Metal Artifact Reduction of Biopsy Needles in Digital Breast Tomosynthesis

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The quality of reconstructed volumes in digital breast tomosynthesis (DBT) suffers from the occurrence of out-of-plane artifacts caused by structures outside the focal plane. For instance, metal biopsy needles appear as multiple copies in the reconstructed volume, and infer visual assessment. In this work, we developed a multi-stage approach for artifact reduction of biopsy needles, while preserving a natural look in the reconstructed volume. This is accomplished by a per-projection separation of biopsy needle and breast tissue, separate reconstruction and recombination of the reconstructed volumes. Among the implemented variants, a Canny edge detector for the needle segmentation and linear interpolation performed best. In future work, we aim to use a Hough transform for the localization of the needle in 3D-space to recombine the separated volumes.

Keywords: Digital breast tomosynthesis, artifact reduction, multi-stage, biopsy.

I. INTRODUCTION

Projection based mammographic systems like full field digital mammography or their analog counterparts, share a common limitation. Both imaging methods are two dimensional, and therefore lack depth information. With this limitation, overlapping dense breast tissue may obscure lesions or mimic abnormalities. Digital Breast Tomosynthesis (DBT) is a three dimensional imaging modality that promises to overcome these limitations. In DBT, a series of low dose projections, captured at different angles, is used to reconstruct cross sectional image slices of the breast at different heights, parallel to the detector plate. Studies including clinical cases demonstrated that DBT may provide superior image quality over conventional mammographic images [1] [2].

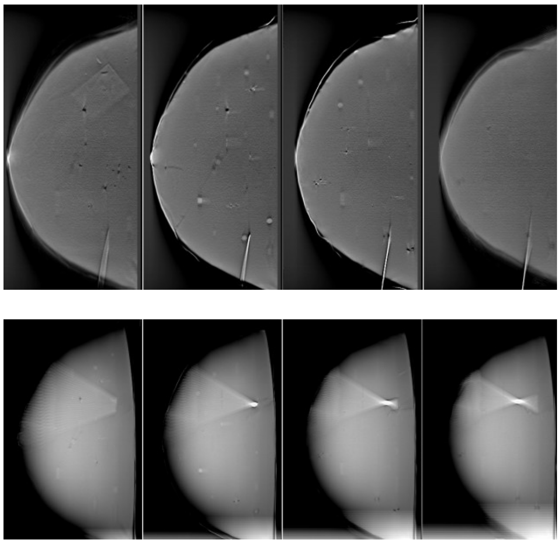

Figure 1. Typical out-of-plane artifacts from high-attenuation objects at consecutive heights in the reconstructed volume. Top: needle insertion position is parallel to the X-ray emitter motion lane. Bottom: Needle insertion direction is perpendicular to the X-ray emitter motion lane. Pictures courtesy of Siemens Healthcare Sector.

Typical DBT acquisitions are limited up to 50 projections over a narrow angular range of 50 degrees or less. The object sampling is therefore incomplete and thus supports artifact emergence. The algorithms used for DBT reconstruction in this paper are filtered back-projection (FBP) [3] and shift and add tomographic blur from structures outside the focal plane, which results in poor object detectability inside the plane of interest. Artifacts caused by high attenuating objects like metallic biopsy needles will not only appear as blurred structures, but as multiple copies of the same object in every reconstructed plane except the origin plane of the object. These artifacts severely interfere with the visual assessment of a radiologist and are therefore one of the major obstacles in DBT. Since DBT is relatively new medical imaging modality, only few related works are addressing this problem [1] [2] [3] [4] [5].

Fig. 1 shows examples of these artifacts for in consecutive planes of the reconstructed volume. These artifacts are relatively weak when the needle is inserted parallel to the X-ray emitter motion (top). When the needle is inserted in non-parallel position, or perpendicular, direction to the X-ray emitter motion, disturbing artifacts clearly emerge (bottom).

