Scanning Electron Microscopy: Power Spectrum Analysis

M.E. Rudnaya, J.M.L. Maubach, R.M.M. Mattheij

Dept. of Mathematics and Computer Science, Eindhoven University of Technology, PO Box 513, 5600 MB, Eindhoven, The Netherlands

m.rudnaya@tue.nl
Keywords: Power Spectrum, SEM, automation, Chebyshev polynomials

In Scanning Electron Microscopy, careful and fast analysis of an image's Fourier Transform (FT) is important for the automatic improvement of the image quality. The shape of the Point Spread Function in SEM can not be directly measured and is generally unknown. The image's Power Spectrum (PS) - i.e., the absolute squared value of its FT - is widely used for automated defocus and astigmatism corrections [1], for blind deconvolution procedures to improve image quality [2], [3], and for other purposes. In order to decrease the amount of computations one sometimes only analyzes the PS's profile (intersection of the PS with a line through the origin) as in [2]. The restriction to the PS's profile fails if the PS is not symmetric, for instance due to the specimen's geometry or machine aberrations, such as astigmatism, etc. (see the pictures in the second row of Figure 1). SEM images usually suffer from noise, which results in a noisy PS. The noise can influence the quality and performance of post-processing algorithms. Noise in the image is the major limitation of the blind deconvolution technique described in [3], where the acquisition of one experimental image took 10 minutes in order to obtain a sufficient signal-to-noise ratio.

This work proposes a new method for analyzing the full two-dimensional Power Spectrum. It is based on the assumption, that the logarithmic scaled PS can be closely approximated with a linear combination of predetermined shapes, called basis functions. The goal of the algorithm is to calculate the contribution of each of the basis functions in this linear combination, i.e., their related coefficients **c.** This paper uses as basis functions the monomials (to obtain the discrete image's moments) as well as Chebyshev and Legendre polynomials basis functions. The matrix **A** of the l2-inner products of the basis functions and the vector **b,** the inner products of the basis functions with the given logarithmically scaled PS, are computed. The coefficients **c** of the linear approximation solve **Ac=b**. In the case of Chebyshev and Legendre polynomials the matrix **A** is close to diagonal, which makes the computations numerically more robust. The method is non-iterative (uses a direct solver), i.e. the amount of required operations depends only on the image's dimensions and, amount and complexity of the basis functions. For the proper selection of set of the basis functions for a certain specimen, the proposed method accurately determines the approximation within a couple of seconds of time on a current desktop computer CPU.

The images for the numerical experiments were obtained with FEI's Strata SEM [4]. Figure 1 shows the results of PS approximation for a Tin Balls sample with the Chebyshev basis functions. The Least Squares Difference between the PS of a SEM measured image and it's approximation with analytical functions is provided just above the plots in Figure 1. The difference is about 5%, which is not large, taking into account the high amount of noise in the original PS.

The proposed method can be used for the fast analytic fitting of the obtained discrete data into the analytical model. This can be useful for the blind deconvolution techniques and automated defocus and astigmatism correction algorithms. The proposed method can be used as a PS noise reduction technique, as well.

DOI: 10.3217/978-3-85125-062-6-091,

The method was successfully tested on a number of SEM samples. The method's assumptions are general enough: It can be extended to a wider range of imaging devices [5].

1. K.H. Ong et al., Scanning, **20** (1998) p357.
2. A.S. Carasso et al., Opt. Eng., **41** (2002) p2499.
3. W.E. Vanderlinde et al., Scanning, **30** (2008) p268.
4. We kindly acknowledge R. van Vucht and S. Sluyterman (FEI) for support with the image recording and helpful discussions.
5. This work has been carried out as a part of the CONDOR project at FEI Company under the responsibilities of the Embedded Systems Institute (ESI). This project is partially supported by the Dutch Ministry of Economic Affairs under the BSIK program.

