Exercise 1 report: Medical Imaging

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AI for Healthcare course with Ayelet Akselrod-Ballin, Reichman University, 2023

1 Introduction

The goal of our project is to summarize the first part of the course, in which we learn about image reconstruction in computed tomography (CT). More particularly, we performed basic back projection, filtered back projection and iterative reconstruction. We used the Shepp-Logan head phantom and the supplied circle and line pictures to demonstrate the calculation, those pictures are presented in Figures 1, 2 and 3.

First, we calculated the sinogram of each picture using 180 projection angles. and performed reconstruction using non-filtered back projection. Second, we varied the number of projection angles for each picture and did a similar process of creating a sinogram and perform reconstruction using 18,24,90,120 and 150 projection angles. Next, we used filtered back projection to demonstrate the difference between both approaches. We did it for each tested number of projection angles and used Shepp-Logan filter. Finally, we used SART as the algebraic iterative reconstruction technique and performed 12 iterations reconstruction using a sinogram that was built with 180 projection angles.

1.1 Tools

The code was written on a Google Collab notebook in Python language. We used the images that was given in the exercise's instructions. To implement the algorithm we used implemented functions from scikit-image Python library. We based our answers on the videos of ASTRA Toolbox [1] that was provided as reference and also a youtube channel.

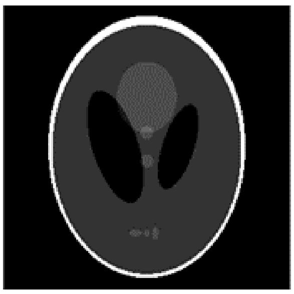

Figure 1: Shepp-Logan head phantom

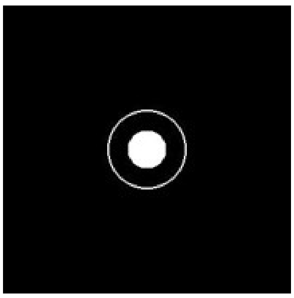

Figure 2: Geometric image: "dot"

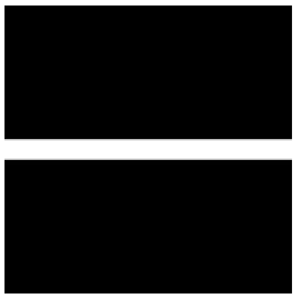

Figure 3: Geometric image: "line"

2 The methods

2.1 Sinogram

A sinogram is a visual representation of the measurements taken in a computed tomography (CT) scan. To create a sinogram, a beam of X-rays is passed through the object at various angles, and the intensity

[1] https://www.youtube.com/channel/UCcnUlWuFeS9miMR_o8-6v3w/videos?app=desktop

of the X-rays passing through the object is measured on the other side. This process is repeated for many different angles, resulting in a set of measurements that can be plotted on a graph. In a sinogram, the X-axis represents the angle at which the measurements were taken, and the Y-axis represents the intensity of the X-rays that passed through the object. Each line on the sinogram represents the set of measurements taken at a particular angle. In general, a higher number of projection angles results in a better quality image with higher spatial resolution and less noise. This is because a larger number of angles provide more information about the internal structure of the object being imaged, allowing for a more accurate reconstruction.

2.2 Back projection and Filtered back projection

Those methods are used for reconstructing images from sinograms obtained in CT. Back projection is the simpler method for image reconstruction that includes summing up the intensity values along each projection line and assigning the resulting sum to the corresponding pixels in the reconstructed image. Back projection mostly results in a blurred and noisy image, especially using a low number of projections. Filtered back projection (FBP) is the more advanced method, that involved applying a filter to the sinogram before the basic back projection. The filter is designed to remove high-frequency noise from the sinogram, while preserving low-frequency information. This helps reduce the blurring and noise of the reconstructed image. FBP is slower due to the additional filtering step.

2.3 Algebraic Iterative Reconstruction using SART

Algebraic iterative reconstruction is a technique used in tomography that aims to reconstruct images from a set of projections by solving a system of linear equations. It assumes that the value of a single ray in a particular projection is a sum of all the pixels the ray passes through in the object. Algebraic iterative reconstruction involves solving the inverse Radon transform as a large set of linear equations. At each iteration, the goal is to minimize the difference between the estimate and the actual projection data.

