

High Energy 3-D Nuclear Medicine Imaging using Coded Apertures with a Conventional Gamma Camera

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Abstract

Standard nuclear medicine imaging uses photon collimation and thus suffer from very low sensitivity, especially if high energy (>511 KeV) isotopes are to be imaged. Coded aperture techniques use a coded pattern mask instead of a collimator to encode the photon source distribution, thus every photon source contributes to the signal in the whole detector area. It significantly improves the system sensitivity while retaining the spatial resolution of the reconstructed images. We have developed coded aperture arrays which are specifically designed for near field imaging, rather than the far field imaging appropriate to X-ray astronomy and have placed an emphasis on reducing sidelobe response in order to increase utility for images with background.

We have used a cyclic difference set uniformly redundant array as the coded aperture pattern; have conducted imaging experiments for point sources, 2-D sources (sources in a plane with arbitrary distribution), and 3-D sources (sources in 3-D with arbitrary distribution) of 511 KeV through phantoms; and have compared the experimental results with those from collimator systems. The coded aperture experiments have been conducted using a Siemens E.CAM gamma/SPECT camera. Results from our experiments show significantly improved sensitivity for a coded aperture imaging system over collimator systems, while retaining reasonable resolution. We have demonstrated the possibility of using coded apertures and a conventional gamma camera to image gamma rays of high energy, such as 511 KeV, in nuclear medicine.

I. INTRODUCTION

PET, SPECT, and planar gamma imaging are standard in diagnostic nuclear medicine imaging. All these techniques use some form of photon collimation; electronic in the case of PET and geometrical lead collimation for the latter two. As a result, they suffer from very low efficiency or sensitivity. Conventional collimator systems trade off spatial resolutions for sensitivity. A typical collimator system has sensitivity of only 0.1% or less. Coded aperture techniques use a coded pattern instead of a collimator to encode the photon source information (strength and location), thus each detector resolution element sees the entire field of view and every photon source contributes to the signal in all detector resolution elements. This significantly improves the system sensitivity while retaining the spatial resolution of the reconstructed images when appropriate patterns are chosen,

thus decreases the dose needed to generate images of a certain quality. In nuclear medicine, high energy photon imaging requires expensive high sensitivity detectors. Coded apertures can increase system sensitivity thus when combined with a commercial gamma camera, can image gamma rays of high energy such as 511 KeV.

II. THEORY

Coded aperture imaging is a technique for producing images of radiation emitting objects by using a mask (coded aperture) with spatially varying opacity distributed according to some mathematical algorithm. A radiation source (such as a photon source) will cast a shadow onto a position sensitive detector, thus encoding the spatial information contained in the source. The resulting shadowgram can be deconvolved with a suitable decoding algorithm to reconstruct the original source distribution. The sensitivity improvement for coded aperture methods over a pin-hole camera, whose size is the same as the size of each individual coded aperture, is in principle proportional to the square root of the number of holes in the coded aperture pattern when the pattern open fraction is not greater than 50%. The choice of aperture patterns determines the spatial resolution as well as the system response function. We have used a cyclic difference set as the coded aperture pattern; the system point spread function is a delta function and thus no spurious sidelobes are introduced.

III. EXPERIMENTS

We have conducted coded aperture imaging experiments with a 41 by 43 pattern for phantoms simulating 511 KeV photon sources from 1-D to 3-D, and have compared the results with those from collimator systems. Experiments have been conducted using Siemens E.CAM and MULTISPECT 2 gamma/SPECT cameras. The above experiments are for fluorine-18 (511 KeV gamma rays) radiopharmaceuticals used routinely in nuclear medicine.

The coded aperture imaging experiments have been performed through single-view 3-D imaging methods. Multiple-view 3-D coded aperture imaging will be our next experiments. We have tested the possibility of using coded apertures and commercial conventional gamma cameras to image photons of high energy such as 511 KeV in nuclear medicine.

IV. RESULTS

Results from experiments we have performed show significantly improved sensitivity for a coded aperture imaging system over pin-hole cameras and collimator systems.

Our experimental results show that the system point spread function of our coded aperture system is very clean. Figure 1 shows such a result, which was obtained by reconstructing a point 140 KeV gamma-ray source imaged with coded apertures.

