Dose Computational Time Reduction For Monte Carlo Treatment Planning

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ABSTRACT

It has been noted that Monte Carlo simulations are the most accurate method to calculate dose distributions in any material and geometry. Monte Carlo transport algorithms determine the absorbed dose by following the path of representative particles as they travel through the medium. Accurate Monte Carlo dose calculations rely on detailed modeling of the radiation source. We modeled the effects of beam modifiers such as collimators, blocks, wedges, etc. of our accelerator, Varian Clinac 600C/D to ensure accurate representation of the radiation source using the EGSnrc based BEAM code. These were used in the EGSnrc based DOSXYZ code for the simulation of particles transport through a voxel based Cartesian coordinate system. Because Monte Carlo methods use particle-by-particle methods to simulate a radiation transport, more particle histories yield the better representation of the actual dose. But the prohibitively long time required to get high resolution and accuracy calculations has prevented the use of Monte Carlo methods in the actual clinical spots. Our ultimate aim is to develop a Monte Carlo dose calculation system designed specifically for radiation therapy planning, which is distinguished from current dose calculation methods. The purpose of this study in the present phase was to get dose calculation results corresponding to measurements within practical time limit. We used parallel processing and some variance reduction techniques, therefore reduced the computational time, preserving a good agreement between calculations of depth dose distributions and measurements within 5% deviations.

Keywords: Monte Carlo, BEAM, DOSXYZ, parallel processing, variance reduction

1. INTRODUCTION

Monte Carlo methods can be described as statistical simulation methods which utilize sequences of random numbers. Dose calculation accuracy is a critical part of radiation therapy and the Monte Carlo technique for dose calculation is considered to be the only technique capable of accurately computing the dose under almost all circumstances.[1] Today various Monte Carlo codes are available for use in particle transport simulations and dosimetry. Of these, the EGS4 code or the EGSnrc code in which the transport physics is greatly improved over that in EGS4[2] has been adapted for specific applications such as the BEAM code for the modeling of radiation therapy machines and the DOSXYZ code for the simulation of coupled photon-electron transport through a voxel based Cartesian coordinate system. The BEAM code and the DOSXYZ code was originally within the larger OMEGA project (a collaboration between NRC, the University of Wisconsin and the Ottawa Cancer Clinic) which was to develop a 3-D dose calculation engine for use in clinical treatment planning systems for radiation beam therapy. Although the major emphasis in this project has been on simulating electron beams, the codes turned out to be equally applicable to photon beams from accelerators.[1)]
In this study the EGSnrc based BEAM and DOSXYZ codes were used to calculate dose for 6MV photon beam from a Varian Clinac 600C/D. The dose calculation was achieved by a BEAM simulation of the accelerator and a DOSXYZ mathematical water phantom setup. These obtained results were then compared with the measured dose values.

2. CARRYING OUT THE CODES

2.1. Modelling of an accelerator

One element of the design philosophy of BEAM is that the model is built up from a series of individual component modules (CMs), each of which operates completely independently of the other component models and occupies a slab at right angles to the beam axis. It allows many very different designs of machines to be simulated because the various CMs can be used in a wide variety of configurations.

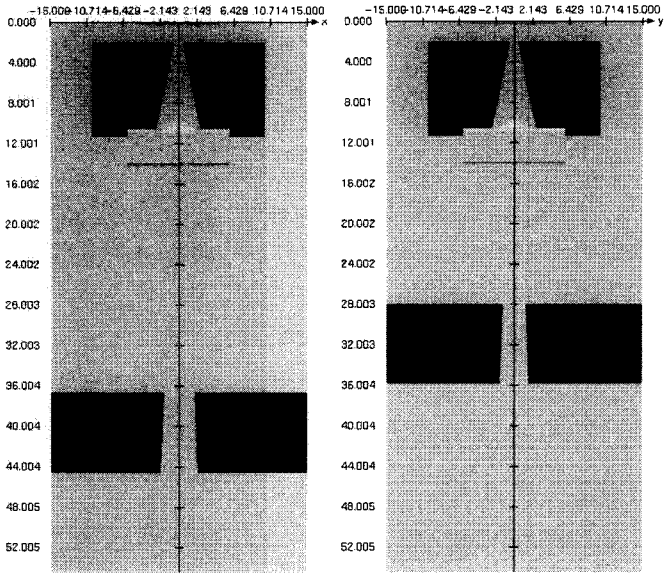

Fig. 1: xz and yz views of the model of the accelerator based on a Varian Clinac 600C/D, built up from the various

As seen above, we modeled our machine, Varian Clinac 600C/D with the use of a series of CMs: SLABS, CONS3R, FLATFILT, CHAMBER, MIRROR, JAWS and SLABS (the CMs have been named after the components they were originally written to model, but they can be applied to many more structures[1]).