The Simultaneous Algebraic Reconstruction Technique (SART) is a specific algorithm used for iterative image reconstruction in tomography. SART is known as a technique that can achieve good reconstruction results even in its early iterations. It works by iteratively updating the reconstructed image and it does the update pixel by pixel.

3 Experiments

3.1 Step 1: calculate sinogram and Back projection

As mentioned in the introduction part, we built a sinogram by calculating the synthetic projection using radon transform with 180 projection angles for each image. We then performed a non-filtered back projection. All 3 sinograms are presented in the next figures:

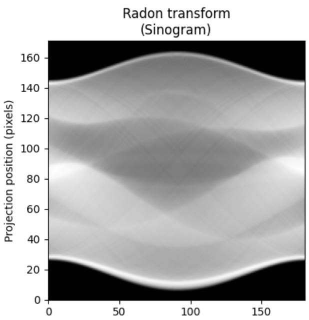

Figure 4: Brain sinogram for 180 projection angles

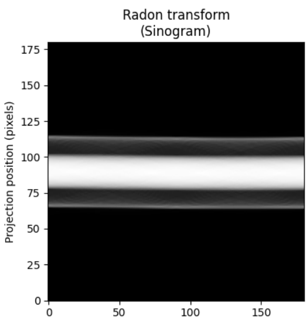

Figure 5: Circle sinogram for 180 projection angles

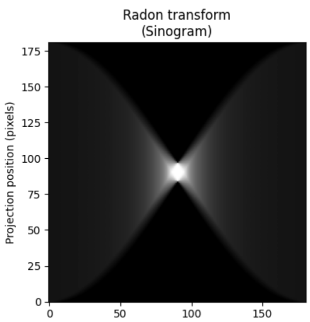

Figure 6: Line sinogram for 180 projection angles

The Shepp-Logan phantom is a complex geometric shape with various of features of different sizes and locations, therefore the resulting sinogram is also complex and contains information about the different features. It has a complex pattern of sine functions, with a series of curves that represent the X-rays that passed through the structures in the phantom at various angles. On the other hand, Since a circle has a uniform density, the resulting sinogram consists of a set of identical projections, each of which is a sine wave. The thick line surrounded by 2 thin lines in the sinogram represents the projection of the x-rays through the original thin circle, then through the thick one and finally through the other side of the thin circle. The sinogram of the thick line contains many bright lines that spread out. This is because a thick object casts a wide projection onto the detector at each angle, resulting in a broader range of intensity values across the sinogram. The intensity values gradually increase as the angle of projection changes, reach a maximum at the center of the sinogram as we can see, and then gradually decrease as the angle of projection continues to change.

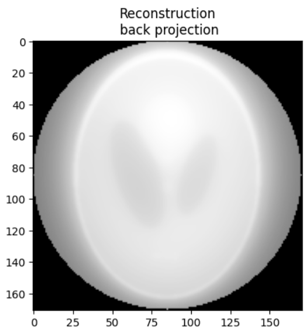

Figure 7: Brain reconstruction for 180 projection angles

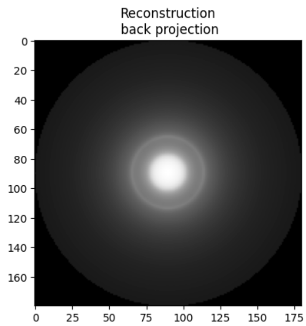

Figure 8: Dot reconstruction for 180 projection angles

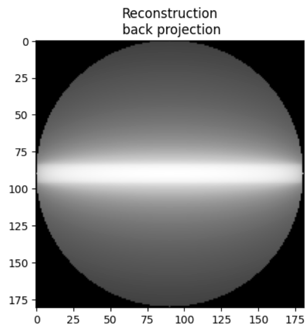

Figure 9: Line reconstruction for 180 projection angles

We can also see that the reconstruction part provided blurry images because we used back projection. That will be probably solved using filtered back projection which is detailed in section 3.3.

