An EM Reconstruction with Improved Signal-to-Noise Ratio for Coded Aperture Imaging

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Objective

- Early detection of coronary artery disease using a non-invasive, Tc-99m labeled targeting imaging agent.
- Reduce the minimum detectable activity (MDA) required at the site of the plaque.
Methodology

- Develop a 3D image reconstruction
  - to improve spatial resolution and
  - signal-to-noise ratio (SNR),
    - thereby decreasing the MDA.

- Evaluate the spatial resolution and SNR
  - by simulations and
  - experiments.
A Brief History

- Coded apertures have been used to image stars.

- There are a few different types:
  - non-redundant array (NRA),
  - uniformly redundant array (URA),
  - product array, and random array.

- The URA is designed to have
  - a flat modulation transfer function (MTF) and
  - mitigate noise in the reconstruction.
Coded Aperture Plate

- Plate has 1,920 pinholes (~1mm)*,
- in a thin tungsten sintered plate*,
- with 4 cycles of the basic pattern*, and
- is antisymmetric upon 90° rotation*.
  - Mask plus antimask images removes an artifact*.

* Design by Roberto Accorsi
Data Encoding

1 point source

Spiral source

3 point sources

Mini hot rod phantom
2D Image Reconstruction

- Convolution theorem
- “Dirac delta function”
- Pinhole imaging
- Added noise
The Linear Correlation
Reconstruction

<table>
<thead>
<tr>
<th>Pinhole pattern</th>
<th>Decoding array</th>
</tr>
</thead>
</table>
| ![Pinhole pattern](image) | \[
1 0 -1 0 1 0 1 1 \\
0 0 0 0 0 0 0 0 \\
-1 0 1 0 -1 0 -1 \\
0 0 0 0 0 0 0 0 \\
1 0 -1 0 1 0 1 1 \\
0 0 0 0 0 0 0 0 \\
1 0 -1 0 1 0 1 1
\] |
The Reconstruction

- Basic pinhole imaging
- Mask and antimask
- CA to detector distance (35 cm)
- Cosine cubed factors
  - Weight the projections
- Diameter of a pinhole (1.114 mm) and plate thickness (1 mm)
  - Determines radius of the circular projection
- Height of the reconstruction plane
  - Determines the demagnification factor
- Location of a pinhole
  - Shifts the projections
  - Detector array index
- EM:
  - Stored projection arrays
  - Added a noise removal method
Algorithm Test Procedure

5 pinholes

Coded aperture pattern

Projection of $F$

Projection of $F$
Blurring Artifacts

- Out of focus planes produce blurring artifacts.
Virtual Reduction in Field of View

- Appearance of this artifact limited the useful field of view.
Rotational Artifact

- Pitch of detector and plate were not aligned
  - yaw/slight clockwise rotation was observed.
- Center of rotation moved
  - creating two distinct sources.
Tic-Tac-Toe Like Artifact

- Tried to model the artifact but image used to remove noise in the image reconstruction did not coincide.
Ghosting Artifacts

- Ghosting artifacts were reconstructed due to the backprojection of pinhole projections of unknown aperture origin.

Many ghosts observed
Poor magnification in this data set caused the observed reconstruction artifact.
Cross Hatching

- Ray tracing reconstruction produced background noise.
3D Point Spread Function
Analytic Reconstruction

Focal plane of point source
3D Point Spread Function

Analytic Reconstruction

- Reconstruct a point source on various image planes above and below the source plane
- View the size of the 2D point on each plane
- Compare the various planes by stacking the 2D functions
Modulation Transfer Function

EM Reconstruction

- Rod diameters of 4.8 mm, 4.0 mm, and 3.2 mm are resolved.
- Rods of diameter 1.2 mm, 1.6 mm, and 2.4 mm are not resolved.
- 0.156 cycles/mm

\[ F = \frac{1}{2\Delta} \]

\[ MTF(f) = |FT\{LSF(x)\}| \]
Bone Imaging Agent

- 28.5 cm plane
- 29 cm plane
- 28.5 cm plane
- 29 cm plane
Mitigation of Noise

74,000,000 counts

195,000,000 counts
Noise Removal

- Reconstruction of the mask data once with mask pattern and once with the antimask pattern.
Dynamic range is defined as the range of input and output signals that a system can process without overflow or distortion.
- Simulated discs of 4s, 12s, and 24s.
- 4:1 to 6:1.
Discussion

- Geometry was poor for the plaque uptake studies.
  - Detector surface wasn’t used efficiently.
    - Decreased field of view.
    - Decreased magnification factors.
    - Decreased resolution.
Recommendations

- Use a thin, efficient detector.
- Reduce the size of the pinhole to 1 mm.
- Change the geometry.
  - Lower the plate from 35 cm to 20 cm.
    - Magnification factors allow z-resolution.
- Need at least 4 orthogonal views for 3D imaging (assuming 2-headed camera).
Conclusions

- SNR and dynamic range improved.
- MDA in plaque reduced by twofold.
  - Expect roughly 0.1 μCi to be visible in 45 μCi with coded aperture.
  - Expect roughly 0.2 μCi to be visible in 45 μCi with ordinary collimators (Rose’s criterion).
Thanks to:

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