A Method for Producing Simulated Mammograms: Observer Study

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Introduction

- Large databases with known truth are needed to develop CAD systems

- Limitations of databases:
  - Accurate truth information is not available
    - exact mass borders, exact shape and size of microcalcifications
  - Optimization of CAD depends on imaging system properties
    - transition to a new imaging system requires new dataset, and acquiring truth for all lesions
Overview

- Developed a method for producing simulated mammographic images
- Performed observer study to evaluate the quality of the simulated images
Part I: Simulating Mammograms

The method proposed here simulates mammograms with accurate truth information:

- High-quality radiographs of cadaver breasts, mastectomy, and biopsy specimens
- Combining the radiographs of the cadaver breast with lesion radiographs
- The combined image used as input to the model of the image formation
- Accurate model of the process of image formation in a mammographic screen-film system
1. Input Images

- High fidelity images of cadaver breast specimens
  - Faxitron MX-20 system
  - direct exposure X-Omat TL film
  - geometric magnification (2X)
  - obtained high resolution and low noise radiographs

- Digitized at 50μm pixel size
  - 25μm in the object plane
  - Lumiscan 85 laser film scanner
Flowchart of the Components of the Simulation

1. Input Image
2. Optical density, film noise
3. Simulation of phosphor screen
4. Light quanta to pixel value conversion
5. Pixel value to x-ray quanta conversion
6. Add Poisson noise
7. Add Scatter
8. Output Image
2. X-ray Quanta Distribution

- We calibrated the system by:
  - Acquiring images with different thicknesses of Lucite and exposure times using direct x-ray film
  - Measuring the exposure for each thickness with a dosimeter (model 10100A, Keithley Radiation Measurement),
  - The photon fluence $\Phi$ per unit exposure $X$ was estimated by:

$$\frac{\phi}{X} = \frac{0.00873 \ J}{h \nu \left( \frac{\mu_{ab}}{\rho} \right)_{air} \ kg.R}$$
2. X-ray Quanta Distribution

- The x-ray quanta are assumed to be mono-energetic with 20 keV energy

- Calculated number of photons per pixel of the high fidelity image

- Noise was added by a random number generator
  - Poisson distribution with a mean equal to the number of photons per pixel
3. Scattered Radiation

- Low scatter in the input images, due to magnification

- Compensated by estimating the scatter field using the simulation data (Boone et al. 2000)
  - Simulation data from 4cm thick breast and 28 kVp x-ray beam

- A symmetric PSF was generated and convolved with the input data to estimate the scatter field
Example: x-ray field and scatter field

Input image

Scatter image
3. Model of the Phosphor Screen

- Depth dependent MTF was used to account for the thickness of the scintillating screen.

- For each depth, MTF is obtained by diffusion equation approximation (Swank 1973).

- Parameters used in the simulation were determined by matching the MTF and NPS to experimental data from Min-R 2000 screen (courtesy P. Bunch, Eastman Kodak company).
Screen MTF

- experiment
- X simulated

Modulation Transfer Function

Spatial Frequency (cycles/mm)
Screen NPS

![Graph showing Relative Noise Power Spectrum vs. Spatial Frequency (cycles/mm)]

- △ Experimental
- × Simulated
3. Model of the Phosphor Screen

- The light photon density onto the film due to x-ray interaction at depth \( t \) is:

\[
r(x,y,t) = FT^{-1}\{FT\{q(x,y,t)\} \Phi_{u,v}(u,v,t)\}
\]

- \( r(x,y,t) \) output light quanta fluence, \( q(x,y,t) \) input x-ray fluence, \( \Phi_{u,v}(u,v,t) \): OTF at depth \( t \).

- The resulting distribution from each sublayer is summed to create the final distribution of light quanta.

- The light distribution output was converted to optical density using H&D curve of the film.
Example: Input and output images of the phosphor screen

Input x-ray distribution onto the phosphor

Output light distribution from the phosphor
4. Film Granularity Noise

- Gaussian white noise was generated for each model pixel filtered by the shape of the film NPS for Min-R 2000, and added to screen output image.

- The characteristic curve of the digitizer was used to convert from optical density to pixel value.
Real and Simulated Images

Screen-film image

Simulated image
Part II: Observer Study

- The goal of the study is to determine how well observers can distinguish simulated mammograms from real ones.
- The quality of the simulated mammograms is evaluated using an observer study.
- The ROC curves are generated for each observer.
- The area under the ROC curve (AUC) is computed.
  - AUC indicates the accuracy with which they can distinguish the two types of images.
Observer Program Interface

Example Simulated Image

Example Screen/film Image

START
Adjust Colortable
Next Training Case
QUIT

Select your confidence level on the scale that the image is a real mammogram

100

0
Overview of the Observer Program

- Six training images are given
- The observer indicates their confidence that the image is a real mammogram on a continuous 0-100 scale
- Each observer reads 130 images (half simulated and half real)
Observer Study

- For the preliminary study, five non-radiologist observers were asked to complete the task
  - All were experienced (> 4 yrs) in CAD for mammography and were familiar with the appearance of mammograms
- We used the LABROC program to generate ROC curves and calculate the AUC for each observer
Results: ROC curves
## Results: AUC Values

<table>
<thead>
<tr>
<th>Observer</th>
<th>AUC (LabROC)</th>
<th>Standard Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.461</td>
<td>0.049</td>
</tr>
<tr>
<td>2</td>
<td>0.572</td>
<td>0.049</td>
</tr>
<tr>
<td>3</td>
<td>0.551</td>
<td>0.050</td>
</tr>
<tr>
<td>4</td>
<td>0.527</td>
<td>0.050</td>
</tr>
<tr>
<td>5</td>
<td>0.538</td>
<td>0.050</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>0.530</strong></td>
<td><strong>0.042</strong>*</td>
</tr>
</tbody>
</table>

* Standard Deviation of AUC values
Conclusions

- The observer study showed that observers could not distinguish simulation images from real screen-film images.
- Our method can produce realistic simulated mammograms.
Future Work

- We will repeat the observer study using expert breast radiologists
- We will use our method for:
  - developing CAD systems
  - developing and optimizing x-ray imaging systems