3.2 Step 2: Reconstruction using various number of projection angles

In that section we were requested to test various number of projection angles and perform reconstruction after each angle increment. We wanted to see whether the type of the phantom (the original image) affects the results so we tested the same projection number for all 3 phantoms. The results were similar and therefore the analysis is relevant for all tests. Regarding the sinograms, it is noticeable that the sinogram's resolution improves while using a larger number of projection angles, but the general shape always remains the same for all sinograms. Regarding the reconstructions, the resolution improvement is less conspicuous in that case. On the other hand, we can see that the noise decreases along with the incrementation of the projection angles, as the "halo" around the phantom becomes a clear white, comparing to the smaller projection numbers where the halo also included some squares and lines patterns. For both sinograms and reconstructions, we see no massive improvement in the results after reaching 90 projection angles and higher. In fact, both sinograms and reconstructions for 90 and 180 projection angles (from previous section) looks almost the same.

The following figures presents the resulting sinograms and reconstructions for all the phantoms tested.

3.2.1 Shepp-Logan head phantom

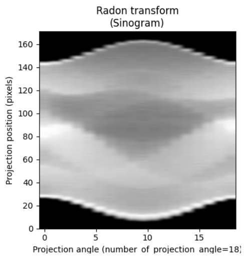

Figure 10: Brain sinogram for 18 projection angles

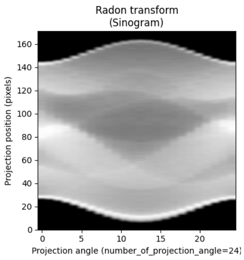

Figure 11: Brain sinogram for 24 projection angles

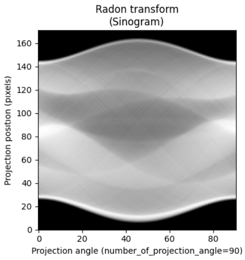

Figure 12: Brain sinogram for 90 projection angles

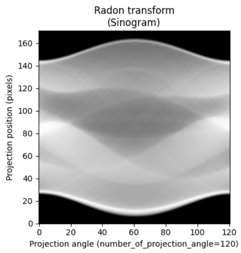

Figure 13: Brain sinogram for 120 projection angles

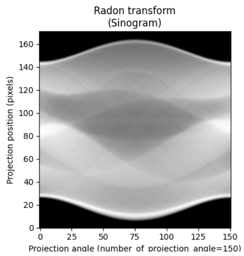

Figure 14: Brain sinogram for 150 projection angles

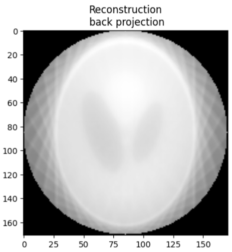

Figure 15: Brain recon. for 18 projection angles

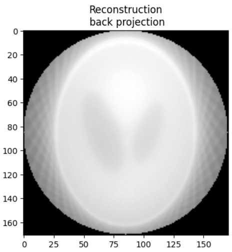

Figure 16: Brain recon. for 24 projection angles

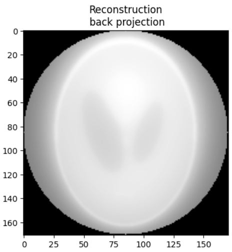

Figure 17: Brain recon. for 90 projection angles

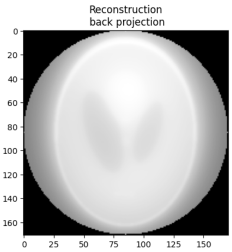

Figure 18: Brain recon. for 120 projection angles

