

Using Calibrated Samples for Uncertainty Analysis of X-ray Computed Tomography

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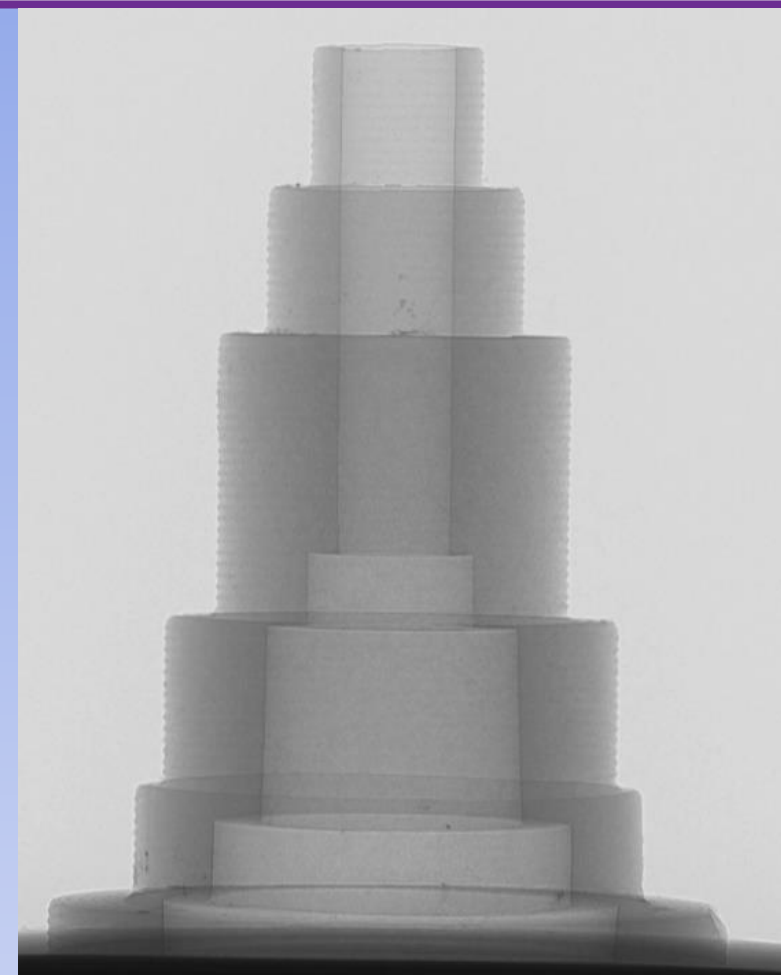
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Introduction and Aims

- ❖ Within X-ray computed tomography (XCT), the use of thorough and validated metrology practices is necessary to achieve confidence of both internal and external measurements.
- ❖ The methodology I have outlined below makes use of a combination of XCT optimisation procedures and bespoke made measurement phantoms to collect the overall response of an object's digital reproduction to its true sizes.
- ❖ I have used the internationally recognised VDI/VDE 2630 XCT measurement method of maximum permissible error (MpE) to gain a series of coefficient values to be used in the Guide to the Expression of Uncertainty in Measurement (GUM) formula to produce my final values.
- ❖ The successful implementation of this process will allow for future users of XCT, with access to a Coordinate Measuring Machine (CMM), to produce a verifiable uncertainty budget for any XCT scan. This method is especially useful for a project which requires repeated scans of similar objects as the data gathering scan will only need to be done once.

