Impulse Response Characterization of Breast Tomosynthesis Reconstruction with Parallel Imaging Configurations

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ABSTRACT

Early detection, diagnosis, and suitable treatment are known to significantly improve the chance of survival for breast cancer (BC) patients. To date, the most cost effective method for screening and early detection is mammography, which is also the tool that has demonstrated its ability to reduce BC mortality. Tomosynthesis is an emerging technology that offers an alternative to conventional two-dimensional mammography. Tomosynthesis produces three-dimensional (volumetric) images of the breast that may be superior to planar imaging due to improved visualization. In this paper we examined the effect of varying the number of projections (N) and total view angle (VA) on the shift-and-add (SAA), back projection (BP) and filtered back projection (FBP) image reconstruction response characterized by impulse response (IR) simulations. IR data were generated by simulating the projection images of a very thin wire, using various combinations of VA and N. Results suggested that BP and FBP performed better for in-plane performance than that of SAA. With bigger number of projection images, the investigated reconstruction algorithms performed the best by obtaining sharper in-focus IR with simulated parallel imaging configurations.

Keywords: mammography, tomosynthesis, shift-and-add (SAA), back projection (BP), filtered back projection (FBP), impulse response (IR).

1. INTRODUCTION

Breast cancer is the most prevalent cancer among women and affects approximately one million women worldwide. Breast cancer accounts for 30 per cent of all female cancers in USA and approximately 1 in 9 women in USA will get breast cancer sometime during their lifetime. Men can also develop breast cancer [1-6]. It is universally accepted that mammography is the most efficient tool for the early detection of breast cancer. Mammography is a specific type of imaging that uses a low-dose x-ray system to examine breasts [13]. Because of the low quality of the images and low degree of accuracy during the 1930s, most investigators were discouraged from pursuing mammography [2]. However, a few researchers still continued the study of mammography in diagnosis of breast cancer, including Gershon-Cohen [7,8,9], Albert Strickler[7], Helen Ingleby[8], Charles Gros and R. Sigrist[10], and Raul Leborgne[11,12].

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Digital tomosynthesis refers to a new technique that provides three-dimensional images of the object with high detailed resolution based on the finite number of projection images \[13\]. Digital breast tomosynthesis offers a number of exciting opportunities including the possibility of reduced breast compression, improved diagnostic and screening accuracy, 3-D lesion localization and enhanced 3-D imaging. The goal is to provide 3D information at the same high resolution and reasonable dose as mammography \[13\]. Since the system will be based on digital mammography, it will also be faster and cheaper than alternatives requiring dedicated equipment such as CT and MRI. For these reasons, breast tomo may be first technique that can actually replace mammography in the near future, providing improved sensitivity and specificity of the breast cancer diagnosis. The radiation dose is relatively low for each projection image, while the total radiation dose to acquire all the projection images of a tomosynthesis sequence is equivalent to or slightly higher than that in the standard single-view mammography.

Breast tomosynthesis is built on the full field digital mammography (FFDM) framework, which offers an alternative to conventional two-dimensional mammography \[13-21\]. By adopting suitable image reconstruction algorithms, it is capable to reconstruct three-dimensional information of the breast. Most of current available breast tomosynthesis prototype systems utilize a partial-isocentric imaging configuration, where the X-ray tube moves along an arc above the compressed breast. Recently a novel multi-beam X-ray source has been developed \[24\] that uses a parallel imaging configuration. It has great potentials to improve image resolution and reduce imaging acquisition time.

There are a variety of tomosynthesis reconstruction algorithms, including the image-stretching method by Niklason and colleagues, maximum likelihood iterative algorithm by Wu et al \[20,21\], tuned –aperture computed tomography(TACT) reconstruction methods developed by Webber and investigated by Suryanarayanan \[31,32,33\], algebraic reconstruction techniques (ART) \[22\], filtered back projection (FBP) \[26,27,28\], matrix inversion tomosynthesis (MITS) \[17,29\].

In breast tomosynthesis, several imaging parameters including the number of projections and view angle are important. The selection of optimal acquisition parameters and reconstruction algorithm plays an important role in producing better performance. In this paper we will examine the effect of varying the number of projections (N) and total view angle (VA) with three different reconstruction algorithms based on impulse response characterization. The tomosynthesis data used for this study were images generated by computer simulations. Three algorithms including shift-and-add method (SAA) \[25\], back projection (BP) \[15\] and filtered back projection (FBP) \[26-28\] were studied and compared.

