Digital Breast Tomosynthesis Denoising Using Deep Convolutional Neural Network: Effects of Dose Level of Training Target Images

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Introduction

• Digital Breast Tomosynthesis (DBT) is the newest screening tool for detection of early breast cancer.

• The total dose level of DBT is kept comparable to that of a 2D mammogram.

• Investigate the use of deep convolutional neural network (DCNN) methods to denoise reconstructed DBT images.

• Need to preserve important signs of malignancy such as subtle microcalcifications (MCs) and spiculated masses.
Motivation

• Generative adversarial network (GAN) based DCNN methods have shown state-of-the art performance in natural image super-resolution, CT denoising and MRI de-aliasing.

Methods

- DCNN training stage

Patches are extracted from DBT slices reconstructed using 3 iterations of simultaneous algebraic reconstruction technique (SART).

Methods

- DCNN deployment stage

LD full DBT slices → 10-layer DCNN denoiser → Denoised full DBT slices
Materials

- **Training set / validation set: physical phantoms**
  - Heterogeneous 1-cm-thick slabs of 50% glandular/50% adipose material
    - Prepared 5 phantoms by stacking 5 slabs in different orders and orientations, 5 cm thick
  - LD/HD paired scans
    - LD — standard dose mode (STD): Rh/Ag 34 kVp, mean 31.7 mAs
    - HD — manual: Rh/Ag 34 kVp, 125 mAs
    - A dose ratio of 4
  - 4 phantoms for training, 1 for validation
    - Simulated MCs (glass beads) in the validation phantom for contrast-to-noise ratio (CNR) calculation
Materials

• Training set: virtual phantoms
  - Digital breast phantoms by VICTRE [1]
    • Prepared 24 phantoms, 4.5 cm thick
  - CatSim, an x-ray imaging simulation toolkit by GE Global Research [2]
    • Configured to model a GE Pristina DBT system
  - LD/HD paired scans
    • LD: Rh/Ag 34 kVp, 24 mAs
    • HD: Rh/Ag 34 kVp, 72 mAs, 120 mAs, 360 mAs, or noiseless
    • A wider range of dose ratios: 3, 5, 15, or ∞

### Materials

#### Summary of the training sets

<table>
<thead>
<tr>
<th>Phantom type</th>
<th>No. of phantoms</th>
<th>LD exposure</th>
<th>HD exposure</th>
<th>Dose ratio</th>
<th>No. of extracted LD/HD patch pairs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical</td>
<td>4</td>
<td>~31.7 mAs</td>
<td>125 mAs</td>
<td>4</td>
<td>~209,000</td>
</tr>
<tr>
<td>Virtual</td>
<td>24</td>
<td>24 mAs</td>
<td>72 mAs, 120 mAs, 360 mAs, or noiseless</td>
<td>3, 5, 15, or ∞</td>
<td>~200,000 for each dose ratio</td>
</tr>
</tbody>
</table>

#### Summary of the validation set

<table>
<thead>
<tr>
<th>Phantom type</th>
<th>No. of phantoms</th>
<th>LD exposure</th>
<th>HD exposure</th>
<th>No. of simulated MCs (glass beads)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical</td>
<td>1</td>
<td>~31.7 mAs (not used in training)</td>
<td>125 mAs</td>
<td>0.150-0.180 mm: 236, 0.180-0.212 mm: 227, 0.212-0.250 mm: 159</td>
</tr>
</tbody>
</table>
Effect of Dose Level of HD Images in Denoiser Training

Background ROIs from validation set (phantom DBT)
Effect of Dose Level of HD Images in Denoiser Training

CNR comparisons of MCs in validation set (phantom DBT)
Results — 0.212-0.250 mm MC Cluster
ROIs from validation set (phantom DBT)

LD (noisy input)
CNR = 5.04

Physical phantom trained
CNR = 8.15

24mAs/120mAs
CNR = 8.92

24mAs/noiseless
CNR = 10.95

HD (for ref)
CNR = 7.73
Results — 0.180-0.212 mm MC Cluster
ROIs from validation set (phantom DBT)

LD (noisy input)
CNR = 4.44

HD (for ref)
CNR = 6.95

Physical phantom trained
CNR = 6.63

24mAs/120mAs
CNR = 7.28

24mAs/noiseless
CNR = 9.36
Results — 0.150-0.180 mm MC Cluster
ROIs from validation set (phantom DBT)

LD (noisy input)
CNR = 3.59

HD (for ref)
CNR = 5.24

Physical phantom trained
CNR = 4.21

24mAs/120mAs
CNR = 4.85

24mAs/noiseless
CNR = 5.93
Results — Test Set: Human Subject DBTs

Example:
Invasive ductal carcinoma (mass)
Results — Test Set: Human Subject DBTs

Example:
Ductal carcinoma in situ (MC cluster)
Discussion

• Proposed to denoise reconstructed DBT images using a DCNN.
• Using a higher dose training HD images led to less noisy denoised images.
• The DCNN could be trained with either digitally simulated or physical phantom DBT data.
• A DCNN trained with phantom data was applicable to denoising of human DBTs.
Future Work

• Further improve the denoiser to enhance the conspicuity of subtle MCs in the images.

• Study the robustness of the DCNN across reconstruction methods or DBT systems.

• Validate the effectiveness of the trained DCNN in clinical DBTs.
Acknowledgments

This work is supported by NIH grant R01 CA214981.

We thank GE Global Research for providing the CatSim simulation tool, and Christian Graff, Ph.D., for the open-source digital breast phantom generation program.
Thank You