CODED APERTURE TOMOGRAPHY REVISITED

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Coded aperture (CA) Tomography never achieved wide spread use in Nuclear Medicine, except for the degenerate case of Seven Pinhole tomography (7PHT). However it enjoys several attractive features (high sensitivity and tomographic ability with a static detector). On the other hand, resolution is usually poor especially along the depth axis and the reconstructed volume is rather limited.

We believe that :

- CA tomography can be useful for imaging time-varying 3D structures, if its major drawbacks (poor longitudinal resolution and difficulty in quantification) are overcome,

- poor results obtained with 7PHT can be explained by both a very limited angular range sampled and a crude modelling of the image-formation process. Therefore improvements can be expected by the use of a dual-detector system, along with a better understanding of its sampling properties and the use of more powerful reconstruction algorithms,

- non overlapping multipinhole plates, because they do not involve a decoding procedure, should be considered first for practical applications. Use of real CA should be considered for cases in which non overlapping multipinhole plates do not lead to satisfactory solutions. We have been and currently are carrying out theoretical and experimental works, in order to define the factors which limit CA imaging and to propose satisfactory solutions for Dynamic Emission Tomography.

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1.0 DUAL SEVEN PINHOLE TOMOGRAPHY

Firstly we have extended 7PHT to the case of a dual camera system with the detector oriented orthogonally. The procedure preserves the simplicity of the conventional method, and provides improved performances, i.e. larger reconstruction region and uniform voxel size.

The reconstruction algorithm is broken into two parts. The first one is projection independent and calculates for each voxel of a cubic reconstruction region, a projection array from calibration images (point source at the system center, and flood field). The projection array consists, for each of the 14 projections, in the projection location and a weighting factor taking into account the length of the ray through the voxel, the solid angle with which the pinholes sees the voxel, and the attenuation factor under a constant attenuation model. As the number of voxels and the size of the reconstruction region can be chosen independently, the algorithm can handle a large range of resolution and reconstruction size needs. The first part of the algorithm has to be run only when geometric characteristics of the system or the digitization of the reconstruction region are modified. The second part performs the reconstruction per se. In order to obtain a first estimate, a voxel is assigned a value equal to the lowest projection counts corrected by the weighting factor. When some projections are outside the field of view of the detector, the algorithm operates with the available subset of projections, and thus the reconstruction is estimated for a larger volume than with conventional 7PHT. The 3D estimate is refined iteratively using a simple backprojection, until the distance between experimental projections and projections of the 3D estimate are close in a least squares sense. Because the algorithm is broken into two parts, it is very efficient when several 3D structures must be reconstructed under the same geometric conditions, as is the case for time-varying radioactivity imaging.

Improvements in terms of sensitivity, resolution, resolution uniformity and reconstruction volume have been assessed with point sources, more realistic phantoms and animal studies. Very encouraging results have been obtained: sensitivity is larger than sensitivity of a typical parallel hole collimator system, for standard source distributions (7 500 cps/(uCi/cc)). Resolution is isotropic and varies much less than with a single detector system. FWHM in the reconstruction volume varies from 8 mm when the source is at 230 mm from each detector, to 15 mm when the source is at 480 mm from each detector. These results compares favorably with SPECT using parallel hole collimator systems, and are very much better than has been reported for conventional 7PHT.

2.0 SAMPLING PROPERTIES OF MULTIPINHOLE PLANAR SYSTEMS

Secondly a geometric transformation of the reconstruction space has been developed, which maps the fan beam problem into a parallel beam geometry, for non overlapping multipinhole planar detectors. This transformation leaves the projection plane invariant, is independent of the pinhole locations in the collimator plate, and corresponds to a variable scaling along lateral axes according to depth. Therefore projection integrals can be Fourier transformed, and the slice theorem can be utilized. Tomographic ability of multipinhole planar systems can be assessed from the distribution of the planes sampled in the Fourier transform of the 3D radioactivity distribution. This method is being used to design optimal collimators for various physical/clinical situations with particular attention to heart and brain imaging. Fast, powerful algorithms developed for parallel beam geometry, in particular those for limited angle reconstruction, are being used in these analyses.

3.0 IMAGE FORMATION UNDERSTANDING

Thirdly the influence of the finite size and the shape of the aperture onto the quality of the reconstruction is studied. This problem is currently understood very badly and oversimplification of the process could result in major inaccuracies in the reconstruction. Variations of sensitivity and impulse response of a pinhole system with source location are now under measurement, in order to validate a model. The latter will be used to optimize the design of the aperture, and to correct for the effects of finite aperture size and shape.

4.0 REAL CA IMAGING VS. NONOVERLAPPING MULTIPINHOLE

Fourthly physical characteristics of competing CA (as FZP and time-varying pinhole array collimator) are compared with the current Dual Seven Pinhole Tomography (D7PHT). If a static configuration of two CA mounted detectors can be predicted to have far better sensitivity and resolution than the current dual 7PHT, then the work developed for the latter will be extended to that CA.

5.0 CONCLUSION

In summary, it is our thinking that CA can be used for Dynamic Emission Tomography, using multiple static detectors. Using two orthogonal detectors improves the angular scanning range and the number of projections, making the resolution more uniform and more isotropic. A better understanding of the image formation process and the subsequent improvements in the reconstruction algorithm are key factors for producing better reconstructed images with this method. Finally non overlapping configurations make the reconstruction problem far easier, and the choice of a non degenerated CA is valid only when improvements in projection images are not cancelled by the noise amplification in the decoding process.

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