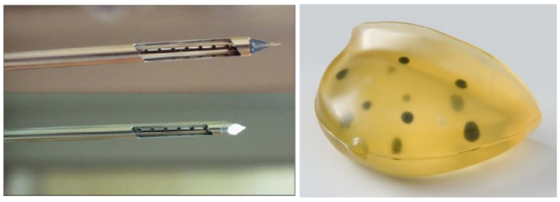

Figure 2. Mammotome vacuum core biopsy needle and CIRS Inc. stereotactic needle biopsy phantom model 013.

The artifact reduction method presented in this paper addresses the projections space, in order to prevent high attenuating objects to surface in the reconstructed volume. The high attenuation object, in this case a biopsy needle, is separated from the breast tissue before reconstruction. Breast and needle are reconstructed separately. Thus, artifacts from the needle reconstruction occur only in the needle volume. This is preliminary work. In the current state, we present the separation of needle and breast tissue, and the separate reconstruction of the breast without the needle. We also present an approach to detect the needle among its reconstruction artifacts. The evaluation of the full pipeline is subject to future work.

II. Materials and Methods

First, we give an overview on the data acquisition procedure. Then, we provide a general description of the implemented framework, and third the algorithmic details of the critical steps for the presented approach to the reduction of high attenuation artifacts.

A. *Data acquisition*

The experimental dataset used in this thesis was acquired with the Siemens Mammomat Inspiration. The system uses a 50 degree (-25° to +25° w.r.t. the vertical axis) scan acquiring 25 projections with a pivoting point lying 4.7 centimeters above the detector surface. The detector plate is a solid-state amorphous selenium flat-panel detector with an array dimension of 2816x3584 pixels at a pixel pitch of 85µm. Two biopsy needles were used during the experiments, 8 gauge and 11 gauge MAMMOTOME vacuum core biopsy units [6]. These needles were targeted at different masses and calcifications in a CIRS needle biopsy phantom [7]. Example images for the needles and the phantom are shown in Fig. 2.

Different insertion angles were chosen in order to simulate different biopsy situations. The phantom was

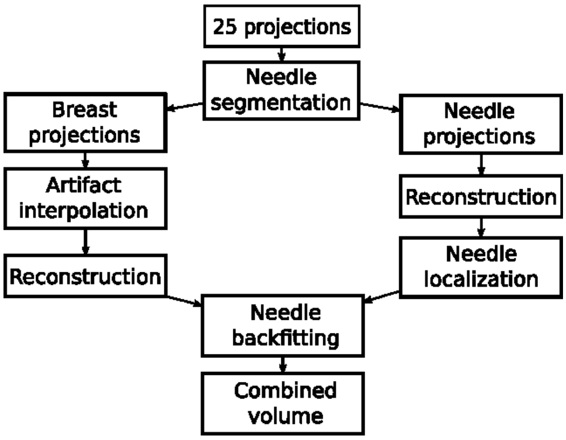

Figure 3: Overview of the proposed method. The projections are segmented in 2D into needle and breast, separately processed, and spliced together into a combined volume.

compressed to 47mm thickness in cranio-caudal position, and the exposure dose was set to 28kV.

A typical biopsy procedure consists of three acquisitions. First, an overview acquisition is conducted for detecting and targeting regions for further examination. Second, the needle position check acquisition confirms the correct position of the needle inside the breast tissue. Finally, the biopsy validation acquisition reassures that the examined regions have been sampled. The last acquisition has been left out of the experiments, since it is not necessary for evaluating artifact reduction of high attenuation objects. In detail, we collected 8 datasets for both, overview acquisition and needle check acquisition.

