Development of a Collimator Representation in the TITAN Transport Code for SPECT Simulation

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Introduction

Traditionally, Monte Carlo methods have been used for the simulation of Single Photon Emission Computed Tomography (SPECT). The TITAN code is a hybrid deterministic transport code that is being used to develop a fast methodology for SPECT simulation. The TITAN code uses a discrete ordinates method within the phantom and a simplified ray-tracing formulation in the air around the phantom. Previous work has shown that the TITAN methodology is less accurate for a larger phantom acceptance angle. Here, we develop a collimator representation to accurately model collimators of a variety of sizes. The MCNP5 Monte Carlo code is used to benchmark the TITAN code’s result for a simple cube phantom.

The TITAN Code Methodology

The TITAN code is referred to as a “hybrid” code because it allows the user to specify different solvers in different regions (called coarse meshes) of a problem. Either a discrete ordinates ($S_0$) method or a characteristics method can be used in any coarse mesh. For the simulation of SPECT, a four-step hybrid solver combining the $S_0$ method and a simplified ray-tracing formulation was developed:

1. $S_0$ transport calculation in the phantom with a regular quadrature set
2. Generation of fictitious quadrature set with circular ordinate splitting for a projection angle
3. One extra transport sweep in the phantom with the fictitious quadrature set using the Step 1 converged flux moments to evaluate the scattering source
4. Simulation of projection using the simplified ray-tracing formulation outside the phantom.

This efficient methodology allows TITAN to simulate any number of projection angles without recalculating the phantom flux from Step 1.

Two new features are added to improve the COS technique:

1. Split directions are weighted by the detector surface area projected along that direction to the front of the collimator.
2. The number of directions per concentric circle is scaled to the circle area, except for the innermost, which is user specified.

Model Description

To test the new collimator algorithm, we create a simple model that can be easily represented in both the TITAN and MCNP5 codes. A 101x101x101 cm$^3$ cube of water contains a 1.25x1.25x1.25 cm$^3$ cube of $^{99m}$Tc at its center. In the MCNP5 code, a row of colimators are modeled as shown in the figure. As discussed previously, the TITAN code does not directly model the collimators. The flux reaching the detector surface behind each collimator is then normalized and compared. Multigroup cross sections were generated using the CEPSX code. The XSMCNP code was then used to convert the deterministic cross-section data for use in multigroup MCNP5. The source-containing first group (126.45-154.55 keV) is the energy group of interest. Two collimator cases are considered.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Case 1</th>
<th>Case 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collimator</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acceptance Angle</td>
<td>2.1°</td>
<td>7.7°</td>
</tr>
<tr>
<td>Aspect Ratio</td>
<td>13.5:1</td>
<td>3.7:1</td>
</tr>
<tr>
<td>Detector</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Detector Pixel Size</td>
<td>0.17x0.17 cm$^2$</td>
<td>0.625x0.625 cm$^2$</td>
</tr>
<tr>
<td>Number of Detector Pixels</td>
<td>15</td>
<td>7</td>
</tr>
</tbody>
</table>

Results

For the 2.1° acceptance angle:

- The weighted COS technique does not show any clear improvement over the original algorithm; however, the comparison with MCNP5 is close for both techniques.
- No significant difference is seen as the number of concentric circles and directions is increased.

For the 7.7° acceptance angle:

- The weighted COS technique is consistently 5% better than for the MCNP5 results.
- The original COS solution appears to diverge as the number of circles and directions is increased.

**Comparison of serial computation times**

<table>
<thead>
<tr>
<th>Acceptance Angle</th>
<th>MCNP5</th>
<th>TITAN*</th>
<th>Speedup</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1°</td>
<td>110175 sec (16 ≤ 4.7%)</td>
<td>2.2 sec</td>
<td>5.0x10$^4$</td>
</tr>
<tr>
<td>7.7°</td>
<td>11720 sec (16 ≤ 1.0%)</td>
<td>2.2 sec</td>
<td>5.3x10$^3$</td>
</tr>
</tbody>
</table>

*There is no appreciable difference in computation time between the two COS methods for this model.

Conclusions and Future Work

A new collimator representation called weighted COS has been developed for SPECT simulation using the TITAN deterministic transport code. The new algorithm still produces excellent results when compared with MCNP5 for a small collimator acceptance angle (2.1°). For a larger collimator acceptance angle (7.7°), the weighted COS algorithm shows improved accuracy over the original COS algorithm and consistent behavior with varying parameters. A computation time comparison demonstrated speedups of several orders of magnitude achieved by TITAN over MCNP5.

Future work will focus on the development of an iterative reconstruction algorithm for SPECT. This algorithm will incorporate the TITAN code for forward projection. Our goal is to demonstrate that the TITAN code’s inclusion will result in a fast and accurate reconstruction algorithm. Also, this new collimator algorithm could be applicable in other areas, such as modeling streaming radiation through ducts in a reactor.

Acknowledgements

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