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Abstract. We demonstrate a new method for x-ray microscope image enhancement using frequency spectrum analysis. Fine sample characteristics are well enhanced with homogeneous visibility and better contrast from single image. This method is easy to implement and really helps to improve the quality of image taken by our imaging system.

1. Introduction

A full-field, high-resolution transmission hard x-ray microscope (TXM) based on zone plate and operated at the photon energy from 7 to 11 keV has been installed at the U7A beamline at National Synchrotron Radiation Laboratory (NSRL) [1]. This facility can provide images with 50 nm spatial resolution and be able to image some weak absorption material at 8 keV by using Zernike phase ring to enhance the contrast. Although phase contrast imaging is powerful, the image contrast sometimes is still not so satisfactory. Another defect of the images are caused by the nonuniform illumination. The common solution is to divide the sample image by a flat field image. But since the illumination cannot be stationary in this sensitive system all the time, the divided images sometimes might not be so homogeneous. In addition, it's hard to take each flat field image immediately after taking the projection image during tomography. So other complementary method would be needed.

Image enhancement techniques have been applied in many kinds of fields to improve image quality. Special frequency enhancement is one of the effective methods [2]. In this paper, we propose an approach for image enhancement of x-ray microscope, which can achieve homogeneous visibility and enhanced contrast from single image on our imaging system.

2. Method

By the Fourier transform theory, the frequency scale of original signal is based on the spatial scale of the signal [3]. Based on this theory, we propose an image enhancement approach for our x-ray microscope: according to the priori knowledge of the characteristic scale range of the sample, the frequency special can be separated into three regions, high-frequency (HF), intermediate-frequency (IF) and low-frequency (LF). Each frequency band corresponds to the different spatial scale. In order to improve image quality and contrast, the power of IF and HF will be increased, which represents the

sample information and detail information; and the power of LF will be decreased, which represents the nonuniform background.

The steps of proposed approach can be followed as:

a)   Assume that the normalized original image is *I*. At first, let *I'=ln(I+1)*. This step can change multiplicative noise to additive noise, which is advantageous for further process [4].

b)   Secondly, two dimensional Fast Fourier Transform (FFT2) is applied to *I'* to obtain frequency special *F* of the image: *F=FFT2{I'}*. Based on the Gaussian low-pass filter and high-pass filter [3], *F* can be separated into three frequency region: *LF*, *IF* and *HF*. The cut-off frequency of Gaussian filters can be designed by the characteristic scale range of the sample and parameters of our imaging system.

c)   Thirdly, set *F'=a*LF+b*IF+c*HF*, in which *a, b, c* are called enhancement coefficients. Via changing these three coefficients, different enhanced images can be achieved.

Figure 1. The flow chart of the frequency enhancement algorithm

d)   At last, two dimensional inverse Fast Fourier Transform (IFFT2) and exponent arithmetic are applied to obtain the final enhancement image *EI*: *EI=exp(IFFT2{F'})*
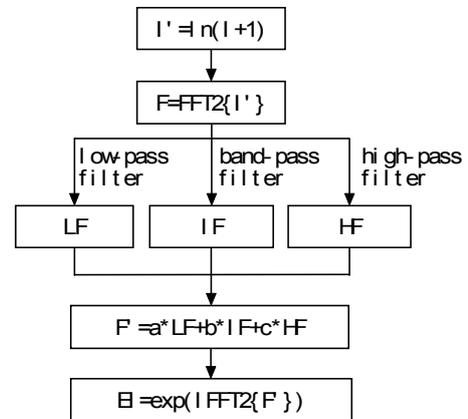
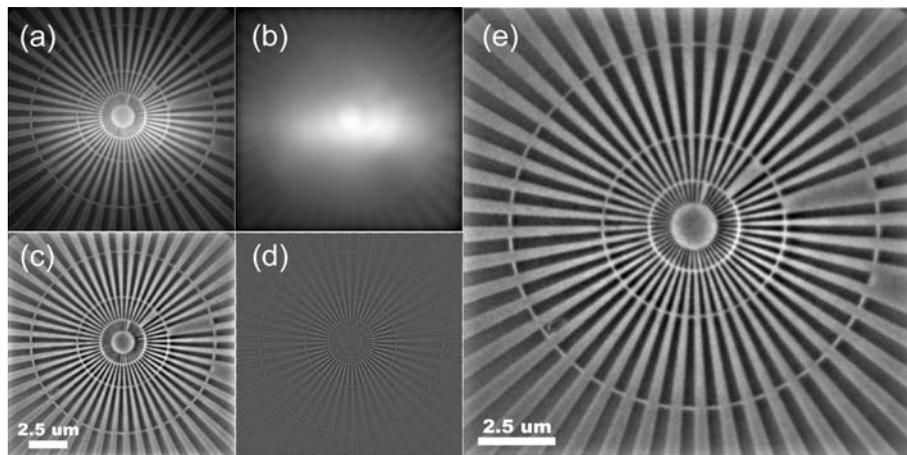The total procedure is summarized in figure 1.