1-D and 2-D Sources The reconstructed images for coded apertures in this set of experiments are shown in Figure 3-8. The pixel size for all images is 2.14 mm x 2.14 mm.

In Figure 1, (a) and (b) are from collimators; (c) and (d) are from coded apertures. (a) and (c) are for a point source; (b) and (d) are for a line source. We see the images from coded apertures are brighter than the images from collimators. For images from coded apertures, i.e. (c) and (d), the noise far away from the sources are outside the system FOV due to the large-detector geometry used in this experiment.

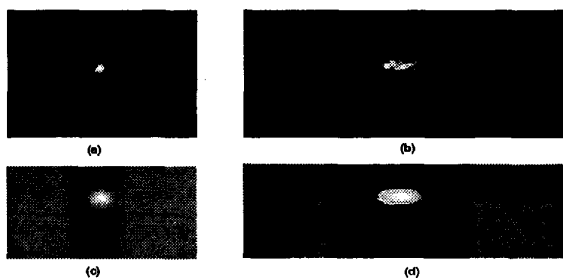


Figure 1. Reconstructed images of 1-D and 2-D fluorine-18 (511 keV) gamma-ray sources. This figure contains the reconstructed images of fluorine-18 gamma-ray sources. (a) and (b) are from collimators; (c) and (d) are from coded apertures. (a) and (c) are for a point source; (b) and (d) are for a line source. We see the images from coded apertures are brighter than the images from collimators. For images from coded apertures, i.e. (c) and (d), the noise far away from the sources is outside the system FOV due to the large-detector geometry used in this experiment.

For the point source, the count rate for coded apertures is 2.5×10^4 /min/ μ Ci; the count rate for collimators is 160/min/ μ Ci; thus the sensitivity improvement for point source is 156. (Radioactive decay has been corrected.)

For the line source, the count rate for coded apertures is 1.88×10^4 /min/ μ Ci; the count rate for collimators is 76/min/ μ Ci; thus the sensitivity improvement for point source is 247. (Radioactive decay has been corrected.)

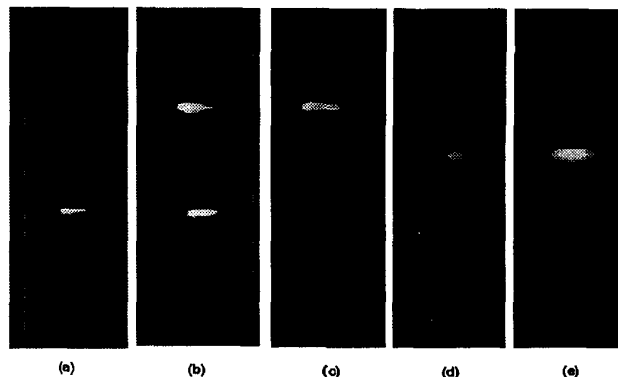


Figure 2. Reconstructed images of 3-D fluorine-18 (511 keV) gamma-ray sources. This figure shows the reconstructed images of fluorine-18 (511 keV) gamma-ray sources. Using CAL, with only one data collection, different object layers have been reconstructed. We see the sources on the reconstructed layer stand out.

3-D Sources The reconstructed images for coded aperture methods in this set of experiments are shown in Figure 2. The pixel size for all images is 2.14 mm x 2.14 mm. Using CAL, with only one data collection, when different object layers are reconstructed, we see sources on the reconstructed layer stand out. In the figure, the bottom source is farthest to the pattern (23 cm), the top source is closer to the pattern (20 cm), and the middle source is closest to the pattern (17.5 cm).

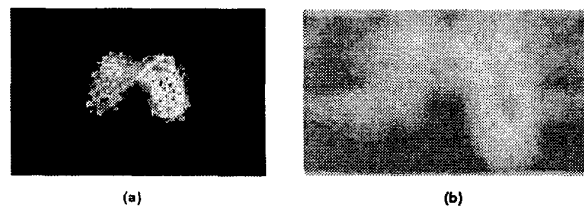


Figure 3. Images of a thyroid phantom filled with fluorine-18 (511 keV gamma ray). This figure shows images of a thyroid phantom filled with fluorine-18. (a) is the image from collimators; (b) is the reconstructed image from coded apertures.

