Post-processing of STEM Data for instability and drift compensation

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Improving the resolution of conventional transmission electron microscopy (CTEM) and scanning transmission electron microscopy (STEM) has been of great importance to modern materials science. A significant part of this has been through the development of hardware aberration correctors [1-2]. This new hardware has enabled these instruments to become some of the most precise and high-resolution scientific tools available. With this development a variety of both imaging and spectroscopic techniques have all seen benefit (for some examples see Ref. [3]).

A microscopist might assume that just purchasing an aberration-corrected microscope would enable imaging at improved resolutions. However, it is also important to also consider how data is recorded in these microscopes and the ways that disturbances can affect performance. With the STEM's high magnification comes great sensitivity to environmental or instrumental disturbances. These can include such things as acoustic, mechanical or electromagnetic interference. This interference can induce distortions in the recorded images and degrade both the resolution and the signal-noise performance. In addition stage or sample drift may cause the images to appear warped and can lead to lattice parameter measurements being unreliable.

To operate at high resolutions, each of the aberration coefficients in the microscope must be below calculated tolerances [4], however equally important are the environmental stability specifications of the instrument. Analysis by Harrach, Muller and others has shown that high performance CTEM and STEM microscopes are highly sensitive to instabilities and that instrument suite design is critical [5-6]. Instabilities can arise from either mechanical or acoustic vibrations, instabilities in any of the power supplies for the lenses or alignment coils, or from varying magnetic or electric fields in and around the microscope or suite. The environmental instabilities listed above can affect the microscope to differing degrees, each separately or cumulatively degrading the resolution benefit afforded by aberration correction.

As the STEM records images by serial acquisition, different regions of the recorded image may be distorted differently by any time-varying instability. As a result recorded image features may appear 'torn' (rows locally shifted horizontally), 'sliced' (feature rows reordered vertically), or 'sheared' (features smoothly elongated by drift). Generally such distorted images are smoothed to mask their effects, resulting in a loss of resolution and often signal to noise ratio (SNR) or simply ignored. In fact though these effects are separable, quantifiable and can be, at least partially, corrected for in post-processing.

To analyse and restore distorted images a piece of image-processing code has been written, which is freely available for academic use at www.lewysjones.com. The reconstruction's approach is a pixel-by-pixel analysis of each pixel's immediate surroundings. In this way the distortions both parallel and perpendicular to the scan direction can be mapped. This is then used to reconstruct the image as if the distortion was not present during the acquisition. Finally, stage/sample drift is measured by inspecting deviations in the crystallographic lattice plane angles. Once determined this is counteracted by a matrix transformation. An example is shown below in Figure 1 where the properties of the raw data and the restored image are compared quantitatively. An improvement in resolution of 16.0%, and an improvement in SNR of 57.4% was achieved as well up to 100% correction of the image drift. Qualitatively it has also been found that such image restoration can simplify image interpretability and model comparison.

As a by product of the above analysis the distortion as a function of time is determined. The Fourier transform of this gives a frequency spectrum of the distortion that may be useful for diagnosing the microscope suite for sources of instability (Figure 2). The image-processing code was developed for atomic resolution STEM but are equally applicable to other serial-recording microscopy techniques such as scanning electron / scanning tip microscopy techniques [7].

