Application of Ordered-Subsets Expectation- Maximization (OSEM) Algorithm to Cone-Beam SPECT for Accelerated 3D Reconstruction

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Abstract— **We investigated the performance of an ordered-subsets expectation-maximization (OSEM) algorithm for accelerated reconstruction in cone-beam SPECT. SPECT scans were performed using a Defrise phantom filled with 0.9 µCi/ml of Tc-99m and a dual-head gamma camera equipped with one cone-beam (CBC, f = 70 cm) and one parallel-beam collimator (PBC). Images were reconstructed using a fully-3D approach with resolution and attenuation modeling and an ordered-subsets version of a maximum-likelihood expectation-maximization algorithm (MLEM). Three grouping patterns of subsets were applied: consecutive, orthogonal, and uniform. In contrast to PBC SPECT, we observe that, in CBC SPECT, the reconstruction grouping pattern of the subsets is very important for the image quality obtained. Only when the projection data grouped into a subset were selected as uniformly as possible from all the acquired views, were the image quality and the noise in the images very close to results obtained using MLEM. However, we note that, for both CBC and PBC SPECT, the loglikelihood for a given iteration is practically the same for different grouping patterns of subsets.**

I. INTRODUCTION

Cone-beam SPECT can be used to improve the trade-off between sensitivity and resolution for small organs that fit in the tomographic field of view of a cone-beam collimator (CBC). This technique requires fully-3D reconstruction with resolution and sensitivity modeling, and is hindered by artifacts in the non-central slices. These artifacts might be caused by truncation and by the fact that cone-beam SPECT data collected in a circular orbit contain insufficient information for exact reconstruction of non-central slices. It has been shown that the maximum likelihood expectation maximization (MLEM) algorithm could alleviate these problems to some degree but, due to its slow convergence, the reconstruction time is prohibitively long. We investigated the performance of an ordered subsets EM (OSEM) algorithm for accelerated reconstruction in this context.

II. MATERIALS AND METHODS

We performed SPECT scans (90 views in 360° circular orbit, ROR=24cm, 25 sec/view) of a Defrise phantom filled with 0.9 µCi/ml of Tc-99m using a dual-head gamma camera (E.Cam, Siemens) equipped with one cone-beam (CBC, f = 70 cm) and one parallel-beam collimator (PBC). The cone-beam SPECT reconstructions were initiated from tomographic images obtained using OSEM of the PBC SPECT data [1-2]. We performed fully-3D reconstructions with distance-dependent resolution and sensitivity, and attenuation compensation. In OSEM, the projection data are grouped into subsets of projection images. During subiteration, each image estimate is updated after application of the MLEM algorithm [3-4] to only one subset of projections until all projections are used (full iteration). We investigated the influence of the number and grouping pattern of subsets on the reconstruction time, image quality, loglikelihood, and noise in the images obtained.

The images were reconstructed using a maximum-likelihood expectation maximization algorithm (MLEM) in its ordered subset version [1-2]. We performed fully-3D

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reconstruction with resolution and attenuation modeling. We used our of version of the MLEM algorithm [5]:

$$\lambda_k^{n+1} = \lambda_k^n \frac{1}{\sum_{i\in S_0} c_{ik}} \sum_{i\in S_0} c_{ik}\cdot\gamma_{iJ_i} \frac{Y_i}{\sum_{m\in P_i} \lambda_m^n \cdot c_{im}\cdot\gamma_{iJ_i}} + c_{ik}(1-\gamma_{iJ_i}) \quad \cdot \qquad (1)$$

The meaning of the symbols is as follows:

i projection subscript,

J_i number of pixels in the ray I,

j pixel subscript ($j < J_i$),

P_i set of pixels contributing to projection i,

S_0 subset of the projection bins corresponding to a particular set of views,

R_{k0} subset of projections that belongs to S_0 to which pixel k contributes,

Y_i total (random) number of photons recorded by the detector bin i,

λ^n_j current estimate of source intensity of pixel j (*i.e.* the mean number of photons emitted by pixel j),

μ_j linear attenuation coefficient of pixel j,

l_{ij} the length of intersection of the pixel j, *i.e.* the fraction of the ray orignated from the center of detector bin i intercepted by pixel j

γ_{iJ} probability of surviving attenuation between the source in the pixel j for the photon heading towards the detector bin i, c_{ij} known probability (corrected for the decay rate and the time interval of *ith* projection) that photon leaving pixel j is directed toward detector bin i.

Summation in (1) is performed over a subset S_0 of the projection bins corresponding to a particular set of views. The images are updated after a user-specified number of projection views (OS size) that form the subset S_0. The OS size may vary from unity (the smallest possible) to the number of acquired views (the largest possible).

We have reconstructed the CBC and PBC SPECT data using an OSEM algorithm with three grouping patterns: consecutive, orthogonal, and uniform. They are schematically illustrated in Fig. 1.

