A Second Pass Correction Method for Calcification Artifacts in Digital Breast Tomosynthesis

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I. PURPOSE

Digital breast tomosynthesis (DBT) aims for improving the diagnosis of breast cancer and reducing the false positive rates by going from 2D projection mammography to 3D volume information. With the acquisition of a series of projection images, taken over a limited angular range, DBT allows for tomographic reconstruction with high in-plane but reduced depth resolution. Therefore, anatomical structures get blurred along the depth direction and produce out-of-plane artifacts. Prominent streak artifacts can be observed for high-contrast objects such as calcifications, which degrade the image quality, see for example Figure 8(a) - (f) in [4]. In this work, a second pass method for correcting these streak-like artifacts is introduced. For evaluation of this method, a software based breast phantom has been developed from segmented MRI breast data.

II. METHODS

Current acquisition methods for digital breast tomosynthesis take 10 - 30 X-ray projections over an angular range of 25° - 50°. In contrast to fully three-dimensional modalities such as breast CT, DBT is affected by the limited angular range in a decreased depth resolution. In particular, high-contrast objects are producing strong streak artifacts in the tomosynthesis reconstruction due to the missing data. Here, a new second pass method is proposed which is based on a segmentation of the high-contrast structures in a first pass reconstruction by hysteresis thresholding. The segmented structures are then forward projected onto the projection views. Then the measured projections are replaced at these particular positions with interpolated values obtained from a local neighbourhood. The modified projection data are used in a second pass reconstruction to generate an artifact-free volume image. Finally, the segmented high-contrast objects are combined with the artifact corrected reconstruction. Similar artifact-correction schemes have been proposed in [1] and [2] for correcting cone-beam artifacts due to missing data in circular cone-beam CT.

The suggested method has been applied to a series of simulated breast phantom data, which have been generated from segmented MRI data.

Fig. 1. Illustration of a breast phantom model. Top row: original breast shape (left), breast shape after compression (right). Bottom row: coronal slice view of original (left) and compressed (right) breast phantom.

a) Breast Phantom and Data Simulation: For this simulation study a series of breast phantoms have been generated from contrast-enhanced MRI images by segmentation into three tissue compartments representing adipose, glandular and skin tissue. Each tissue compartment has been assigned the corresponding attenuation coefficient of adipose, glandular and skin tissue, respectively. Since the MR examinations are performed with a moderate compression compared to mammography, additional compression has been simulated using a thin-plate spline deformation model. To this end, the boundary of the breast shape is triangulated and the boundary mesh is transformed with linear scaling factors $s_x$, $s_y$, $s_z$ such that

$$ s_x = s_y , \quad s_z = \frac{1}{s_x \cdot s_y} . $$

The complete volume deformation is then computed by thin-plate-spline interpolation using the boundary mesh as control points. Figure 1 illustrates a breast phantom with additional compression. High-contrast calcification inserts are simulated as ellipsoidal objects with half axis sizes ranging from 0.25 - 1.0 mm. To illustrate the image degradation due to the arising streak artifacts, two additional anatomical structures are modeled within artifact degraded image planes. To this end a spherical lesion insert of 1.5 cm diameter and a tubular duct segment with micro-calcifications inside has been generated, see Figure 2. In this simulation study a digital breast tomosynthesis system with a static detector with 100 µm pixel pitch has been modeled. The tube travels along a 32° angular range acquiring 17 equally sampled projection views. The iso-center
is located 85 mm above the center of the first detector row and the radius of the tube movement is $r = 580$ mm.

**b) Artifact Correction Method:** The proposed method requires the following steps:

1) A DBT acquisition is performed as described in the previous Paragraph.
2) An initial reconstruction is generated with a ramp filtered backprojection (FBP) algorithm.
3) The initial reconstruction is segmented into calcification and breast tissue with a hysteresis thresholding approach yielding the calcification image. High-contrast objects (calcifications) are identified.
4) The identified calcified structures are forward projected onto the detector and the corresponding detector values are replaced with interpolated values.
5) The projection data of step 4 is reconstructed with a FBP algorithm producing an artifact-free breast tissue image.
6) The calcification image is inserted at the positions of the identified calcifications in the breast tissue image. Hereby, a final artifact-free image is generated.

For the FBP reconstruction a standard ramp filtered backprojection algorithm [3] has been implemented. In the second-pass method, the first pass ramp-filtered reconstruction is used for segmentation of the high-contrast calcifications using a hysteresis thresholding technique. An upper and lower threshold is selected manually and all voxels above the upper threshold are identified as seed points. Then, all voxels in the $3 \times 3 \times 3$ neighbourhood of the seed points are added to the segmented regions if their value is above the lower threshold. The procedure is repeated with the newly added voxels as seed points until no further voxel can be added.

Having identified the high-contrast structures by hysteresis thresholding, a set of modified projection data is generated, where the projected positions of the high-contrast-structures are replaced by linear interpolated values of the neighbouring detector elements. In a second pass FBP reconstruction, an artifact-free image without the segmented high-contrast structures can be obtained. The final reconstruction is then computed by replacing the values of the artifact-free image at the positions of the segmented high-contrast structures with the values in the corresponding first pass reconstruction.

**III. RESULTS**

The method is illustrated with the breast phantom depicted in Figure 2. The phantom belongs to a small dense breast and has been equipped with a spherical carcinoma lesion of 3 cm diameter at $z = 35$ mm. Three additional microcalcifications between 200 and 400 $\mu$m in diameter are located in this plane, too. At $z = 25$ mm, three larger calcifications (0.5 mm to 2.0 mm diameter) are positioned. Finally, slice
Fig. 4. Axial slice reconstructions of the breast phantom. From left to right: original phantom, FBP reconstruction (ramp), second pass correction.

Fig. 5. Axial slice reconstructions (ROI) of the breast phantom. From left to right: original phantom, FBP reconstruction (ramp), second pass correction.

z = 20 mm contains a duct structure with three clusters of microcalcifications (200 - 400 µm) inside.

Figures 4 - 3 compare the original phantom with the ramp filtered backprojection as well as with the proposed second pass method.

Figure 3 illustrates that the strong streak artifacts are significantly reduced and Figure 4 shows the artifact-corrected mass lesion together with the standard reconstruction technique. Moreover, Figure 5 compares the reconstruction of the high-contrast calcifications, which are clearly visible without shadow-artifacts in the second pass correction. Only minor artifacts remain at the bottom calcification. Finally, the reconstruction of the duct structure with micro-calcification inserts, Figure 6, emphasizes the importance of the application of artifact correction methods in DBT. While the standard FBP reconstruction misses two of the three micro-calcification clusters in the duct structure due to significant out-of-plane artifacts, the second pass method yields an artifact-corrected images with all three microcalcification clusters visible.

IV. CONCLUSION

The proposed method yields an artifact corrected reconstruction method for digital breast tomosynthesis based on a hysteresis thresholding segmentation and a second-pass correction method. The method has been applied on simulated breast phantom data showing a significant reduction in out-of-plane artifacts from the high contrast inserts.

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REFERENCES