Method to determine image sharpness and resolution in Scanning Electron Microscopy images

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Image sharpness is very important for the perceived quality of any image. Under certain assumptions sharpness can be related to resolution. For SEM images it lies typically in the nanometer range. If image formation is simplified to a linear system with a point spread function (PSF) we can measure the system blur and relate it to the minimal resolvable distance using a (Rayleigh/Abbe or Sparrow) criterion.

A fully automatic, noise robust image processing algorithm is introduced to find, extract and measure suitable edges from SEM images. The extracted edges of blurred step edges are assumed to have the shape of error functions. A parametric fit to these edges reveals the standard deviation of the underlying Gaussian function, and thus is a measure for the sharpness, i.e. the PSF.

It needs to be stressed that the sharpness in images is measured, not the performance of the machine per se (spot size). However, the image sharpness and related resolution is probably the single most important feature for any microscopy user. Our simplified image formation and analysis model does not take into account the more general problem of resolution definition in images. This would require an object model, a statistical estimation process and most important a full understanding of the sample beam interactions and detector properties. In light microscopy where this is greatly simplified, there has been recent success to tackle this issue in the case of single molecule fluorescence imaging [1,2].

Our fully automated algorithm is based on the extraction of edge profiles and fitting error functions to them. The edges are found in regions of high contrast change. Edge profiles are extracted perpendicular to the found edge line. An error function fit returns the only relevant fitting parameter, the Gaussian σ. A typical image after edge detection and profile extraction is shown in Figure 1. The selected edge profiles must represent a 'nice' edge profile (shown in green in Figure 1), which are a subset of all initially extracted edges (show in red). The algorithm returns the average σ fit to a number of edges (typically 500-1000). It can handle anisotropic pixel sizes in x and y scan directions and can compute the sharpness in different image orientations to detect astigmatism, compare Figure 2.

We tested the consistency and robustness of the algorithm on simulated SEM images [3] with addition of noise, vibrations, defocus, astigmatism and edge effect. For all distortions except the edge effect our method performed very well (within a few percent of the simulations). A higher sharpness is expected in this case as we measure the image

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sharpness and the edge effect gives rise to a steeper slope. Tests on real SEM images showed also expected values.

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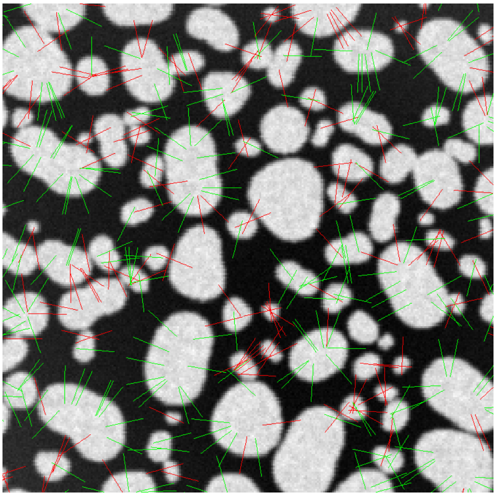

Figure 1. Part of a simulated SEM image. The red lines are rejected edge profiles and green profiles are suitable to measure the edge sharpness.

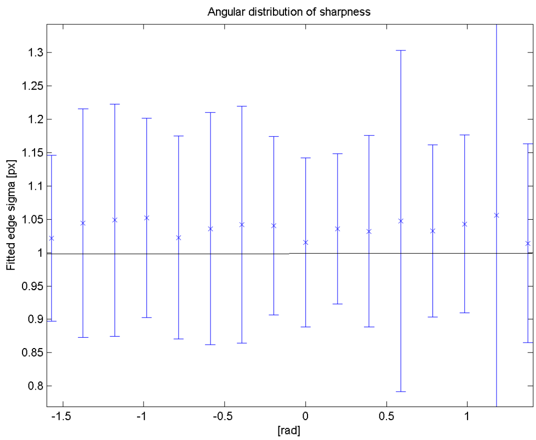

Figure 2. Angular distribution of the edge sharpness, simulated value 1.0.