Data processing II: data drift challenge

Looking for smarter alignment techniques

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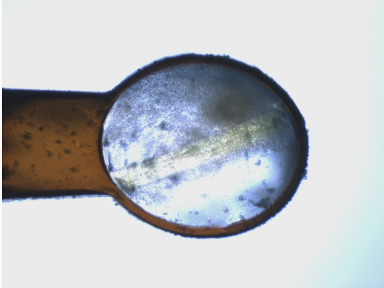
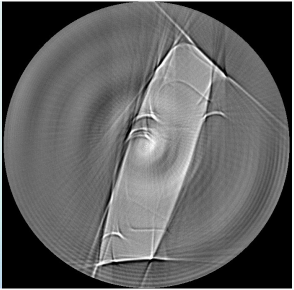
Diamond Light Source

How tomographic projection data is collected on I23 beamline

- The collected tomographic absorption projection data is of a protein crystal of roughly 100 μm $\times$ 200 μm $\times$ 50μm in size[1]

[1] https://www.diamond.ac.uk/Instruments/Mx/I23.html

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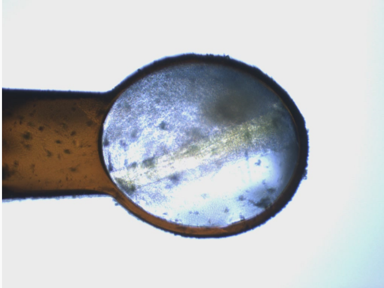

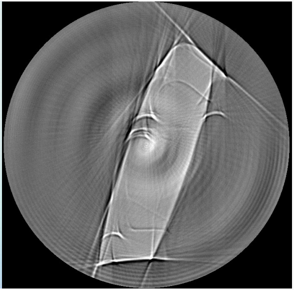

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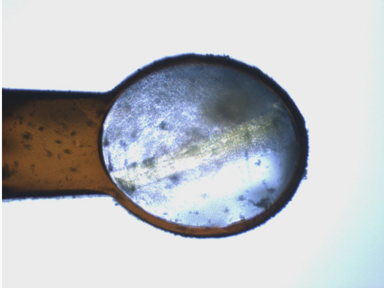
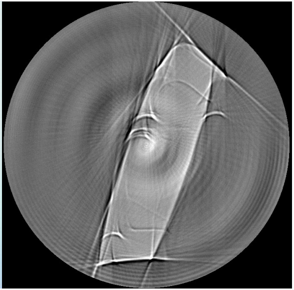
- The data collected using a long robotic ‘arm’ which extended into the X-ray beam
- The ‘arm’ randomly drifts with 3 degrees of freedom which results in inaccurate measurements





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Beer-Lambert attenuation law and normalisation

The attenuation of a monochromatic X-ray beam is described by the Beer-Lambert law, stating that:

$$p = I_0 \exp\left(-\int \mu(l)dl\right),$$

where p is the measured intensity, I_0 is the incoming intensity, μ is the attenuation coefficient of an object and l is the coordinate along the X-ray path. The integral $\int \mu(l)dl$ is the **total attenuation** of the beam along a given ray.

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Prior to the reconstruction of a cross section or a volume, the projection data are **normalised** with respect to I_0:

$$\int \mu(l)dl = -\ln\frac{p}{I_0}$$

The normalisation procedure is also known as the **flat field correction** (FFC) https://en.wikipedia.org/wiki/Flat-field_correction.

Data normalisation in practice

Flat and **dark** field images or ‘flats’ and ‘darks’ are collected routinely before every tomographic experiment

- **Flat** field is an image which is measured with the X-rays on, but without a sample in the beam. The non-uniformity of the flat field includes effects of the non-uniform nature of the beam, inaccuracies of the scintillator and the CCD detector.
- **Dark** field is an image without the X-rays and without a sample (shutter closed). Measurements of the background radiation.

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Collected projection data are normalised using ‘flats’ and ‘darks’:

$$n_j = \frac{p_j - \bar{d}}{\bar{f} - \bar{d}},$$

where $\bar{f}$ and $\bar{d}$ are the average of all colected flat and dark fields. The **corrected projection data** are obtained as $\hat{n}_j = -\ln n_j$. Note that $0 < n_j < 1$ since data cannot be negative.

