High-Resolution and Large-Volume Tomography Reconstruction for X-Ray Microscopy

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ABSTRACT

This paper presents a method of X-ray image acquisition for the high-resolution tomography reconstruction that uses a light source of synchrotron radiation to reconstruct a three-dimensional tomographic volume dataset for a nanoscale object. For large objects, because of the limited field-of-view, a projection image of an object should to be taken by several shots from different locations, and using an image stitching method to combine these image blocks together. In this study, the overlap of image blocks should be small because our light source is the synchrotron radiation and the X-ray dosage should be minimized as possible. We use the properties of synchrotron radiation to enable the image stitching and alignment success when the overlaps between adjacent image blocks are small. In this study, the size of overlaps can reach to 15% of the size of each image block. During the reconstruction, the mechanical stability should be considered because it leads the misalignment problem in tomography. We adopt the feature-based alignment method to solve this problem. Finally, we apply the proposed method for a kidney of mouse for verification.

Keywords: High-resolution tomography, X-ray microscopy, image stitch, synchrotron radiation

1. INTRODUCTION

A noticeable application of X-ray microscope is to construct a high-resolution tomography of an object without physically slicing the object. Theoretically, a high-resolution volume data set can be created by a tomographic reconstruction method with a sequence of high-resolution X-ray projections taken over angular ranges of 0° to 180°.[1] However, the reconstruction may be prevented by field-of-view restriction when the resolution increases to a certain level. For large objects, a projection image of an object should to be taken by several shots from different locations, and using an image stitching method to combine these image blocks together. Fig. 1 shows a high-resolution image of a cancer cell stitched from a 3×3 patch of 1024×1024 pixel images. After a sufficient number of projections acquired, we then can apply a tomography reconstruction algorithm to reconstruct a high-resolution volume. All stitching algorithms require that any two adjacent image blocks have a large area of common overlap which contains sufficient significant information.[2] In this study, the overlap of image blocks should be small because our light source is the synchrotron radiation and the X-ray dosage should be minimized as possible. According the properties of synchrotron radiation[3],[4] we simplify several steps of image alignment to enable the stitching success. First, the projection model of the synchrotron microscopy is regarded as the parallel beam that means we can ignore the scaling factor. Object tilting during the acquisition also can be ignored if the object is fixed in a container. Thus, we only consider the vertical and horizontal displacements. In addition, the neighbors of each image block are determinate because the arrangement of all image blocks is a uniform gird. To verify the image stitching method, we apply the proposed method to reconstruct a high-resolution volume data set for a kidney of a mouse. During the reconstruction, the mechanical stability should be considered because it leads the misalignment problem in tomography reconstruction. To solve this problem, we adopt the feature-based alignment method that find the trajectories of features from all projections and align these trajectories to their best-fit sine curves.[5]

The rest of the paper is organized as follows. Section 2 describes the proposed method. The results of the proposed method are shown in Section 3. Section 4 represents the conclusion and future works.

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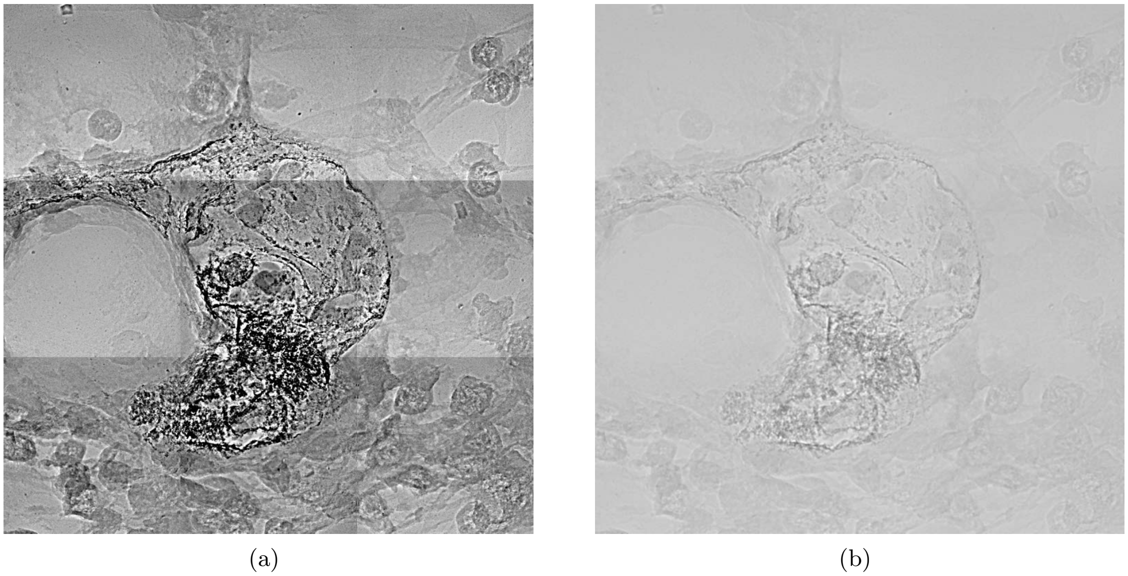


(a) (b)

Figure 1. **The stitched image of a cancer cell.** (a) Nine image blocks acquired. (b) The stitched result.

