Evaluation of Scattered Radiation and Modulation Transfer Function in a Digital Mammography System

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Promoter: Hilde Bosmans
Introduction

✓ Project:

“Proposition and large scale verification of optimized dose settings for 2D and 3D digital mammography”

✓ Dose risk/Image quality

✓ Study of the dose

- Insertion of a template in an image
- Voxel models and Monte Carlo simulation
Insertion of a template in an image

✓ Image of a lesion
✓ Insertion of the lesion in a breast image
✓ Correction of the template
  ➢ Scatter
  ➢ Modulation transfer function (MTF)
  ➢ Heel effect
  ➢ Noise
Why are they important?

✅ Scatter
  ➢ Contrast reduction

✅ MTF
  ➢ Resolution
    • Modulation Transfer Function: ability of a detector system to transfer the spatial frequency information of an object to the image
Modulation Transfer Function (MTF)

MTF \((u, v)\) offers a description of the fidelity with which an imaging system records spatial frequencies.
Overview

Measurements

✓ Beam Stop
  ➢ Transmission of primary, Tp
  ➢ Glare to Primary ratio, GPR
  ➢ Bucky factor, Bf
  ➢ Scatter Transmission, Ts
  ➢ Scatter to primary ratio, SPR
✓ MTF of detector and system
  ➢ Leuven MTF Vs Cooper MTF

Simulation

✓ Monte Carlo simulation
  ➢ Scatter contamination
  ➢ Scatter to primary ratio, SPR
  ➢ Scatter point spread function
Beam stop Method*

✓ Objects and Parameters
- Field Of View (FOV)
- 6 Beam stops
- PMMA 2, 4, 6, 8 cm
- 26, 28, 30, 32 kV
- Grid in / Grid Out

“The effect of scatter and glare on image quality in contrast-enhanced breast imaging using an a-Si/Csl (T) full-field flat panel detector”
Ann-Katherine Carton et al., Med. Phys (36), 2009

18/03/2009 Louvre Seminar
Beam stop: Configuration of the measurements

1° Configuration

Source

PMMA

Detector

Primary + Glare

2° Configuration

Source

PMMA

Detector

Beam stop

Primary + Glare

3° Configuration

Source

PMMA

Detector

Detector

Scatter + Primary + Glare

Primary = (Primary + Glare) - Glare

Scattered radiation = (Primary + Glare + Scatter) - (Primary + Glare)
Beam stop: $T_p$

Transmission of primary: $T_p = \frac{P^+}{P^-}$

$P^+$ = primary radiation, grid in

$P^-$ = primary radiation, grid out

$T_p$ increases with $kV$
Beam stop: GPR

Glare to Primary Ratio: \( \text{GPR} = \frac{G^k}{P^K} \)

K refers to the presence (+) or the absence (-) of the antiscatter grid

GPR is almost energy independent

This effect could be caused by low quantities of primary at 26kV by using 6 cm and 8 cm of PMMA
Beam stop: Bf

Bucky factor: \( Bf = \frac{(P^- + S^- + G^-)}{(P^+ + S^+ + G^+)} \)

Increases for larger phantom thicknesses but is almost energy independent.

Decreases as a function of kV and increases for larger phantom thicknesses.
Beam stop: $T_s$

Transmission of scattered: $T_p = S^+/S^-$

Energy and phantom thickness independent

Increases as a function of kV and for larger phantom thicknesses
Beam stop: SPR
Scatter to Primary Ratio = \( S^k/P^K \)

**Grid in Place**

**Grid out of Place**

Increase with thickness

Increase with energy and thickness
Monte Carlo simulation

Scatter Contamination

Source

PMMA

Detector

Primary + Glare

Source to detector distance 66cm

Is this distance enough to avoid scatter contamination at the detector ???
Monte Carlo Simulation

✓ MCNP5
✓ Recording of primary and scattered radiation
✓ Perfect energy integrating detector
  ➢ All energy is absorbed at the point of interaction independent of incident angle and detector material
    • Good approximation for low kV (mammography)
  ➢ Modeled as a detector surface

\[ *F1 = \sum W \cdot E \]

