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Using Iteration Algorithm to Solve the Twin Image Problem For Shadow Imaging

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Electron in-line holography was proposed as a means to overcome the resolution limit of electron Microscopy by Gabor[1]. Even though it is simple and easy to implement, its application has not been very successful [2]. One major difficulty is that no reliable methods could remove the blurring effect of the twin image if using one hologram for the reconstruction. In this work we demonstrate a way to overcome this difficulty.

It is also well known that for a STEM equipped with a field emission gun, if an underfocused or overfocused beam is used to illuminate a sample, complex interference could happen in the far field. For a very thin sample, this diffraction pattern is often called "shadow image" or Ronchigram, Since it is similar to the original form of holography proposed by Gabor, in some research the shadow image is also called an in-line point projection hologram. Using the weak phase approximation, without considering the absorption effect, John Cowley successfully reconstructed an image of a test object digitally[3]. Instead of solving the twin image problem, he showed that with a large defocus value, the degrading effect of the twin image is not very serious for certain samples.

In recent years, some researchers have re-visited the idea of using iteration algorithms to retrieve the exit wave from diffraction patterns of a small and isolated object. This technique utilizes coherent parallel beam illumination and assumes the shape and size of the testing object could be known approximately. If the size of the diffraction area is small enough, the phase information of the exit wave could be encoded into the diffraction pattern through an interference process. For a small crystal, interference happens among the broadened Bragg peaks. For amorphous materials, the interferences could be understood as coming from the overlapping of "pseudo" Bragg peaks. Since a shadow image is generated from a small region, and it also records the complex interference effects in the far field, it is interesting to try an iteration algorithm similar to the one used for diffractive imaging to reconstruct the object function for shadow imaging.

For a very thin specimen, f(x), under the illumination of a coherent convergent wave and the assumption of kinematical scattering, the shadow image could be expressed as:

$$I(K)=|F(K)\otimes H(K)|^2. \qquad 1).$$

F(K) means the Fourier transform of the object function, f(x), and H(K) is the complex aperture function with the inclusion of the aberration function. Sign ⊗ stands for the convolution product. In order to digitally reconstruct the testing object, the complex aperture function is multiplied to both side of the equation and an inverse Fourier transform is performed. Expanding the result and neglecting the high order components, the reconstructed image can be understood as the true image (the first component on the right side of equation 2) , blended with a twin image with an aberration value two times of the real image (the second component in equation 2). [2]

$$I_h(x) = h(x).f(x) - h_2(x)\otimes\{h^*(-x).[1-f^*(-x)]\} \qquad 2).$$

The blurring effect of the twin image complicates the reconstruction process. However, under the phase object approximation, which is generally true for shadow imaging, the intensity of the first component on the right side of equation 2) should be the same as the intensity of the beam. The intensity of the second component on right side of equation 2 is neither constant nor proportional to the beam intensity. Thus, after the $I_h(x)$ is calculated using the method proposed by Cowley, a simple iteration algorithm is added to further remove the blurring effect of the twin image. The iteration algorithm includes two steps since two criteria must be satisfied for the reconstruction process. 1). The intensity of Function f(x).h(x) must be equal to that of h(x). 2). The power spectrum of f(x).h(x) should be equal to the diffraction pattern. At the present stage, no feed back mechanism as HiO algorithm is included.

Numerical experiments were performed to test the algorithm. Figure 1 is a photographic image used as a target under the weak phase approximation (white=0.5 radian phase shift, black=0, object diameter ≈ 10nm), and figure 2 is the shadow image Figure 3 and figure 4 are the numerical reconstruction results, with and without using the iteration algorithm, respectively.

References:
[1]. D. Gabor, Nature, 161, P777, 1948
[2]. L.Wu, Y.Zhu, and J.Tafto, Physical Review Letters, V(85)P5126-5129
[3]. J. A. Lin and J. M. Cowley, Ultramicroscopy, V(19), P179-190
[4]. Finance Support from BNL, US DOE LDRD Project BNL#04-061, is greatly appreciated.

Figure 1. A "weak phase object" is used for the simulation test.