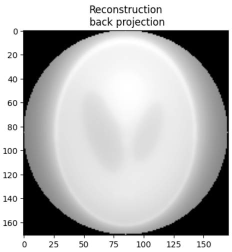

Figure 19: Brain recon. for 150 projection angles

3.2.2 Circle phantom

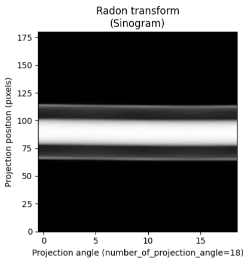

Figure 20: Circle sinogram for 18 projection angles

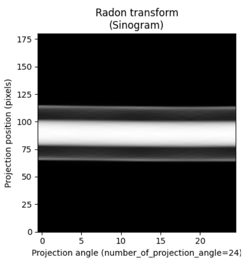

Figure 21: Circle sinogram for 24 projection angles

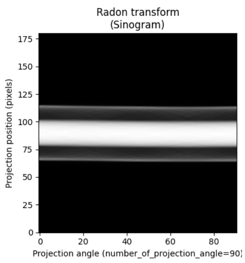

Figure 22: Circle sinogram for 90 projection angles

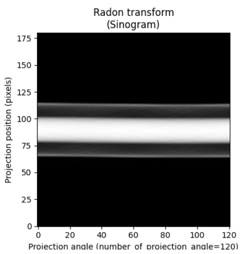

Figure 23: Circle sinogram for 120 projection angles

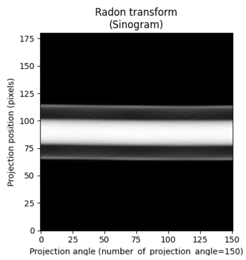

Figure 24: Circle sinogram for 150 projection angles

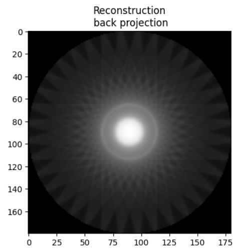

Figure 25: Circle recon. for 18 projection angles

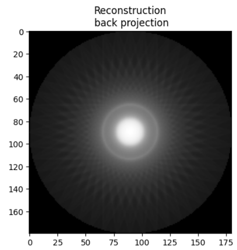

Figure 26: Circle recon. for 24 projection angles

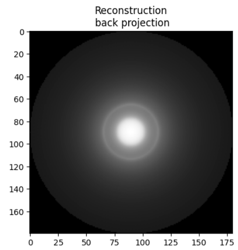

Figure 27: Circle recon. for 90 projection angles

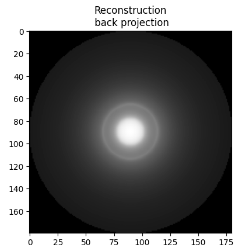

Figure 28: Circle recon. for 120 projection angles

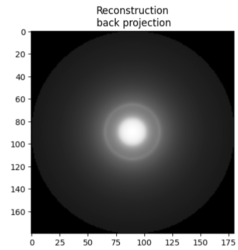

Figure 29: Circle recon. for 150 projection angles

3.2.3 Thick line phantom

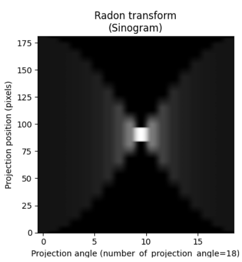

Figure 30: Line sinogram for 18 projection angles

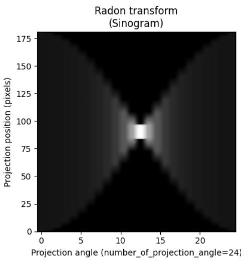

Figure 31: Line sinogram for 24 projection angles

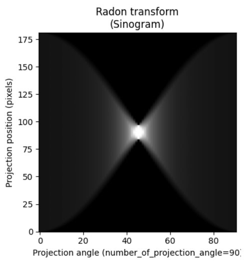

Figure 32: Line sinogram for 90 projection angles

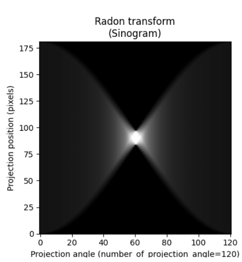

Figure 33: Line sinogram for 120 projection angles

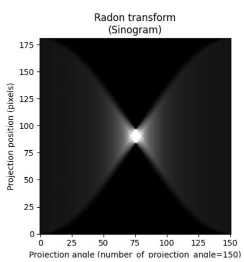

Figure 34: Line sinogram for 150 projection angles

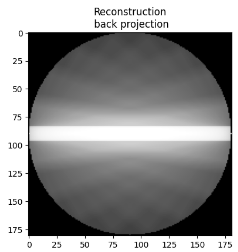

Figure 35: Line recons. for 18 projection angles

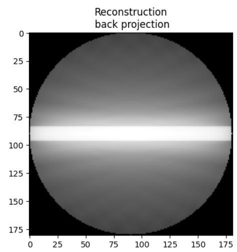

Figure 36: Line recon. for 24 projection angles

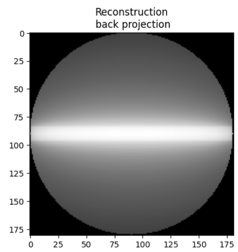

Figure 37: Line recon. for 90 projection angles

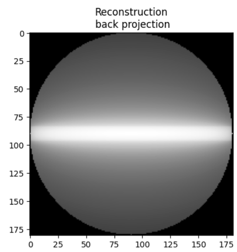

Figure 38: Line recon. for 120 projection angles

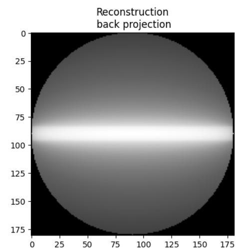

Figure 39: Line recon.for 150 projection angles

3.3 Step 3: Comparing Back projection & Filtered back projection

To demonstrate the difference between back projection and Filtered back projection, we used *Shepp-logan* filter.

