Published in final edited form as:

Proc SPIE Int Soc Opt Eng. 2010 ; 7622: 76220H. doi:10.1117/12.844295.

Multi-beam X-ray source breast tomosynthesis reconstruction with different algorithms

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Abstract

Digital breast tomosynthesis is a new technique to improve the early detection of breast cancer by providing three-dimensional reconstruction volume of the object with limited-angle projection images. This paper investigated the image reconstruction with a standard biopsy training breast phantom using a novel multi-beam X-ray sources breast tomosynthesis system. Carbon nanotube technology based X-ray tubes were lined up along a parallel-imaging geometry to decrease the motion blur. Five representative reconstruction algorithms, including back projection (BP), filtered back projection (FBP), matrix inversion tomosynthesis (MITS), maximum likelihood expectation maximization (MLEM) and simultaneous algebraic reconstruction technique (SART), were investigated to evaluate the image reconstruction of the tomosynthesis system. Reconstructed images of the masses and micro-calcification clusters embedded in the phantom were studied. The evaluated multi-beam X-ray breast tomosynthesis system is able to generate three-dimensional information of the breast phantom with clearly-identified regions of the masses and calcifications. Future study will be done soon to further improve the imaging parameters' measurement and reconstruction.

Keywords

mammography; tomosynthesis; carbon-nanotube; back projection (BP); filtered back projection (FBP); matrix inversion tomosynthesis (MITS); maximum likelihood expectation maximization (MLEM); simultaneous algebraic reconstruction technique (SART)

1. Introduction

Tomosynthesis has been investigated for a few different clinical applications, such as chest imaging, arthritis imaging, dental imaging ^[1], etc. Recently, tomosynthesis technique has been spread into a large variety of biomedical communities ^[1], including research on breast

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cancer detection. Digital tomosynthesis typically acquires two-dimensional limited-angle projection images and reconstructs three-dimensional image volume based on image reconstruction algorithms.

In breast imaging fields, mammography is currently a standard clinical screening and diagnosis tool for breast cancer detection [2]. Quite a few limitations exist [3, 4], such as recall rates and false negative rates, which bring unnecessary anxiety and increase the medical costs. With traditional two-dimensional digital mammography technique, three-dimensional object information is projected onto the detector to generate the two-dimensional images. Overlapped anatomical structures will be shown as superimposed. Breast Tomosynthesis technique overcomes this limitation by providing three-dimensional volume of objects. Compared to the standard mammography technique, breast tomosynthesis enhances the diagnosis by removing the ambiguities of overlapped tissues and providing the depth information. Therefore, it is promising to reduce recall rates, to improve the biopsy selection of patients, and to increase cancer detection accuracy [3].

Although breast tomosynthesis has not been approved by FDA as of yet, extensive attention from academic communities and industrial vendors have been paid to this promising field [1, 3]. The typical breast tomosynthesis prototype systems acquire projection images with the x-ray tube moving along an arc path. This kind of implementation can reutilize the traditional mammography equipments, decrease the cost and reduce the training procedure for the operators. However, the x-ray tube's movement may introduce blur [5] to tomosynthesis images and cause patients' discomfort.

Recently, a novel multi-beam X-ray source, developed by Zhou et al. [6-8], has been investigated for breast tomosynthesis applications. The breast tomosynthesis system was built up with fixed multi-beam field-emission X-ray (MBFEX) sources based on unique properties of carbon nanotube electron emitters [7]. Parallel imaging configuration was applied to multi-beam x-ray system design where the path of the x-ray tube lies in a plane that is parallel to the detector plane [9]. Compared with commercial prototype systems, it increases the tomosynthesis imaging speed with simplified system design. With the fast-speed imaging and fixed x-ray sources, it shows great potentials to reduce patients' discomfort and the motion blur associated with x-ray tube's movement of typical prototype systems.

With tomosynthesis technique, two-dimensional projection images are acquired first. Reconstruction algorithms are designed to achieve three-dimensional image volume. A few image reconstruction algorithms have been investigated by various research groups, including Niklason's image stretching method [4], back projection (BP) reconstruction algorithm [10], filtered back projection (FBP) algorithm [11-15], maximum likelihood expectation maximization (MLEM) [16-18], matrix inversion tomosynthesis (MITS) [1, 19, 20], simultaneous algebraic reconstruction techniques (SART) [21, 22], tuned-aperture computed tomography (TACT) reconstruction methods [23, 24], etc. FBP and MITS apply deblurring algorithms to enhance the contrast and sharpness so increase the conspicuity [5]. MLEM acquires the reconstruction results by maximizing the likelihood with the measured

projection images on the detector and assuming Poisson distribution model [17]. SART solve the liner equations of x-ray attenuation [22].

