

**Experiment 28**  
**X-ray Computed Tomography (CT)**

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2:00 P.M - 5:00 P.M

## Introduction:

The purpose of this experiment is to study the graphical representation of  $\mu$  using Computed Tomography (CT),  $\mu$  being the absorption coefficient of the materials being bombarded by an X-ray beam of intensity  $I_0$ . Since we know theoretically an X-ray beam passing through a material with an absorption coefficient should result in an exit X-ray beam with a alternate intensity  $I_s$ . This relationship is known as the Lambert Law:

$$I_s = I_0 e^{-\mu s} \quad (1)$$

Where  $s$  is the path length the beam takes through the material.

Eventually this concept was expanded all the way out, using the Radon Transformation which allowed us to integrate the function over its full path, as long as the X-ray beam was travelling in a straight line, which had an associate co-ordinate system in three dimensional space  $(x, y, z)$ .

$$\ln \frac{I_s}{I_0} = - \int_0^s \mu(x(s'), y(s'), z(s')) ds' \quad (2)$$

It is this mathematical concept which is used today to reproduce 2D and 3D images of multi-layered objects which can't immediately be observed to the human eye but consist of different materials internally. Being able to discover the absorption coefficient of the different components allows the reproduced images to differentiate between different materials and display the distinction through brighter and darker shades of grey or using different colours depending on the configuration of the software.

## Method:

A large portion of this experiment is dedicated to adjusting the devices sensors, both physically by turning a thumb screw which adjusts the X-ray image sensor in both the x and y axis as well as through the software by adjusting the settings to ensure the most accurate and high resolution image achievable.

After initially producing an X-ray image of the LEGO®brick stack the image appeared mis-aligned with the red line markers displayed in the software. This meant that we would have to manually adjust the image sensor to account for this alignment issue. Ultimately the goal is to have the distance from the top of the LEGO®bricks to the center line be the same as the distance from the center line to the bottom of the bricks, this would imply that the object is placed perfectly in the center of the image. Although we were not able to achieve this adjustment with perfect accuracy we were able to get extremely close, with the distance from the top of the lego bricks being about 0.5mm short of the distance from the bottom.

After the X-ray image was correctly aligned we were ready to configure the software to obtain the best image possible of the LEGO®bricks. We changed the Sensor resolution, projection size and reconstructions size all the way up to the highest pixel size possible, this ensures that we have largest image possible for viewing on the computer monitor which will make correcting it easier later on.

Once we begin taking a measurement of the lego bricks and the measurement completes we are given a fairly rough image of the iconic LEGO®brick silhouette. At this point we can move the slider along the bottom to view different sections of the 5 brick stack, or correct the rotary axis by a few pixels which goes a long way in cleaning up the image and reducing contours which appear all around the image.

Once the software has actually optimised the image for the 1st and 2nd position it actually suggests adjustments that can be made to the rotary axis by telling you what direction to rotate image sensor thumb screw and by how many microns it needs to be moved. This ensure that your image quality is of the highest precision possible. Once the images of the lego brick were captured and of a high enough quality we then moved on to using a 'Phantom'.

The 'Phantom' was placed into the lego mount with the marked side facing up. A measurement was taken, choosing the number of projections to be 720 angles, this resulted in the measurement taking 40 minutes to complete.

Upon completing the measurement, a full scan of the 'Phantom's multiple layers was visible in 2D and 3D, the image displayed on the screen also showed varying degrees of dark and light implying that certain parts of the Phantom had different absorption coefficients to the main structure. As well as 2D and 3D there were many other graphical effects we could apply to our scan including adding a colour spectrum with 2,3,4 or 5 colours present, this made it even easier to differentiate between varying absorption coefficients, switching lighting on which made the scan more visible in the 3D viewing mode, changing the Intensity and transparency with the intensity increasing the visibility of the scan while the transparency allowed us to get a somewhat internal look of the Phantom. The stereoscopic view added a 3D affect over top of the 3D scan which allowed it to be viewed through 3D glasses for a more true to life representation.

We captured a few images of the varying layers within the Phantom in both 2D and 3D mode and also measured the distance between diameters of holes in one of the layers which we can include in our results section.