2. METHOD

The procedures of image acquisition and stitching are described as follows. First, the whole image space is divided into a set of uniform gird blocks as shown in Figure 2. The size of each overlap area was ranged 15%-20% of the image blocks. We then estimate the vertical and horizontal displacements for each image block to maximize the similarity of all overlaps. In this paper, we use the mutual information as the similarity of overlaps.[6] For an image block I_a, we align it to its two neighbors which are the horizontal and vertical neighbors (I_{b1} and I_{b2}) as shown in Fig. 3. We estimate the transformations and similarities between I_a and both neighbors respectively. The similarities then are used as the interpolation ratios to calculate the transformation of I_a by the linear interpolation. Because the center image block usually contains the most significant information, we choose the center image block to be the main reference and sequentially align other image blocks to it.

Notice that the overlapped area may contain insufficient features such that a wrong displacement estimated. Therefore, we bound the displacements in a limited range as shown in Fig. 4. If a displacement is out of the limited range, we replace it by the average of the displacements estimated from the other image pairs.

The multi-band image blending method[7] proposed by Burt and Adelson is applied to blend the overlaps. Finally, to correct the misalignment problem, we use the feature-based alignment method[5] that find the trajectories of features from all projections and align these trajectories to their best-fit sine curves.

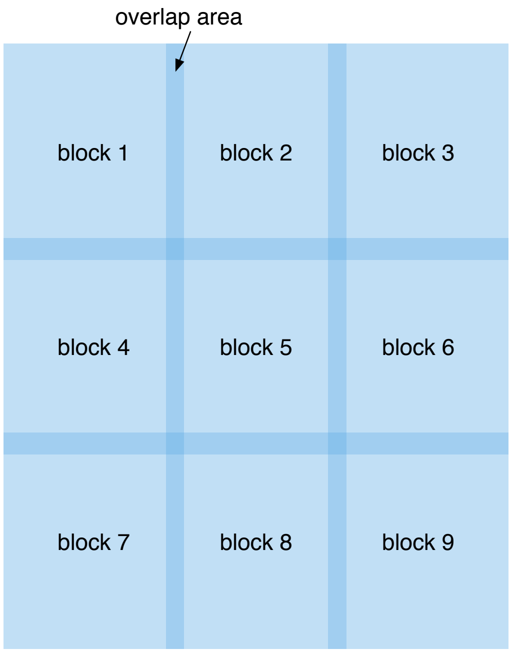


Figure 2. **The acquisition for a large image.** An example of 3 × 3 uniform image blocks. The label of each block represents the acquisition order. There is a small overlap (15% to 20%) between each adjacent blocks for alignment and stitching.

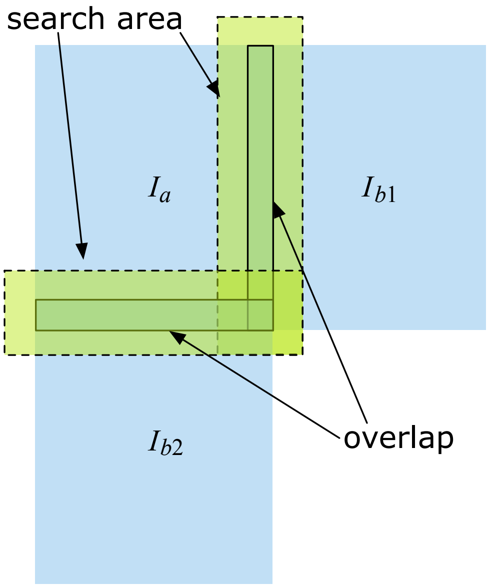


Figure 3. **The alignment of multiple references.** The transformation of I_a is estimated by linear interpolation from the transformations between I_a and all references (I_{b1} and I_{b2}).