In our SPIE 2009 paper [9], we reported the preliminary tomosynthesis reconstruction study of a simple phantom. In this paper, we present our further investigations of image reconstruction with bigger number of projection images and wider view angle. Different reconstruction algorithms, including BP, FBP, MLEM, MITS and SART are evaluated in this paper.

2. Methods

The novel multi-beam X-ray source developed by Zhou et al. [6-8] was used to generate the tomosynthesis projection images. Figure 1 shows the tomosynthesis system with parallel-imaging geometry. Fixed multi-beam field-emission X-ray (MBFEX) sources were aligned up along a straight line that is parallel to the detector plane. For our preliminary experiments, the source to image distance (SID) was 680.2 mm. θ represents the view angle. Corresponding imaging parameters are listed in Table 1. Twenty-five projection images with the size of 1920×1536 were acquired with the system in this paper. The pixel size was 0.127 mm. The reconstruction slice thickness was 1mm.

A standard breast biopsy training phantom [25] (CIRS company) was used in this preliminary experiment. Solid masses and two micro-calcification clusters inside the phantom were considered as the targets of evaluation. Figure 2 shows a picture of the original biopsy phantom.

A series of low-dose projection images of the biopsy training breast phantom were acquired and reconstructed by different algorithms. To evaluate the tomosynthesis imaging of the breast phantom, 25 projection images at a total exposure of 100 mAs (4mAs/projection) were obtained. Figure 3 shows the low dose middle (0°) projection image of the training phantom acquired by the tomosynthesis system. Five representative algorithms including back projection (BP), filtered back projection (FBP), matrix inversion tomosynthesis (MITS), maximum likelihood expectation maximization (MLEM) and simultaneous algebraic reconstruction technique (SART) were investigated to generate reconstruction images.

Shift-And-Add (SAA) algorithm was the common mathematical reconstruction algorithm [1], and it lines up each projection image in term of its relative shift amount to acquire the reconstructed slice at the specified depth. Back-Projection reconstruction (BP) is quite similar, but it improves the image quality of the reconstructed volume by taking into account shift amounts of each pixel location on every reconstructed slice [10]. Many reconstruction algorithms take SAA and BP as their foundation for further deblurring [10]. Both MITS and FBP are fast-speed reconstruction methods with enhanced image contrast and sharpness with deblurring algorithms to remove out-of-plane blur: FBP applied filters to reconstruct from transformed projection images [5], and MITS used SAA to compute matrix inversion deblurring of each reconstructed slice [5].

MLEM and SART are time-consuming methods with large size of the breast image volume. Both of them compute the attenuation when the projection line passes through the voxel in reconstruction volume. Ray-tracing method was used to calculate the length of the path when the projection line penetrates the voxel. The iteration number is 8 for our accelerated MLEM^[26] and 1 for SART to be consistent with the literature^[17, 22].

3. Results

Five representative tomosynthesis reconstruction algorithms were investigated in this paper, including back projection (BP), filtered back projection (FBP), matrix inversion tomosynthesis (MITS), maximum likelihood expectation maximization (MLEM) and simultaneous algebraic reconstruction technique (SART). Figure 4 shows the reconstructed regions of interest (ROI) of a mass ($z=81\text{mm}$ away from the detector) with above five algorithms correspondingly. Figure 5 shows the ROI of a reconstructed micro-calcification cluster ($z=74\text{mm}$ away from the detector) inside the phantom.

All the investigated five reconstruction algorithms were capable to provide three-dimensional information and z -depth location of the breast phantom. FBP and MITS reconstructions show clearly-captured edge information of the mass (Figure 4b, 4c) and good reconstruction of the calcifications (Figure 5b, 5c).

Due to limitations of the detector and imaging parameters measurement at current stage, one can see some stripe artifacts on reconstructed ROIs. BP, FBP and MITS can tolerate this kind of inaccuracy by showing relatively smooth reconstructed images. With the iterative MLEM and SART techniques, the reconstructions are sensitive to the limitations. In order to remove the stripe artifacts, a 5×5 mean filter was applied to the reconstructed mass with MLEM and SART ROIs (Figure 4d and 4e) and a Band-pass filter was applied to the reconstructed micro-calcifications in Figure 5d and 5e as an initial trial. Further work is undergoing to improve the detector and imaging parameters measurement.