*F1 = track weight
E = Particle energy
Monte Carlo Simulation

✓ Exactly the same geometry and parameters
✓ No antiscatter grid
Monte Carlo simulation

Primary and scatter image

- Binning of the photons

ROI to calculate primary and scattered radiation: SPR
Monte Carlo simulation

No influence of scatter: The distance between source and detector is large enough!!!
Monte Carlo Simulation: SPR

- Same Geometry and same Parameters
- Grid out of Place
Monte Carlo Simulation: SPR

**Beam Stop Measurement**

**Monte Carlo Simulation**

<table>
<thead>
<tr>
<th>Stdev</th>
<th>26</th>
<th>28</th>
<th>30</th>
<th>32</th>
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<tbody>
<tr>
<td>2 cm</td>
<td>8%</td>
<td>10%</td>
<td>11%</td>
<td>13%</td>
</tr>
<tr>
<td>4 cm</td>
<td>5%</td>
<td>9%</td>
<td>7%</td>
<td>6%</td>
</tr>
<tr>
<td>6 cm</td>
<td>5%</td>
<td>7%</td>
<td>5%</td>
<td>4%</td>
</tr>
<tr>
<td>8 cm</td>
<td>7%</td>
<td>7%</td>
<td>6%</td>
<td>4%</td>
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</tbody>
</table>
MTF of detector and system

✓ Objects and Parameters

- EUREF steel Edge
- 28kV
- PMMA 2, 4, 6, 8 cm
- Grid in / Grid Out
MTF configurations

**Leuven Method:** Edge fixed at 2 cm from the detector

**Cooper Method***: Edge on the top of the PMMA

System MTF

Leuven Grid In
- grid-in_PMMA-2cm
- grid-in_PMMA-4cm
- grid-in_PMMA-6cm
- grid-in_PMMA-8cm

Cooper Grid In
- grid-in_PMMA-2cm_C
- grid-in_PMMA-4cm_C
- grid-in_PMMA-6cm_C
- grid-in_PMMA-8cm_C

Leuven Grid Out
- grid-out_PMMA-2cm
- grid-out_PMMA-4cm
- grid-out_PMMA-6cm
- grid-out_PMMA-8cm

Cooper Grid Out
- grid-out_PMMA-2cm_C
- grid-out_PMMA-4cm_C
- grid-out_PMMA-6cm_C
- grid-out_PMMA-8cm_C

MTF (u)
spatial frequency [mm⁻¹]
System MTF
Leuven MTF Vs Cooper MTF grid in

2 cm

4 cm

6 cm

8 cm
Is it possible to calculate the quantity of Scatter from the MTF?

✔ Beam Stop:
  ➢ Time consuming
  ➢ Result after a quite long analysis of the data

✔ MTF:
  ➢ Fast
  ➢ Immediate results

Question: How is the low frequency drop of the system MTF related with the Scatter Fraction (SF)?
Monte Carlo simulation:

Point spread function (PSF):

- Point source / Pencil Beam
- Same parameters
- Four different thicknesses of PMMA
- *F1 Tally for the detector
- Scatter MTF
- System MTF validation
Impossible to evaluate the scatter MTF with a mammographic system

- Detector MTF
- System MTF
Scatter MTF

Which is the relation between?*

\[ \text{MTF}_{\text{sys}} = \{(1 - \rho)\text{MTF}_F \left[ (m - 1)\frac{f}{m} \right] + \rho \text{MTF}_S(\frac{f}{m}) \} \text{MTF}_D(\frac{f}{m}), \]

No influence of the focal spot between 0 and 8 cm from the detector

\[ \text{MTF}_{\text{sys}} = [\rho \text{MTF}_S(\frac{f}{m})] \text{MTF}_D(\frac{f}{m}), \]

\( \rho = \) scatter fraction

\( f/m = \) the factor \( 1/m \) translates the spatial frequency \( f \) from the detector plane to the object plane.

