

DE-MULTIPLEXING FOR MULTI-PINHOLE SPECT IMAGING

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ABSTRACT

The projection data of multi-pinhole SPECT often produce overlapping of several projections through the pinholes that are used to define the range of directions where photons can be detected. The purpose of this work is to identify the influence of overlapped projections in multi-pinhole (MP) SPECT imaging and to present a de-multiplexing method to remove the ring artifacts caused by the overlapping. We developed a separation method which accurately estimate the pinhole-specific projection from overlapped ones. We used Monte Carlo simulations to demonstrate the performance of the proposed method. The simulation assumes that the detector module was designed to have $50 \times 50 \text{ mm}^2$ detection area, and perpendicular lead septa were employed to reduce overlapping projections and hence to improve image quality in reconstruction. The performance of multi-pinhole SPECT imaging was evaluated by the reconstructed images of resolution and MCAT phantoms. Images were reconstructed by dedicated maximum likelihood expectation maximization (MLEM) algorithm with the system matrix specific to the multi-pinhole SPECT. The result shows that the proposed method suppress the overlapping-related artifacts effectively.

INTRODUCTION

High-resolution pinhole SPECT can be very useful in molecular imaging of experimental and clinical studies. The conventional single-pinhole system, however, suffers from poor sensitivity due to an inferior geometric efficiency of the high-resolution collimator. Recently, in order to increase the sensitivity without degrading spatial resolution, there has been great interest on developing a multi-pinhole SPECT [1], [2], [3]. However, as the detector size is limited, this results in increasing overlap of projections (multiplexing) and leads to a new problem in image reconstruction. Generally, it is very difficult to use direct methods for projections with multiplexing; direct methods require directional information, and multiplexing makes it impossible to do so. By using cut-off sheds, it is possible to avoid multiplexing, however, this can cause artificial deterioration of projections at the same time. Such artifacts are more harmful to direct methods than iterative ones in most cases. Therefore, iterative methods [4], [5] are the methods of choice for image reconstruction in the multi-pinhole SPECT.

Several SPECT systems employing the multi-pinhole collimator have been investigated and demonstrated a superior performance for in vivo imaging of small animals [1], [2], [3]. The pinholes in their works were focused on a small field of view (FOV) and generated overlapped projections through the different pinholes. In a similar study, a stationary system dedicated to

the imaging of small animals with non-overlapped projections was proposed [6]. It is shown that this system provides sub-millimeter details of tracer uptake and hence it make it possible to assess tracer dynamics in organs of the living mouse.

These systems demonstrated that a multi-pinhole collimator could provide an excellent resolution and sensitivity compared to single-pinhole and parallel-hole collimators. Due to the small FOV of about 50 mm, however, the application of those multi-pinhole systems is limited to small animal imaging. Most multi-pinhole systems employ conventional gamma camera which has the range of 3 to 5 mm intrinsic spatial resolution, and thus, to have high spatial resolution even with relatively poor intrinsic spatial resolution, must use large magnification. This kind of imaging environment is not suitable for clinical practice.

In this investigation, we are especially interested in a multi-pinhole collimator for clinical purpose. To do do, we consider the multi-pinhole SPECT with lead vertical septas. The lead septas are designed to provide easy control over resolution and sensitivity trade-off, and reduces the overlapping of projections. Originally, the lead septas were designed to block the overlapping completely, but, due to the mechanical difficulty, blurring in crystal, and the sensitivity, they have to allow some overlapping. Generally, the data obtained at the overlapped region is very small, but the influence of those overlapped projections often produce some artifacts in reconstruction.

The purpose of this work is to identify the influence of overlapped projections in multi-pinhole SPECT imaging and to present a de-multiplexing method to remove the artifacts caused by the overlapping.

