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3D Ordered Subset Expectation Maximization (OSEM) Algorithm for a Compton camera

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1. Introduction

The Compton camera is an single-photon imaging device that employs an electronic collimation based on the relationship between energy transfer and Compton scattering angle of γ-ray in the detector. In this study, the expectation maximization (EM) approach along with its accelerated version based on the ordered subsets principle was applied to the problem of image reconstruction for a Compton camera, which is known to be computationally challenging. This study also compared several methods of constructing subsets for the optimal performance of these algorithms.

2. Methods

A Compton camera system consisted of three pairs of two detectors, scatterer and absorber, which were parallel to each other as shown in Figure 1 [1].

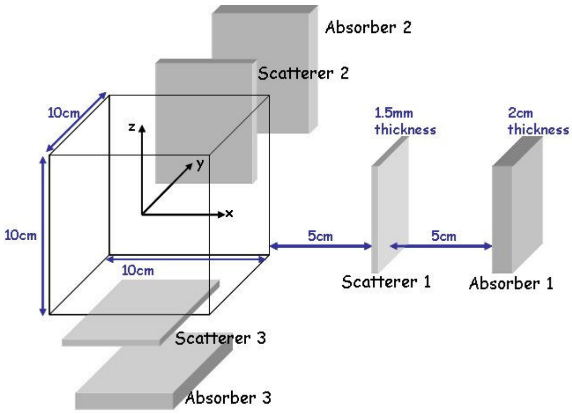

Figure 1. Compton camera system consisted of three pairs of parallel scatter and absorber.

For each combination of interaction positions in the two detectors and a scattering angle, the Compton projection data can be obtained by the conical surface integral with respect to the source distribution and expressed by

$$g_{mn\varpi} = \sum_i f_i H_{i;mn\varpi} \quad (1)$$

where $g_{mn\varpi}$ and f_i represented the projection data and the source distribution, respectively. The system matrix $H_{i;mn\varpi}$ represented the probability that a photon emitted from a voxel *i* is scattered at a position *m* of the scatterer with a scattering angle *ω* and detected at a position *n* of the absorber. Using the ray-tracing method, the projection process were modelled [2].

In this study, we considered three reconstruction algorithms: simple backprojection (SBP), expectation maximization (EM), and ordered subset EM (OSEM). The SBP methods can be implemented by simply reversing projection process. The OSEM algorithm, which was useful iterative reconstruction method for nuclear medicine imaging system such as SPECT and PET [3,4] was given by

$$f_i^{(k+1,j+1)} = \frac{f_i^{(k,j)}}{\sum_{\{mn\varpi\}\in S_j} H_{i;mn\varpi}} \sum_{\{mn\varpi\}\in S_j} \frac{H_{i;mn\varpi} g_{mn\varpi}}{\sum_t f_t^{(k,j)} H_{t;mn\varpi}} \quad (2)$$

where $k = 1,\Lambda,K$ and $j = 1,\Lambda,J$. The K and J denoted iteration and subset number, respectively and OSEM behaved like EM algorithm when *J* equals one. For OSEM three different schemes for choosing the nonoverlapping subsets were considered; scatter angle-based subsets (OSEM-SA), detector position-based subsets (OSEM-P), and both scatter angle- and detector position-based subsets (OSEM-ALL).

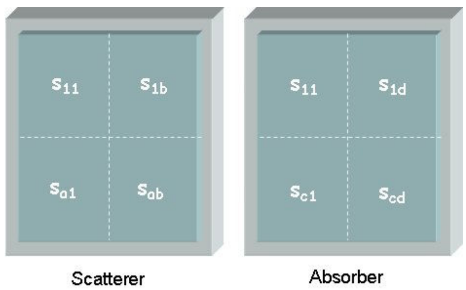

Figure 2. Grouping projection data formed by the scatterer-absorber pair into subsets. The positions of scatterer and absorber were sorted into $a \times b$ and $c \times d$ position subsets, respectively.