Scanning Methodology

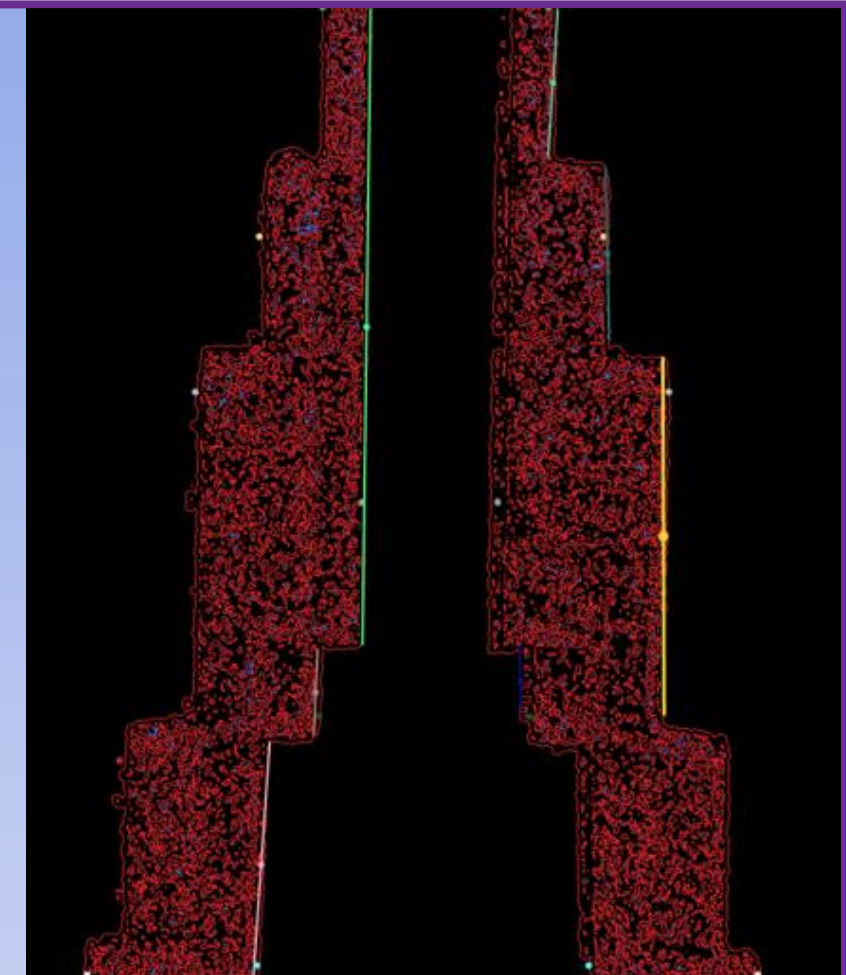
1. Obtain a measurement phantom which is of a similar material, density and size to the object to be scanned and gain full CMM data for it. I have used a top-hat style shape to contain both internal and external features.
2. Find magnification and voxel size of the scan by moving the sample into position in your XCT system.
3. Set the focal spot size to be slightly smaller than the voxel size. I have carried out spot size measurements, if this information is unknown than a safe choice would be using a beam power 0.5 W smaller than your voxel size (in microns).
4. Through use of filters and varying the energy of the beam, gain a transmission ratio of 20%-25% through the densest location on a radiograph.
5. Increase exposure to allow for the background counts to be ~8000 less than the saturation of the detector.
6. Choose the number of projections to be greater than, or equal to, the field of view of the object multiplied by $\pi/2$ — choose averaging based on available system time.