2.2. Mathematical water phantom setup

Another element of the design philosophy of BEAM is that the BEAM code produces a phase space output of the beam (*i.e.* the position, energy, direction, charge and history tag for each particle) at any specified plane in the model. This phase-space file can be used as an input to the dose computation algorithm such as the DOSXYZ code directly.

A mathematical water phantom was constructed in DOSXYZ with dimensions of 30.5cm×30.5cm×25cm in the x, y and z directions. It contained a 61×61×50 array of cubical voxels with equal side lengths of 0.5cm. The BEAM generated phase space files (beam sources) were directly perpendicularly to the xy plane with the central beam axis coincident with the z axis. The origin was located in the center of the xy plane. The isocenter was located at the origin of the water phantom (x, y, z)=(0, 0, 0). We extracted the depth dose data for a given field size from the DOSXYZ 3-D dose distribution output file, and then compared them with the measured beam data.

3. TIME REDUCTION

3.1. Parallel processing

It is possible to parallelize Monte Carlo codes for particle transport problem, making use of independency of the calculation for each particle. BEAM and DOSXYZ simulations can be split into smaller jobs which can then be run on different processors in parallel and combined at the end of the runs to reduce the elapsed time required for a simulation. Our Beowulf computer cluster currently consists of 10 Intel Pentium 4 based personal computers running Red Hat Linux 7.2 with the 2.4.7 kernel. Each compute node has a 1.7GHz processor and 512 MB of memory. The computers are interconnected by a private fast ethernet (100 Mbps) network. Generally, in running BEAM or DOSXYZ codes, the elapsed time was precisely in inverse proportion to the number of nodes used.

3.2. Variance reduction techniques

Efficiency of a Monte Carlo calculation, ε is defined as:

$$\varepsilon = \frac{1}{Ts^2}$$

where T is the time taken to do the calculation (*e.g.* CPU seconds) and s is an estimate of σ, the variance, *i.e.* uncertainty on some quantity of interest. Efficiency is inversely proportional to the time taken to achieve a given statistical uncertainty, and the purpose of employing variance reduction techniques is to reduce the time it takes to

calculate a result with a given variance. Various variance reduction techniques can be used in BEAM to make calculations more efficient. Of these, we used photon forcing, and Bremsstrahlung photon splitting and Russian roulette. We reduced the computational time in contrast to analogue method, preserving a good agreement between calculations of depth dose distributions and measurements within 5% deviations.

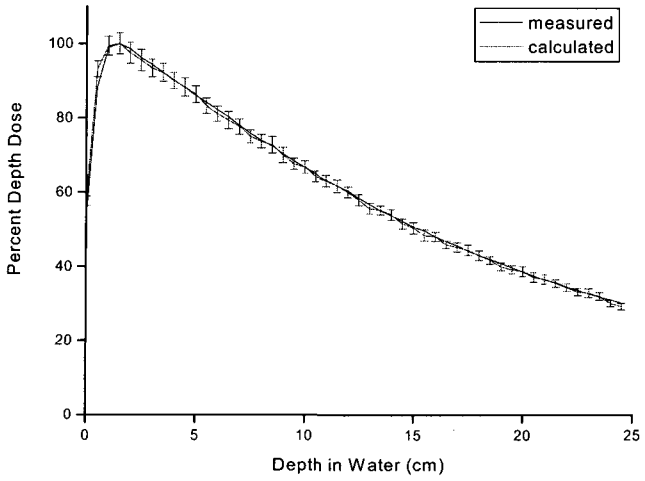

Fig. 2: Comparison of the calculated and the measured cetral-axis depth dose data for the 6MV photon beam of the Varian Clinac 600C/D accelerator ($10\times10\,cm^2$ field at 100cm SSD).

In spite of the time reduction, this calculation in which one billion histories were used took about 25 hours.

4. CONCLUSIONS

We used parallel processing and some variance reduction techniques to reduce the computational time. Although we got dose calculation results corresponding to measurements, we can't say we achieved it within practical time limit. Our methods need making improvements for an application to radiation therapy planning in the actual clinical spots. We will find the ways to make parallel processing performance more competently and to use variance reduction techniques more adequately. In addition, we will investigate useful simulation time saving methods such as beam characterization.

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