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Inpainting Assisted Controlled Rotation Tomography (CORT)

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The resolution of a tomographic reconstruction is dictated by the number of projections taken at different orientations (Crowther's criteria) [1]. For beam sensitive organic and hybrid soft-hard samples, the incident radiation of the electron probe can induce sample damage and prevent the recording of an accurate and meaningful tilt series. To maintain the integrity of the sample, only a reduced number of projections over the angular range is performed and therefore reduce the resolution of the resulting three-dimensional structure. Herein, we introduced a novel sampling strategy that will increase the number of projection images at different orientation for the same amount of exposure time by sparsely imaging the object in real space for general scanning probe transmission microscopy. Since the amount of information between adjacent pixels in a single projection image is relatively limited, near-randomly under-sampled electron projection images are highly amenable to inpainting to restore an accurate estimation of the true projection [2]. Our scheme can therefore maximize the time spent recording pixels with different angular views of the specimen, maximizing the information per unit of electron exposure.

In the conventional acquisition of a tilt series, the sample rotates in a staccato manner, meaning the sample will be parked at a certain orientation and a fully sampled image recorded. We have developed a novel sampling strategy in which the sample will not stop rotating within each image frame while the electron beam scanning over the grid of defined pixels. The sample and the scanning probe will move at the same time at different speeds (Figure 1). Multiple will be taken during the course of imaging while the sample rotates in a preprogrammed and controlled fashion, thus the name Controlled Rotation Tomography (CORT). In CORT, although the microscope still outputs individual images, each image frame is composed of pixels captured at different orientations. To process CORT data, the pixels that have the same orientation are sorted into the same frame to form a sparsely-sampled projection image. Since typically the scanning speed of the beam is much greater than the rotation of the sample, each pixel will therefore be an integration of a very small range of angles observing the specimen. Before reconstructing the tomograms, inpainting algorithms (such as beta process factor analysis, 3D wavelet inpainting, etc. [3, 4]) was used to fill in missing pixels in the sinogram. The reason to inpaint the sinogram instead of the projection is that under CORT sampling, the mask (pixels that have been visited) in sinogram will form a check-board pattern and therefore more evenly distributed. After inpainting, the fully recovered sinograms will be used for conventional tomography reconstruction. The work flow of CORT is demonstrated in Figure 1.

In this work, we have simulated metadata from axial tilt series of carbon nanotube collected experimentally [5]. For the metadata generation, we first reconstructed the 3D object by SIRT, and then applied the CORT sampling to the 3D object. As an example, the CORT process for the carbon nanotube [4] used a total dose for 31 conventional frames, and the integration spans 1 degree (Figure 2A). We used non-negativity constrained 3D wavelet inpainting algorithm to reconstruct the sinogram (Figure 2B). The 3D tomography reconstruction was carried out by 40 iterations in SIRT. The tomograms from CORT were compared with ground truth by cross-correlation (Figure 2C), and we found that CORT exhibited high tomogram quality (cross correlation>0.9) compared to the ground truth [6].

References:

[1] Penczek, P *et al,* Electron Tomography. (Springer, NY) p. 307.
[2] Hujsak, Karl *et al,* Microscopy and Microanalysis **22.4** (2016), p. 778.
[3] Zhang, Jian *et al,* IEEE Transactions on Im Processing **23.8** (2014), p. 3336.
[4] Wang, Guojie *et al,* Environmental Modelling & Software **30** (2012), p. 139.
[5] Levin, Barnaby DA *et al,* Scientific Data **3** (2016), p. 160041.
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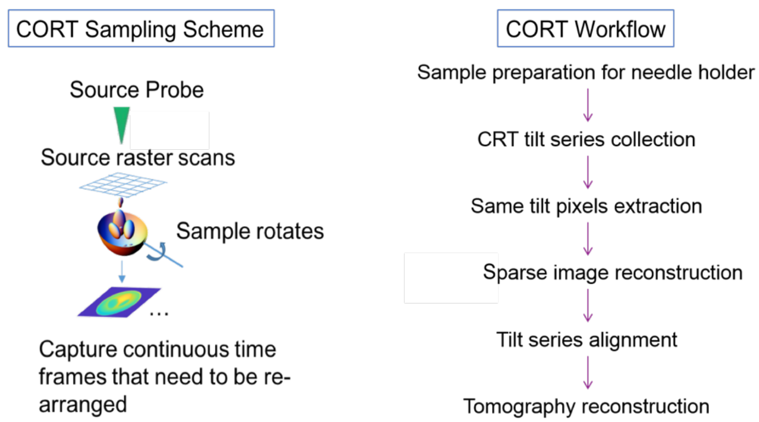

Figure 1. Sampling scheme and workflow of CORT. In CORT, the sample rotates non-stop during imaging. To process CORT data, pixels collected at the same sample orientation will be sorted and placed in the same image frame. The undersampled sinogram will be inpainted, and the recovered sinogram will be used in tomography reconstruction.

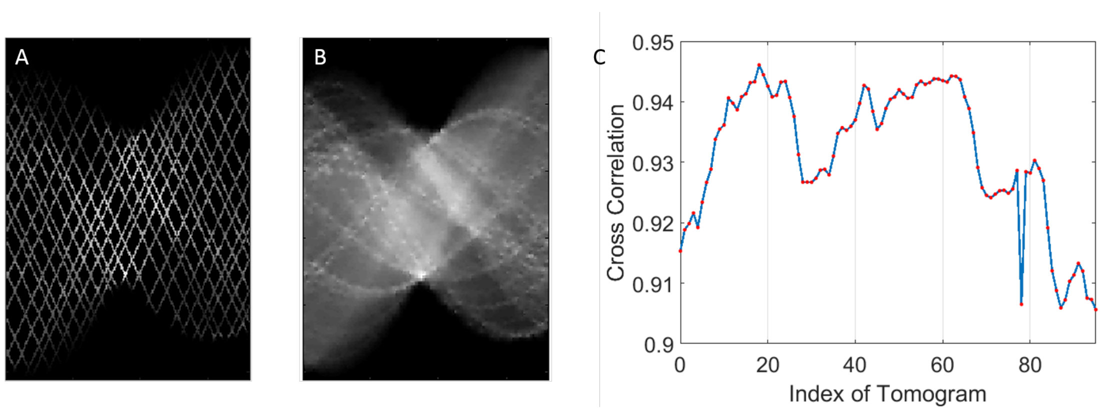

Figure 2. CORT demonstration of low dose tomography reconstruction. The total dose in the simulation equals to 31 conventional frames. A shows the undersampled sinogram by CORT, and B is the recovered sinogram after inpainting. C shows the cross correlation coefficient of tomograms reconstructed after inpainitng and the ground truth. For all frames, we see high correlation (>0.9).

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