* “Generalizing the MTF and DQE to include x-ray scatter and focal spot unsharpness: Application to a new microangiographic system” Kyprianou et al., Med. Phys (32), 2005
## Scatter MTF: Results

### Table

<table>
<thead>
<tr>
<th>f(u)</th>
<th>f(u)/m</th>
<th>MTF_d</th>
<th>MTF_f</th>
<th>MTF_s</th>
<th>MTF_cpf</th>
<th>MTF_cpf</th>
<th>CooperGrid Out</th>
<th>MTF_cpf</th>
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<td>0.00</td>
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<td>1.00</td>
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<td>1.00E+00</td>
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<td>4.86E-04</td>
<td>0.49</td>
<td>0.505</td>
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</tr>
</tbody>
</table>

### Graph

![MTF Graph](image-url)
Scatter MTF: Results

**2 cm**
- Scatter fit
  - $a_1 = 0.9492$
  - $a_2 = -3.1460$
  - $1 - \frac{S}{S+P}$
  - $\rho = 0.1660$ primary fraction
  - $\rho_{\text{fit}} = 0.1651$
  - $\text{sd} = 7.25\%$

**8 cm**
- Scatter fit
  - $a_1 = 0.7857$
  - $a_2 = -3.6940$
  - $1 - \frac{S}{S+P}$
  - $\rho = 0.4140$ primary fraction
  - $\rho_{\text{fit}} = 0.4531$
  - $\text{sd} = 15.41\%$
Scatter to Primary Ratio or Scatter Fraction?

- Validation of Scatter Fraction
- Is it possible to calculate the SPR from the SF?

<table>
<thead>
<tr>
<th>Thickness PMMA</th>
<th>Position of the grid</th>
<th>SPRm</th>
<th>MTF</th>
<th>Value of glare</th>
<th>Glare correction</th>
<th>SF</th>
<th>SPRc = SF/(1-SF)</th>
<th>StDev</th>
</tr>
</thead>
<tbody>
<tr>
<td>2cm in</td>
<td></td>
<td>0.051</td>
<td>0.923</td>
<td>0.029</td>
<td>0.952</td>
<td>0.048</td>
<td>0.051</td>
<td>0%</td>
</tr>
<tr>
<td>4cm in</td>
<td></td>
<td>0.089</td>
<td>0.888</td>
<td>0.033</td>
<td>0.921</td>
<td>0.079</td>
<td>0.086</td>
<td>3%</td>
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<tr>
<td>6cm in</td>
<td></td>
<td>0.154</td>
<td>0.831</td>
<td>0.036</td>
<td>0.867</td>
<td>0.133</td>
<td>0.154</td>
<td>0%</td>
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<tr>
<td>8cm in</td>
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<td>0.187</td>
<td>0.809</td>
<td>0.039</td>
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<tr>
<td>2cm out</td>
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<td>0.260</td>
<td>0.792</td>
<td>0.042</td>
<td>0.834</td>
<td>0.166</td>
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<tr>
<td>4cm out</td>
<td></td>
<td>0.541</td>
<td>0.688</td>
<td>0.043</td>
<td>0.731</td>
<td>0.269</td>
<td>0.367</td>
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<tr>
<td>6cm out</td>
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<td>8cm out</td>
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<td>1.124</td>
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<td>0.048</td>
<td>0.586</td>
<td>0.414</td>
<td>0.706</td>
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</tr>
</tbody>
</table>
Conclusion

✓ Scatter free geometry for the practical measurements validated by Monte carlo

✓ Measurement of scatter and simulation of scatter: in agreement

✓ MTF based method to obtain scatter fraction: preliminary validation

✓ Evaluation on the SPR from the SF in presence of the grid
Future Work

✓ Optimize the exposure settings for specific patient groups

- Collect database of images for different exposure conditions
- Simulate **physically correct** lesions
- Quantify visibility

- Create database of Voxel model
- Include **physically correct** lesions
- Adjust to specific system and investigate exposure conditions
- Quantify visibility

✓ Repeat in 3D
Leuven & Cooper MTF
Leuven MTF Vs Cooper MTF grid out

2cm
- grid-out_PMMA-2cm
- grid-out_PMMA-2cm_C

4cm
- grid-out_PMMA-4cm
- grid-out_PMMA-4cm_C

6cm
- grid-out_PMMA-6cm
- grid-out_PMMA-6cm_C

8cm
- grid-out_PMMA-8cm
- grid-out_PMMA-8cm_C

Louvre Seminar