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Correction of Linear and Nonlinear Raster Distortion from Orthogonal Image Pairs.

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Experimental measurements using rastered scan techniques like STEM are subject to significant spatial distortion from the accumulation of error in the probe position. These distortions lead to degradation in spatial analysis including any technique requiring multi-image alignment such as time series, tomography, or multi-image averaging. The case where this error is constant over the timeframe of the experiment has received much prior treatment [1]. However, data often contains significant non-constant positional error which requires nonlinear corrections. In this work we present a method for analyzing and compensating for both linear and non-linear error using pairs of rastered datasets rotated orthogonal to one another. It requires no a-priori assumptions of the sample features or symmetry. The efficacy of this technique is demonstrated using HAADF STEM images (Figure 1) although it is applicable to any rastered data.

The proposed method of nonlinear error correction is predicated on the comparative correctness of information transfer along the fast-scan direction, each dataset using the “good” axis to correct the “bad” axis of the other. The nature of this error can be seen in the lattice strain analysis of the atomic scale STEM images in Figure 1. The images are taken of the same region of a perovskite film/substrate interface with the scanning axis rotated 90°. The lattice spacing in the direction of the slow scan axis exhibits large modulations with standard deviations ~1.7 times larger than the relatively uniform fast scan axis. This leads to the primary operating principle for this method: applying shifts to each scan line to best match the data between the two orthogonal images. The corrected image, shown at the bottom of Figure 1, appears as a best-case combination of the fast-scan axis from the two input images. This is further highlighted by comparing the minimal data spread in the histogram of the lattice-spacings of the film in the corrected image.

Determination of the linear and non-linear corrections is done by subregion alignment of the two images. Difference (Δ) vectors are calculated between aligned reference points (Figure 2a) and this difference is fit as two components. The first is a linear correction which applies shear and scale operations to the two datasets bringing them both to a best-match intermediate image. This component appears as a plane in the Δ images in Fig 2. The nonlinear correction is the local x or y offset applied along the entire axis of the image which minimizes Δ, subject to appropriate smoothing according to the reference point density and positional uncertainty. This component appears in Fig 2 as vertical and horizontal stripes. It is readily observable in Figure 2b that these two components clearly describe the observed difference vectors for these images.

Results for these images show the linear distortions contribute up to 2.37Å and 3.83Å of deviation in x and y, respectively. Nonlinear distortions contribute up to 1.35Å and 2.00Å in x and y. In this case the nonlinear distortions are of the same order as the linear components and the correction of both is necessary for any practical spatial analysis or image alignment.

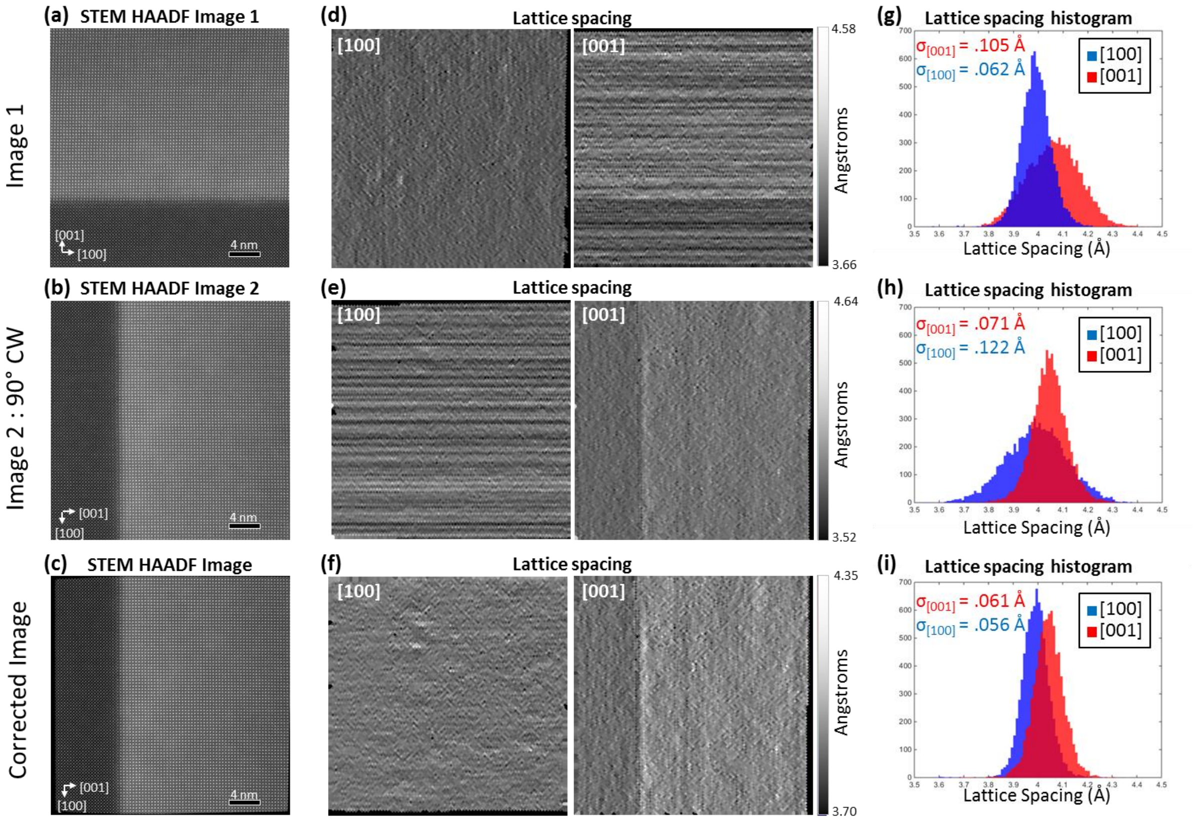

Figure 1. (a-b) Atomic scale HAADF STEM images from the same region with the scan axis rotated 90°. (c) Atomic scale HAADF STEM image corrected for linear and nonlinear distortion. (d-f) Corresponding lattice spacing maps in the [100] and [001] directions. (g-i) Corresponding histograms of the [100] and [001] lattice spacings.

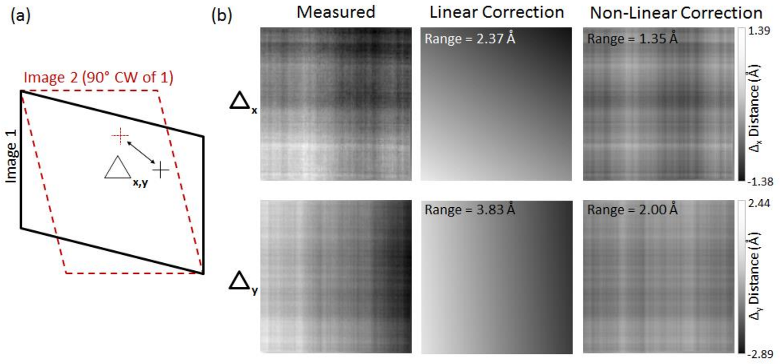

Figure 2. (a) Illustration of two linearly distorted orthogonal images such as from sample drift. A difference vector ($\Delta_{x,y}$) is calculated between reference points. (b) Difference vector (Δ) maps in x and y as measured (left), the best fit linear component (middle), and the best fit nonlinear component (right).

References:

[1] X. Sang, and J.M. LeBeau, Ultramicroscopy **138** (2014), p. 28.

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