DE-MULTIPLEXING METHOD

To deal with the geometric complexity caused by multi-pinhole SPECT, we assume a linear algebraic model[8] and use ML-EM iteration[4] for image reconstruction. We use induces following notations with induces b for projection bins and v for phantom image voxels:

- f_v activity at voxel v
- Y_b photon counts by multi-pinhole collimation at projection bin b
- $P_{b,v}$ entries of the system matrix P

Using these notations, we can write the relation between unknown phantom image voxel values f_v and projection data Y_b as $Y_b = \sum_v P_{b,v} f_v$. Then the problem of de-blurring and reconstruction becomes finding a solution of the system of linear equations. Following this approach, we use ML-EM[4], where the new image f^{n+1} is updated from the current image f^n by

$$f_v^{n+1} = f_v^n \sum_b P_{b,v} \frac{Y_b}{\mu_b^n} / \sum_c P_{c,v}, \quad \mu_v^n = \sum_b P_{b,v} f_v^n. \quad (1)$$

The projection data Y_b are summed result of projections through several pinholes. For instance, let Y_b^i be the projection data through the i -th pinhole. Then

$$Y_b = \sum_i Y_b^i. \quad (2)$$

Normally, it is possible to make the portion of overlapping small by using lead septas. In such cases, in most projection bin b , there is only one pinhole which contributes to the sum, i.e.,

$Y_b = Y_b^{i_0}$. But due to the mechanical difficulty, blurring in crystal, and the sensitivity, it have to allow some overlapping.

Figure 1 shows the projection of 'cylinder' phantom through 5 pinholes. Figure 2 is the reconstructed image of 'cylinder' phantom, which suffers from the ring artifacts caused by overlapping in projection.

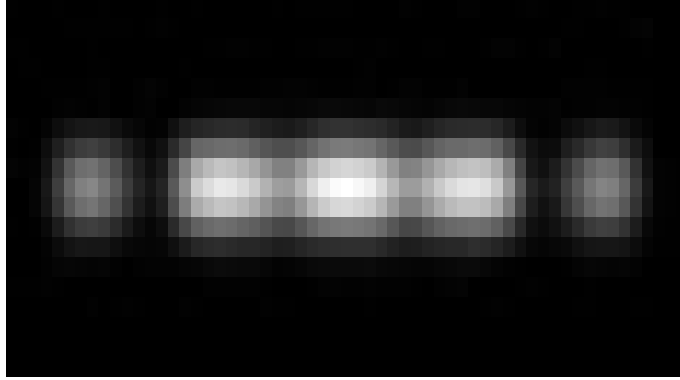


Figure 1. Projection of 'cylinder' phantom at a fixed angle



Figure 2. Reconstructed image by the standard ML-EM.

To reduce the artifacts caused by overlapping, we suggest to use non-overlapped projections, i.e., pinhole-specific projection. As we mentioned before, this is not practically possible, we must estimate those pinhole-specific projection from overlapped projection. To be specific, we use following iteration

$$f_v^{n+1} = f_v^n \sum_i \sum_b P_{b,v}^i \frac{Y_b^i}{\mu_b^{n,i}} \bigg/ \sum_c P_{c,v}^i, \quad \mu_v^{n,i} = \sum_v P_{b,v}^i f_v^n, \quad (3)$$

where $P_{b,v}^i$ are the system matrix entries corresponding to the i -th pinhole, and Y_b^i are the estimated projection through the i -th pinhole only.

SIMULATION AND CONCLUSION

We conducted computer simulation with 'cylinder'(Figure 3-a) and 'cold rods'(Figure 3-b) phantom images to test the performance of the proposed method. As we can see, the ring artifacts, which is very visible in Figure 2, are removed quite well in Figure 3.

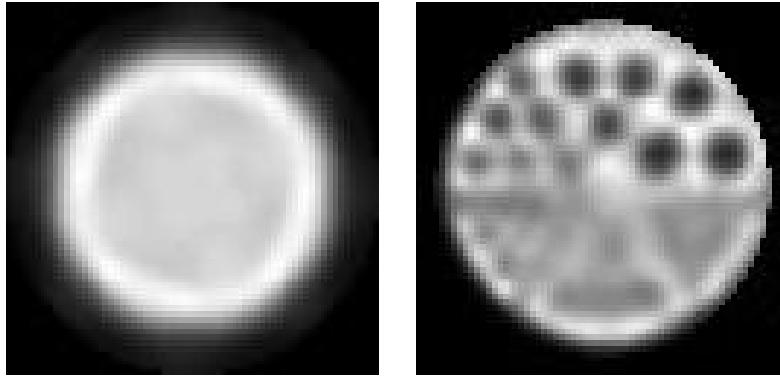


Figure 3. Reconstructed images by the proposed method, a(left) - 'cylinder', b(right) - 'cold rods'

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