## Results:

### Lego Brick Calibration

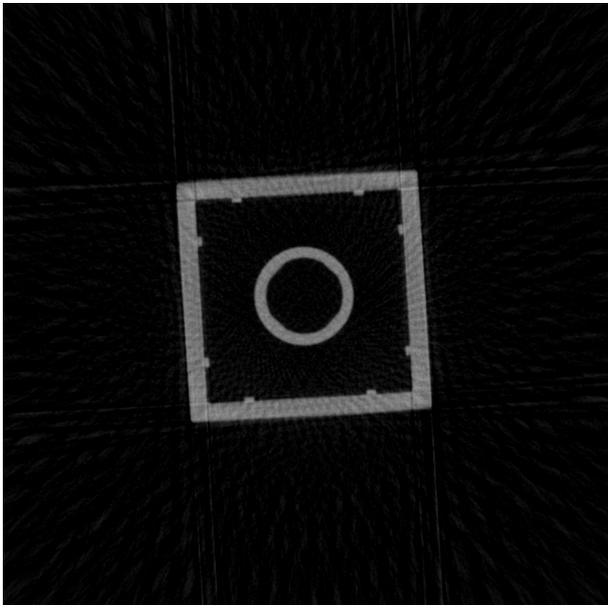


Figure 1: Lego Brick before calibration

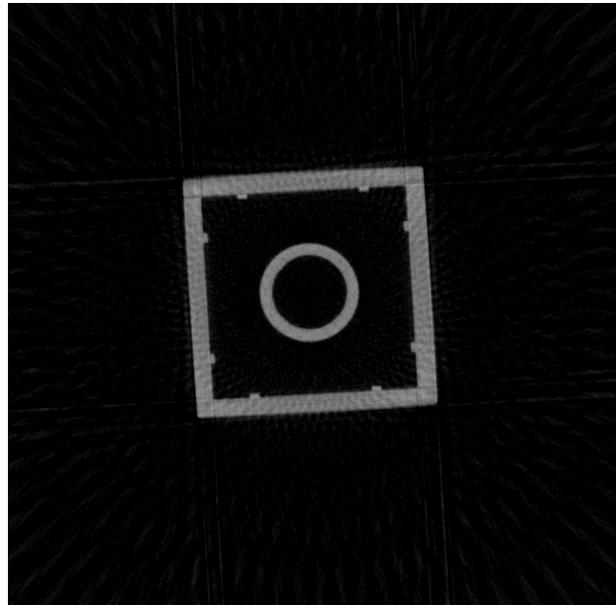


Figure 2: Lego Brick after calibration

### Phantom's sectional plane containing different material samples

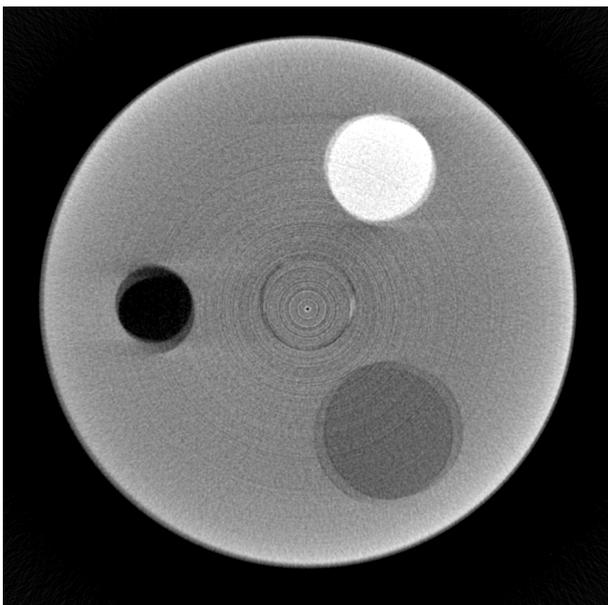


Figure 3: Phantom plane before calibration

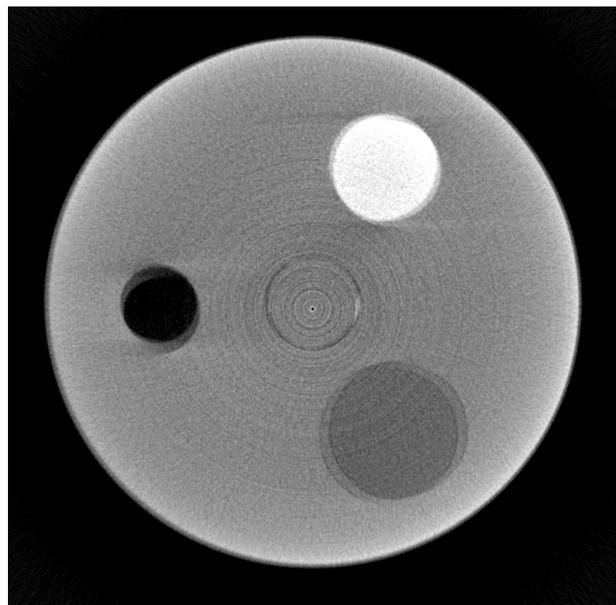


Figure 4: Phantom plane after calibration

## Phantom's sectional plane containing different diameter holes

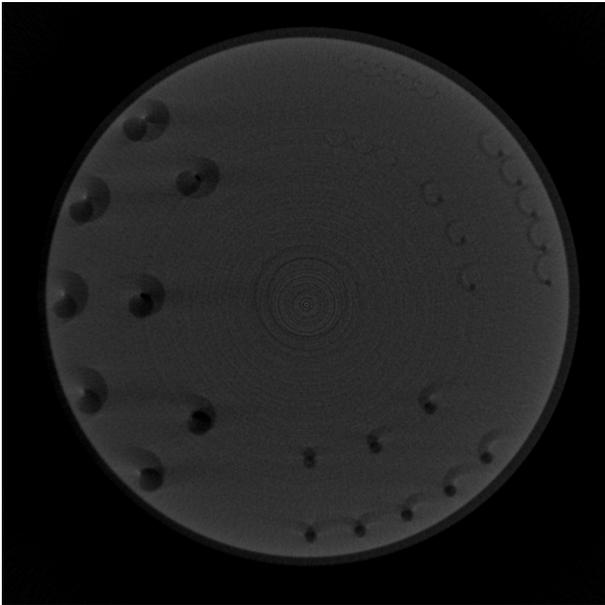


Figure 5: Phantom plane before calibration

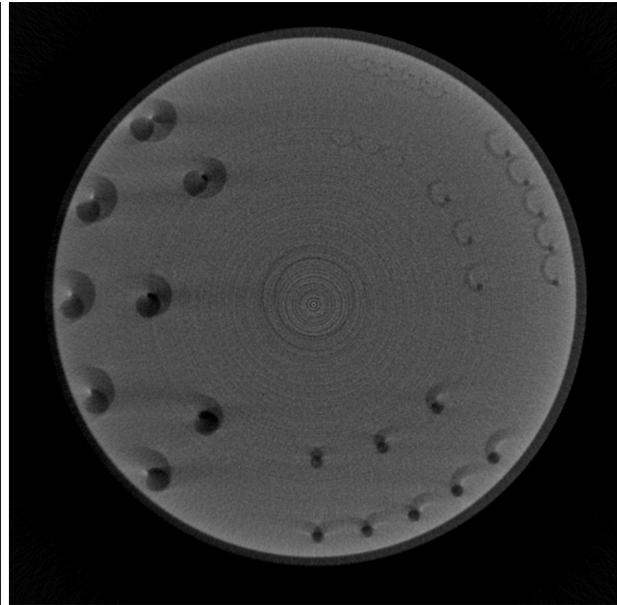


Figure 6: Phantom plane after calibration

## 3D Phantom Scan in Colour

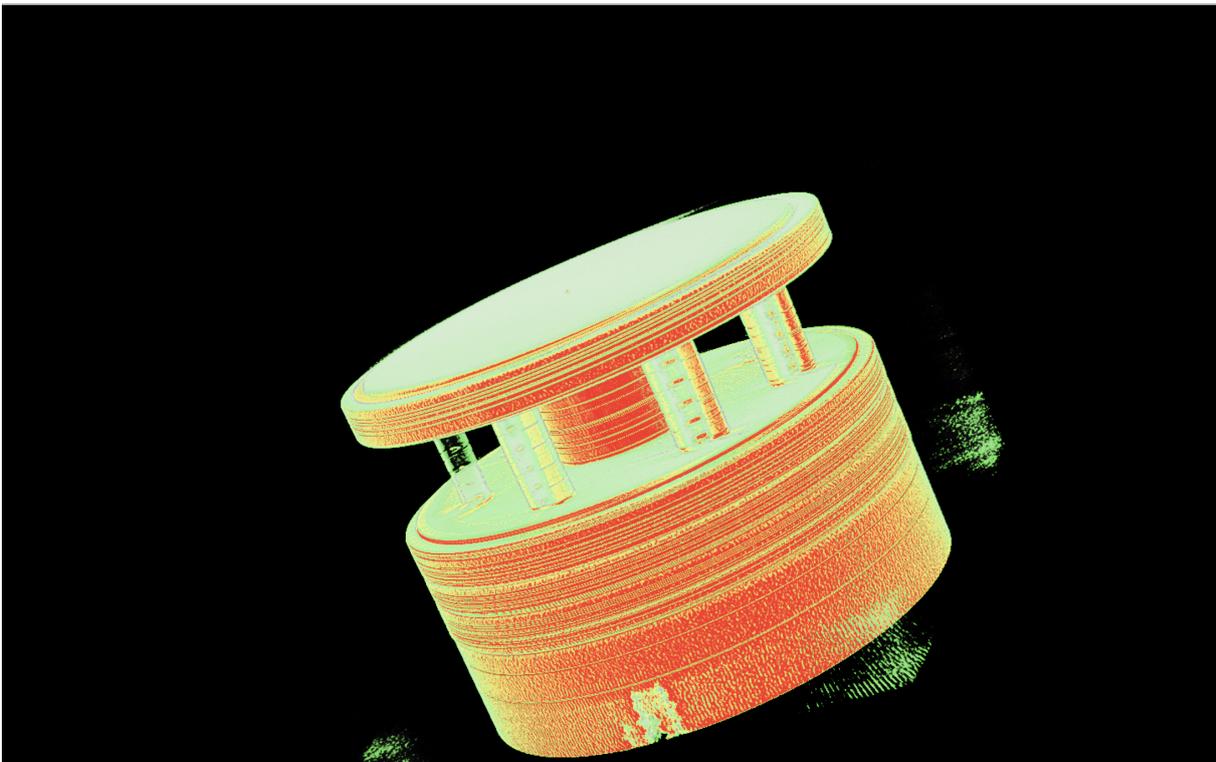


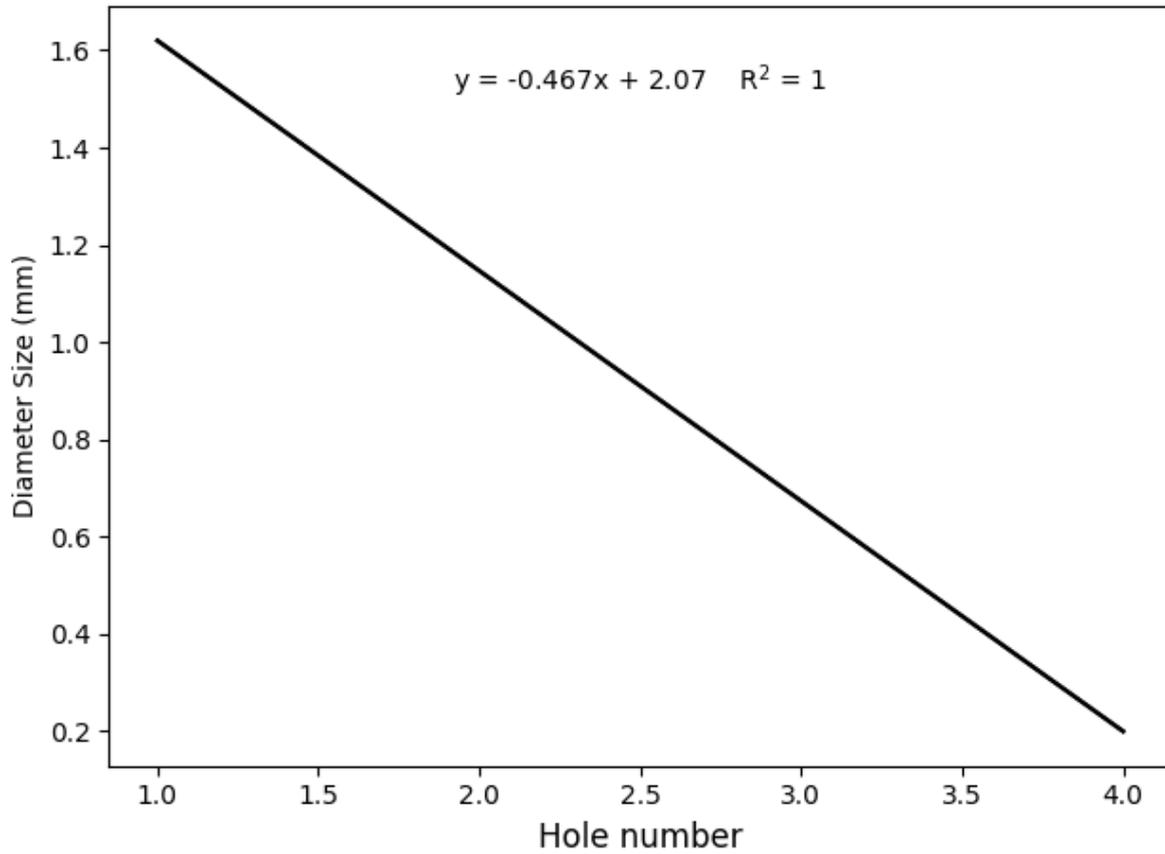
Figure 7: 3D side view of phantom

| Hole Diameters |              |              |              |              |
|----------------|--------------|--------------|--------------|--------------|
|                | Size 1 in mm | Size 2 in mm | Size 3 in mm | Size 4 in mm |
| Original Size  | 1.60         | 0.80         | 0.40         | 0.20         |
| Measured Size  | 1.62         | 0.69         | 0.51         | 0.14         |