4. Conclusions

Digital breast tomosynthesis has been demonstrated as promising for breast cancer detection. The novel carbon-nanotube technology based multi-beam X-ray source breast tomosynthesis system shows great potentials in improving the imaging resolution and reducing patients' discomfort^[7, 8]. This paper presents our recent study on image reconstruction with 25 projections images and improved X-ray breast tomosynthesis system.

The investigated breast phantom reconstruction study demonstrates that this novel parallel-geometry multi-beam x-ray tomosynthesis system has great clinical potentials. All five investigated algorithms are capable to reconstruct the embedded masses and micro-calcifications by showing edge, shape and three-dimensional location information. FBP and MITS can tolerate the detector and measurement inaccuracy. Although the current detector and measurement limitations influenced the reconstruction results of MLEM and SART, they are still successful in discerning the objects.

Further investigations will be done soon to investigate deblurring filters of FBP and MITS to improve the conspicuity of small objects, such as micro calcifications, and to optimize the reconstruction and system.

Acknowledgments

We thank Dr. James T. Dobbins III at Duke University Medical Center for helpful discussion. This work is supported by our grant NIH/NCI R01 CA134598-01A1.

References

1. Dobbins JT III, Godfrey DJ. Digital X-ray tomosynthesis: current state of the art and clinical potential. *Phys Med Biol.* 2003; 48:65–106.
2. Nass, SJ.; Henderson, IC.; Lashof, JC. *Mammography and Beyond: Developing Technologies for the early Detection of Breast Cancer.* National Academy Press; Washington, DC: 2001.
3. Park JM, Franken EA Jr, Garg M, Fajardo LL, Niklason LT. Breast tomosynthesis: present considerations and future applications. *Radiographics.* 2007; 27(Suppl 1):S231–240. [PubMed: 18180229]
4. Niklason LT, Christian BT, Niklason LE, Kopans DB, Castleberry DE, Opsahl-Ong BH, Landberg CE, Slanetz PJ, Giardino AA, Moore RH, Albagi D, DeJule MC, Fitzgerald PA, Fobare DF, Giambattista BW, Kwasnick RF, Liu J, Lubowski SJ, Possin GE, Richotte JF, Wei CY, Wirth RF. Digital tomosynthesis in breast imaging. *Radiology.* 1997; 205:399–406. [PubMed: 9356620]
5. Chen, Y. Ph D dissertation. Duke University; 2007. Digital breast tomosynthesis (DBT) - a novel imaging technology to improve early breast cancer detection: implementation, comparison and optimization.
6. Zhang J, Yang G, Lu JP, Zhou O. Multiplexing radiography using a carbon nanotube based x-ray source. *Applied Physics Letter.* 2006; 89:064106.
7. Lalush, DS.; Quan, E.; Rajaram, R.; Zhang, J.; Lu, JP.; Zhou, O. Tomosynthesis reconstruction from multi-beam x-ray sources. *Proceedings of 2006 IEEE International Symposium on Biomedical Imaging;* 2006. p. 1180-1183.
8. Yang G, Rajaram, Cao G, Sultana S, Liu Z, Lalush D, Lu JP, Zhou O. Stationary digital breast tomosynthesis system with a multi-beam field emission x-ray source array. *Proc SPIE.* 2008; 6913:69131A.
9. Chen Y, Zhou W, Yang G, Lu J, Zhou O. Breast tomosynthesis reconstruction with a multi-beam x-ray source. *Proc SPIE.* 2009; 7258:725859–8.
10. Chen Y, Lo JY, Dobbins JT III. Importance of point-by-point back projection (BP) correction for isocentric motion in digital breast tomosynthesis: Relevance to morphology of microcalcifications. *Med Phys.* 2007; 34(10):3885–3892. [PubMed: 17985634]
11. Mertelemeier T, Orman J, Haerer W, Dudam MK. Optimizing filtered backprojection reconstruction for a breast tomosynthesis prototype device. *Proc SPIE.* 2006; 6142:131–142.
12. Stevens GM, Fahrig R, Pelc NJ. Filtered backprojection for modifying the impulse response of circular tomosynthesis. *Med Phys.* 2001; 28:372–380. [PubMed: 11318319]
13. Lauritsch G, Haerer W. A theoretical framework for filtered back-projection in tomosynthesis. *Proc SPIE.* 1998; 3338:1127–1137.
14. Matsuo H, Iwata A, Horiba I, Suzumura N. Three-dimensional image reconstruction by digital tomosynthesis using inverse filtering. *IEEE Trans Med Imaging.* 1993; 12:307–313. [PubMed: 18218419]
15. Chen Y, Lo JY, Baker JA, Dobbins JT III. Gaussian frequency blending algorithm with Matrix Inversion Tomosynthesis (MITS) and Filtered Back Projection (FBP) for better digital breast tomosynthesis reconstruction. *Proc SPIE.* 2006; 6142:122–130.
16. Lange K, Carson R. EM reconstruction algorithms for emission and transmission tomography. *Journal of Computer Assisted Tomography.* 1984; 8:306–316. [PubMed: 6608535]

