

OPTIMIZATION OF MONTE CARLO CODES PENELOPE 2006 AND PENFAST BY PARALLELIZATION AND REDUCTION VARIANCE IMPLEMENTATION

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Abstract

Introduction

The TELEDOS project aimed to improve the accuracy of the deposited dose by radiation while reducing the time required for this calculation in treatment planning system in radiotherapy. Typically, one of the goals was to produce dose distributions in less than 10 minutes with a statistical uncertainty of 2% at 1 standard deviation. The required accuracy will be achieved by introducing a Monte Carlo code, that has the ability to yield results close to reality, but the calculation times are much longer compared to analytical or ray tracing algorithms. Nevertheless the reduction of time spent in these calculations can be obtained by two methods. The first is to introduce variance reduction techniques in the PENELOPE 2006 code, and the second is to parallelize the code. This paper highlights one hand the contribution of variance reduction introduced in the code and secondly, it shows the gain in performance achieved by parallelization, using MPI (Message Passing Interface).

Material and methods

MC calculations are typically split into two parts (figure 1) : the first step consists in a detailed simulation of the particle transport through the accelerator head. An impact detector is located at the bottom of the treatment machine. When crossing this scoring plane, particle characteristics (i.e. type of the particle, position, energy, direction and weight) are stored in a PSF (Phase Space File) which is used as input data in the second step to calculate the three-dimensional dose distribution in a voxelised representation of the patient or the phantom (such as one obtained from a CT scan). In this work, the PENELOPE 2006 code [1-3] has been chosen to calculate the PSF. The second step was executed with a new transport algorithm for fast simulation of dose distributions in computerized tomography (CT) structures, PENFAST who was also been parallelized. Both of them have been developed by Salvat *et al.* [4-6].

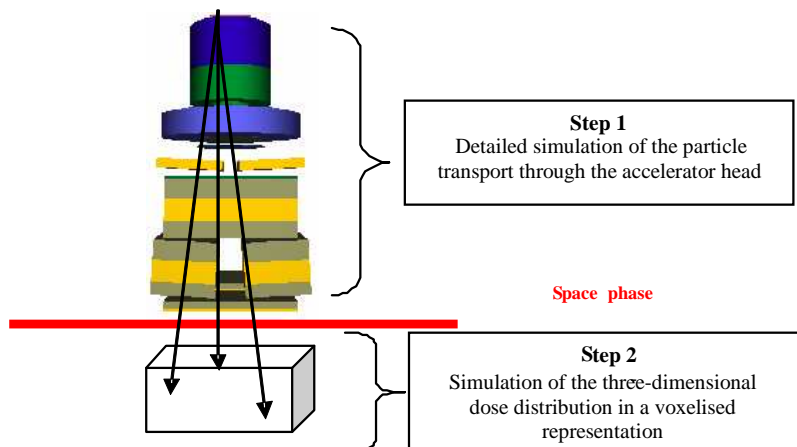


Figure 1 : Simulation of particles transport in two steps

Variance reduction techniques

As part of optimizing the code, several algorithms for reducing variance, ensuring an unbiased result, have been implemented. These include bremsstrahlung splitting, Russian roulette coupled with splitting and circular splitting in the case of geometries with rotational symmetry (figure 2). These variance reduction techniques implemented in PENELOPE aimed to accelerate this part of a photon beam simulation. We demonstrate that further improvements of efficiency can be done by optimizing the variance reduction parameters used in the simulation. These methods increase the simulation efficiency by a factor of up to 100 compared with the analogue simulation (i.e. with all particles having an unit weight) (figure 3a). To validate these techniques, calculations are performed both in analogue and non analogue mode (figure 3b).

Although particularly suited to the simulation of particle transport in the head of a radiotherapy accelerator, these algorithms are quite general and may apply to any other field. The toll in terms of gain in computing time will be provided for all these techniques.

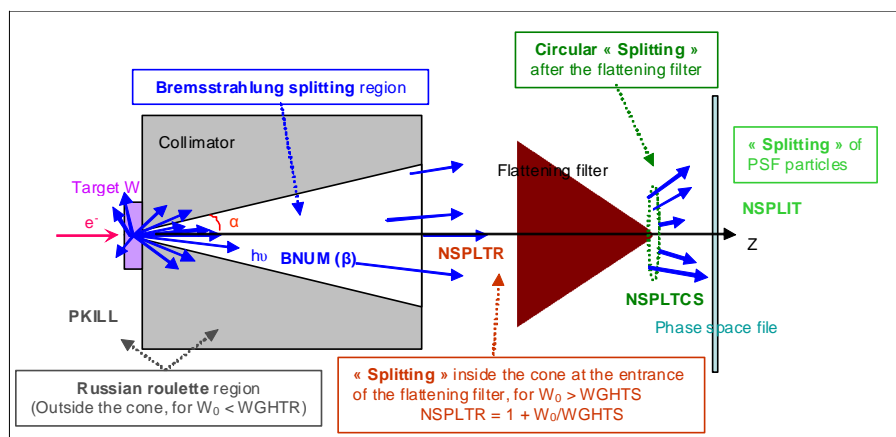


Figure 2 : Schematic overview of variance reduction methods implemented in PENELOPE 2006 version.