Table 1: Hole diameters obtained from the line profiles

| Hole Distances |              |              |              |              |
|----------------|--------------|--------------|--------------|--------------|
|                | size 1 in mm | Size 2 in mm | Size 3 in mm | Size 4 in mm |
| Measured Size  | 3.22         | 4.09         | 1.55         | 0.5          |

Table 2: Hole distance obtained from the line profiles



Graph 1: Plot of biggest and smallest holes from line profile

## Analysis:

Using the equation

$$\frac{|\text{Experimental value} - \text{Known value}|}{\text{Known Value}} \times 100 = \text{Percentage Error} \quad (3)$$

We can find the percentage error for each of our measured hole diameters from Table 1.

$$\text{Size 1 : } \frac{|1.62 - 1.60|}{1.60} \times 100 = 1.25\%$$

$$\text{Size 2 : } \frac{|0.69 - 0.80|}{0.80} \times 100 = 13.75\%$$

$$\text{Size 3 : } \frac{|0.51 - 0.40|}{0.40} \times 100 = 27.5\%$$

$$\text{Size 4 : } \frac{|0.14 - 0.20|}{0.20} \times 100 = 30\%$$

## Discussion:

When carrying out the measurement for the Phantom it was decided to use the highest number of projections available, 720 angles in an effort to get the highest quality scan possible and hopefully get more accurate results by doing so. This caused the