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Review of Single Image Signal-to-Noise Ratio Estimation for SEM Image

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Abstract. Scanning electron microscope (SEM) image signal-to-noise ratio (SNR) depends on the beam current, the materials present in the specimen, and the specimen topography. It is desirable to quantify the SNR in SEM images, as it is a parameter, along with spatial resolution, that quantifies the image quality. SNR measurement usually requires at least two images, to avoid this requirement, a method of SNR estimation with only a single image is described here. The SNR could be quantified as the ratio of signal variance to noise variance. The autocorrelation of image at its peak (zero offset) is used to estimate the noise variance and the signal component in accordance to the corresponding original autocorrelation and mean of the image while assuming the signal and the noise are uncorrelated.

Keywords: signal-to-noise ratio, cross-correlation, noise variance.
PACS: 07.78.+s; 05.40.Ca; 07.05.Pj

INTRODUCTION

Several methods of SNR estimation have been discussed over the past decade. In 1975, [1] used the cross-correlation technique on two images to obtain an estimation of SNR. In 1982, [2], and later in 2000, [3] analyzed the electron microscope's SNR using the cross-correlation method. In 2002, [4] proposed SNR estimation method in scanning electron microscope images by using a single image. Statistical autoregressive (AR) model was used by [5],to predict the SNR. Mixed Lagrange time delay autoregressive (MLTDEAR) model was developed by [6]for single image SNR estimation. The performance of the MLTDEAR was later evaluated by [7]. In 2006, the AR model was used by [8] to estimate the noise variance from the estimated single image SNR. Image noise cross-correlation model was developed by [9] for SEM single image SNR estimation. Later in 2012, the cramer-rao lower bond for image noise cross-correlation model was derived by [10], and the performance of the method was evaluated.

Over the past few years the performance and accuracy of different SEM SNR estimators have been analyzed and published. To provide a relevant comparison, and avoid the difficulty of assessing the relative performance of these estimators, we examined each estimator through MSE in this paper. The results are obtained from the simulation of the first order linear interpolator and the simple method [4], the autoregressive model [5], the MLTDEAR model [6], and the image noise cross-correlation model [7].

THE PROBLEM

A corrupted image can be expressed as $f(x,y) = s(x,y) + n(x,y)$, where the additive white noise and the original image are represented by $n(x,y)$ and $s(x,y)$, respectively. Figure 1 graphically describes the autocorrelation function (ACF) as we assume that noise is added to the image over the y-axis. The power of white noise and the power of the image are represented by $r(0)-\bar{r}(0)$ and $\bar{r}(0)-\mu^2$ respectively. The SNR of the image is given by:

$$SNR = \frac{\bar{r}(0)-\mu^2}{r(0)-\bar{r}(0)} \quad (1)$$

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In order to estimate the SNR using Eq. (1) the zero-offset pick of the autocorrelation of the original image, $\overline{r}(0)$, need to be estimated.

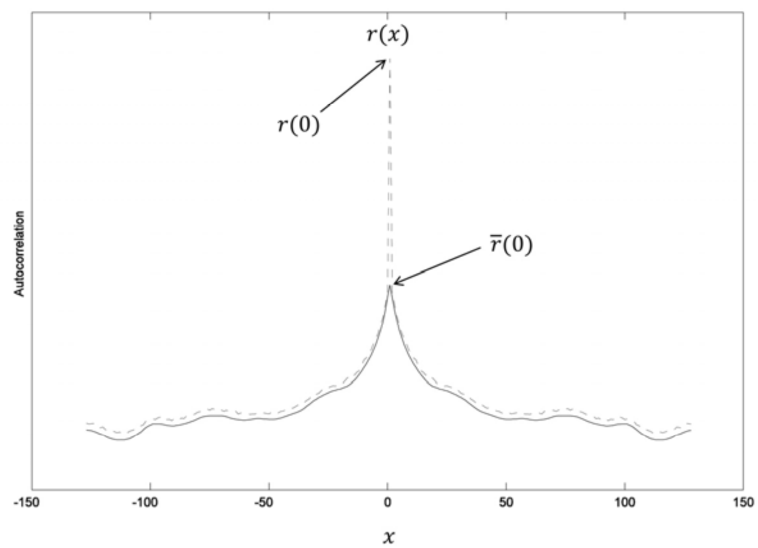

FIGURE 1: The autocorrelation function representation of noisy SEM image [4,5]

THE SNR ESTIMATORS

In this section we review a few single image SNR estimators.

The Simple Method and The First Order Linear Interpolation

In this model, [4] used either of two adjacent autocorrelation values, which are $r(1)$ or $r(-1)$, in order to estimate the ACF of the original image, denoted as $\overline{r}(0)$. Thus, we have:

$$\overline{r}(0) = r(1) = r(-1) \tag{2}$$

$$\overline{r}(0) = \frac{r(1) + r(-1)}{2} \tag{3}$$

where Eq. (2) and Eq. (3) represent the simple and the first order linear interpolation, respectively.

The Autoregressive Method

2N-point autocorrelation sequence $r(-N), r(-N+1), ..., r(-1), r(1), r(2), ..., r(N)$ could be used with AR model to estimate the zero offset point *r(0),* which is not in the sequence with an AR model of the signal. This approach was developed and used by [5].

The Mixes Lagrange Time Delay Estimation Autoregressive

In the mixed Lagrange time delay estimation autoregressive (MLTDEAR) model was proposed by [6].The Lagrange time delay estimator is then correlated with the autocorrelation samples by Eq. (4) to estimate the missing zero offset point.

$$y(k) = r(k - \tilde{R}) = \sum_{n=-q}^{\tilde{q}} h_{\tilde{D}}^{\Phi}(n) r(k-n) \tag{4}$$

Image Noise Cross-Correlation Estimation

In this method proposed by [9], the noise power spectrum and the zero-offset pick of the noise ACF itself, denoted as noise at zero offset is estimated as a separate value with respect to the noise variance. The ACF of the original image is then estimated using this result.

DISCUSSION

The result of SNR estimation was discussed in various papers [4], [5], [6], [7], [8], [9], and [10]. The estimation results are very much depended on the structure of images whether they are magnification, under magnification or morphology of images.

The power of original image is estimated using interpolation technique with AR model, but the various factors as well as size, resolution and variations in texture could affect the accuracy of estimation. Some inaccuracy would be introduced, due to the noise effect on the autocorrelation, there could be inaccuracy on its peak value.

Although the MLTDEAR method provides a consistent performance for SNR estimation but due to limitation of optimized fractional delay determination it could not be used as a general SNR estimation solution.

The image noise cross-correlation method [9] uses the information about the noise variance to estimate both the power of the signal and the power of the noise. The estimation obtained using this method is much more accurate compared to other methods discussed in this paper. Overall, all the estimation methods are less dependent on the power of the additive noise.

CONCLUSION

The SNR could be quantified as the ratio of the signal variance to the noise variance. The autocorrelation of image at its peak is used to estimate the noise variance and the signal component in accordance to the corresponding original autocorrelation and mean of the image. Various estimated methods are developed to estimate the SEM SNR value.

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