Nucl Eng Technol 47 (2015) 472–478

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: http://www.journals.elsevier.com/nuclear-engineering-and-technology/

Original Article

THE ADAPTATION METHOD IN THE MONTE CARLO SIMULATION FOR COMPUTED TOMOGRAPHY

HYOUNGGUN LEE [a], *CHANGYEON YOON* [a], *SEUNGRYONG CHO* [b], *SUNG HO PARK* [c], *and WONHO LEE* [a,*]

[a] *Department of Bio-convergence Engineering, Korea University, Seoul 136-703, South Korea*

[b] *Department of Nuclear and Quantum Engineering, Korea Advanced Institute of Science and Technology, Daejeon 305-701, South Korea*

[c] *Department of Neurosurgery, Ulsan University Hospital, Ulsan 682-714, South Korea*

ARTICLE INFO

Article history:
Received 7 May 2014
Received in revised form
19 September 2014
Accepted 9 January 2015
Available online 25 March 2015

Keywords:
Adaptive method
Deterministic method
Monte Carlo simulation

ABSTRACT

The patient dose incurred from diagnostic procedures during advanced radiotherapy has become an important issue. Many researchers in medical physics are using computational simulations to calculate complex parameters in experiments. However, extended computation times make it difficult for personal computers to run the conventional Monte Carlo method to simulate radiological images with high-flux photons such as images produced by computed tomography (CT). To minimize the computation time without degrading imaging quality, we applied a deterministic adaptation to the Monte Carlo calculation and verified its effectiveness by simulating CT image reconstruction for an image evaluation phantom (Catphan; Phantom Laboratory, New York NY, USA) and a human-like voxel phantom (KTMAN-2) (Los Alamos National Laboratory, Los Alamos, NM, USA). For the deterministic adaptation, the relationship between iteration numbers and the simulations was estimated and the option to simulate scattered radiation was evaluated. The processing times of simulations using the adaptive method were at least 500 times faster than those using a conventional statistical process. In addition, compared with the conventional statistical method, the adaptive method provided images that were more similar to the experimental images, which proved that the adaptive method was highly effective for a simulation that requires a large number of iterations—assuming no radiation scattering in the vicinity of detectors minimized artifacts in the reconstructed image.

* *Corresponding author.*
E-mail address: wonhol@korea.ac.kr (W. Lee).

http://dx.doi.org/10.1016/j.net.2015.01.010

1. Introduction

A very important subject in radiology is the increasing patient dose that has paralleled the development of more advanced diagnostic techniques. The American Association of Physicists in Medicine reports that imaging modalities used for radiation treatment planning such as portal imaging, computed tomography (CT), and fluoroscopy are associated with a substantial patient dose, and many researchers have studied ways to reduce the patient dose from these devices [1–3]. A large number of parameters must be considered in planning radiation therapy; therefore, designs and pretests using simulations are desirable. Most computational simulations for radiation doses use the Monte Carlo method [4]. Increasing the number of parameters and the complexity of the geometries has improved the accuracy of Monte Carlo simulations, although these steps have also increased the time needed for the simulation. To obtain realistic simulations in a limited time, advanced technologies require computational devices with improved hardware and software and improved calculation methods (e.g., variance reduction techniques), which can reduce the simulation time without degrading the accuracy of the simulation itself. Several technologies have been developed with this goal [5–8].

For a CT scanner, the number of emitted photons from the x-ray tube is normally 100 to 1,000 times higher than the number emitted by a plain radiographic device [9]. The simulation time using a conventional Monte Carlo method also increases in proportion to the quantity of x-rays, and thereby limits the application of the Monte Carlo method with a general computational device to simulate CT radiation exposure [9]. To reduce the computation time for calculations, a deterministic method using analytic formulae that are based on the attenuation coefficient and geometrical conditions without photon transport can be applied. The deterministic method, however, omits photon transport such as the interaction between radiation and materials that produce secondary exposure such as scatter, annihilation, and fluorescent radiation. This results in a reconstructed image that has nearly no artifacts or noise, and deviates from an actual CT image.

In this paper, we applied an adaptive method that combines a conventional Monte Carlo method with a deterministic calculation to simulate the CT image reconstruction, and compared its performance to that of the conventional simulation technology in terms of reconstructed images and calculation time. We assessed the artifacts in the reconstructed CT images that were obtained by applying the adaptive process, and identified a practical solution to minimize them.

2. Materials and methods

In the conventional Monte Carlo method, dose simulation follows statistical processes such as random sampling of an initial radiation emission and of every interaction between radiation and materials [10]. Thus, the Monte Carlo simulation can represent the random properties of radiation transport in experiments. This method ideally tracks every photon emission and interaction during the overall process; however, most scattered radiation spreads out and cannot reach the detectors to be recorded. As a result, only a small number of the generated photons can be accurately used for dose calculation or image reconstruction. If the size of the detector or collimator is small, the time required for simulation increases dramatically, especially for radiation detection using a large number of small detectors in high radiation flux situations such as CT (~10^{12} photons per projection).

With conventional methods, it takes a tremendous amount of time for general computers to calculate the transport and interactions of high-flux photons in CT; therefore, we applied an adaptive method using deterministic methods [Eq. (1)] and statistical methods for simulation. In the adaptation method, a deterministic calculation is applied to the initial emission and to each interaction step of the radiation transport, which reduces the variance of the simulation results, compared with the statistical method run for an equivalent time in an equivalent calculation time [11]. As Fig. 1 shows, when a photon is emitted from a source, the probability of it being incident to a detector without any other interaction is calculated based on geometry, radiation, and material information such as the emission direction (Ω_p), solid angle ($d\Omega_p$), distance (R), the energy of the radiation, and the attenuation coefficient of the materials. After calculating the directly detected probability in the detector area (dA), the photon transport is simulated in a conventional statistical Monte Carlo process. If a photon interacts with the material in the conventional simulation, the deterministic method is applied again to calculate the probability of a photon scattering in the direction of a detector (based on formulae such as Klein–Nishina for Compton scattering or Thomson scattering with a solid angle, distance, and exponential attenuation in material). The azimuthal distribution of radiation emitted from a source and scattered from a material is symmetric. After the probability of scattering is calculated, photon transport is again calculated by a conventional statistical process. In summary, a conventional statistical method is used for photon transport, but the probability of detection for each emission or scattering step is calculated by the deterministic method. Therefore, even if the probability of a photon interacting with a detector is very low and the conventional method requires a large amount of simulation time, the probability of detection is

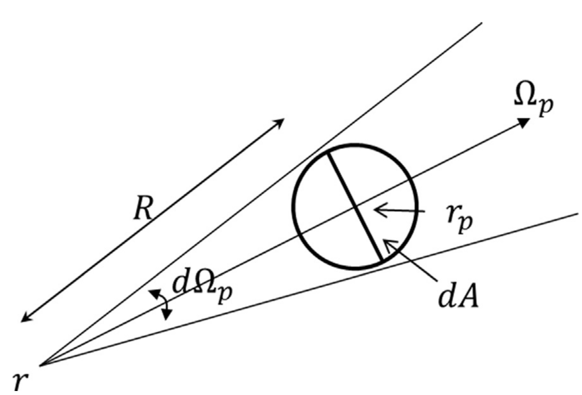

Fig. 1 – Schematic diagram of the deterministic calculation.