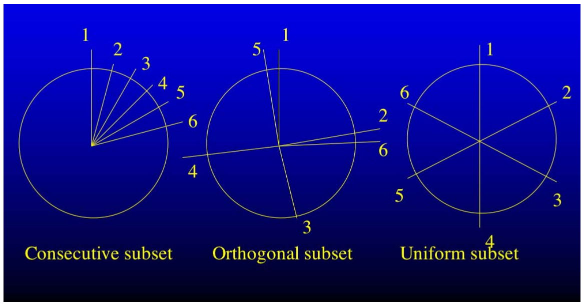
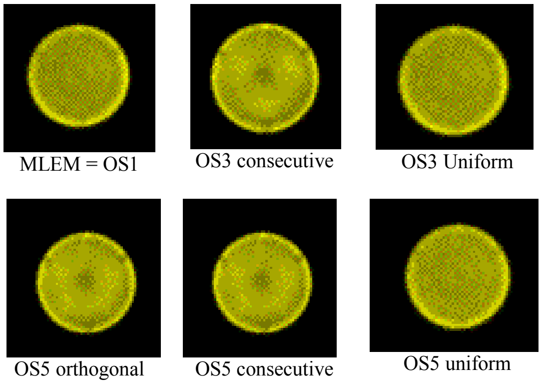


Fig. 1. The considered grouping pattern of subsets used in tomographic reconstruction. In this example, six views are selected from all views to perform the image update: left — consecutive; center — orthogonal; right—uniform.

III. RESULTS

In contrast to PBC SPECT, we observe that, in CBC SPECT, the reconstruction grouping pattern of subsets is very important for the image quality obtained. Only when the projection data grouped into subsets were selected as uniformly as possible from all the acquired views, were the image quality and the noise in the images very close to results obtained using MLEM (Fig. 2). The consecutive and orthogonal grouping of projection data into subsets resulted in image artifacts and increased noise and bias (Fig. 1). Uniform OS5 produced images as good at 10 iterations as uniform OS3 at 20 iterations, and comparable to 70 iterations required for MLEM.


MLEM = OS1

OS3 consecutive

OS3 Uniform

OS5 orthogonal

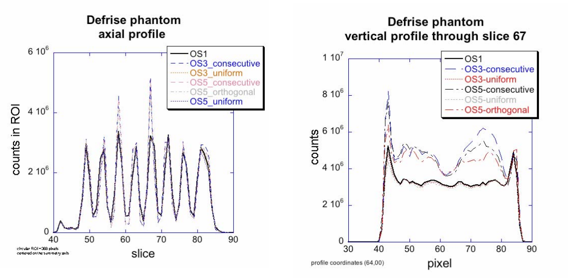
OS5 consecutive

OS5 uniform

Fig. 2. Reconstructed slice 67 of a Defrise phantom cone-beam SPECT obtained using MLEM (OS1), and OSEM with three (OS3) or five (OS5) subsets with consecutive, orthogonal, and uniform grouping patterns of subsets.

The axial profiles (i.e. the total number of counts in a region-of-interest vs. transaxial slice number) and the line profiles (in transaxial planes) of the images reconstructed for Defrise phantom cone-beam SPECT data are shown in Fig. 3. They were obtained in reconstructions that were performed using MLEM (OS1), and OSEM with three (OS3) or five

(OS5) subsets with consecutive, orthogonal, and uniform grouping patterns of subsets.

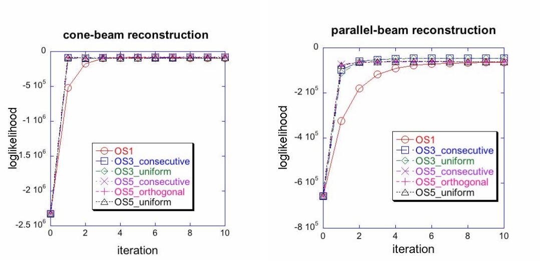


A. Axial profiles through the reconstructed Defrise phantom.

B. Line profiles through slice 67 of the reconstructed Defrise phantom.

Fig. 3. Axial and line profiles obtained for Defrise phantom cone-beam SPECT data reconstructed using MLEM (OS1) and OSEM with three (OS3) or five (OS5) subsets with consecutive, orthogonal and uniform grouping pattern of subsets.

We also investigated the behavior of the loglikelihood vs. iteration number for various grouping patterns. In cone-beam reconstruction, the loglikelihood for a given iteration is practically the same for different grouping patterns of subsets (Fig. 4A). Similar observations apply for the OSEM reconstruction of parallel–beam SPECT data (Fig. 4B).



A. Loglikelihood vs. iteration for cone-beam SPECT data.

B. Loglikelihood vs. iteration for parallel-beam SPECT data.

Fig. 4. Loglikelihood vs. iteration obtained for Defrise phantom cone-beam and parallel-beam SPECT data reconstructed using MLEM (OS1) and OSEM with three (OS3) or five (OS5) subsets with consecutive, orthogonal, and uniform grouping pattern of subsets.

IV. CONCLUSIONS

Significant acceleration of cone-beam SPECT 3D reconstruction, without introducing artifacts or increasing noise, can be achieved with OSEM, provided that the subsets are selected uniformly from all the acquired views.

V. REFERENCES

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