measurement to take over 40 minutes to complete as well as made the scan incredibly complex resulting in the computer buffering each time a change was made to the settings or attempting to view a different plane for roughly 5 to 10 seconds each. This caused huge delays in the experiment and ultimately resulted in running out of time, in future it would be wise to sacrifice any extra quality gained from the extra angles in return for a faster measurement time and a smoother experience obtaining the data needed. This wouldn't be an issue for medical professionals carrying out CT Scans in the field as their equipment would be fitted with the fastest graphics cards which can provide the highest quality scans in short succession so that the patient can receive an accurate diagnosis as quick as possible.

While saving the images of the 2D scans the software only offered black and white png file types, so even though some of my 2D scans were saved to the USB while in colour the file type changed them back to being black and white. This wasn't an issue for the 3D scan as the software provided a .bmp file type for that, which I later converted to a .png file type to include in this lab report. It may have been wise to use the snipping tool provided by windows to capture the 2D scans in colour to compare with the black and white scans.

Its clear that the line profiles for the hole diameters became less accurate as the diameters became smaller, this is in part due to the fact that the precision of the lines became more of an issue as the diameters became smaller and smaller, ultimately increasing the error from  $\approx 1\%$  all the way up to  $\approx 30\%$ .

## **Conclusion:**

In this experiment we became familiar with the concept of material absorption coefficients, how they differ between objects and how medical professionals use equipment in their everyday careers to differentiate between materials in CT scans.

We learned how to carry out our very own CT Scans in both 2D and 3D using specialised software which improved the quality of the scan as adjustments were made to both the physical apparatus as well as to the configuration within the software itself.

Finally we used line profiles to measure small distances between objects in a 2D CT scan and compared our experimental values (1.62 mm, 0.69 mm, 0.51 mm, 0.14 mm) to the known values (1.60 mm, 0.80 mm, 0.40 mm, 0.20 mm) and calculated the percentage errors between them which were 1.25%, 13.75%, 27.5% and 30% respectively.