cutoff frequency as more noise gets filtered. The filter that had the best results was Hamming, which lead to the least noise and the best object CNR in the reconstructed images. We provide the following graphs that summarize the results and justify our conclusions. Lastly, looking at the edge blur we can't reach a safe conclusion as easily. On average Hamming filtering seams to cause slightly more blur on the reconstructed images, but as the edge width is difficult to calculate precisely, there is not a safe margin to justify a decision.


Noise Levels for Different Filters
60
50
40
30
20
10
0
100%
90%
80%
100%
90%
80%
100%
90%
80%
Ram Lak
Shepp Logan
Hamming
Noise average


CNR for Different Filters
60
50
40
30
20
10
0
100%
90%
80%
100%
90%
80%
100%
90%
80%
Ram Lak
Shepp Logan
Hamming
CNR object1
CNR object 2



Question 2

Considering the graphs and by visual inspection, we consider the Hamming filter with 80% cutoff frequency as the combination for optimal detectability of the two materials we chose. The numbers on noise and CNR give a clear lead to the Hamming filter while the 80% cutoff is an obvious preference. ESF results do not suggest the same, however in our case it is not deemed as a definitive factor given the uncertain measurements. But as all factors should be taken into account depending on the application and the criteria, we can reach the even more complete following conclusion. Ram Lak provides the best sharpness and preserves high frequency information but is not optimal in noise reduction, Hamming on the other hand offers the best noise reduction but adds blur to the image and Shepp Logan offers a compromise between the 2 with more average results in noise, contrast and edge blur.