B. *Framework overview*

Out-of-plane artifacts that disturb the visual appearance of the object occur after 3D-reconstruction of the breast. The general idea is to eliminate out-of-plane artifacts by removing the corresponding high attenuation objects already in projection space. Thus, in projection space, high attenuation objects are expected to be easier to segment, as they did not yet infer artifacts in the dataset. Subsequently, the breast without the needle and the needle can be reconstructed separately. Here, only the reconstruction of the needle exhibits the typical high attenuation artifacts, while the reconstructed breast is mostly unaffected. At the same time, in the needle-only reconstruction, it is more straightforward to segment the true needle volume from the artifacts. Then, the artifact-free segmented needle volume is reinserted in the reconstructed breast volume. Fig. 3 gives an overview on the algorithmic framework. The first segmentation step splits the reconstruction problem into two, breast and needle reconstruction. In the left branch, the breast area where the needle has been removed is interpolated in order to allow a smooth reconstruction. In the right branch, the needle is reconstructed and has to be localized among the reconstruction artifacts. Reconstructed breast and the segmented needle are subsequently recombined via backfitting.

C. Algorithmic details

We describe in detail three important steps in this pipeline. First, the detection and segmentation of the needle in the projection images. Second, the interpolation of the breast region where the needle has been removed, and third the localization of the reconstructed needle in the reconstructed 3D-volume.

1) Needle detection and segmentation

Needle and breast tissue are separated before reconstruction, in the 2D projections. Initially, low intensity background elements are removed using Otsu-Threshold selection [8]. A region of interest (ROI) is automatically selected that excludes high attenuation objects from the capturing device. The remaining challenge is to separate the breast from the needle. Here, we experimented with two approaches. First, an approach based on principal component analysis (PCA), and second a segmentation based on Canny edge detection. The PCA approach aimed at exploiting the fact that the biopsy needle is a straight, high attenuation object in the projection images. Thus, if the main axis of this object is found, the position of the needle is known. We followed the approach by Lee et al. [9]. It does not compute PCA directly on the intensity values. Instead, it computes PCA on the edge profile of the image, separated in horizontal and vertical direction. For details, see [9]. In the second approach, we used a slightly modified Canny-edge detector. During Edge filtering, we replaced the Sobel gradient operator by the Kirsch operator. The Kirsch operator distinguishes 8 gradient directions, i.e. has a gradient spacing of 45°, in contrast to the 90° spacing of the Sobel operator. In order to finally detect the biopsy needle, we applied a Hough transform on the output of the Canny edge detector, again exploiting the straight shape of the biopsy needle.

2) Interpolation

In the 2D breast projections, the area where the needle has been removed is interpolated, in order to create as little reconstruction artifacts as possible. We implemented and evaluated several interpolation strategies, which are briefly outlined in this paragraph. First, we implemented the pixelwise mean of nearest neighbors in the projection image. For linear interpolation, we used the two closest breast tissue pixels perpendicular to the needle position. For bilinear interpolation we reinterpolated between the linearly interpolated lines. We also experimented with interpolation by one- and two-dimensional polynomials. In the one-dimensional case, we used a Lagrange polynomial between breast tissue pixels perpendicular to the needle direction. In the second-dimensional case, this area is reinterpolated along the needle direction. For one-dimensional cubic splines, we used the same pixel selection strategy as above, but computed additionally the first derivative of the corresponding sample pixels. Analogously, two-dimensional cubic splines are in the second step interpolated along the needle direction.

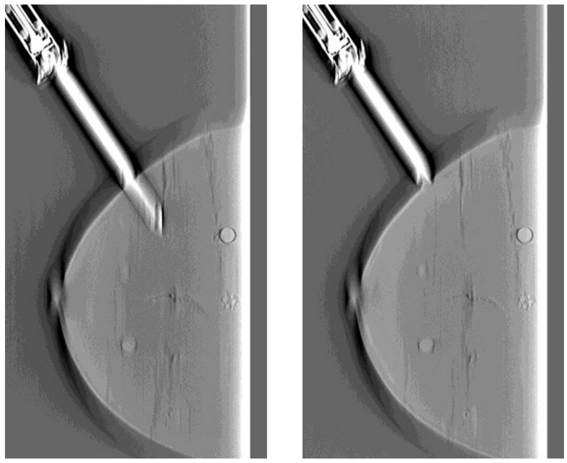

Figure 4. Example images showing the reconstructed breast without needle interpolation (left) and with needle interpolation (right). The interpolation region is overall smooth and causes no artifacsts.

