Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 18-19, 2023

Tomosynthesis Reconstruction of Coin-Cell Battery by Weighted Filtered Back-projection

Jichan Kim, Heon Yong Jeong, Sung Oh Cho*
Dept. of Nuclear & Quantum Engineering, Korea Advanced Institute of Science & Technology, Daejeon, Republic of Korea, 34141
**Corresponding author: socho@kaist.ac.kr*

1. Introduction

Tomosynthesis is conventional imaging method which provides 2D sliced layer images of target material, which is still widely used in medical field such as mammography. Tomosynthesis has some novel properties such as relatively low dose, short exposure time, low cost and small device. One particular feature of tomosynthesis is it provides not only top view image but also the inner structural information in layer-wised form. Therefore it has an advantage on investigating the material or item with layered structure.

Performance of tomosynthesis reconstruction is highly affected by the algorithm. The most conventional ideas are Shift-and-add (SAA) algorithm and Point-by-point back-projection (BP) algorithm. Both algorithms share similar idea in reconstruction step to shift the projected image with regard to the displacement from original point-of-interest position. The major difference of two algorithm is that SAA shifts all projected image at once with respect to the center of plane-of-interest displacement, but BP shifts each pixel separately. It is known that BP gives better result than SAA. Nowadays, much advanced algorithms are suggested to improve the performance and quality of result image [1].

Thanks to good features stated above, tomosynthesis can be very useful tool to deal with layer structured items such as Coin-cell battery. Coin-cell battery is one of the most spotlighted item with some novel properties, and have simple layered structure. Research on the inner structure of Coin-cell battery used to perform by micro-CT which provide nice 3D images [2], but it has weakness of relatively high cost and long time. In this study, we will compare the performance of some basic and improved algorithms of tomosynthesis and take images of Coin-cell battery to give a clue that tomosynthesis can be an appropriate tool for Coin-cell research.

2. Method

2.1 Equipment and Materials

In this study, we used X-ray Tomosynthesis system coupled with optical lens, which have scintillator below target material so that internal structural information of the target becomes optical signal. This light is gathered by objective lens and tube lens to provide signal to sCMOS detector. Also, partial isocentric X-ray source with fixed detector is chosen as a system geometry.

This study consists of two parts. In the first section, JIMA Resolution Chart (RT RC-04) was used as a target material. In the latter section, Si nanoparticle layer coated on Cu layer was adopted to confirm the effect of tomosynthesis applied on Coin-cell anode material.

2.2 Tomosynthesis Algorithms

As we mentioned, the simplest Tomosynthesis algorithms are SAA and BP method. Only difference between them is shifting method. SAA algorithm shift all images projected on the sensor at once, with respect to the distance that the center of the Plane of interest is displaced. Unlikely, BP algorithm reconstruct each POI respectively, so the shifting displacements are different for all points on the Plane of interest. In general, BP is known to show better result. However, both algorithms do not include additional calculation before forward projection or after reconstruction, which can give merit in terms of resolution and contrast.

2.2.1. Filtered Back-projection (FBP)

FBP is algorithm with applying 'filter' on image projected on target. Filter is mathematically defined by convolution of some appropriate function. Various filters are suggested already but Ram-Lak filter is the most widely used as a high-pass filter and Hann filter as a low-pass filter [3]. Definition of Ram-Lak filter and Hann filter are given in equation (1) and (2).

$$\mathrm{H}_1(\omega) = \begin{cases} |\omega| & where\ |\omega| < K_1 \\ 0 & otherwise \end{cases} \quad (1)$$

$$\mathrm{H}_2(\omega) = \begin{cases} 0.5\left(1 + \cos\left(\frac{\pi\omega}{K_2}\right)\right) & where\ |\omega| < K_2 \\ 0 & otherwise \end{cases} \quad (2)$$

Convolution of two filters work as a filter with function of both filters. In particular, it was suggested that convolution of Ram-Lak filter and Hann filter give benefit to reduce the background noise and cutting off the error peak at once. In this study, we followed this idea to use the composition of two filters, which is the form of $H=(H_1H_1^T)(H_2H_2^T)$, where H_1 and H_2 are from (1) and (2), and cross product is for expansion of filter from 1D form to 2D form [4].

