EVALUATING BREAST TOMOSYNTHESIS WITH A MULTI-PROJECTION OBSERVER FOR ARBITRARY LESION SHAPES

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INTRODUCTION

Digital breast tomosynthesis (DBT) systems have a wide variety of detector types, acquisition geometries and reconstruction techniques. Because the reconstruction affects image quality, it is useful to decouple reconstruction during optimization of system parameters. A multi-projection channelized Hotelling observer (MP-CHO) [1-3] is developed that does not require a reconstructor but uses the full set of projections for characterization of DBT. A partial least squares (PLS) estimation of the channels is used for detecting lesions of complex shape.

AIM

- Develop an MP-CHO for DBT independent of the reconstruction method
- Useful for arbitrary lesion shapes
- Demonstrate in a simple detection task for different dose budgets

DETECTION TASK

- Channel output $\mathbf{v} = \mathbf{U}^t\mathbf{g}$, (channel, image, weights)
- Test statistic (linear observer): $t = \boldsymbol{w}^t\mathbf{v}$
- Detectability (signal present – signal absent) $d' = \frac{\langle t|1\rangle - \langle t|0\rangle}{\sqrt{\frac{\sigma_0^2+\sigma_1^2}{2}}}$ (1)
- Detectability from covariance matrix:

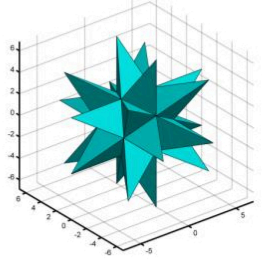
$$d'^2 = \widehat{\Delta\mathbf{v}}^t \widehat{\mathbf{K}_\mathbf{v}}^{-1}\widehat{\Delta\mathbf{v}} \quad (2)$$

- Decoupled covariance matrix estimation (DCE) approach [4-6],

$$\mathbf{K}_\mathbf{v} = \boldsymbol{K}_\mathbf{v}^{\text{poiss}} + \boldsymbol{K}_\mathbf{v}^{\text{gain}} + \boldsymbol{K}_\mathbf{v}^{\text{elec}} + \boldsymbol{K}_\mathbf{v}^{\text{obj}} \quad (3)$$

modelled; from 'noise-free' anatomic background and object

METHOD



Breast model with anatomic noise

- Random binarized 3D voxel volume with power-law spectral content.
- Spherical and stellate lesion shapes

DBT Simulation

- Indirect conversion detector
  - Includes optical gain, quantum noise, dark noise
  - Ignores scatter, k-fluorescence, glare effects.
- Equal dose and Central dose budget (1/2 dose to central projection)

Signal Known Exactly / Background Known Statistically Experiment (SKE-BKS)

- Step 1: "PLS-train" set (noise free signal contrast ×10) - channel shapes
- Step 2: "DCE-train" set (noise free) + DCE solve for channel weights and d'
- Step 3: "Noisy test" set –full noise (quantum + dark) simulation

RESULTS

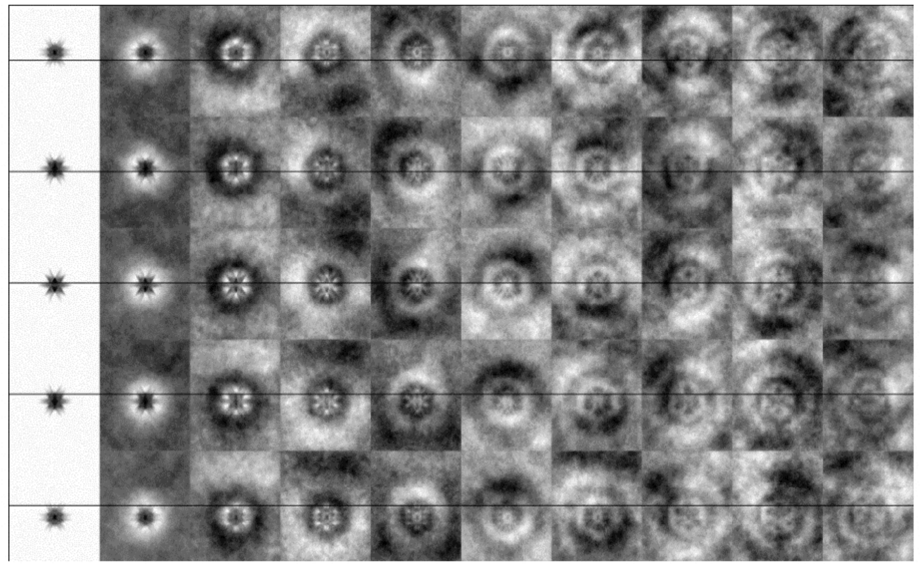


Figure 1 The first 10 PLS channels for a P=5 projection (50° scan angle) set for a stellate lesion, sphere-equivalent R=6mm. Each row of images represents a projection angle (-25°, -12.5°,0°, 12.5°, 25°) and each column represents a channel. A black line is added to each projection row to indicate the midpoint of the detector.