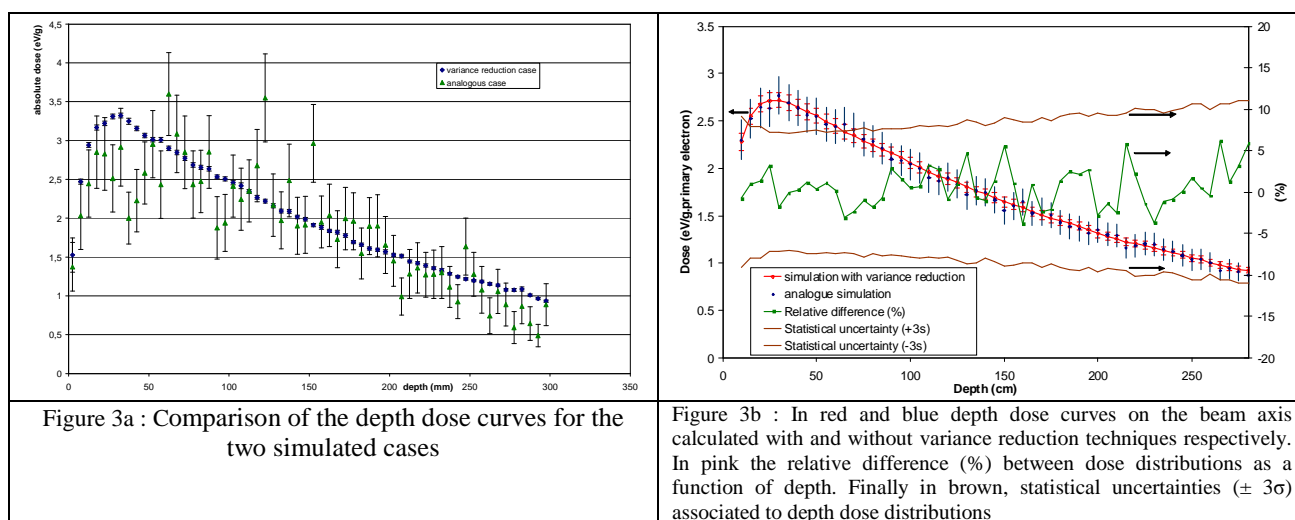


Figure 3a : Comparison of the depth dose curves for the two simulated cases

Figure 3b : In red and blue depth dose curves on the beam axis calculated with and without variance reduction techniques respectively. In pink the relative difference (%) between dose distributions as a function of depth. Finally in brown, statistical uncertainties ($\pm 3\sigma$) associated to depth dose distributions

Parallelization of PENELOPE code

Parallelization of PENELOPE 2006 and PENFAST was achieved using MPI, version mpich2 1.0.6. As PENELOPE and PENFAST codes, it has been implemented in FORTRAN 77, except for the random generator and PSF management in read mode that are in C language. Efficiency and precision are based on the selection of a good random number generator. The generator chosen for the parallel version is that of RP Brent [7], whose main interest is its period of about 10^{1230} (compared to that of the generator RANECU used by the source code, which is 10^{18}), and to generate long period independent random series for each processor. The parallelized versions of PENELOPE and PENFAST are available for any number N_p of processors with $N_p \geq 1$. For $N_p > 1$, a processor "master" is responsible for managing files while $N_p - 1$ processors "slaves" are dedicated to the Monte Carlo calculation.

The parallelization of the PENELOPE and PENFAST codes allows to gain a time factor proportional to the number of processors, at least up to 20 processors. We have verified that the results obtained in parallelized mode were identical to those obtained with the original versions.

Discussion - conclusion

The MC method can decrease uncertainties in dose calculation for radiotherapy. Currently some MC engines incorporate variance reduction methods to speed up the simulation time. This paper presents an evaluation of the variance reduction techniques implemented in the PENELOPE 2006 code, and their performances regarding the gain in simulation efficiency are discussed. Unbiased results of dose distribution are demonstrated by the good agreement with analogue simulation. In addition, when variance reduction parameters are well applied, the simulation time is reduced at least by a factor of 100.

Thanks to variance reduction coupled with parallelization, PENELOPE and PENFAST codes allow to achieve the reasonable computation time with the required statistical uncertainty.

References

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