2.2.2. Weighted Back-projection (Weighted BP)

Another idea for BP method is giving weight while reconstruction. During the forward projection, ray from the source pass through each imaginary voxel of target material in different path length. Also, the backward projection of pixel on the sensor plane which the projected ray reaches may not be exactly same to the pixel on the plane of interest. Therefore reconstruction should not be done point-wisely, but the path length through each voxel and area of imaginary projected pixel should be considered by giving some weight on each point [5]. For the earlier case, we call the path length a 'line weighting factor', and for the latter case we call the portion of area a 'plane weighting factor'.(Fig. 1)

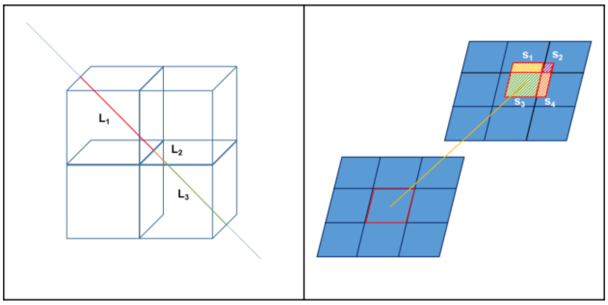

Fig. 1. Line Weighting Factor and Plane Weighting Factor.

In this study, we did not apply simple weighted BP algorithm but used algorithm which apply both filter and weighting factor. Two method is compatible since filtering and weighting occur sequentially. We will call this weighted FBP later on this article.

3. Results and Discussion

As already mentioned, this study was proceeded in 2 steps. In the first section, we used JIMA Resolution Chart as a target material. In the first experiment of section 1, we compared the images made by SAA, BP, and FBP algorithms with Signal-to-noise (SNR) ratio calculation on some sample area [6]. Definition of SNR is expressed in equation (3).

$$(SNR = \mu_{ROI}/\sigma_{ROI}) \quad (3)$$

In the equation, μ_{ROI} is mean of signals of voxels in the region of interest and σ_{ROI} is standard deviation of signals. In the second experiment of the first section, FBP, line weighted FBP, and plane weighted FBP were conducted.

In the latter section, we took Si anode layer image by FBP and weighted FBP. Original top view image and optical image are also provided to observe the original structure of Si anode layer.

3.1 JIMA Resolution Chart imaging

In the first experiment, we applied SAA, BP, and FBP algorithms on JIMA Resolution Chart imaging. The result image is shown in Fig. 2.

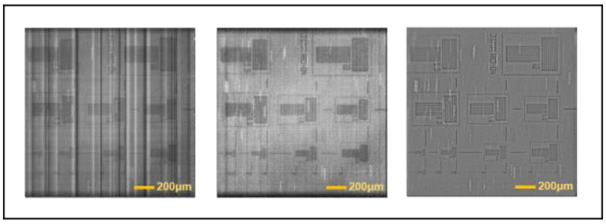

Fig. 2. From the left, SAA, BP, and FBP image respectively.

Comparing result images, we can observe that SAA result image shows relatively low contrast and resolution with vivid vertical line errors. BP image shows relatively clearer image than SAA as known already. FBP reconstructed image shows the best contrast among them.

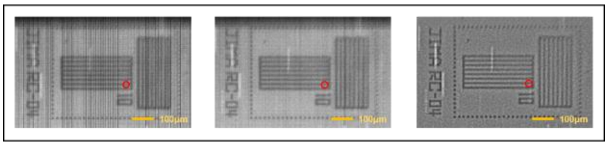
Fig. 3. Sample area for SNR ratio calculation, 10μm JIMA focused image.

To compare the result quantitatively, we picked some sample place to get SNR ratio to confirm the result image clearly distinguish the target and background. SNR ratio of those algorithms were 2.54, 2.62, and 2.69 respectively, which support the conclusion that FBP provides better image than SAA and BP algorithms.

Next we had an image of same JIMA Resolution Chart with 7μm area focused, which is reconstructed by FBP, line weighted FBP, and plane weighted FBP algorithms respectively. The result image is shown in Fig. 4. For clear contrast, 10 times magnified images with SNR ratio sample area is provided in Fig. 5.

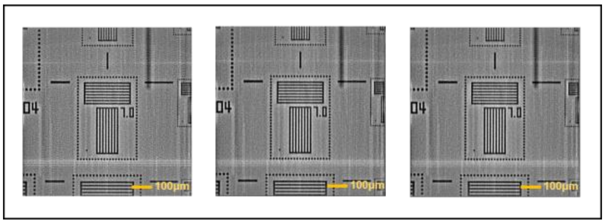
Fig. 4. From the left, FBP, line weighted FBP, and plane weighted FBP image respectively.

