Motion compensating X-ray micro-CT of diamonds in a processing stage

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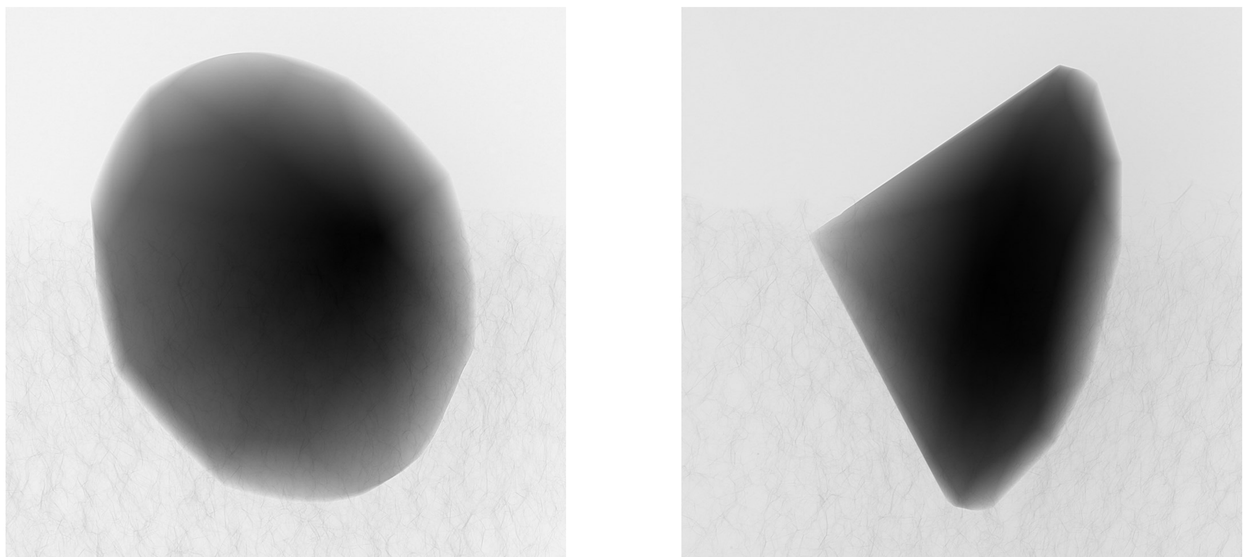
Introduction

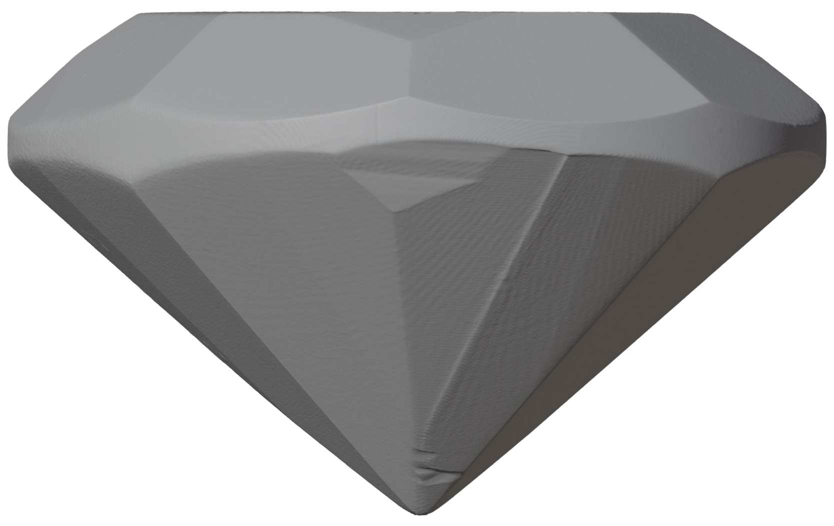
- X-ray micro-CT: non-destructive visualization of the object's interior in 3D.
- A valuable tool for reconstructing the non-convex outer shape and inclusions of diamonds during its polishing process.
- Fixation materials at the diamond surface hinder post processing. Without fixation, however, the diamond moves during scanning.
- We estimate and compensate its motion using a rigid motion compensating reconstruction technique.

X-ray CT imaging

- Acquisition of x-ray radiographs at many different angles.

