A fast finite size pencil beam algorithm for dose calculation using GPUs

Introduction

Fast and accurate dose calculation is a primary requirement for online adaptive radiotherapy. It is therefore very important to rely on development of a fast and accurate dose calculation algorithm. In last four years, various techniques have been proposed to accelerate dose calculation using a Graphics Processing Unit (GPU) [1, 2]. The main objective of this work is the implementation of a GPU-accelerated dose calculation engine based on a finite size pencil beam (FSPB) algorithm to be used for different radiotherapy applications, including online re-planning and Intensity-Modulated Radiation Therapy (IMRT) optimization.

Material and Methods

The finite size pencil beam algorithm for photon consists of decomposing a radiation field into small beamlets. The FSPB algorithm is based on an analytical kernel describing the dose distribution of each beamlet. The parameters of this kernel are determined from the dose of broad beams obtained with the EGSnrc Monte Carlo code [3]. The total dose is calculated by summing the dose contribution for each beamlet. CPU and GPU-based FSPB algorithm versions were implemented in an identical algorithmic strategy. The CPU version was single threaded and executed on a Quad core 2.53 GHz Intel Xeon CPU processor. The GPU-based FSPB algorithm was implemented using the CUDA API and was executed on a single NVIDIA GeForce GTX480 card. The performance of the CPU implementation depends on various factors such as the number of beamlets, voxel size and the GPU configuration. The heterogeneity correction strategy used was based on the work of Jelen et al [4], and was performed in three different directions, an x and y lateral correction and a longitudinal correction. For validation, the GPU-based FSPB algorithm was compared to the CPU version and to the analytic anisotropic algorithm (AAA) implemented in the Eclipse Treatment Planning System. Dose calculation scenarios using heterogeneous phantom and clinical cases with different numbers of beamlets were used as evaluation cases.

Results

The GPU-based FSPB and AAA algorithms provided equivalent results in a heterogeneous medium. Figure I. show a typical profile and depth dose curves calculated with FSPB and AAA techniques using the water-lung-water phantom. The execution times for the CPU and the GPU for various numbers of beamlets are presented in Table I. The overall time spent for the dose calculation scenario equivalent to seven fields prostate plan (2500 beamlets) was 214 seconds on the CPU while the GPU implementation completed the same task in 0.45 seconds, achieving identical results 477 times faster.

To evaluate the speedup performance of the GPU implementation in a heterogeneous medium, the GPU-based FSPB was compared to the CPU-based AAA on water-lung-water phantom. The benchmarking was conducted for a single beam with heterogeneity correction in FSPB and AAA. The results were obtained using a single computing core for AAA. The computation times and the speedup factors were assessed as a function of calculation grid sizes. Overall, the acceleration factors were almost 6 times. The GPU-based FSPB algorithm was also validated against AAA for some clinical cases including 3D conformal prostate plans. The difference between both algorithms was about 2% for three prostate plans with seven beams.
Figure I. Profile and depth dose curves in the heterogeneous media obtained with FSPB and AAA.

Table I. CPU and GPU-based FSPB computation times and acceleration factors as a function of the number of beamlets.

<table>
<thead>
<tr>
<th>Number of Beamlets</th>
<th>CPU Time [sec]</th>
<th>GPU Time [sec]</th>
<th>Acceleration factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>8.5</td>
<td>0.24</td>
<td>35</td>
</tr>
<tr>
<td>400</td>
<td>34.5</td>
<td>0.29</td>
<td>119</td>
</tr>
<tr>
<td>900</td>
<td>78.3</td>
<td>0.35</td>
<td>224</td>
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<tr>
<td>1600</td>
<td>131.8</td>
<td>0.39</td>
<td>338</td>
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<tr>
<td>2500</td>
<td>214.6</td>
<td>0.45</td>
<td>477</td>
</tr>
</tbody>
</table>

Conclusion

We have successfully implemented a GPU-accelerated finite size pencil beam method for 3D photon dose calculations in radiotherapy. The results obtained were similar to those obtained with the AAA algorithm in a heterogeneous phantom and in clinical cases. The uncertainty between both methods was approximately 2% in terms of dosimetric accuracy, while the GPU-based FSPB was 6 times faster. The GPU-accelerated finite size pencil beam allows dose calculation in a timeframe commensurate with online adaptive radiotherapy.

Reference