3) Segmentation of the needle in volume space

The separately reconstructed needle, as a high-attenuation object, creates considerable out-of-plane artifacts. Thus, for recombining the breast and the needle volume, a separation of the true needle from the reconstruction artifacts is required. One challenge here is the fact that needle and artifacts exhibit similar properties with respect to the image intensities. Additionally, the spread of the artifacts depends on the insertion angle of the needle during surgery. In our ongoing work, this step in the pipeline is still subject to future study. In a first attempt, we considered to

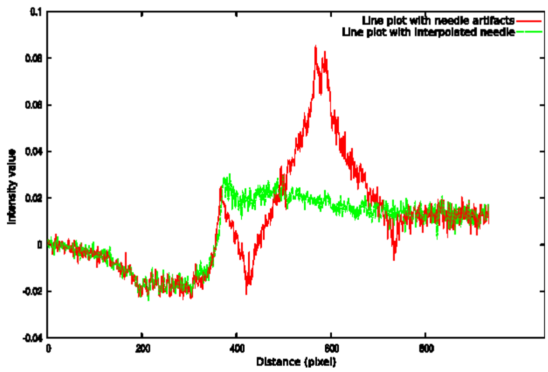

Figure 5. Intensity profile of the interpolation region along the vertical axis.

compute the Hough transform on the focal planes of the needle volume. Prominent peaks in the Hough space are chosed as candidates for the true needle. This is done on every reconstructed plane, resulting in a set of intersecting points. These points are aligned along the main axis of the real needle, revealing the position of the needle in a plane perpendicular to the detector surface. Note, that theoretically this approach fails if needle and artifacts are parallel to each other, and thus do not intersect. This can occur when the needle is inserted in a plane that is exactly parallel to the reconstructed planes. However, we are confident that this special case can be detected by exploiting the fact that the spread of the artifacts changes consistently with the distance of the examined plane to the plane where the needle has been inserted.

III. Results and Discussion

We evaluated the first two steps in the pipeline, namely the detection of the needle in the 2D projections, and the interpolation of the breast area where the needle has been removed. We used the needle check acquisitions, as these contain both breast tissue and the needle. For the 2D needle segmentation, the PCA based approach was able to correctly identify the boundary between needle and breast tissue in all 8 datasets. We set a seed point in the needle shaft and were able to properly segment the needle by flood filling the area. The Canny-based approach performed very robustly on the test images. Therefore, we decided to continue with the Canny-based approach.

For the evaluation of the interpolation methods, we conducted a qualitative evaluation of the interpolated image, guided by experts from Siemens. Fig. 4 shows an example from the evaluated dataset. On the left side, an original projection with the contained needle is shown, and on the right side the same projection with the interpolated needle region. The reconstructed volume turned out to be very smooth in the interpolated regions, and the interpolated region introduced only barely noticeable little artifacts to the breast tissue (Fig. 5). All interpolation results appeared to work for our case. Eventually, we decided for linear interpolation, as this approach already lead to the good results, and was eventually preferred as the simplest satisfying interpolation method.

In its current status, needle and breast tissue are cleanly separated, and the breast without the needle can be reconstructed in a visually pleasing way. The immediate next step is to thoroughly test the algorithm for the 3D needle separation from the artifacts and to assemble the full pipeline.

IV. Conclusion

We presented a method for reducing out-of-plane artifacts from high attenuation objects in digital breast tomography. The core idea is to separate needle and breast in the set of 2D projection images before reconstruction. Both are reconstructed separately, such that the artifacts occur only in the volume of the needle. Thus, when the true needle is detected in the 3D volume, it can be separated from the artifacts and reinserted in the breast volume. This is preliminary work. In the current status, we implemented and evaluated the 2D segmentation of the needle and the interpolation in the breast tissue. Evaluation showed that the preferred method of needle segmentation is Canny-based edge detection, combined with a Hough transform. The preferred interpolation method, according to experts at Siemens, is linear interpolation.

V. References

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