Figure 2. (a) is the original image; (b)-(d) are regarded as the LF, IF and HF images separately; (e) is an enhancement image obtained by the proposed approach. (a)-(d) are with same scale bar.

3. Experiments and Results

Here a spoke pattern image (figure 2a) taken by our system with the size of 512×512 was used to deal with the frequency enhancement algorithm. The pixel size of the image is 29nm and the characteristic scale range of the spoke pattern is about 50nm-500nm, which can be considered as the priori knowledge to design the three filters. Figure 2(b)-(d) show the intermediate results, which represents the nonuniform background, main information and the detail information of the spoke. Finally an enhanced image shown in figure 2(e) was obtained by setting the enhancement coefficients as *a*=0.05, *b*=0.4, *c*=0.55. The coefficients *a* reduces the nonuniform background while the coefficients *b* and *c* increase the main information and detail information of the spoke sample.

Another example of carbon microtube [5] shown in figure 3 is used to evaluate the enhancement effect between enhanced and original images (the dark spheres are golden dots used for alignment of

tomography). The enhancement coefficients can be chosen as a=0.05, b=0.8, c=0.15 and the filter was designed by the characteristic scale range of the carbon microtube (~100nm-1um). Figure 3(a) is the original image and figure 3(b) is the enhanced image obtained by our approach. Figure 3(c) and 3(d) are two uniform images obtained by the common approach mentioned above. The flat filed image used in figure 3(d) was acquired several hours later than the one used in figure 3(c). Compared with the image in figure 3(c) and 3(d), the enhanced image in figure 3(b) has better homogeneous visibility. The contrasts of carbon microtube in the enhanced image and original image were also calculated. Figure 3(e) and 3(f) show the line profile indicated by the yellow line of two normalized images in figure 3(b) and 3(c) separately. The contrast of carbon microtube is about 18% in figure 3(e) and 13% in figure 3(f). These results reveal that the enhanced image of carbon microtube has better visibility and contrast than original one.
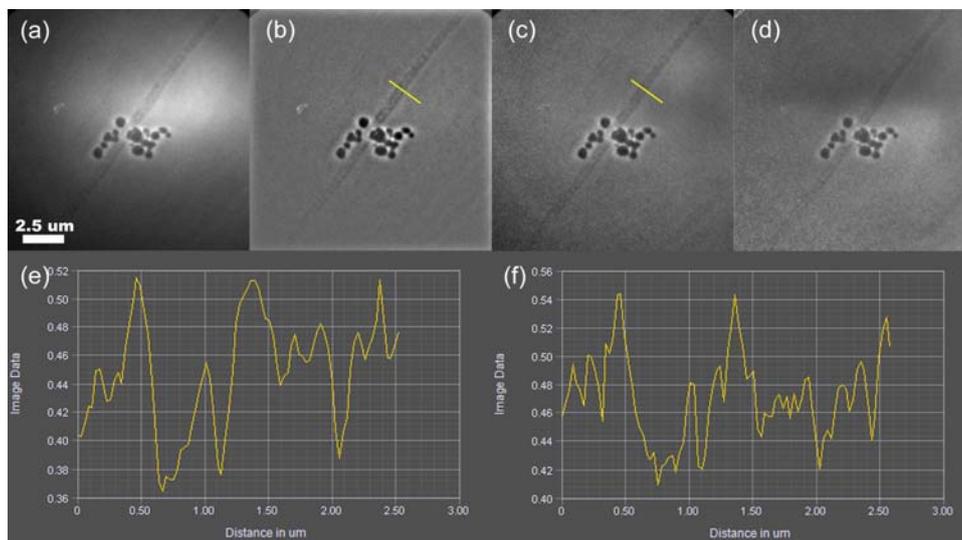

Figure 3. (a) is the original image of carbon microtube; (b) is the enhanced image; (c) and (d) are the images divided (a) by two different flat field images; (e) and (f) are the line profiles indicated in (b) and (c) separately.

4. Conclusion

To improve image quality of our TXM, we propose an approach for image enhancement using frequency spectrum analysis. The algorithm suggested in this study is mainly to reconstruct an image with better visibilities and contrast. It really helps to enhance the sample characteristics of TXM images. In future more features would be applied to develop the algorithm with better effect.

Acknowledgments

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