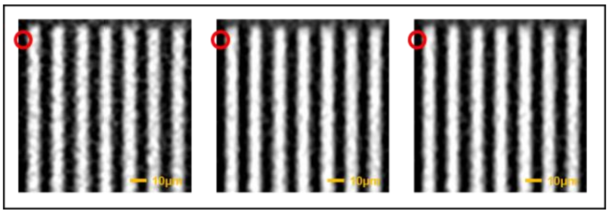

Fig. 5. Center-focused image of 7μm JIMA.

It is hard to tell the resolution and contrast difference of three images in Fig. 4, but it is shown that FBP image is dimmer and blurrier than others in Fig. 5. The SNR ratio results are 2.70, 3.31, and 3.35 respectively, which also support the idea that weighted FBP shows better result than simple FBP, regardless the weighting method we select.

3.2 Si Anode imaging

Experiments of the second section are performed with Si layer coated on Cu layer of thickness 10μm. In the first experiment, we used bare Si layer without any scratch on the surface. Result images are given in Fig. 6.

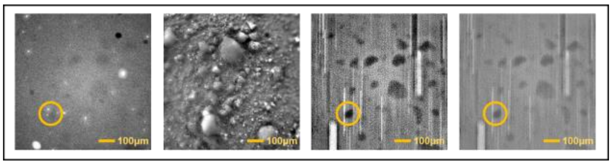

Fig. 6. From the left, original, optical, FBP reconstructed, and weighted FBP reconstructed image respectively.

In the optical image of Fig. 6, we can observe some loaves of Si nanoparticles which are not separated evenly on the surface. We can also observe some blurry features of aggregation of Si nanoparticles in the original image. In FBP and weighted FBP images, the black spot of loaves become more distinguishable than original one. SNR ratio for the three images with respect to the yellow circled regions are 3.78, 3.28, and 4.33 respectively. SNR ratio of FBP image is relatively small even though it shows clear black spots. The reason is white and black vertical lines on the images, which are reconstruction error made from the white and black spots of the original image. Otherwise, SNR ratio of weighted FBP image is rather high since it kills out the vertical line errors well.

In this section, we confirmed that it is able to observe anode surface structure with tomosynthesis, including the gathering of Si nanoparticles. We expect to get the better reconstruction image with more advanced tools and algorithms.

4. Conclusions

In this study, we tested several algorithms of tomosynthesis such as SAA, BP, FBP, and weighted FBP, and among them weighted FBP showed the best result in terms of SNR ratio. Moreover, we were able to observe the surface structure of Si coated layer, which is used as an anode material of Coin-cell battery. FBP and weighted FBP reconstruction image showed the aggregation of Si nanoparticles much better than the simple top view image. We expect that tomosynthesis can be helpful to see through the inner structure of Coin-cell, in much practical manner, with some advanced methodology.

REFERENCES

[1] Y. Chen, J. Y. Lo, J. T. Dobbins, Importance of point-by-point back projection correction for isocentric motion in digital breast tomosynthesis: relevance to morphology of structures such as microcalcifications, Medical Physics, Vol. 34, No. 11, p. 3885-3892, 2007.

[2] C. Tan, S. R. Daemi, O. O. Taiwo, T. M. M. Heenan, D. J. L. Brett, P. R. Shearing, Evolution of Electrochemical Cell Designs for In-Situ and Operando 3D Characterization, Materials, Vol. 11, No. 11, p. 2157-2172, 2018.

[3] M. Lyra, A. Ploussi, M. Rouchota, S. Synefia, Filters in 2D and 3D Cardiac SPECT Image Processing, Cardiology Research and Practice, Vol. 2014, 2014.

[4] H. H. Lee, Y. S. Kim, Y. J. Lee, S. H. Choi, S. W. Lee, H. S. Park, H. J. Kim, J. G. Choi, Y. W. Choi, A Study of Various Filter Setups with FBP Reconstruction for Digital Breast Tomosynthesis, PROGRESS in MEDICAL PHYSICS, Vol. 25, No. 4, p. 271-280, 2014.

[5] M. Heyndrickx, T. Bultreys, W. Goethals, L. V. Hoorebeke, M. N. Boone, Improving image quality in fast, time-resolved micro-CT by weighted back projection, Scientific Reports, Vol. 10, 2020.

[6] D. H. Lee, S. W. Lee, B. Y. Kim, D. B. Yim, K. B. Nam, J. H. Cho, Analysis of Image Quality According to Imaging Parameters in Digital Tomosynthesis, Journal of Korean Society of Radiology, Vol. 14, No. 4, p. 477-485, 2020.