Regarding all 3 phantoms, comparing these results to the results that were provided using Back projection, the FBP results reconstructed images in higher resolution for all tests.

In all cases, The noise remains in a pattern of lines around the phantom but instead of being blurry and white, it has sharper gray lines. In all tests, increasing the number of projection angles to 90 provided a satisfying reconstruction and the blurry noise appeared in the results of 3.2 is not apparent. We can also see that in the cases of the circle and the line, using more then 90 projection angles improves the reconstructed image even more- it is noticeable in the background difference between Figures 52, 53 and 54

The following figures presents the result for the FBP process using 18,24,90,120 and 180 projection angles. The attached notebook also contains the tests for 150 projection angles and the results were very similar to the results with 180 projection angles.

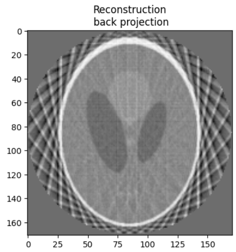

Figure 40: Brain recon. using FBP-18 projection angles

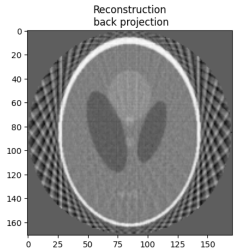

Figure 41: Brain recon. using FBP-24 projection angles

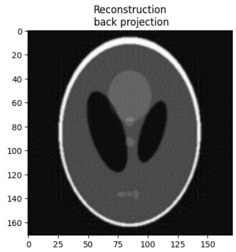

Figure 42: Brain recon. using FBP-90 projection angles

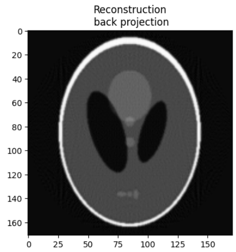

Figure 43: Brain recon. using FBP-120 projection angles

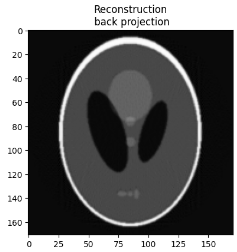

Figure 44: Brain recon. using FBP-180 projection angles

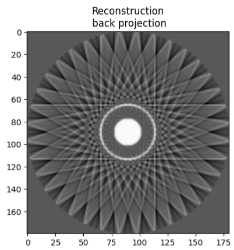

Figure 45: Circle recon. using FBP-18 projection angles

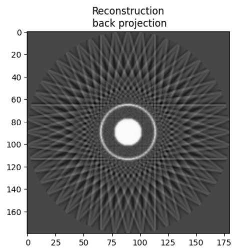

Figure 46: Circle recon. using FBP-24 projection angles

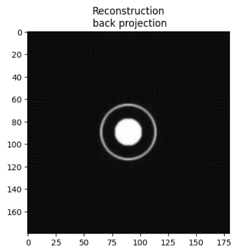

Figure 47: Circle recon. using FBP-90 projection angles

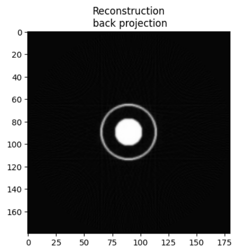

Figure 48: Circle recon. using FBP-120 projection angles

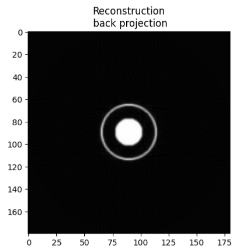

Figure 49: Circle recon. using FBP-180 projection angles

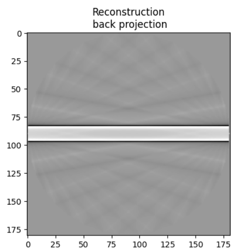

