**Latest Advances in Digital Breast Tomosynthesis**

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**Limitation of Mammography**

- False diagnoses due to superposition of breast tissue  
- Solution: 3D imaging  
  - Breast CT: Cone-beam CT (180°) with dedicated prone table  
  - Breast tomosynthesis: modified mammography with limited angular range (15°-60°)

**Breast Tomosynthesis**

- Fast clinical transition  
- Limited angular range: 15°-60°  
- Slice thickness: 1mm  
- Projections: 11-50  
- Dose: ~1 - 2 times single mammogram

**Mammogram**  
**Tomosynthesis**  
**Biopsy proven cancer**  
**Courtesy: B. Ren, Hologic**
### Different DBT Design

<table>
<thead>
<tr>
<th>Company</th>
<th>System param.</th>
<th>Views</th>
<th>Detector</th>
<th>Scan time (s)</th>
<th>Recom.</th>
</tr>
</thead>
<tbody>
<tr>
<td>GE</td>
<td>±20°, step/shot (MGH, Sunnybrook)</td>
<td>15</td>
<td>CsI/A-Si 100 um</td>
<td>15-23</td>
<td>MLEM</td>
</tr>
<tr>
<td></td>
<td>±30°, step/shot (U. of Michigan)</td>
<td>21</td>
<td></td>
<td>7 s</td>
<td>SART</td>
</tr>
<tr>
<td>Holologic</td>
<td>±7.5, continuous Multiple sites</td>
<td>11</td>
<td>a-Si, 70 um, 2x2 binning</td>
<td>10</td>
<td>FBP</td>
</tr>
<tr>
<td>Siemens</td>
<td>±22.5°, step/shot Duke, Malmo, SUNY</td>
<td>25</td>
<td>a-Si, 85 um, 12.5/20 Bin/full</td>
<td>30 s</td>
<td>MLEM</td>
</tr>
<tr>
<td>Dexela</td>
<td>±12-20° (U. of Virginia)</td>
<td>13</td>
<td>Fiber optic coupled CCD</td>
<td>3-8 s</td>
<td></td>
</tr>
<tr>
<td>X-counter</td>
<td>±13°</td>
<td>48</td>
<td>Gas counting, 48 slit, 60 um</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sectra</td>
<td>±5.5°, 6-site trial</td>
<td>21</td>
<td>Si counting, 21 slit, 50 um</td>
<td>3-8 s</td>
<td>FBP iterative</td>
</tr>
</tbody>
</table>

### Factors Affecting Image Quality

- **Detector performance**
  - DQE at low dose: $1/N_{\text{view}}$
  - Temporal performance: lag and ghosting
- **Imaging geometry**
  - Angular range, number of views
  - Focal spot blur: continuous tube travel
- **Reconstruction algorithm**
  - Analytical: FBP (filter design)
  - Iterative

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**Detector Performance**

- Data line direction: $\text{mR} / \text{bin}$
  - 0.43 mR
  - 2.15 mR
  - 6.01 mR

**Imaging Geometry: spatial vs. frequency domain**

B. Zhao and W. Zhao, Med. Phys. 2008
3D Image quality metrics: MTF, NPS and DQE

- Slice thickness 1 mm: Noise aliasing in z
- Slice thickness filter: eliminate aliasing

In-depth NPS

- Experiment
- Model

- Ramp x Hann

- Ramp x Hann x ST (width =0.47cycles/mm)

NPS vs. angular dose distribution

- Effect of angular range θ
- Effect of reconstruction filters
- Effect of 3D sampling, ST filter

In-plane NPS

- Measured 2D NPS from top slice
- Measured 2D avg NPS from all slices
- Calculated 2D avg NPS

Reconstruction: Ramp + Hanning

3D NPS

Oversampled Point Spread Function (PSF)

70 um wire tilted 20 degrees

PSF/artifact vs. Angular Range

- ±20°
- ±15°
- ±10°
- ±5°
MTF – Dependence on Filters

Impact of Angular Range on In-Plane MTF

• Increasing angular range improves MTF at low frequencies

In-Plane MTF Measurement

In-Plane MTF

Low f drop caused by ramp filter and limited angular range
High f drop caused by other reconstruction filters
Dependence on Angular Range

ACR phantom imaged at 28kVp, W/Rh, 1.7mGy
Recon: FBP with ST filter

Reconstruction filter designs

- Ramp + limited angle: loss of low frequency (breast density)
- Modified filters: recovers density, but increased out-of-plane blur
- Iterative recon: improvement at the cost of computation


Reconstruction filter comparison

- FBP with Ramp
- SIRT
- Polynomial

Adapted from Ludwig et. al. (IWDM 2008)

Clinical Application of DBT

- Screening/diagnosis
- Contrast enhancement: angiogenesis
- Multimodality imaging:
  - DBT + automated ultrasound (AUS)
    - P. Carson et. al. U. Michigan
  - DBT + optical tomography
    - Boas et. al. MGH
  - DBT + limited angle SPECT
    - M. Williams et. al., U. Virginia
Dynamic Contrast-Enhanced (CE) Tomosynthesis

- X-ray projections
- Pre
- Post
- Tomo reconstruction
- Kinetics
- Subtraction (CE)

CE-Tomosynthesis

- Mamm tomosynthesis
- CE-Tomo

Temporal vs. Dual-Energy CE-DBT

- DS DBT system, GE Medical Systems
- Automated tube motion
- No anti-scatter grid
- HE:
  - Rh target - 0.25 mm Rh + 0.25 mm Cu filter
  - 49 kVp
- LE:
  - Rh target - 0.25 mm Rh filter
  - 32 kV
- 7 projections: 40° arc, 6.7° apart
- Dose per HE/LE data set - single mammographic view (~2 mGy)
- Filtered backprojection

Case 1: poorly differentiated invasive ductal carcinoma

- Courtesy Ann Katherine Carton

Case courtesy Ann Katherine Carton
U. Michigan
GE Gen II Research Tomo Unit
60° angle
21 projections
7.5 sec
Dual-modality compression paddle
Stationary digital x-ray detector

GE Logiq 9 US system

Automated US Scanning System

• Translator & transducer are flipped up out of field for tomo acquisition
• Translator & transducer flipped down for AUS acquisition

TPX paddle
US transducer
xy translator

Co-location Reader Study Display GUI showing Corresponding VOI's in DBT & AUS

Invasive Cancer

- AUS-suggested ductal extension

mammo
tomo
AUS

Courtesy: Drs. Carson & Goodsitt

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Further Development for DBT Systems

- **Gantry:**
  - Faster scan, more views

- **Generator/tube:**
  - Dual-energy, shorter pulse/less focal spot blur

- **Detector:**
  - Better low dose performance, faster readout
  - Photon-counting

New detectors: Improve low dose performance

Summary

- Physics of DBT: 2D→3D
  - Optimization of acquisition and recon.

- New clinical applications:
  - Contrast enhanced CEDBT
  - Multimodality imaging

- Challenges for further system development

Acknowledgements

- Financial support:
  - Siemens AG
  - Army Breast Cancer Research Program
  - NIH

- Contributing slides:
  - Drs. Baorui Ren, James Mainprize, Mitch Goodsitt, Ann-Katherine Carton, Mats Danielsson