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DUAL SEVEN PINHOLE TOMOGRAPHY

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NOTICE

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ABSTRACT

Emission tomography using two orthogonal sets of projections through seven pinhole collimators is considered. This paper describes the acquisition system, the reconstruction algorithm, presents results obtained in phantom studies, and discusses the advantages and disadvantages of this method over conventional Seven Pinhole Tomography.

INTRODUCTION

Seven Pinhole Tomography^{3,4,5} (7PHT) (reconstruction of a 3D radioactivity distribution from projections onto a 7 pinhole collimated scintillation camera) has long been known as a simple and cost effective tomographic technique. As it uses a conventional nuclear medicine detector, it can be performed in many nuclear medicine departments. As the detector is stationary, it is well suited for imaging time-varying 3D distributions. However, its low sensitivity and depth resolution yield poor quality reconstructed images.

This paper investigates the potential improvements of this tomographic process when a dual detector imaging system is used. By doubling the number of apertures, sensitivity is increased. From sampling considerations, the optimal angle made by the two detector axes is 90° . However, for practical clinical situations, angulations from 60° to 120° may be appropriate. In any case, resolution is improved by the increase in number of projections and in their angular range. When more than one detector is used, the reconstruction volume cannot be decomposed into the non-uniform voxels used in the original 7PHT algorithm, which decomposition is correct from a sampling viewpoint. Therefore, uniform cubic voxels were chosen since they lead to a more natural representation of space. Finally, because 7PHT is intended to be used for dynamic studies the algorithm has been broken into distribution-independent, and distribution-dependent procedures in order to speed up the reconstruction process.

This paper describes the imaging system developed at Brookhaven National Laboratory to acquire 7PHT data. Then original features of the reconstruction algorithm are given. Physical characterization of the reconstruction method as well as results from phantom data are presented. Lastly, improvements over conventional 7PHT, in terms of clinical use for dynamic studies, are discussed.

THE ACQUISITION SYSTEM

A dual detector nuclear imaging system^{1,2} (the UNICON, Fig. 1) has been developed at our institution. The two scintillation cameras are mounted on a gantry which can rotate as for rotational tomography. Additionally, each detector can rotate about an axis orthogonal to the gantry axis, such that the angle (α) made by the two detector planes can vary from 0° (facing parallel cameras) to 120° . When each detector is mounted with a 7 pinhole collimator, 7PHT can be performed. In this paper, projection data have been acquired for a 90° angle (orthogonal configuration).

Fig. 1: The UNICON system mounted for D7PHT. A liver phantom with a 3 cm diameter lesion is in position for imaging.

Acquisition and processing are realized using the hardware and software facilities of the UNICON (Fig. 2): camera data are digitized and stored in list mode onto a large disk connected to a PDP11/34. Data are transferred to a VAX11/780 where projection matrices are built and tomographic images are reconstructed. The 3D distribution is visualized, slice-by-slice, on a RAMTEK display attached to the PDP11/34.

Fig. 2: Block diagram of the UNICON hardware.

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CALIBRATION AND ACQUISITION

The system geometry (see Fig. 3) is characterized by the system center (SC) at the intersection of the two detector axes. Distances (d_A, d_B) from the system center to detectors A and B define the maximum reconstruction volume. Strictly speaking, this volume is the intersection of two hexagonal cross-section cylinders with vertex radius (R) equal to the distance from the central pinhole to any peripheral pinhole. However, it has been extended to points having less than 14 projections. The distance (d_1) between the detector and the pinhole plane is also necessary to relate a voxel location to its projection locations.

3D reconstruction from a small set of projections is very sensitive to distortions in projection images. Therefore, a calibration procedure is carried out every time 3D distributions have to be acquired under a new system geometry or tune. First the system parameters (α, d_A, d_B) are measured accurately. Then a point source at the system center is imaged. A 2D least-squares fit to a hexagon of its projections gives optimal estimates of camera offsets, the orientation of the pinhole pattern about the camera axis, and the pixel dimensions. It also provides a distortion index which allows one to decide whether or not the cameras are suitable for tomographic purposes (see Table I).

- REGION WITH COMPLETE PROJECTION SET
- REGION WITH INCOMPLETE PROJECTION SET

Fig. 3: System geometry.

Flood field projections are acquired as part of the calibration procedure. Flood field correction can be considered essentially as a first order correction for variations in solid angle throughout the effective field of each pinhole and simultaneously for variations in detector sensitivity.

Calibration data are therefore very similar to those used in 7PET, but the way they are processed differs.

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*****
ORTHOGONAL SEVEN PINHOLE TOMOGRAPHY
*****
POINT SOURCE FILE NAME : [CRATEK.DAT]PS633.DAT
FLOOD SOURCE FILE NAME : [CRATEK.DAT]FLAB.DAT
PROJECTION FILE NAME : [CRATEK.DAT]LIVTOT.DAT
3-D OBJECT FILE NAME : YRD:TEST1
VOXEL SIZE : 3.357
DISTANCE COLLIMATOR CRISTAL : 129.00
DISTANCE COLL. FOCAL PLANE : 250.00
DISTANCE CRISTAL-1 CENTER : 330.00
DISTANCE CRISTAL-2 CENTER : 330.00
DISTANCE BETWEEN 2 PINHOLES : 62.50
NO OF ITERATIONS : 1
NO OF VOXELS PER ROW : 32
DUMPING FACTOR : 32.00

DETECTOR NB 1          DETECTOR NB 2
ALFA = 63.374          ALFA = 63.376
BETA = 63.778          BETA = 67.739
TETA = 0.016 RAD       TETA = -0.014 RAD
RADIUS = 29.513        RADIUS = 30.436

CENTRAL ERROR = 0.212  CENTRAL ERROR = 0.472
MEAN ERROR = 0.817    MEAN ERROR = 1.020
  
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PIXEL SIZE = 3.357

Table I: Results of the calibration procedure.