In the case of OSEM-P, the projection data was grouped into subsets in a predefined (OSEM-PR) or randomized order (OSEM-PIR).

3. Results

The EM and OSEM with 16 subsets were performed using 64 and 4 iterations, respectively. As shown in Figure 3 to 5, the accuracy of both EM and OSEM was superior to SBP. The OSEM with 16 subsets and 4 iterations was equivalent to the standard EM with 64 iterations.

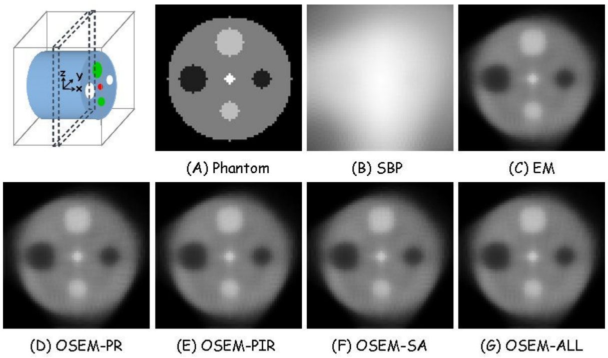

Figure 3. These are the central y-z planes of 3D phantom and reconstructed images.

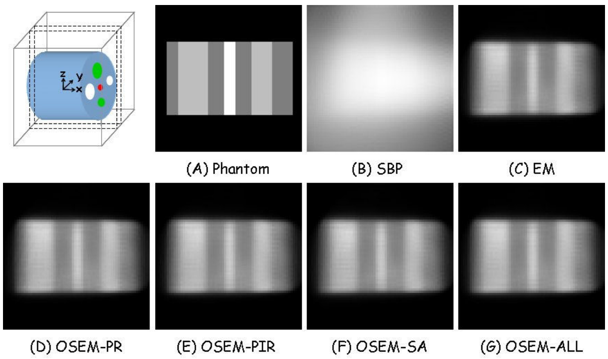

Figure 4. These are the central x-z planes of 3D phantom and reconstructed images.

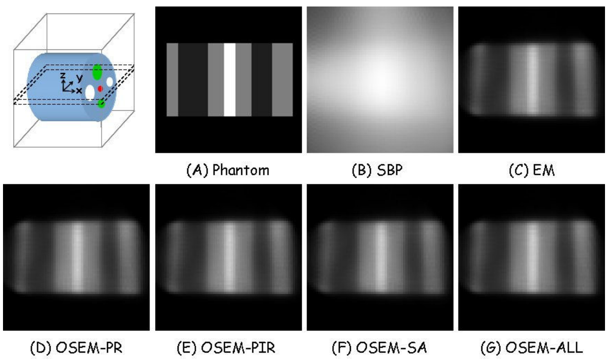

Figure 5. These are the central x-y planes of 3D phantom and reconstructed images.

The performance of three reconstruction algorithms, SBP, EM and OSEM was evaluated in terms of the computation time and the normalized mean-squared error (percent error). As expected, computation time with the OSEM with 16 subsets and 4 iterations was approximately 14 times faster than the standard EM (Table 1). In OSEM, all the three schemes for choosing the subsets yielded similar results in computation time as well as the percent error. No incremental improvement was achieved by the randomized grouping of subsets.

Table 1. Percent errors and computation times for SBP, EM (64 iterations), and OSEM (4 iterations) reconstructions using noiseless Compton data are represented.

	SBP	EM	OSEM-PR	OSEM-PIR	OSEM-SA	OSEM-ALL
Percent error (%)	7.4×10^3	27.6	27.6	27.5	28.8	27.6
Computation time(min)	12.4	1932	138	144	138	144

4. Conclusion

These results showed that the OSEM algorithm, which has proven to be useful in PET and SPECT, can also be applied to the problem of image reconstruction for a Compton camera. With properly chosen subset construction methods and a moderate number of subsets, the OSEM algorithm significantly improved the computational efficiency and maintained the original quality of the standard EM reconstruction.

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