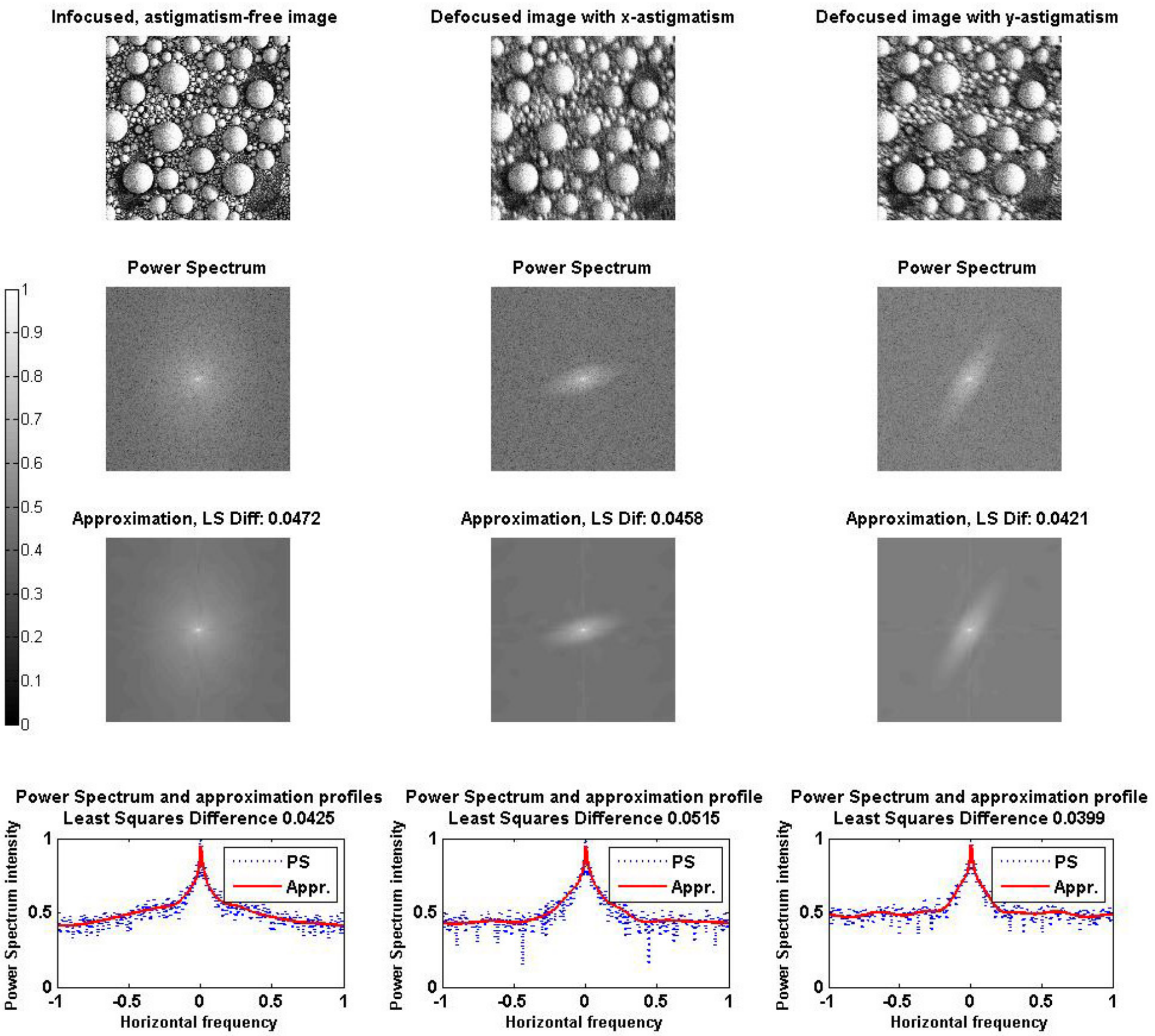

Figure 1. From left to right: infocused and astigmatism free image, defocused image with the presence of x-astigmatism, defocused image with the presence of y-astigmatism. From top to bottom: SEM image of Tin Balls sample, it's Power Spectrum, the approximation of the Power Spectrum with the analytical function, PS and it's approximation profiles (intersection with the horizontal frequency axis) plotted together. The colorbar on the left shows the scaling of the PS intensity: between 0 and 1. Horizontal and vertical frequencies are scaled between -1 and 1.

G. Kothleitner, M. Leisch (Eds.): MC2009, Vol. 1: Instrumentation and Methodology,
DOI: 10.3217/978-3-85125-062-6-091, © Verlag der TU Graz 2009