RECONSTRUCTION ALGORITHM

For a given system geometry and camera distortions, each voxel (k : 3D index) of the reconstruction volume can be associated with up to 14 projections. Each projection (ik : Projection of voxel k through pinhole i) is characterized by its location ($l(ik)$: l is a 2D index) and a weighting factor $w(ik)$, which takes into account the attenuation along the ray and the solid angle with which the pinhole sees the voxel. A projection mask is built from one point source data at the system center, then the projection parameters are computed by simple geometric formulas only once for a given system geometry, and the resulting projection array is stored in a compact form onto disk.

A first estimate of the 3D distribution (A_1) is obtained by backprojection of the experimental projections ($EXPR(l)$) using the projection array. Three estimators have been implemented

- simple backprojection:

$$A_1(k) = (1/N_k) \sum_i \{w(ik) \cdot EXPR(l(ik))\}$$

- impedance estimator:

$$A_1(k) = \left[\sum_i \{1/w(ik) / EXPR(l(ik))\} \right]^{-1}$$

- and minimum estimator:

$$A_1(k) = \min \{w(ik) \cdot EXPR(l(ik))\}$$

where N_k is the number of projections for voxel (k).

The first estimate is then reprojected ($ESPR(l)$) and normalized such that:

$$S = \sum_l EXPR(l) = \sum_l ESPR(l)$$

The difference (D) between estimated and experimental projections is formed and the quality of the reconstruction is measured by:

$$Q = \left(\sum_i D^2(i) \right)^{1/2} / S$$

The 3D estimate is iteratively updated by:

$$A_{n+1}(k) = A_n(k) + h \text{BP}(D(i(k)))$$

where BP(.) denotes a backprojection operator, n is the iteration index, and h is a damping factor, until Q is sufficiently small or after a maximum number of iterations.

The algorithm is summarized in the flow chart given in Fig. 4.

Fig. 4: Reconstruction algorithm flow-chart

RESULTS

This algorithm has been coded in FORTRAN 77 and implemented on a VAX11/780. Several features make it attractive for development purposes and routine use:

- it is divided into distribution-independent and distribution-dependent procedures, such that reconstruction of 3D distributions acquired under the same detector conditions can be speeded up.
- it uses cubic voxels of uniform size such that display of the 3D structure slice by slice yields a natural space representation.
- The number of voxels and the voxel size are chosen independently; thus the reconstruction time can be optimized for a given reconstruction volume and object resolution.

The ability of this new tomographic procedure to reconstruct 3D distributions was evaluated by measuring the global sensitivity and the resolution of the system. Distances d_A and d_B have been set equal to a common value d , and a 250 μCi Tc-99m point source

has been placed at successive locations on the diagonal of the detector axes. Measurements were repeated for various values of d .

Fig. 5 shows how sensitivity varies with d and with the point source location, r (distance to each detector). For small values of r , sensitivity falls off very quickly as the number of projections decreases. This effect is more obvious for small values of d . On the other hand, count rate falls off smoothly with increasing r , because of decreasing solid angle. Therefore, when extended sources are imaged, d_A and d_B must be chosen such that the source is as close as possible to the detector but far enough to allow every point to have a reasonable number of projections.

Fig. 5: Sensitivity variation with distance:
 • ($d = 280$ mm), + ($d = 330$ mm), o ($d = 380$ mm), x ($d = 430$ mm).

Point sources located where sensitivity has been measured have been reconstructed from their projections. In order to estimate the shape of the impulse response, the reconstruction has been oversampled (voxel size = pixel size/4). Reconstruction images are consequently blurred. Variances of the distribution along each axis have been computed, and FWHM have been estimated from them, assuming a Gaussian model. Fig. 6 shows how FWHM varies with d and r over a broad range which covers values of every clinical situation. As expected resolution degrades with distance to the detectors, but improvements compared with conventional 7PHT are dramatic. They can be explained by both the use of a dual detector system and the use of the minimum estimator.

Standard measurement of sensitivity using a 22 cm diameter cylindrical phantom has been performed. 470,000 counts/min/($\mu\text{Ci/cc}$) were detected in a 20% photopeak window when the cylinder was at the system center, 330 mm from the detectors.

Tests using more realistic phantoms have been carried out. Fig. 7 shows the reconstruction of a

Fig. 6: Average resolution versus distance.

Fig. 7: Reconstruction of a liver phantom as shown in Fig. 1. Display of one slice through the lesion. The activity curve along the vertical line going through the lesion is displayed in an overlay.

liver phantom presenting a 3 cm diameter cold lesion in the middle of the right lobe. It can be seen that reasonable reconstruction is achieved despite a very simple attenuation model and a very large reconstruction volume.

CONCLUSION

We have described a new tomographic technique using two orthogonal seven pinhole collimated detectors. The acquisition system, the reconstruction algorithm, and the physical characterization of the system have been described. Encouraging results have been obtained, and improvements are expected by introducing more knowledge about image formation processes into the weighting factors.

It should be pointed out that we intend to use this method for dynamic 3D structures; because it

employs a static detector, D7PHT is well suited for this purpose. The dual detector configuration noticeably improves sensitivity and resolution. Furthermore, resolution variations within the reconstruction volume can be neglected. D7PHT is thus able to estimate relative activity inside a 3D structure, and experiments are to be carried out in order to define an acceptable tradeoff between spatial and temporal resolution.

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