CONTRAST TO NOISE RATIO
LAB MANUAL: 5

Modifications for
P551 Fall 2013
Medical Physics Laboratory
**Introduction**

This laboratory guide introduces the concept of Contrast-to-Noise Ratio (CNR) in CT imaging and investigates the relationship between CNR, dose and low contrast resolution. Again record in your report the results as well as answering the questions asked in the lab.

**Educational Objectives**

- To understand the tradeoff between contrast resolution and noise in the detected photon fluence (analogous to dose in x-ray CT)
- To make measurements of contrast and noise for different imaging conditions and observing the effect of different levels of detector noise
- To demonstrate how the perception of small objects with low contrast is particularly impaired by high-noise conditions

**Why Learn This**

There is a trade-off between imaging dose and image quality in CT. Radiation dose during x-ray CT imaging is an important patient safety concern. Reducing imaging dose reduces risk to the patient; however, reducing dose also reduces the signal and thereby reduces the signal to noise ratio in the resulting CT image. Noise in an image impairs the ability of physicians to resolve small differences in tissue density. This is a critical consideration when attempting to distinguish disease from normal tissue, especially for small lesions.

ALARA (As Low As Reasonably Achievable) is the guiding principle recommended by ICRP (International Commission on Radiological Protection) for optimizing ionizing radiation dose (www.icrp.org).

**Overview**

Contrast-to-Noise Ratio (CNR) is a measure used to specify image quality. It is defined as:

\[
\text{CNR} = (\mu_0 - \mu_B)/\sigma_B = \Delta\mu/\sigma_B \quad [1]
\]

Where \(\mu_0\) is the mean attenuation coefficient of a defined structure (object) in the region of interest, \(\mu_B\) is the mean attenuation coefficient of the image background surrounding this structure and \(\sigma_B\) is the general background noise expressed as a standard deviation of pixel values outside of the targeted region of interest.

In diagnostic x-ray imaging, it is important to minimize the x-ray exposure to the patient. However, reducing the dose to the patient in turn decreases the resulting image quality by introducing more statistical fluctuations in \(\mu_B\) (Figure 1). Common ways of reducing the patient dose include reducing the scan time, number of projections (affecting spatial resolution), x-ray tube current (mA) or tube voltage (kVp). The fluence of the x-ray beam reaching the patient and detector is therefore reduced, resulting in noisier raw data in sinograms and in reconstructed images.

In this lab, DeskCAT™ software is used to simulate noise present in low radiation exposure conditions.
**Figure 1:** Plot of CT attenuation coefficient ($\mu$) across an object of interest (O) surrounded by a background (B). The contrast is the difference in the average attenuation coefficients. The background noise is the standard deviation in the value of $\mu_B$. Higher noise levels may still allow for an accurate diagnosis provided the noise level is not too excessive in comparison with contrast ($\Delta \mu >> \sigma_B$) of a target region of interest.

**Method**

In this lab students will:

1. Measure the contrast-to-noise ratio (CNR) for a set of “finger” structures, each with a different contrast level.
2. Compare the visibility of these objects as a function of size, attenuation, and noise level.

**Lab Materials:**

- Cone-shaped Finger phantom (shown at right)
- Blank Silicone phantom
- 2L Water (preferably distilled)
- DeskCAT™ Multi-slice Optical CT Scanner

**Project Set up and Scanner Calibration**

1. Setup and connect the DeskCAT™ scanner.
2. Fill the aquarium with water to the top of the aquarium window. Capacity is approximately 2L (Fill through the access ports or the large opening with the Rotary Stage removed).
3. Start the DeskCAT™ software and create a new project.
4. Inspect the Camera Video window (upper left), to see if there are any air bubbles in the field of view. *Air bubbles may interfere with the accuracy of your results. They can be removed by directing a stream of water from a syringe through either of the access ports. Alternatively, a short length of wire can be used as a poker to remove the bubbles.*
5. Adjust the camera setting to **50% of maximum brightness** (reducing the brightness allows for evenly distributed noise that will be introduced later in the lab) by selecting **Scanner → Camera Settings**. Adjust **Frame Rate/Shutter Speed** until a few red pixels appear in the Camera Video window (this sets the Frame Rate/Shutter Speed to 100% maximum brightness) and then increasing the **Frame Rate/Shutter Speed** by moving the slider to the right and landing on the midpoint of your original point and the maximum end point.

