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Assessment of SEM Image Quality using 1D Power Spectral Density Estimation

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The performance of a scanning electron microscope is generally evaluated by correlating operating conditions with image properties, such as noise, contrast, and spatial resolution. Current methods utilized for determining these parameters, particularly spatial resolution measurements, often involve subjective analysis. In this paper we describe a technique useful for qualitative correlation between image quality and systematic changes in imaging conditions, based on analysis of their 1D power spectral density (PSD) functions.

The PSD of an image describes how the power in the image varies with frequency. Spatially this corresponds to contrast between pixels at various length scales. In this work the PSD is estimated using Welch's modified periodogram approach resulting in a 2D PSD [1]. This is then reduced to a 1D representation by radial averaging. While the reduction does reduce information relative to 2D data it serves to reduce noise in, and simplify comparison between PSD plots. The first part of this process, windowing the data, is illustrated in Figure 1.

The PSDs profile consist of three distinct zones, moving from small to large sampling periods; a horizontal section, a transition zone, and an upward curving region. To interpret these PSD plots, a single STEM-in-SEM image was modified to simulate systematic changes in image quality by (i) adding Gaussian noise with increasing standard deviation, σ, (ii) increasing image contrast/gain by histogram stretching and (iii) reducing spatial resolution via Gaussian blur. The resulting PSD plots are shown in Figure 2. Increasing image noise raises the power level in the horizontal region confirming that this feature represents the noise floor in the image. Whereas increasing the contrast/gain lifts the power level in the large sample period domain with a corresponding small rise in the noise floor. The latter effect is expected since contrast stretching is equivalent to amplification across all spatial frequencies. The profiles with reducing resolution exhibit a clear relationship between the sampling period of the transition zone and the image spatial resolution. These data confirm that the PSD analysis can be used to easily assess whether or not specific changes in SEM operating conditions provide an improvement in image quality.

To demonstrate the utility of the technique, two STEM-in-SEM micrographs collected under slightly different imaging conditions and their respective PSD plots are presented in Figure 3. These images demonstrate the difficulty in determining differences in image qualities by visual observation alone. Conversely, the PSD data clearly show how the power or contrast at each sample period has changed. The advantage of this technique is evident when a large number of parameter shifts are compared.

References

[1] S. W. Smith, The Scientist and Engineer's Guide to Digital Signal Processing, copyright©1997-1998 by S. W. Smith. Available at http://www.dspguide.com/ch9/1.htm (July 2008)

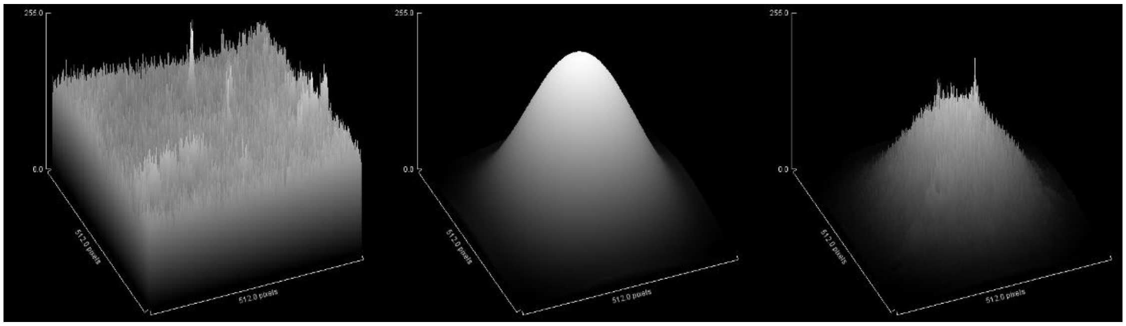

FIG. 1. A raw STEM image left is windowed with the Hamming function (middle image). The 2D Power Spectral Density function (right image) is calculated and reduced to 1D via circular averaging. Image data is 512 x 512 pixels and z-axis is -255 grey levels.

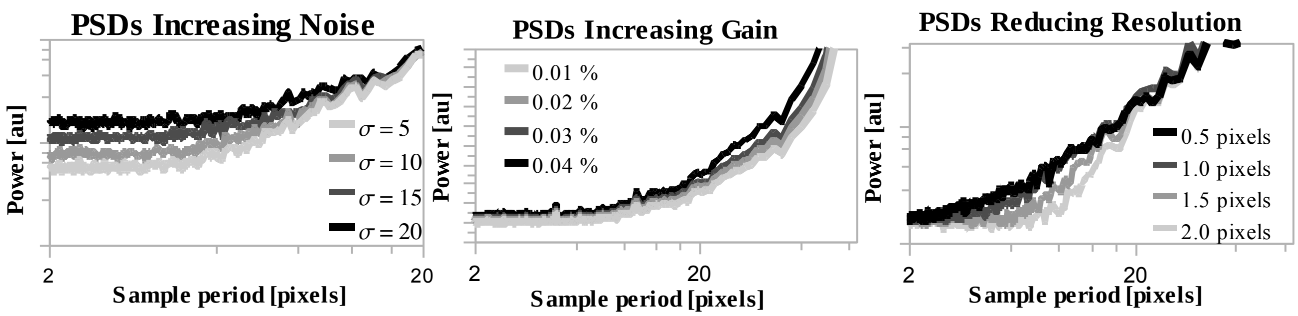

FIG. 2. Resulting PSD functions for simulated changes in image qualities. Left added Gaussian noise with increasing σ. Center histogram stretch with maximum allowed pixel saturation. Right Gaussian blur with increasing radius and addition of Gaussian noise at σ = 15.

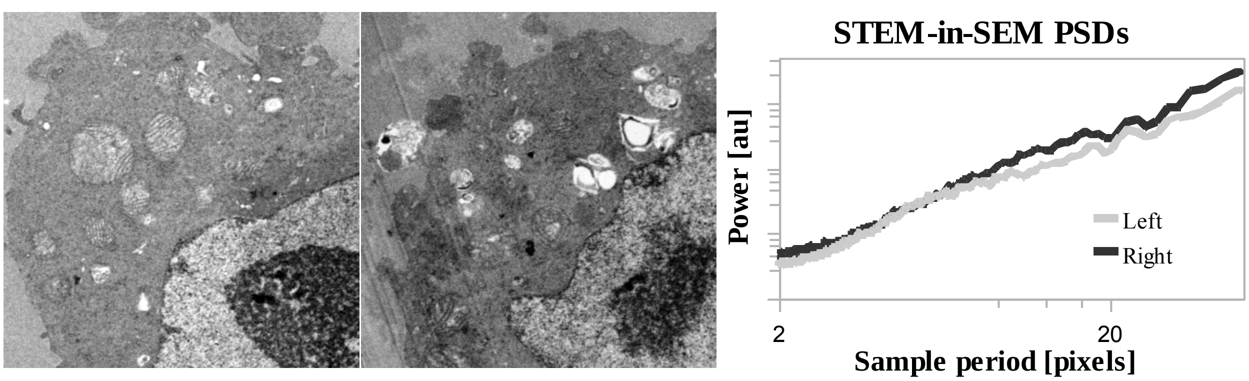

FIG 3. Two STEM-in-SEM images and their respective PSD functions.

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