Looking at flats and darks

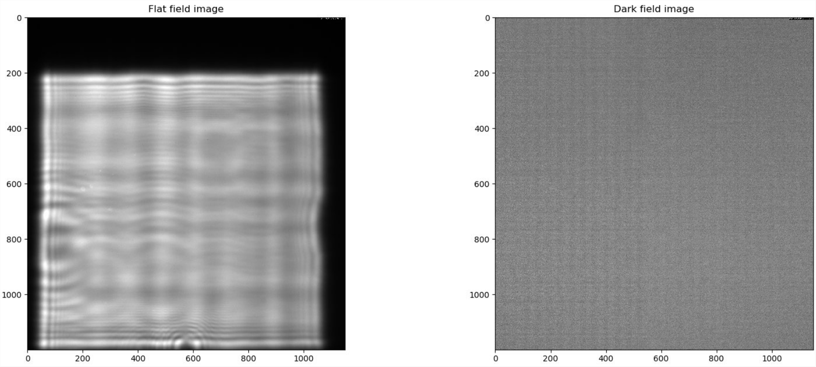
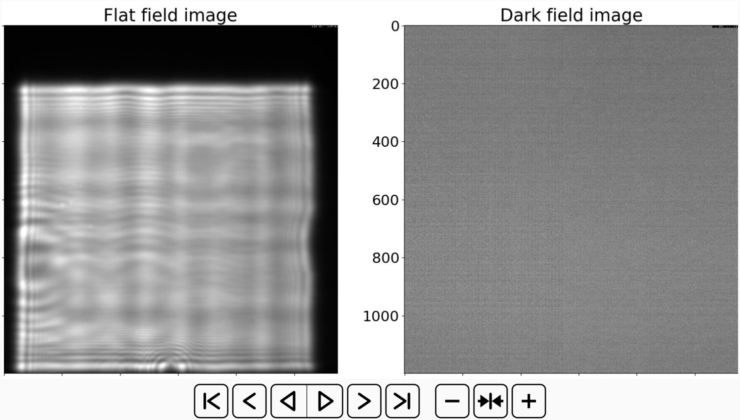


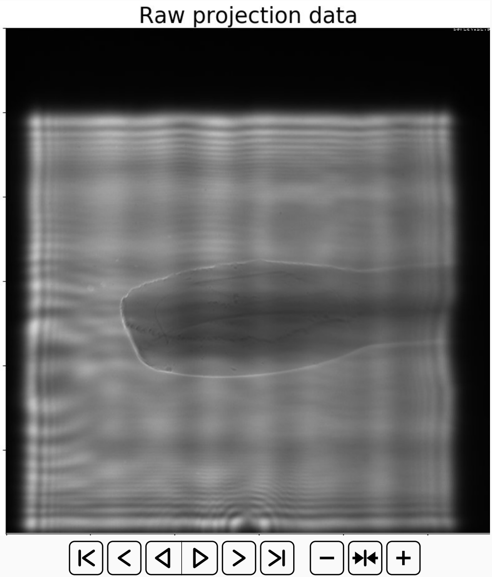
Figure 1: One can see here that the flat field contains some structural (low-frequency) information. While the dark field is predominantly random noise (though some grid structure is also visible).

Looking at flats and darks

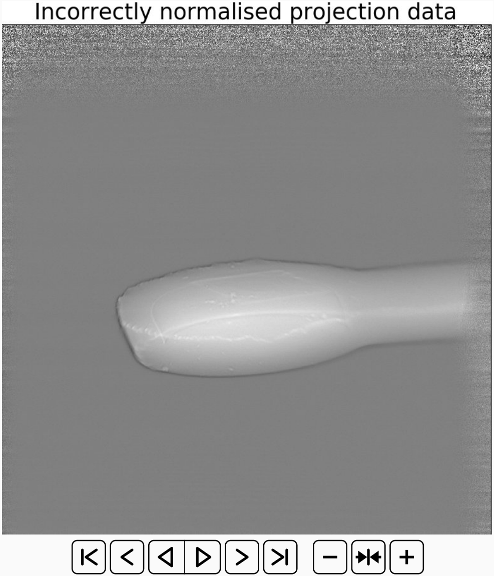


In practice flats can be ‘shifting’ slightly as well, so before averaging it worth to align them first.

Raw (uncorrected) projection data



Normalised projection data



The data alignment challenges

The source of the problem is due to the drift of the robotic 'arm' which causes incorrect flats, misaligned projections and erroneous reconstructions.

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2. The obtained averaged flat field must be applied to each 2D projection differently due to the random drift
3. The normalised data can be converted to a sinogram space where shifts of the object will be corrected
4. The sinogram can be reconstructed to assess the benefits of applied corrections in the image space.

Related research and references

There is various research related to the topic, some papers are located at ITT_BATH_DLS/DataP_II_I23_alignment/literature

- SVD-based research: *Dynamic intensity normalization using eigen flat fields in X-ray imaging* [3]
- PCA-based research: *On the use of flat-fields for tomographic reconstruction*[2]
- Estimation/prediction of flat fields in *A Convex Reconstruction Model for X-Ray Tomographic Imaging With Uncertain Flat-Fields*[1]

Access to the data and software dependencies

Get python scripts, presentations, installation recommendations and related papers from:

https://github.com/dkazanc/ITT_BATH_DLS

- The raw I23 data with flats and darks are accessible here ITT_BATH_DLS/DataP_II_I23_alignment/rawdata
- ITT_BATH_DLS/DataP_II_I23_alignment/ITT_I23data.py Python script shows how to read the data and normalise it
- Reconstruction and normalisation routines are in the **TomoRec** package https://github.com/dkazanc/TomoRec
- Data modelling routines are in the **TomoPhantom** package https://github.com/dkazanc/TomoPhantom

Real data have been kindly provided by **Ramona Duman** ramona.duman@diamond.ac.uk and **Armin Wagner** armin.wagner@diamond.ac.uk

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