X-ray projection image of the measurement phantom

Uncertainty Analysis

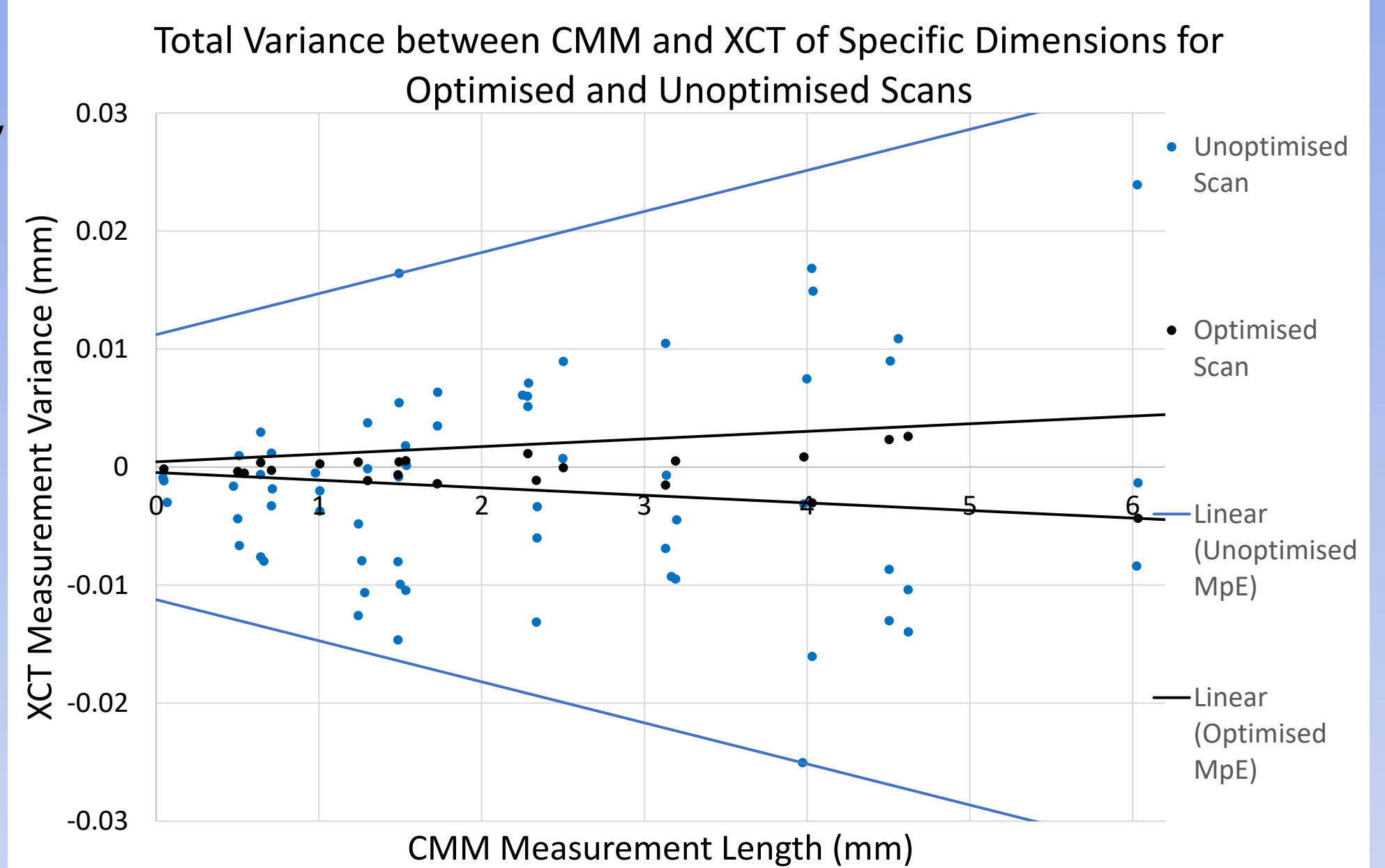
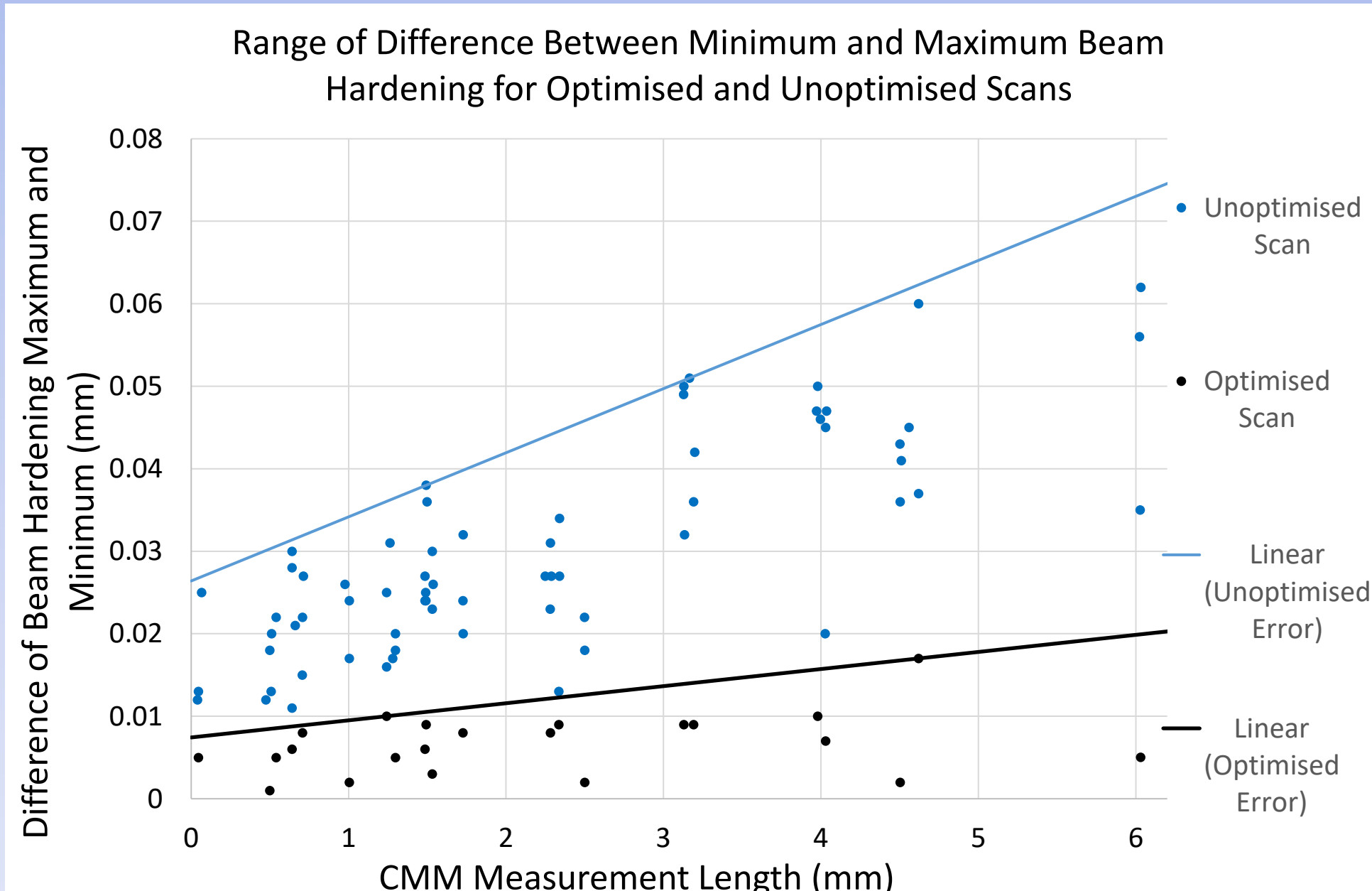
1. Reconstruct the data with optimised beam hardening and digital ring artefact removal.
2. Reconstruct the data again with minimum and maximum beam hardening and digital artefact removal while keeping the other value optimised.
3. At all the reconstructions use a visualisation program, which allows for metrology, and measure the features that match the CMM data.
4. Find the size variance for the difference of the maximum and minimum parameters and divide that value by $\sqrt{3}$ to gain a coefficient of the uncertainty, assuming square-based distribution.
5. For parameters not recorded by the user, such as the measurement error of the CMM system, divide by $\sqrt{12}$ to represent type B uncertainty.
6. Use the coefficients in the GUM formula: $U = k\sqrt{a^2 * b^2 * c^2 \dots}$ where a, b, c, etc. represent each parameter range. k represents the uncertainty factor and is 2 for ~95% result range.



