An Evaluation of Image Quality Metrics for Scanning Electron Microscopy
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Abstract
It has been shown that through the use of image restoration techniques, the quality and resolution of scanned electron microscope (SEM) images can be significantly improved [1]. The purpose of this research is to determine a suitable image quality metric for quantifying the extent of that improvement.

Introduction
Several common image quality metrics were applied to SEM images subjected to various perturbations such as contrast and brightness adjustments, blurring, vibration and statistical noise. Typically, the assessment of image quality involves the comparison of a figure of merit for an observed image against that of a reference image where the observed image is a representation of the true structure obtained under less than ideal circumstances and the reference image is a representation of the true structure obtained under ideal or nearly ideal conditions. The figure of merit criteria discussed here are the mean squared error (MSE) [2], peak signal to noise ratio (PSNR) [2], the contrast transfer function (CTF) [3] and the mean structural similarity index (MSSIM) [4]. In addition to these more established criteria, Nanojehm Inc. has developed a novel and unbiased way to determine resolution.

Equations and Methods
The MSE is frequently used in signal processing as a way to quantify the error in an output signal versus the input signal. This can be applied to images as well.

\[ MSE = \frac{1}{MN} \sum_{x=1}^{M} \sum_{y=1}^{N} (f(x,y) - \hat{f}(x,y))^2 \]

Where:
\[ f(x,y) \] is the true image
\[ \hat{f}(x,y) \] is the perturbed image

The PSNR is used often in conjunction with the MSE to give an indication of the impact of the noise on the reliability of the signal.

\[ PSNR = 10 \log \left( \frac{MAX(f)^2}{MSE} \right) \]

Where:
\[ MAX(f) \] is the peak signal in the true image

The SSIM and MSSIM are metrics that attempt to make a closer comparison of structural components contained in the image rather than simple point by point pixel intensity variations. This particular method was developed to assess image degradation associated with compression methods such as JPEG. A key feature is that it recognizes that two images could have the same MSE, but may have totally different responses to the human visual system (HVS). Specifically, this method involves calculating the luminance, contrast and structural factors independently, and then combining them into a single value for simplified evaluation. The closer the MSSIM is to unity, the more similar the two images are.

The CFT utilizes the Fourier transform of an image to give an indication of the special frequencies present. This is useful not only for determining the relative quantity of feature sizes present but also for giving an indication of the level of noise. Statistical noise, along with vibrations and blurring, have relatively distinct effects on the shape of the CFT curves. While learning to interpret these curves takes significant experience, they can be quite useful for resolution determination.

Conclusions
1) While MSE, PSNR and MSSIM are useful metrics when applied correctly, they are particularly susceptible to contrast and brightness settings in the images. When it comes to determining SEM resolution, these parameters are not as important as blurring, vibration and noise.
2) The CFT provides particularly useful information independent of brightness and contrast settings while at the same time showing relatively unique indications of blurring, vibration and noise. However one drawback is that interpreting the curves is not necessarily intuitive and therefore requires experience with various images.
3) Nanojehm’s technique offers an unbiased attempt to quantify resolution. This technique is particularly suitable for quantifying the resolution improvement achieved by image restoration. [5]

References
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