17. Wu T, Stewart A, Stanton M, McCauley T, Phillips W, Kopans DB, Moore RH, Eberhard JW, Opsahl-Ong B, Niklason L, Williams MB. Tomographic mammography using a limited number of low-dose cone-beam projection images. *Med Phys.* 2003; 30:365–380. [PubMed: 12674237]
18. Wu T, Moore RH, Rafferty EA, Kopans DB. A comparison of reconstruction algorithms for breast tomosynthesis. *Med Phys.* 2004; 9:2636–2647. [PubMed: 15487747]
19. Dobbins, JT, III. Matrix Inversion Tomosynthesis improvements in longitudinal x-ray slice imaging. U.S. Patent #4,903,204. 1990. Assignee: Duke University
20. Chen, Y.; Lo, JY.; Dobbins, JT, III. Matrix Inversion Tomosynthesis (MITS) of the Breast: Preliminary Results. Radiological Society of North America (RSNA) 90th Scientific Assembly; December; Chicago, IL. 2004.
21. Andersen AH, Kak AC. Simultaneous algebraic reconstruction technique (SART): a new implementation of the ART algorithm. *Ultrasound Imaging.* 1984; 6:81–94.
22. Zhang Y, Chan H, Sahiner B, Wei J, Goodsitt MM, Hadjiiski LM, Ge J, Zhou C. A comparative study of limited-angle cone-beam reconstruction methods for breast tomosynthesis. *Med Phys.* 2006; 33(10):3781–3795. [PubMed: 17089843]
23. Suryanarayanan S, Karellas A, Vedantham S, Glick SJ, D'Orsi CJ, Webber RL. Comparison of contrast-detail characteristics of tomosynthetic reconstruction techniques for digital mammography. *Radiology.* 1999; 213:368–369.
24. Suryanarayanan S, Karellas A, Vedantham S, Baker SP, Glick SJ, D'Orsi CJ, Baker SP, Webber RL. Evaluation of linear and nonlinear tomosynthetic reconstruction methods in digital mammography. *Acad Radiol.* 2001; 8:219–224. [PubMed: 11249085]
25. CIRS Company. Available at: <http://www.cirsinc.com/pdfs/013cp.pdf>
26. Zhou W, Balla A, Chen Y. Breast tomosynthesis reconstruction using an accelerated maximum likelihood expectation maximization algorithm with improved data structure based on sparse matrix. *International Journal of Functional Informatics and Personalised Medicine.* 2008; 1(4):16–27.

Figure 1.
Tomosynthesis system with parallel-imaging geometry.

Figure 2.
Breast biopsy training phantom.

Figure 3.
Low exposure middle (0°) projection image of the breast phantom.

Figure 4. Reconstructed ROIs of a mass ($z=81\text{mm}$) with different algorithms including: (a) BP, (b) FBP, (c) MITS, (d) MLEM, (e) SART.

Figure 5. Reconstructed ROIs of a micro-calcification cluster ($z=74\text{mm}$) with different algorithms including: (a) BP, (b) FBP, (c) MITS, (d) MLEM, (e) SART.

Table 1

Imaging parameters of tomosynthesis phantom experiment.

SID	680.2mm
Projection Image Size	(1920, 1536)
Pixel Size	0.127mm
View Angle θ	48°
Number of Projection Images	25
Reconstruction Slice Thickness	1mm