Calibration of an MR-Compatible, CZT Detector Based Stationary Small Animal SPECT system

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Outline

- Objective
  - To develop a simple system calibration method for a ring-type CZT based SPECT insert to be used for small animal SPECT-MR imaging
  - Our system calibration method must
    - Measure any misalignment between collimator and detector
    - Identify energy peak and measure energy resolution for each detector pixel
    - Correct for detector uniformity due to property variations of different detector pixels
    - Identify and correct for malfunctioning detector pixels

- Background
  - Description of the small animal SPECT system
  - Importance of system calibration

- Method
  - Geometric calibration
  - Energy calibration
  - Uniformity calibration
  - Calibration evaluation experiments

- Results
  - Effect of geometric calibration
  - Effect of energy calibration
  - Effect of uniformity calibration

- Conclusion

Objective

The small animal SPECT system consists of 95 CZT detector modules backed by MR compatible ASIC electronics

- Each detector module consists of 16 x 16 pixels, with side length of 1.6mm
- There are 5 contiguous rings consisting of 19 detector modules
- The 95 CZT detector modules form a seamless detector surface with 24320 pixels

SPECT System Description
SPECT System Description

5 rings of 19 CZT detector modules
Multipinhole collimator

3D drawing of the SPECT system

Importance of System Calibration

- Careful system calibration can significantly improve image quality
  - Contrast
  - Resolution
  - Artifact reduction
- Three calibration steps are needed
  - Geometric Calibration
  - Energy Calibration
  - Uniformity Calibration

Geometric Calibration

- Misalignment between detector and multipinhole collimator will cause severe image artifacts
- Co-57 point source scanned at seven positions to measure misalignment
- Measurement included in system matrix used for reconstruction of projection data

Example four sided detector and 4-pinhole collimator
System Calibration Phantom

- Difficult to study the performance of the ring-type SPECT system with conventional phantoms
- An annular shell phantom with uniform shell thickness was developed for the system calibration
- The phantom was filled with 17µCi of Tc-99m solution in system calibration measurements
- Data acquired in listmode format

(a) Side view, (b) top view of the annular shell phantom and (c) with the phantom inside the SPECT system for system calibration.

Energy Calibration

- Energy spectrum variations
  - Found in different detector pixels
  - Also found difference in energy resolution
- Energy calibration method
  - For each detector pixel
    - Record the energy spectrum separately
    - Identify and store energy peak index
    - Measure and store FWHM of energy peak

Energy calibration example:

- Sample energy spectra from 3 representative pixels

Uniformity Calibration Method

- Obtained flood image of the CZT detector modules using the annular shell phantom
- Positioned the energy window around the energy peak of each detector pixel
- Identified malfunctioning pixels from the processed flood image
  - 0.6% are dead
  - 0.3% are ‘hypoactive’
  - 1.1% are ‘hyperactive’
- Replaced values of malfunctioned pixels with zeros and stored locations of pixels
- Generated uniformity correction map with flood image

System Calibration Procedure

- The experimentally acquired projection data were processed with the following procedure
  - Counts extracted from listmode data using stored energy windows to generate initial image
  - Uniformity map applied to initial image
  - Values of stored malfunctioning pixels interpolated from surrounding pixel values

Test flood image (a) before and (b) after uniformity correction from a sample detector module.
Evaluation of System Calibration Method

- Acquired projection data from a uniform cylindrical and a hot rod phantom using a 36-pinhole collimator at two collimator positions
- Images reconstructed using a 3D ML-EM image reconstruction method with modeled collimator detector response
- Assessed quality of the MPH SPECT images

(a) Photo and (b) schematic diagram of the cross-section of a Data Spectrum Hot Rod phantom

Effect of Geometric Calibration

- SPECT images with and without geometric misalignment measurement included in system matrix
- Artifacts dominate image if misalignment measurement not included

Reconstructed rod phantom image without (left) and with (right) geometric misalignment correction

Effect of Energy Calibration

- SPECT images of the hot rod phantom with and without energy calibration
- Results show ~40% improvement in image contrast

SPECT images from hot rod phantom (a) without and (b) with energy calibration. Projection data acquired using a 36-pinhole collimator

Sample profiles through the SPECT images

Effect of Uniformity Calibration

- Raw 36-pinhole projection image from the uniform cylinder shows many nonuniformities
- Reconstructed image shows many artifacts
- Integral uniformity in reconstructed image: 37.5%
Effect of Uniformity Calibration

After application of uniformity correction map

- Uniformity corrected 36-pinhole projection image
- Reconstructed image

- Hot and cold pixels remain in projection image
- Reconstructed image is improved, but still has several artifacts
- Integral uniformity in reconstructed image: 28.3%

 Effect of Uniformity Calibration

After application of uniformity correction map and malfunctioning pixel correction

- Final corrected 36-pinhole projection image
- Reconstructed image

- Projection image has very few (if any) nonuniformities
- Reconstructed image is artifact free
- Integral uniformity in reconstructed image: 5.9%

Effect of Uniformity Calibration

Rod Phantom Without Uniformity Calibration

- Initial 36-pinhole projection image of uniform cylinder
- Reconstructed image

- Initial projection image of rod phantom has many nonuniformities
- Reconstructed image has streaking artifacts and rods have nonuniform pixel values
- Only 2.4mm, 2mm, and 1.7mm rods can be resolved

Effect of Uniformity Calibration

After application of uniformity correction map

- Uniform corrected 36-pinhole projection image
- Reconstructed image

- Projection image still has hot and cold pixels
- Reconstructed image has less streaking, still has nonuniformities in rods
- 2.4mm, 2mm, and 1.7mm resolved, 1.35mm rods mostly resolved
Effect of Uniformity Calibration

After application of uniformity correction map and malfunctioning pixel correction

Final corrected 36-pinhole projection image

Reconstructed image

- Projection image has few (if any) nonuniformities
- Reconstructed image is artifact free
- 2.4mm, 2mm, 1.7mm, and 1.35mm rods resolved, 1mm rods partially resolved

Conclusions

- We have developed and tested a simple and repeatable system calibration method that allows our CZT detector based SPECT system to produce artifact free 3D multipinhole images with high image quality
- The system calibration method allows much improved MPH SPECT image quality in terms of
  - Contrast
  - Resolution
  - Reduction in image artifacts

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Thank you!