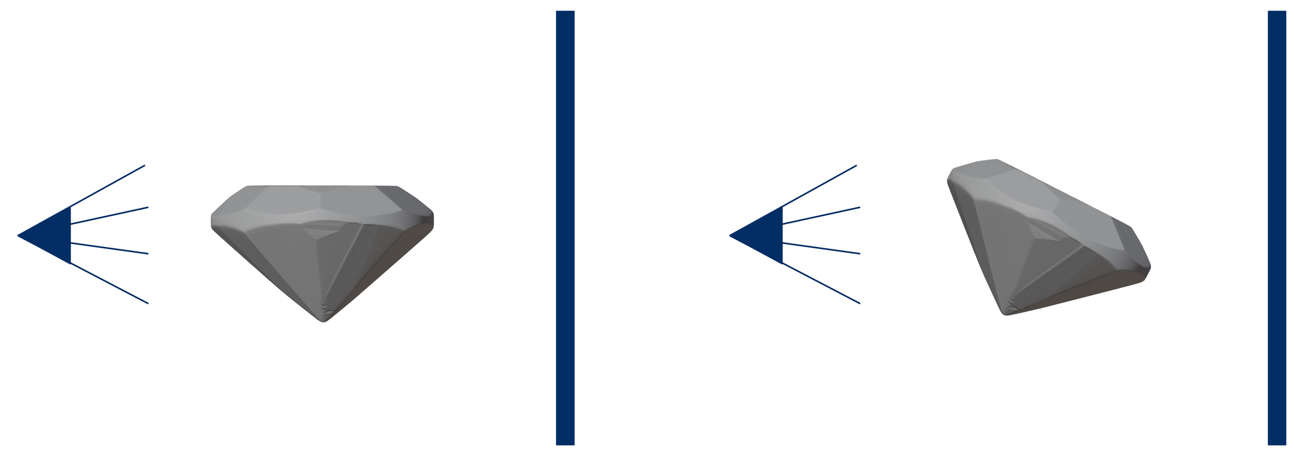


- Reconstructing a 3D image of the object from the radiographs can be formulated as a linear inverse problem: $\boldsymbol{Wx} = \boldsymbol{p}$.
- $\boldsymbol{W}$ is the linear operator that models the projections, $\boldsymbol{x}$ is the 3D image representing the object and $\boldsymbol{p}$ is the measured projection data.
- The radiographs **must be consistent** with each other, with respect to projection model $\boldsymbol{W}$. With a conventional (static) model, the object should not change or move between radiographs.
- Direct inversion is possible using an approximate inverse of the projection model: filtered backprojection: $\boldsymbol{x} \approx \boldsymbol{W}^T\boldsymbol{Fp}$, where $\boldsymbol{F}$ is an appropriate filtering operator [1].
- Iterative inversion is possible with linear least squares solvers.
- Optionally, the 3D volume can be used to generate a surface mesh:

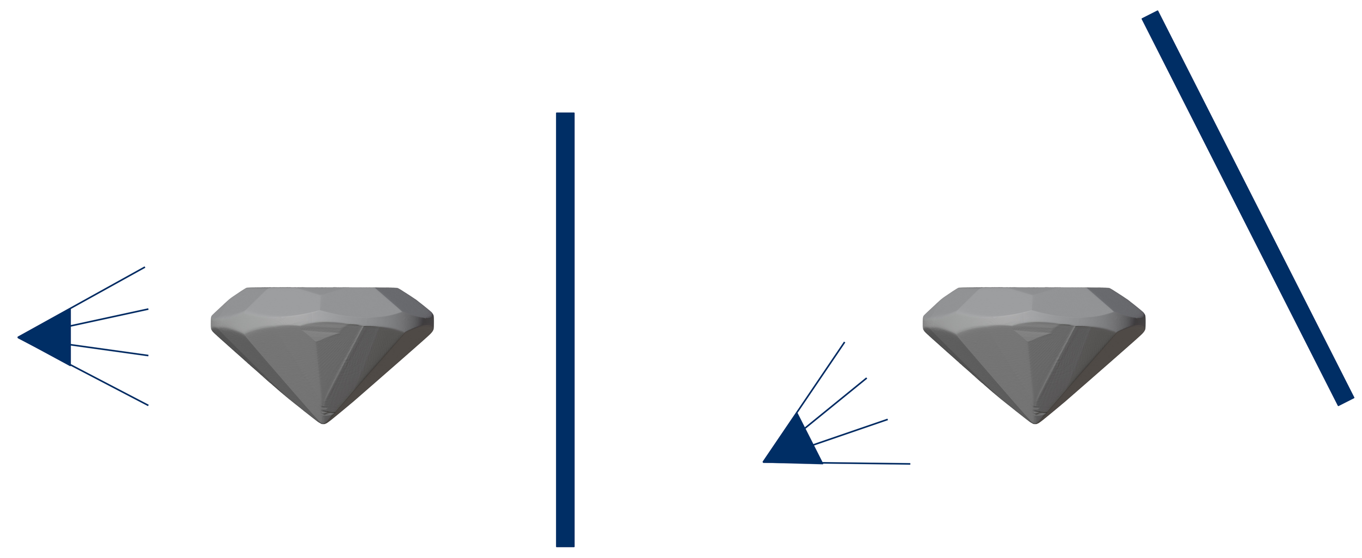


Motion compensated reconstruction

- Motion during the scanning process leads to inconsistent projections with respect to the static model.
- There is **no 3D image consistent with both projections**:



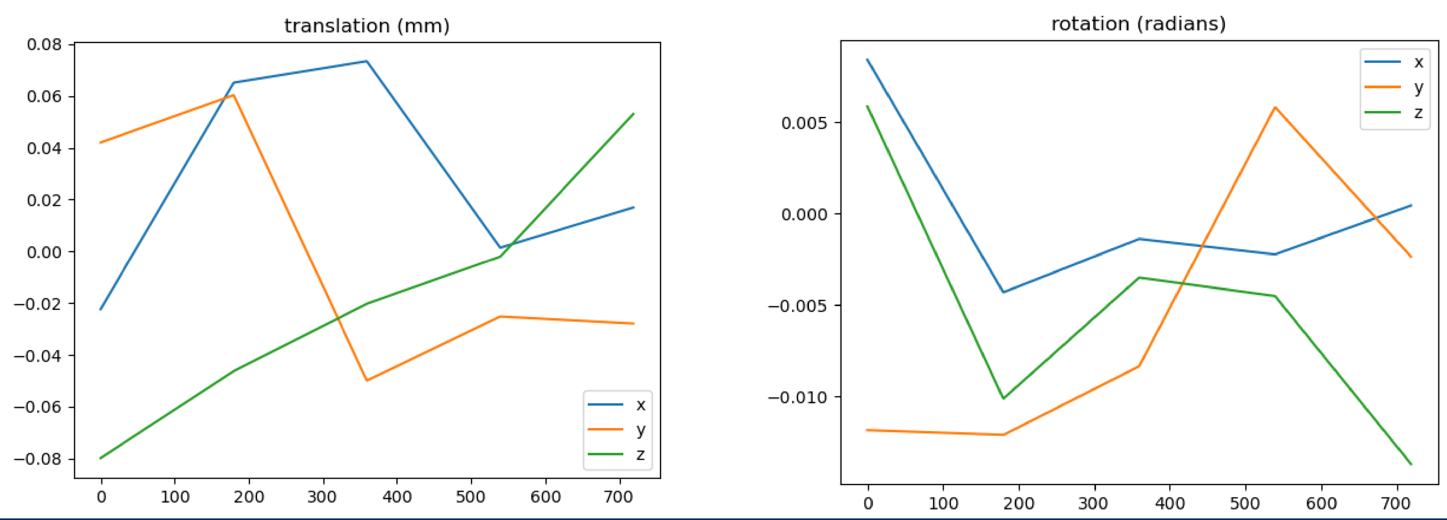
- This inconsistency leads to motion artifacts in the reconstruction.
- To overcome this, the motion needs to be accounted for in the projection model.
- For rigid motion, a **virtual projector geometry** can be used to compensate the motion [2]:



- Using this projector geometry, the **projections are consistent**.
- The **motion needs to be known** before this technique can be applied.

Motion estimation

- Rotation and translation have to be estimated for each projection: 6 parameters per projection.
- To keep the number of parameters low, the motion is only estimated at selected projections, and linearly interpolated for the other projections
- The parameters were estimated by minimizing the image entropy of the filtered backprojection [2].
- The minimization was carried out by the Nelder-Mead method [3].