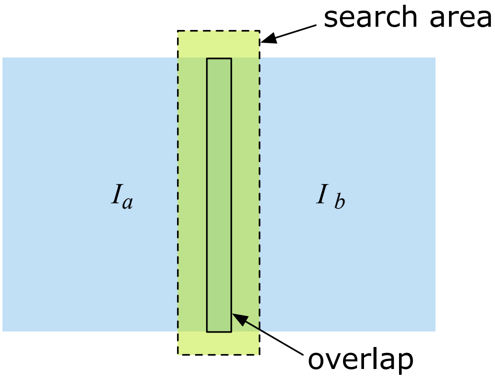


Figure 4. **The search area for alignment.** The alignment is bounded in a search area to avoid the divergent solution.

3. RESULTS

A volume data of phantom containing 512 imitative gold nanoparticles was constructed, and X-ray projections of the shifted volume were generated to simulate the machine vibration and the field-of-view limitation. Fig. 5(a) shows the simulated X-ray image of the phantom, in which 180 projections of 7 × 7 images of 512 × 512 pixels were generated. The rotation angle is 1° between successive projections and the ratio of overlaps was 20%. The amount of displacement of machine vibration was determined according to a random number uniformly distributed over the range ±10 pixels. Fig. 5(a) shows the image blocks of the first projection. The proposed stitching algorithm was used to combine the image blocks of each projection. Fig. 5(b) shows the stitch result of Fig. 5(a). The size of each stitched image was 3072 × 2866 pixels. The feature-based alignment algorithm[5] was then applied to correct the misalignment. Finally, the tomography reconstruction algorithm is applied to reconstruct the stitched images. The size of each reconstructed image was 3072 × 3072 pixels, and 2866 images were reconstructed. Fig. 6(a) shows the tomography result reconstructed by Tomo3D.[8] Fig. 6(b) shows the tomography result reconstructed by the filtered back projection algorithm.[9]

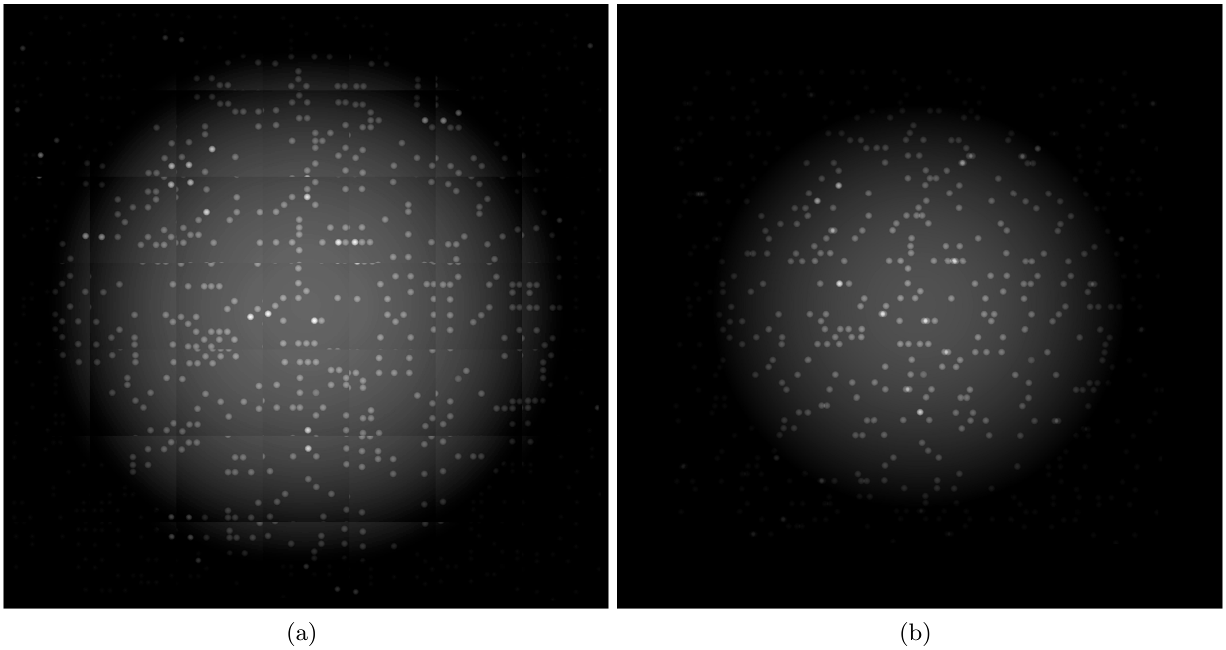
The following describes the run time statistics that were obtained by using Intel i7 3.4GHz, 12GB main memory, nVidia GTX760, and running Windows 8.1. The image stitching consumed 114 seconds per projection angle. The misalignment correction consumed 7023 seconds. The tomography reconstruction consumed 63.6 seconds per image. The total time was 11.5 hours.