Avizo screenshot showing a range of the different measurements made

Results, Discussion and Conclusion

To gain a full understanding of the effects of an optimised and unoptimised XCT scan, the parameters I tested for are: VDI measured MpE ($\pm 4 \mu\text{m}$), beam hardening ($\pm 17 \mu\text{m}$), digital ring artefact reduction, focal spot unsharpness ($\pm 10 \mu\text{m}$), CMM error ($\pm 2 \mu\text{m}$), off-axis rotation, number of measured points within the visualisation package and varied magnification in range of object thickness. Any measurement range (not VDI) that was less than or equal to a single voxel ($9 \mu\text{m}$) were removed from the final budget as it could not be reasonably distinguished from noise.



$$U = 2 \sqrt{\frac{2^2}{\sqrt{12}} + \frac{10^2}{\sqrt{3}} + \frac{4^2}{\sqrt{3}} + \frac{17^2}{\sqrt{3}}}$$

The final result was an unoptimised uncertainty of $178.1 \mu\text{m}$, and an optimised uncertainty of $23.4 \mu\text{m}$.

These values align with what was expected for an optimised scan with a voxel size of $9 \mu\text{m}$. In future work, more phantoms are required to be tested and further parameters, like thermal, are to be studied.

References

- VDI – The Association of German Engineers. (2011). *VDI/VDE 2617 Sheet 13; VDI/VDE 2630 Sheet 1.3*. English VDI/VDE society measurement and automation technology. <https://www.vdi.de/en/home>
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