Post-processing of STEM Data for Instability and Drift Compensation

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Background

Much progress has been made in improving the resolution of scanning transmission electron microscopes (STEMs) through the development of hardware aberration correctors[1,2]; and with this a range of imaging and spectroscopic techniques have all benefited[3]. Unfortunately we cannot assume that simply buying an aberration-corrected instrument will deliver improved resolutions as we must also consider how our images are recorded and how distortions can affect this.

Types of STEM Probe Distortion

With the STEM's high-performance comes great sensitivity to environmental or instrumental disturbances. Acoustic, mechanical or electromagnetic interference as well as sample or stage drift can degrade either the signal-noise or resolution performance or cause the images to appear warped. To operate the STEM at high resolution, it is well known that lens aberrations must be reduced below certain calculated thresholds[4], but equally important are the environmental tolerances of the instrument and these have been analysed in detail in the literature[5,6]. These disturbances can cause the STEM image to become distorted in one of three ways:

1) Horizontal movement of image rows, caused by the STEM probe being offset parallel to the scan direction (feature slicing),
2) Vertical re-ordering of image rows, caused by the STEM probe being offset perpendicular to the scan direction (feature shuffling),
3) Overall warping of the whole field of view producing elliptical atomic columns from either stage or specimen drift (feature shearing).

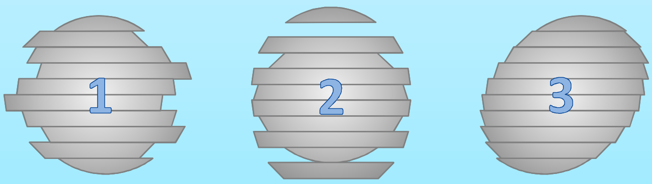

Figure 1. Schematic of three possible types of STEM image distortions; slicing, shuffling & shearing.

The 'Jitterbug' Restoration Algorithm

As described above probe disturbances lead to three types of image distortion. This was investigated in detail and from this a piece of image-processing code was developed to identify and compensate for these probe-offsets. The reconstruction relies on only two a-priori assumptions:

- That the atomic columns in the images should be broadly circular and contain no breaks, jumps or discontinuities, and
- For a periodic crystal the lattice planes should be equally spaced with angles between them of, for example, 90° or 60 °.

With these assumptions in mind the three distortion types can be corrected by:

1) Analysing the horizontal position of intensity profiles of individual rows relative to their vertical neighbours,
2) Analysing the integrated intensity of image rows and the vertical trend in intensity going outwards from feature centres, and
3) Analysing the angles between crystallographic lattice planes within the image to detect and measure drift.

The 'Jitterbug' image-reconstruction code is available free of charge for academic / non-commercial users and runs within MatLab. The code and user-manual can be downloaded from the web-address at the bottom of this poster.

Image Restoration Results

Users are invited to download and try the image-reconstruction code for themselves. The figure below shows a magnified area of the example file included with the code download (HAADF STEM image of strontium titanate). The left figure shows the raw image and on the right the reconstruction.

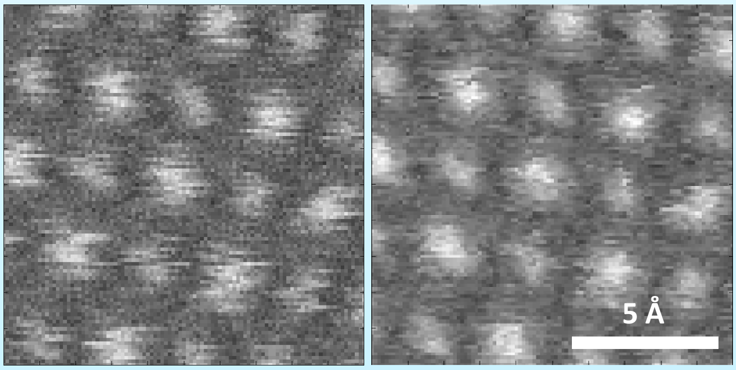

Figure 2. 100 x 100 pixel magnified view of example recorded STEM data (left) and restored data (right). Samples was [100] oriented $SrTiO_3$. Scale marker shows 5 Å.

As the analysis involves determining the offset of the probe from its expected position, a second output of the restoration code is the distortion frequency spectrum (Figure 3). This can be used in microscope suite diagnostics as it will always be better to eliminate distortions at their source.

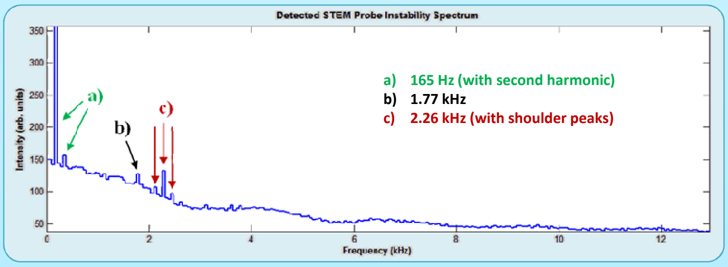

Figure 3. Frequency spectrum of the determined image distortions.

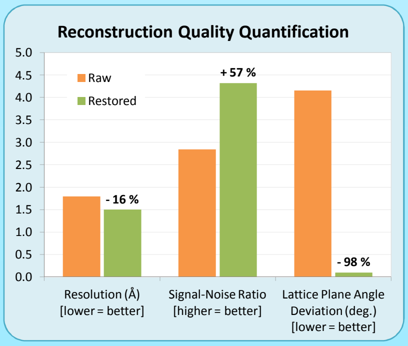

Figure 4. Quantification of image-reconstruction performance shown in Figure 2.

As with any image-processing tool it is important to quantify the results. Figure 4 shows three important performance metrics; the image resolution, signal-noise ratio and the deviation from expected lattice plan angles. These were calculated for both the raw-data and the restored-image shown in Figure 2. Across all three metrics distortion compensation improved the performance noticeably.

Conclusions

- Sub-angstrom probes are now routinely available in the STEM, however instrumental / environmental instabilities can degrade the recorded data.
- Image distortions / drift can be identified from STEM images and quantified in terms of their magnitude and direction / frequency-spectrum.
- Image-processing code was written to compensate for these distortions and in testing demonstrates quantifiable improvements in both resolution and SNR.

References

1) Urban K. et al. *Journal of Electron Microscopy*, **48** (1999) 821-826.
2) Krivanek O. *Ultramicroscopy*, **78** (1999) 1-11.
3) Pennycook S. J. et al. *Phil trans A*, **367** (2009) 3709-33.
4) Haider M. *Ultramicroscopy*, **81** (2000) 163-175.
5) von Harrach, H. *Ultramicroscopy*, **58** (1995) 1-5.
6) Muller D. et al *Ultramicroscopy*, **106** (2006) 1033-40.

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Further Information

Copies of this poster, the associated manuscript, the software described above and the author's contact details are available online at:

www.lewysjones.com