References

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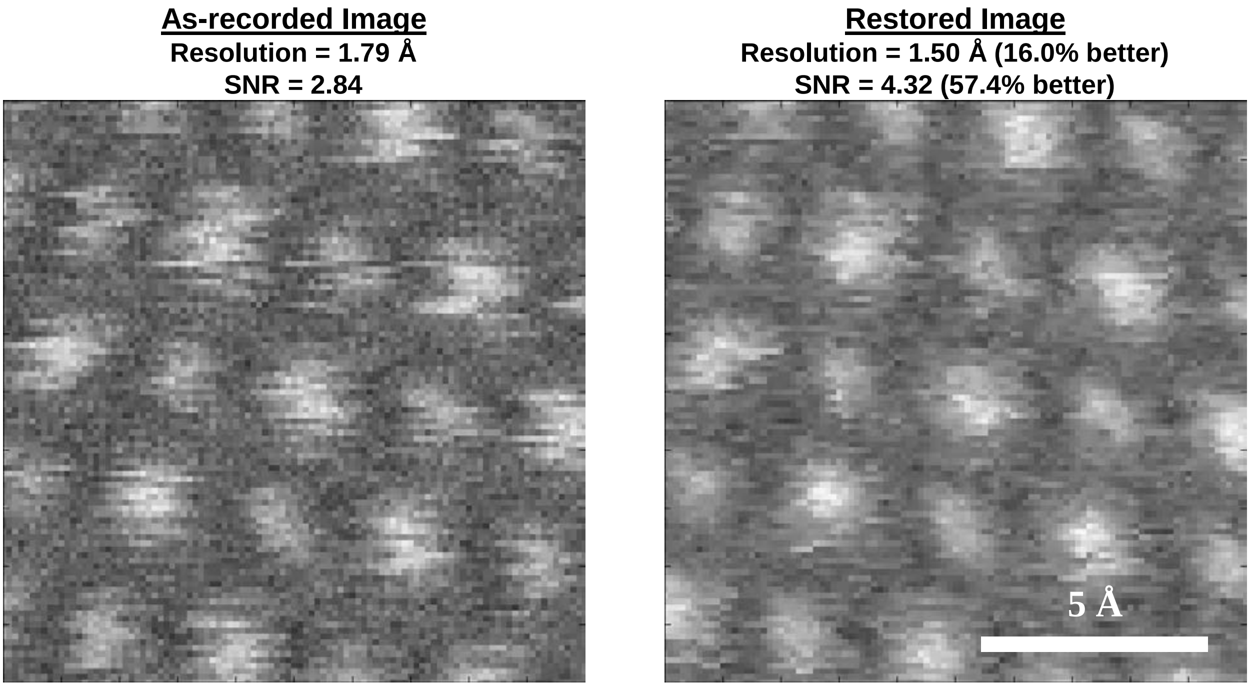

Figure 1. *100x100 pixel enlargment of example raw STEM data (left) and restored data (right). Sample was [100] oriented SrTiO3. Scale marker shows 5nm [7].*

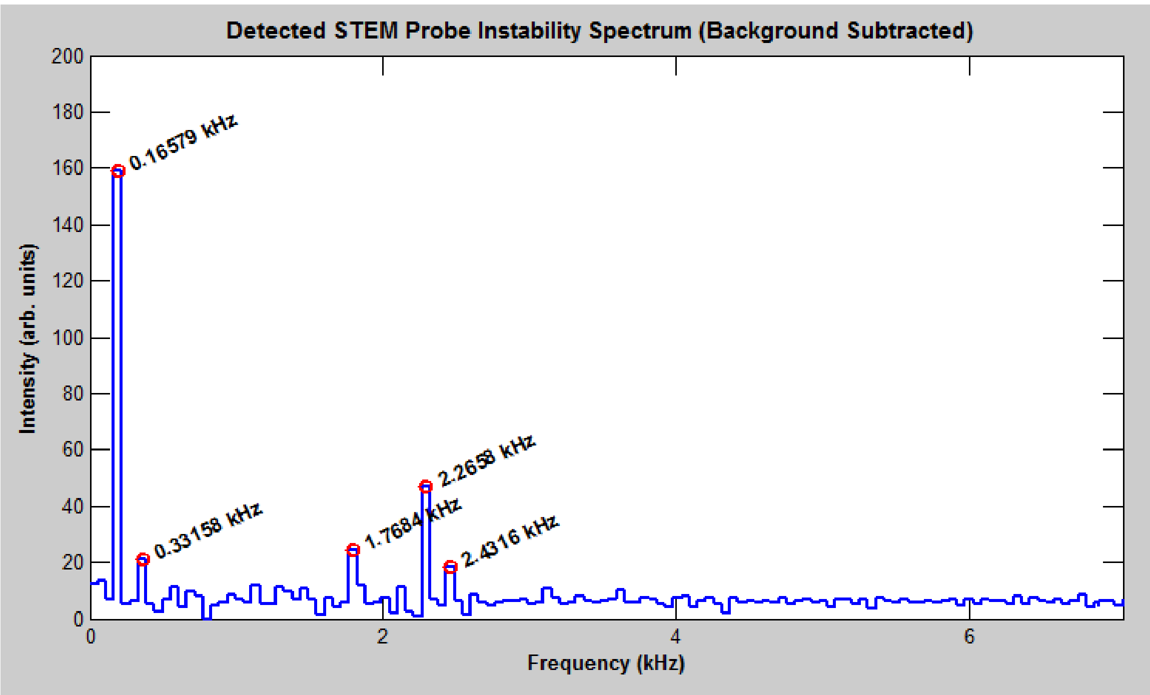

Figure 2. *Calculated distortion spectrum indicating frequencies of interest for microscope suite investigation.*