Figure 50: Line recon. using FBP-18 projection angles

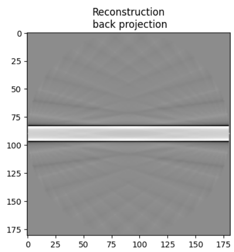

Figure 51: Line recon. using FBP-24 projection angles

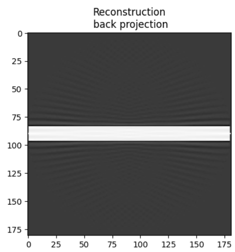

Figure 52: Line recon. using FBP-90 projection angles

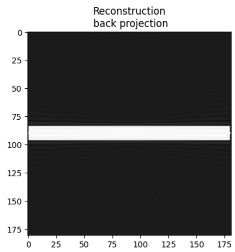

Figure 53: Line recon. using FBP-120 projection angles

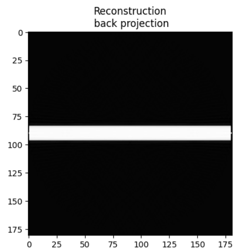

Figure 54: Line recon. using FBP-180 projection angles

3.4 Step 4- Algebraic Iterative Reconstruction (SART)

We executed the SART iterative algorithm for 12 iterations.

this method

Figure 55 presents the result of the reconstruction after each iteration. We can see that the process achieves the most significant improvement and results with a high-resolution image after 2 iteration as expected for SART technique. The rest of the iterations mostly improves the sharpness of the image.

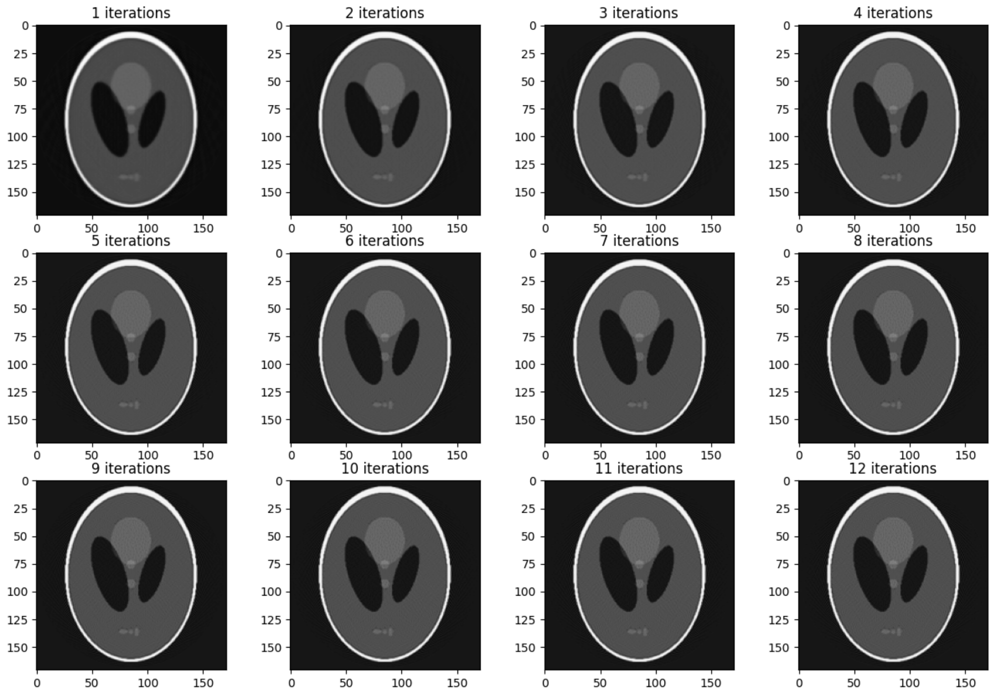

Figure 55: SART- reconstruction results per iteration

4 Discussion

From our results we can conclude that for both back projection and FBP, increasing the number of projection angles to more then 90 does not provide a significant improvement. For back projection, although the noise decreases using high number of projection angles, the process does not result with satisfying results, regardless the number of the projection angles. FBP, on the other hand, provided descent results even for 90 projection angles, and even though increasing the number of projections to more than 90 did improved the resolution of the image, the images resulted for 90 projection angles are clear and sharp. For the algebraic iterative reconstruction technique, SART provided good results in an early phase of the process, as expected, and the results are similar to those were provided using FBP.

5 Code

You can access our public Colab notebook at the following link: `https://drive.google.com/file/d/1OOupEqC1HuWCPX623NuDjNwrnZMBlloM/view?usp=sharing`