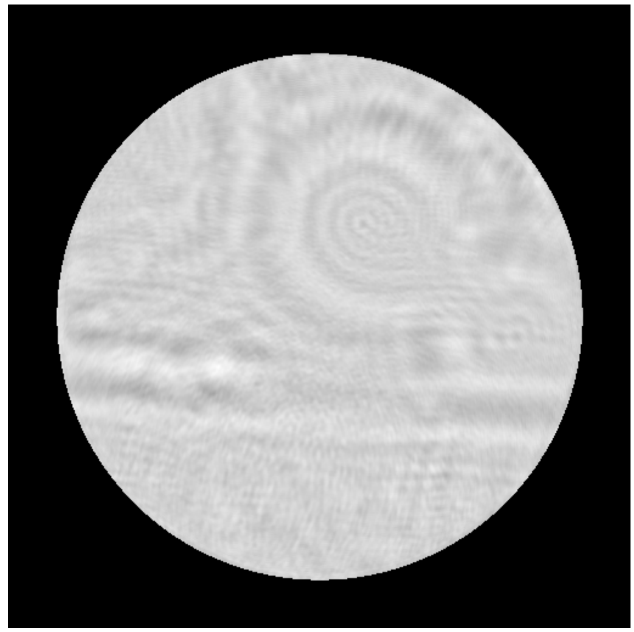

Figure 2. A simulated in-line Hologram under the weak phase approximation. A Perfect spherical wave, 40mrad half aperture size and 150nm defocus value is used.

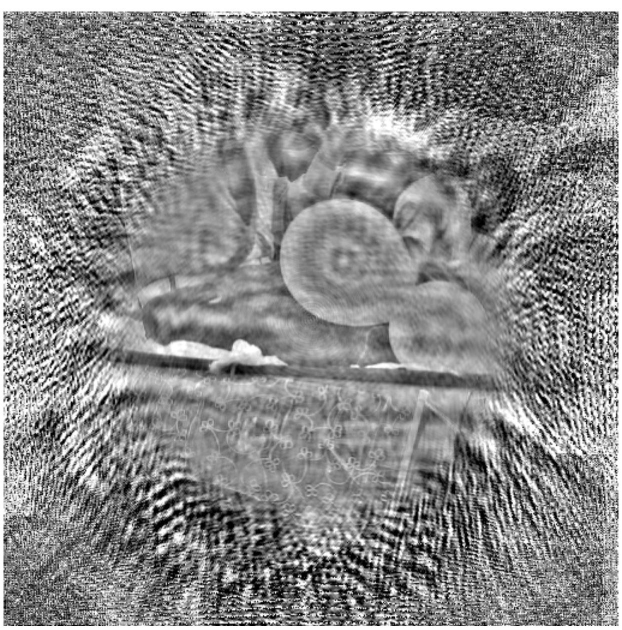

Figure 3. Reconstructed object without using the iteration algorithm.

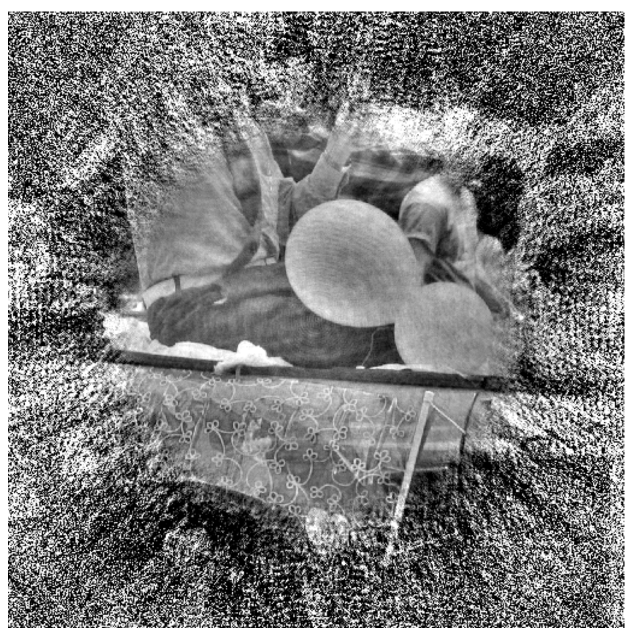

Figure 4. Reconstructed object using the method recommended by John Cowley, in together with an iteration algorithm

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