6. Under **Reconstruction → Reconstruction Options**, select **Hamming Filter**.
7. Under **Calibration → Geometry Calibration** select **Auto-Cal** and accept the values. *Calibration must be done with NO phantom loaded.

### Acquire Scans and Reconstruct CT Image

8. Load the Blank Silicone phantom into the scanner by attaching the phantom to the Rotary Stage using the Jar Clamp and mounting the Rotary Stage onto the scanner. Ensure that the Rotary Stage is properly aligned using the physical alignment tab.
9. Set **Number of Projections** to **400** on the Side Panel.
10. Acquire a reference scan by selecting the **Start Reference Scan** button on the Side Panel.
11. Load the Finger Phantom into the scanner by attaching the phantom to the Rotary Stage using the Jar Clamp and mounting the Rotary Stage onto the scanner.
12. Acquire a Data Scan using the **Start Data Scan** button on the Side Panel. Wait for scan to complete.
13. Select the **High (0.5mm) Voxel Resolution** option and press **Start Reconstruction** to perform a reconstruction.

### Calculate the contrast to noise ratio (CNR)

14. Maximize the 3D Viewer window (bottom right).
15. Select the **Region of Interest (ROI) histogram** tab in the 3D Viewer window. The default ROI cube appears centered in the 3D image. Use the mouse to adjust the location, size and shape of the ROI cube. Center click mouse button on the wire frame to drag ROI to a new location. Left click on a sphere to adjust the position of the plane of the ROI.
16. Move the ROI to the center of the phantom, where there are no fingers present. Measure and record $\mu_B$ (mean) and $\sigma_B$ (standard deviation) of this background ROI.
17. Measure and record $\mu_f$ (mean) for each of the fingers. For a more accurate measurement, reduce the size of the ROI to ensure it is completely within the bounds of the finger.
18. Calculate the Contrast to Noise Ratio (CNR) and its uncertainty (using correct error propagation) for each finger using equation [1].
19. Capture a screenshot of the Slice Reconstruction and include it in your lab report.

Addition of Noise

To simulate low exposure conditions, artificial noise (software-generated Gaussian distribution) is added to the projection data. You will be looping through the above measurements adding a different amount of noise at each step.

20. Select the Projection Viewer button from the Side Panel.
21. Select the Data radio button.
22. Select the Artifacts tab.
   Add noise to the image by using the up/down arrows to select the value 1 on the % of Full Scale in the Random Noise - Standard Deviation input box. Note any observations regarding the projection image. The random noise added to the image is calculated as a Gaussian distribution. The sigma value (standard deviation) used to generate the Gaussian distribution is defined as follows: $\sigma = p/100 \times 65535$ where $p$ is the value entered by the user and 65535 is the brightest pixel value for the camera.
24. Select Enable Snapshot check box in the Main tab of the Projection Viewer window. Acquire the snapshot by selecting Take Snapshot.
25. Close the Projection Viewer window. Record observations regarding the appearance of the sinogram image and include this in your lab report.
26. Select Start Reconstruction to perform a reconstruction (voxel resolution = 0.5mm).
27. Repeat steps 14-19 in the Calculate the contrast to noise ratio (CNR) section above to calculate the CNR for this reconstruction.
28. Repeat steps 20-27 above for the following amounts of noise: 2, 3, 6, 10, and 20.
29. Plot the CNR of the reconstructed fingers as a function of the Gaussian noise added to the projections. Ideally, try to plot the behavior of all five fingers with changing noise on one graph.
Discussion / Additional Questions

1. Comment on the visibility of the finger with the least contrast. Is the finger edge easily distinguished from the background noise as the finger is made smaller? Visualize the smallest finger size by selecting the appropriate transverse slice location. Capture a screenshot for your report. Hint: Adjust the Level slider to the mean $\mu$-value for each finger to enhance detection of the tip of the finger. Optimize Window slider for best display of detail.

2. In general, how is visibility affected by CNR? If we are interested only in contouring high-contrast objects of interest, is it acceptable to tolerate higher levels of noise (i.e., use less imaging dose)?

3. What minimum CNR value was needed to see each finger of interest with confidence?

Further Study

4. What is a Contrast-Detail curve and what is its significance?

5. Plot a set of Contrast-Detail curves for different noise levels for the DeskCAT™ scanner.