1. (/5) Discuss the advantages and disadvantages of 3rd generation CT scanners over 4th generation CT scanners.

2. (/5) Discuss the tradeoffs that occur when decreasing voxel size in CT imaging.

3. (/5) Describe beam hardening in CT imaging. Explain the effects of beam hardening on CT images. Can beam hardening artefacts be removed or compensated for?

4. (/15) In this problem you are to perform a simple and filtered reconstruction on a test object. Use a computer (as opposed to hand-calculations). You can use either a mathematical package (e.g. Matlab) or write your own code (e.g. in C).

   To begin, construct a simple test pattern consisting a non-attenuatig medium with an attenuating block in its centre. Construct the medium to be a square matrix, 21×21 pixels in size. Give this medium a linear attenuation coefficient $\mu = 0$ mm^{-1} . The central 3×3 pixel area is attenuating, set the attenuation coefficient of this region to be $\mu = 5$ mm^{-1}. Each pixel should be 1×1 mm.

   (a) (/2) Consider 3 views: 0° (top → bottom), 45° (diagonal), and 90° (left → right). Calculate the projection for each view. Plot each projection. The combination of the projections is a sinogram.

   (b) (/5) Use the 3 views from part (a) to calculate a simple backprojection. Plot a grayscale image of the simple backprojection.

   (c) (/5) Using the same views as in part (a), calculate a filtered backprojection. For a filter use:

   $$y = \rho_o(2\,\text{sinc}(2\rho_o R) - \text{sinc}^2(\rho_o R))$$

   where $\rho_o = 0.7$ is a constant and R is the radial distance from the centre of the image, $R = -3, -2, -1, 0, 1, 2, 3$. Using this discrete dataset,

   $$y \to -0.1074, 0.1368, -0.3398, 0.6000, -0.3398, 0.1368, -0.1074$$

   Plot a grayscale image of the filtered backprojection.

   (d) (/3) Demonstrate that the second image (filtered backprojection) is an improvement over the first (simple backprojection) by calculating a rough $1/r$ blurring for both images. To do this, calculate the average pixel value for rings of varying radius centred on the image. Each ring is taken to be 1 pixel wide.

5. (/10) Download and install the application CTsim (www.ctsim.org). This program allows you to reconstruct several different images while varying a number of the reconstruction parameters.

(a) (/5) Effects of the number of projections on image quality: Create a "Shlepp-Logan" phantom. Generate projection data with the following parameters:

- number of detectors = 512
- number of samples / detector = 1
- parallel geometry
- Vary the number of projections to be 64, 256, and 320.
- all other parameters as defaulted in the program

Reconstruct (512$\times$512 images with

- convolution method
- linear interpolation
- bandwidth filter
- Hamming parameter = 1

Plot images of the three reconstructions (1 for each projection number). Explain what happens to the images as you increase the number of projections.

(b) (/5) Effects of filter on image quality: Use the same phantom as in part (a). Use the same parameters as in part (a) except;

- keep the number of projections = 320
- use the bandwidth and cosine filters

Reconstruct images using

- convolution method
- linear interpolation
- Hamming parameter = 1

and either the bandwidth or cosine filter. Plot the images. Plot profiles through each image at row 250. Plot an FFT of row 250 for each image.

Discuss the effects of each filter on image quality. Which image would you say is of higher quality? Why? Comment on high frequency components and edge sharpness.