Thyroid Phantom The image from planar gamma imager and the reconstructed image from coded apertures are shown in Figure 3. The pixel size for all images is 2.14 mm x 2.14 mm.

The count rate for the collimator is 71/min/ μ Ci; the count rate for coded apertures is 1.27×10^4 /min/ μ Ci; thus the sensitivity improvement for point source is 177. (Radioactive decay has been corrected.)

V. DISCUSSION

Results from our experiments show significantly improved sensitivity for a coded aperture imaging system over collimator systems, especially for small sources, which are realistic in nuclear medicine imaging such as for tumors.

In our 511 keV experiments, the detector dead time increased from 6% for the point source to 30% for the 3-D source (triple line sources) for coded apertures.

In real diagnostic nuclear medicine imaging applications, an object with point-like sources is more realistic because tumors in patients are usually point-like. For this case, coded aperture techniques are especially well suited as a high sensitivity imaging technique because its SNR improvement is the best for small sources. In mammography using FDG, a pharmaceutical (511 keV gamma emitter) commonly used in nuclear medicine, the typical radioactivity from a tumor is often as much as 20 times as high as that from normal breast tissues. For such a hot region, coded aperture methods may also be useful.

The results presented heretofore show that planar collimator gamma imagers appear to have higher spatial resolution. We need note that the comparison of spatial resolution is not fair because we used coded apertures with sizes of 4 mm in each direction (i.e. the X and Y directions for square holes), but the collimators we used are commercial and have aperture sizes from 1.1 mm to 3 mm in diameter (parallel round holes). This difference results in an inherent spatial resolution difference of up to four times as large. Considering coded aperture techniques have relatively poor resolution in the Z direction, sodium-iodide (NaI) scintillation detectors used in most commercial gamma cameras have an intrinsic resolution of 3 to 4 mm, and 3 mm thick lead is usually needed to block 511 keV photons, we expect coded aperture techniques for nuclear medicine imaging to achieve a spatial resolution of 5 mm with one projection, and down to 4 mm with multiple projections and postprocessing techniques.

In addition, a planar collimator gamma imager can image only 2-D objects, but coded aperture method is a focusing technique, thus has some tomographic capability, which can be used for generating 3-D images even with only one projection (data collection from only one angle).

Coded aperture imaging is a practical solution for improving gamma-ray imaging at all energy levels, as compared to coincidence detection such as PET which is limited to using a very small portion of the available radiopharmaceuticals. With coded aperture techniques, we can greatly enhance the system sensitivity and resolution for photon imaging while maintaining the capability of simultaneous multiple-isotope imaging with all available radiopharmaceuticals at all energy levels.

Our experimental results have shown that coded aperture systems using a cyclic difference set uniformly redundant array pattern can significantly increase the sensitivity of the imaging system. The meaning is twofold:

1. For low energy photon imaging, such as 140 KeV, the high sensitivity makes it possible to use a lower radiation dose to the patients being imaged.

2. For high energy photon imaging, from 511 KeV to 1.3 MeV, the high sensitivity makes it possible to use coded apertures with conventional gamma cameras for imaging, and not require expensive high sensitivity detector materials such as BGO or LSO.

VI. CONCLUSIONS

Coded aperture techniques:

- Provide significantly improved system sensitivity over collimator systems. The sensitivity improvement is proportional to the total open area of the basic coded aperture pattern if the pattern open fraction is the same. The spatial resolution is determined by the aperture size and the imaging geometry;
- Perform better for planar objects than for 3-D objects. Achieve the maximum SNR for point-like objects;
- Can image 511 keV gammas using commercial gamma cameras;
- Complement collimator systems in nuclear medicine imaging.

Coded aperture imaging techniques provide high sensitivity in diagnostic nuclear medicine imaging, compared to collimator systems. It can produce 3-D images with spatial resolutions in the several millimeter region (as low as 5 mm or less) for high energy gamma rays. We have demonstrated the possibility of using coded apertures and a conventional gamma camera to image gamma rays of high energy, such as 511 KeV, in nuclear medicine.

VII. ACKNOWLEDGMENTS

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