Next, we applied the proposed method to a set of X-ray images of a kidney of a mouse, 180 projections of 3 × 3 images of 1600 × 1200 pixels. The rotation angle was 1° between successive projections and the ratio of overlaps was 15%. Fig. 7(a) shows the image blocks of the first projection. We then used the proposed stitching algorithm to combine the image blocks of each projection as shown in Fig. 7(b). The size of each stitched image was 4800 × 3600 pixels. Finally, we applied the feature-based alignment method to correct the misalignment algorithm and used tomography reconstruction method to generate a three-dimensional volume which contains 3600 tomographic images of 4800 × 4800 pixels. Fig. 7(c) shows the visualization result of the reconstructed volume.

4. CONLUSIONS AND FUTURE WORK

We proposed a method to reconstruct high-resolution tomographic volumes for the X-ray microscopy. We used the properties of the synchrotron radiation to enable the image stitching success even the size overlaps is small (15% to 20% of each image block). The phantom and real data set were tested to verify the proposed method.

For the large object tomographic reconstruction, the current hardware system is unable to support the proposed image stitching method when the resolution reaches to nanoscale because the control system of object holder was designed for single-image acquisition of one rotation, i.e., the position on X and Y axes cannot be


(a)

(b)

Figure 5. **Image stitching for the phantom.** (a) 7 × 7 image blocks of 512 × 512 pixels. (b) The stitched result.

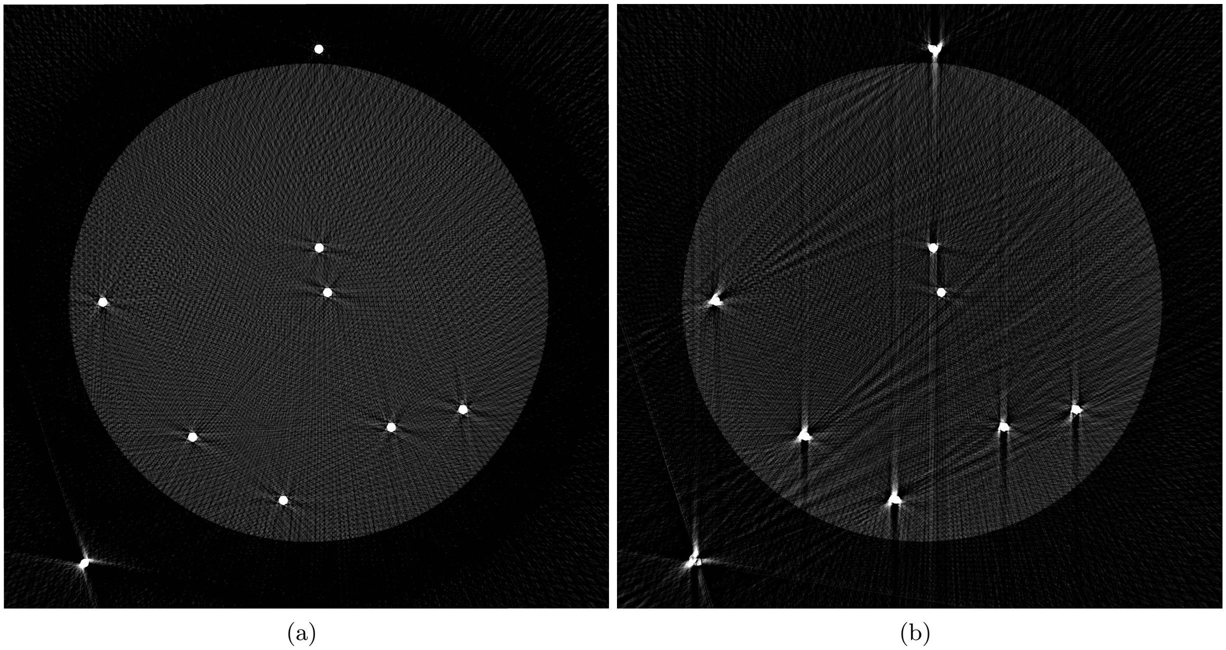

(a)