Results

Scan setup

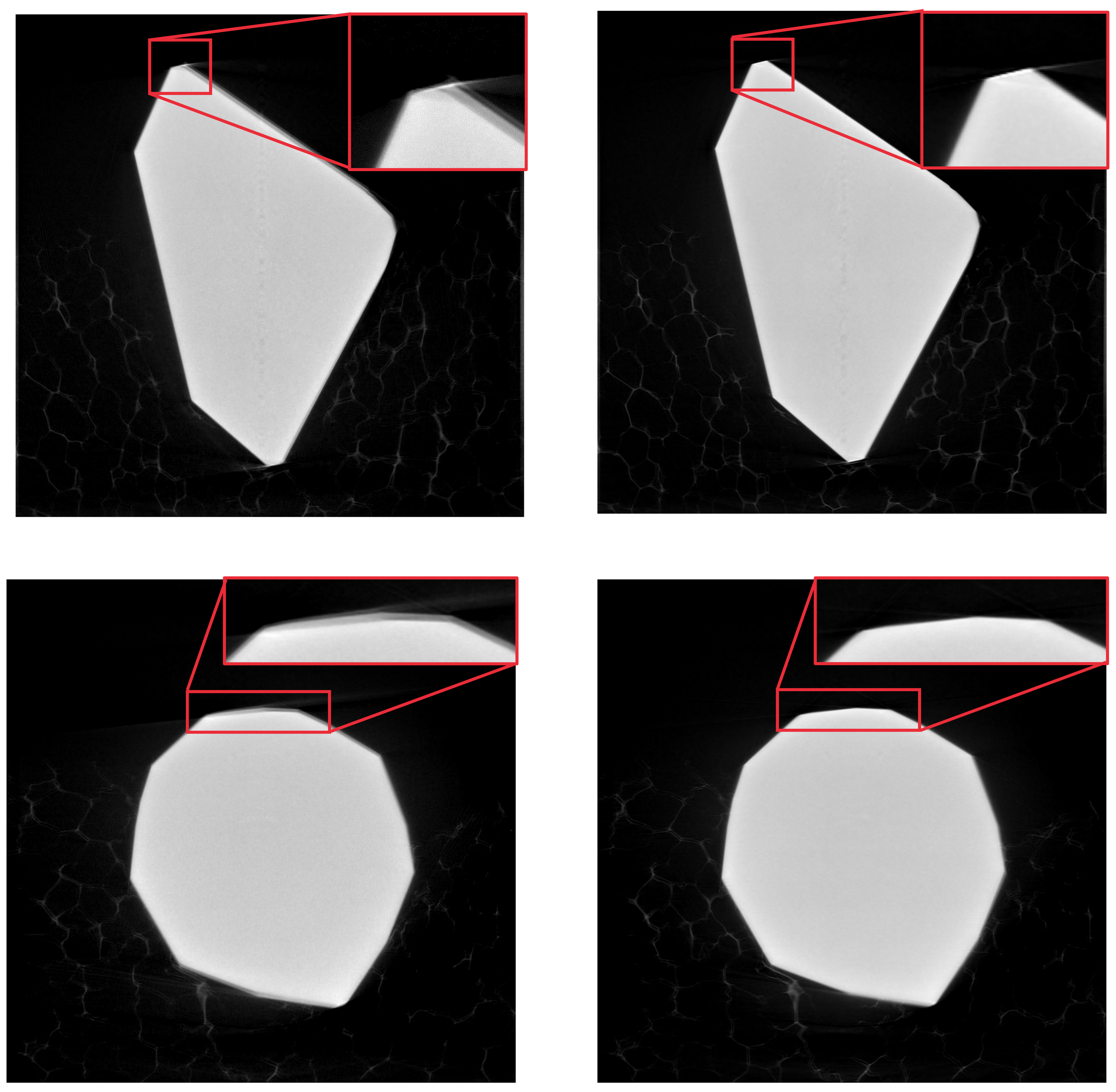
- Circular cone beam geometry
- Angular range: 360 degrees
- Number of projections: 720
- Exposure time: 1700 ms
- Power: 60 kV
- 1920x1896 detector pixels
- Detector pixel size: 0.15 mm
- Voxel size: 0.008 mm

Reconstruction

- Motion estimated at 5 projections, interpolated for the other projections.
- 5 x 6 = 30 unknown motion parameters estimated.
- Final reconstruction with 30 iterations of Barzilai-Borwein method [4].
- Conventional reconstruction uses static geometry as reported by scanner.
- Motion compensated reconstruction uses the virtual geometry which compensates the estimated motion.

Comparison of reconstructions

Conventional reconstruction | Motion compensated reconstruction



Conclusion

- Using rigid motion estimation and motion corrected reconstruction, we were able to accurately reconstruct a 3D CT image of a diamond that underwent rigid motion during scanning.
- The availability of a motion compensating reconstruction technique removes the need for fixating the diamond during scanning.
- Scanning without fixating facilitates multiple CT scanning during the diamond processing procedure.

Acknowledgement

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References

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