Future work will be done soon to investigate other reconstruction algorithms such as iterative algorithms with a similar method, and to compare parallel-imaging configuration with other non-parallel imaging configurations.

## 2. METHODS

Computer simulation study was done to see how above reconstruction algorithms differ from each other based on the impulse response characterization. To evaluate the effects of variation in VA and N, 11, 25 and 49 projection images of a very thin wire running horizontally through the image space, whose depth varies from z=10 mm to z= 40 mm from left to right were simulated \[29\]. Imaging geometry of a novel x-ray source based on carbon nanotube technology \[24\] was used for simulation. Figure 1 shows the parallel-imaging geometry of the tomosynthesis system. Simulated horizontal acquisition allowed the generation of the noise-free projection images that contained only a single impulse for each column in the image. The wire is placed on the detector with an angle \(\theta = 45^\circ\). The source to image distance (SID) was 687 mm. The detector area was 19.5 x 24.4 cm with a pixel pitch of 127 \(\mu\)m. With a computer of 1.86 GHz CPU and 3GB limited memory size, it takes less than 2 minutes to generate reconstruction planes.

The above three representative algorithms were then implemented with simulated tomosynthesis datasets to reconstruct images with a reconstruction plane spacing of 1 mm. Normalized in-plane and out-of-plane pixel intensities in the spatial domain were analyzed for evaluation.
Figure 2 and figure 3 show the impulse response three-dimensional performance with different imaging configurations and reconstruction algorithms. Figure 2 shows the impulse response performance of the imaging configurations with narrow view angle of VA=25°, N=11 and VA=25°, N=49. Figure 3 shows the impulse response three-dimensional performance for wider view angle VA=50°, N=11 and VA=50°, N=49 respectively. Plots (a) and (b) show the performance with SAA reconstruction algorithms. Plots (c) and (d) represent the BP reconstruction results. Plots (e) and (f) show the FBP results correspondingly.

For all plots, normalized pixel intensities in the spatial domain are displayed as the three-dimensional IR plots [29]. The x axis represents the sequential numbers of the reconstruction planes that are parallel to the detector surface plate as described in figure 1. The y axis represents the pixel locations of the column containing simulated wire on the reconstruction plane that is located at the center of the simulated wire space (the wire spreads from z=10 mm through z=40 mm. The center is 25 mm away from the detector face plate). The z axis represents normalized pixel’s intensities equal to it’s gray scale value.

One can see that with smaller number of projection images, out-of-plane artifacts are obvious in all N=11 images by showing strong tails along x axis in figures 2a, 2c, 2e, 3a, 3c, 3e. With a bigger number of projection images of N=49, the out-of-plane are suppressed to a much lower level and sharper in-plane peak performance occurs, as shown in figs 2b, 2d, 2f, 3b, 3d, 3f. With wider angle of VA=50°, the out-of-plane IR tails spread to a wider angle correspondingly (fig. 2b vs fig 3b, fig. 2d vs fig 3d, fig. 2f vs fig 3f). BP and FBP show sharper in-plane impulse response in all cases investigated. There is no obvious difference observed between BP and FBP. With an increasing number of reconstruction planes we get even more sharper in-plane focus.
Fig 2. SAA, BP, FBP reconstructions for (VA=25°, N=11, NP=9) and (VA=25°, N=49,NP=47). NP represents the number of reconstruction planes.
Fig 3. SAA, BP, FBP reconstructions for $(VA=50^\circ, N=11, NP=9)$ and $(VA=50^\circ, N=49, NP=47)$
4. CONCLUSIONS

We found that, with parallel-imaging configuration, BP and FBP were always better than SAA for in-plane response and removal of out-of-plane blur artifacts. BP and FBP were similar in cases examined. When number of projection images increases, algorithms performed better by showing sharper-in-plane performance.

This paper represents our investigation on impulse response characterization of parallel-imaging configurations of breast tomosynthesis, with imaging parameters from a recently developed novel multi-beam breast tomosynthesis imaging system based on carbon nanotube technology by our collaborators Zhou, et al [22]. It is the first paper of our continuing effort to optimize imaging configuration of the system based on computer simulation. Investigations on other iterative algorithms with improved datasets are undergoing.

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