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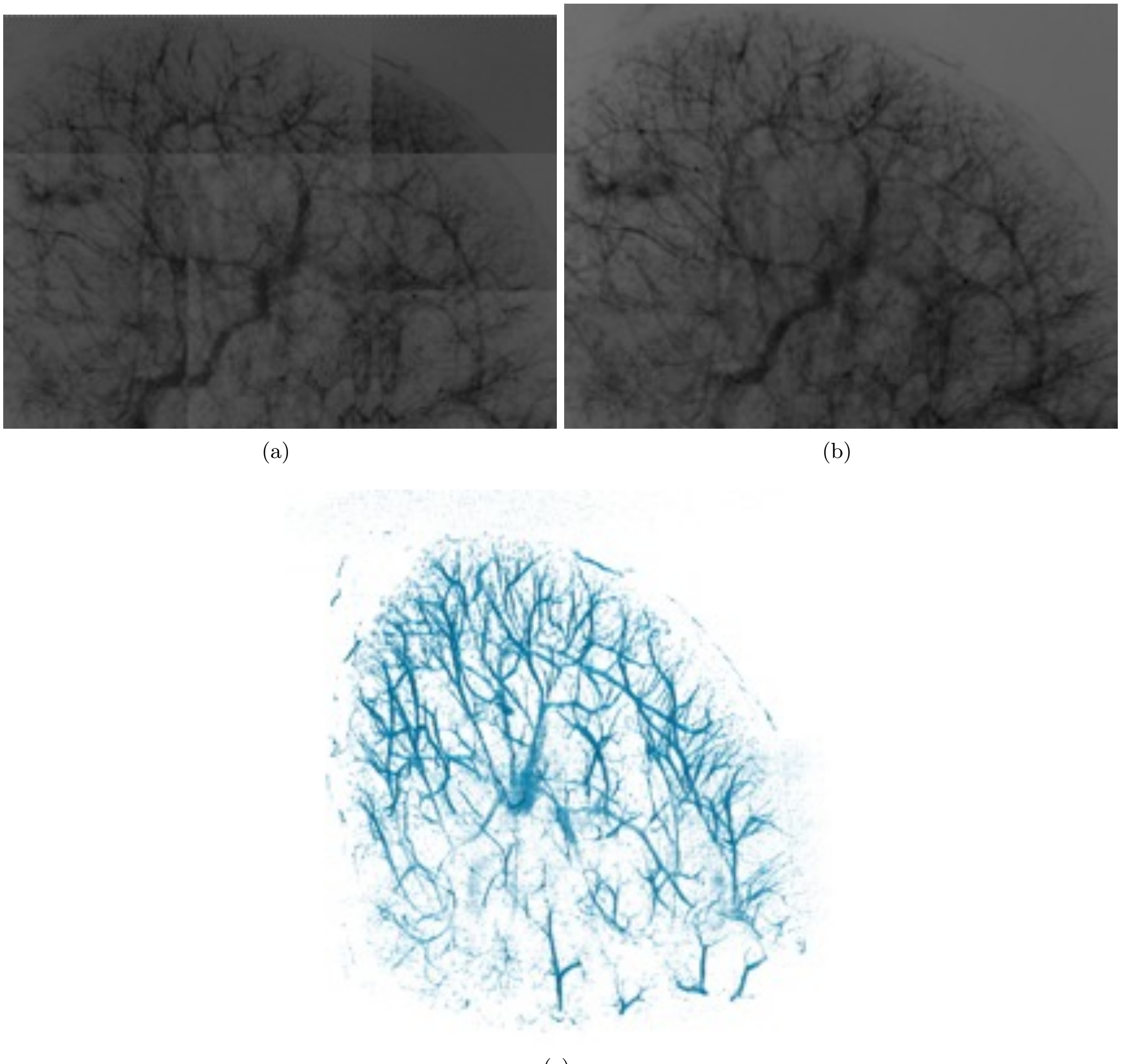
Figure 6. **The tomographic result reconstructed from the stitched images of phantom.** (a) A slice of volume data reconstructed by Tomo3D(SIRT). (b) A slice of volume data reconstructed by FBP



(a)

(b)

(c)

Figure 7. **Reconstruction for the mouse kidney.** (a) 3×3 image blocks of 1600×1200 pixels. (b) The result of stitching. (c) The result of tomographic reconstruction.

moved at each projection angle. Thus, a multiple-image acquisition of one rotation requires several manual operations and an unacceptable amount of time. For example, the acquisition of 5×5 images requires 2-3 hours. The manual operations also could lead a large position error. So far, the propose method is not applied to reconstruct a nanoscale data set for a real sample object.

Another problem is that the reconstruction of outer ring of volume cannot be done well. Both FBP and ART cannot successfully reconstruct the outer ring. This problem can be observed in the phantom data (Fig. 6(a) and 6(b)). There were several particles evenly distributed in the volume. The particles near the center can be reconstructed successfully. However, the particles near the boundary of volume cannot be reconstructed successfully . This problem is caused by the alignment error and large angle between projections. The misalignment correction method is required to be more accurate and the reconstruction algorithm is required to deal with the large projection angle.

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