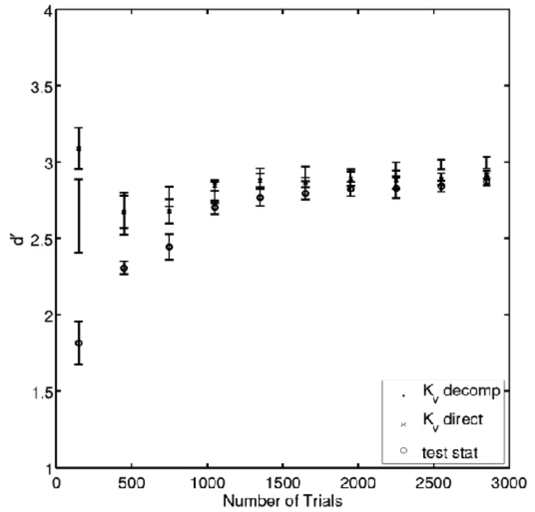


Figure 2 d' as a function of total number trials is increased. Comparing different versions of d' calculated from Eq. (1)-(3). Error bars are standard error (bootstrapped). Sphere-equivalent lesion radius was 3 mm, 10 channels per projection, P=5 projections, and angular scan 64°

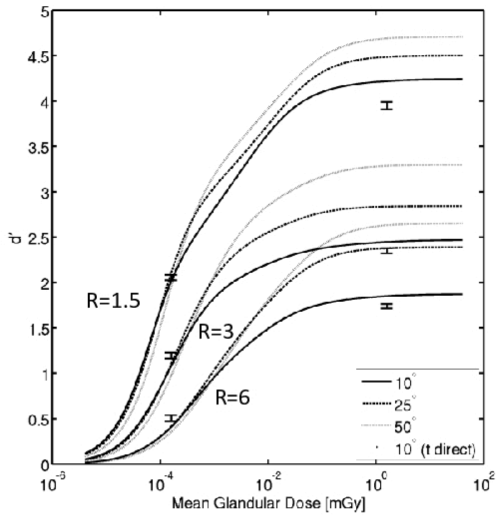


Figure 3 d' as a function of dose for a small, medium and large stellate lesions (R= 1.5, 3, 6 mm). The scan range was evaluated at 10°, 25°, and 50° with P=11 projections. Points with error bars (std. error) are shown at two doses based on d' measured using the "Noisy test" set data for each radius.

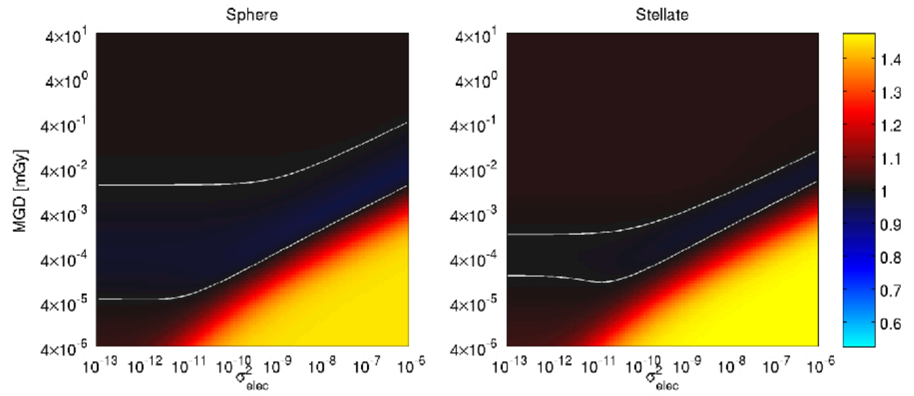


Figure 4 Relative d' for Center dose distribution compared to an Equal dose distribution for the Sphere of radius 3.0 mm (left) and Stellate lesions with equivalent radius (right). The white line indicates the contour lines for a d' ratio of 1.0.

Observations

- The PLS estimation improved with number of volumes used in training, although the improvement was minor for n>1000 volumes.
- The d' improved with increasing channel number, asymptotically beyond 10 channels.
- The stellate lesion shows reduced detectability at low angular ranges compared to spherical lesions.
- The central dose scheme showed 40% increased d' performance under low-dose / low electronic noise conditions, but not at higher doses (>1 mGy).

MODEL PARAMETERS

System Parameter	Value
X-ray energy	20 keV
Total Kerma (Exposure)	4.36 mGy (0.5 R)
Quantum Efficiency	$\eta = 0.7$
Optical Gain	$\bar{k}$=1050 carriers/ absorbed x-ray
Electronic Gain	$\Gamma = 5.13 \times 10^{-9}$ V/secondary

CONCLUSIONS

A channelized multi-projection observer was developed for use in evaluating virtual models of DBT systems without the need for a reconstruction step. This can be a useful tool in optimizing and evaluation the performance of different acquisition approaches. Presented here was a simple detection test and the performance based on lesion shape was similar. The approach can be extended to more complex tasks such as localization or discrimination. The PLS technique is flexible enough to allow for arbitrary lesion shapes and acquisition geometries.

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