Scattering correction method for panel detector based cone beam computed tomography system*

Jia Peng-Xiang(贾鹏翔)[a], Zhang Feng(张 峰)[b], Yan Bin(闫 镔)[b], and Bao Shang-Lian (包尚联)[a]†

[a] *Beijing City Key Lab of Medical Physics and Engineering, Peking University, Beijing* 100871, *China*

[b] *China National Digital Switching System Engineering and Technological Research Center, Zhengzhou* 450002, *China*

(Received 28 February 2010; revised manuscript received 21 April 2010)

A scattering correction method for a panel detector based cone beam computed tomography system is presented. First, the x-ray spectrum of the system is acquired by using the Monte Carlo simulation method. Secondly, scattered photon distribution is calculated and stored as correction matrixes by using the Monte Carlo simulation method according to scanned objects and computed tomography system specialties. Thirdly, scattered photons are removed from projection data by correction matrixes. A comparison of reconstruction image between before and after scattering correction demonstrates that the scattering correction method is effective for the panel detector based cone beam computed tomography system.

Keywords: scattering correction, Monte Carlo simulation, panel detector, cone beam computed tomography system

PACC: 7870C, 8170J, 8760J

1. Introduction

The panel detector based cone beam computed tomography (CBCT) system represents a novel CT approach by the application of a full-field flat-panel digital detector that significantly increases active area to truly isotropic data sampling at a high spatial resolution, thereby providing advantages over conventional multi-slice spiral CT.[1] However, it remains difficult to accurately remove a comparatively large number of scattered photons from projection data, which causes the sample structure to become artifactitious and makes the CT number inaccurate. Therefore, developing an effective scattering correction method is still a major challenge.[2,3] Many methods have been proposed and significantly improved on image quality, although drawbacks still exist. The scattering control techniques belonging to the same category include hardware-based methods and software-based methods. The hardware-based methods in turn include the anti-scattering grid method,[4] air gap method,[5] scattering measurement using a beam stop array method,[6] etc., which suppress or correct scattering events at a certain percentage, or modify the imaging system itself. The software-based methods include convolution method,[7] deconvolution method,[8] model based scattering correction method[9] and Monte Carlo simulation method,[10] etc. To combine the merits of different correction methods, hybrid approaches were brought into being,[11] which can provide a well-balanced tradeoff among correction effectiveness, calculation time, exposure loss, dose increase, etc.

To improve the scattering correction performance, a new scattering correction method for CBCT is proposed here. We calculate and store scattering correction matrixes according to scanned objects and CBCT system specialties by using the Monte Carlo simulation method, and remove scattered photons from each projection data according to pixel values on the panel detector.

2. Materials and methods

2.1. Monte Carlo simulation method

The Monte Carlo (MC) simulation method has been widely used in the field of CBCT[12,13] with its advantages, such as accurate physical model and changeable simulation parameters, etc. Simulations

*Project supported by the National Natural Science Foundation of China (Grant Nos. 60672104 and 10527003), the National Basic Research Program of China (Grant No. 2006CB705705) and the Joint Research Foundation of Beijing Education Committee, China (Grant No. JD100010607).

†Corresponding author. E-mail: bao@pku.edu.cn

© 2010 Chinese Physical Society and IOP Publishing Ltd

were performed by using the general-purpose MC code system PENELOPE in the present paper. This code simulates coupled electron–photon transport in arbitrary material and in a wide energy range from a few hundred eV up to 1 GeV. The reliabilities of physical interaction models and tracking algorithms implemented in PENELOPE have been demonstrated through an extensive set of benchmark comparisons with experimental data and other MC codes.[14] Simulations were designed to describe the image formation in CBCT starting from the generation of x-ray photons up to their absorption in the sensitive detector. Detailed simulations of the x-ray tube, filters, scanned objects, and detector were considered. After x-ray photons attenuating in objects, both scattered and transmitted photons were detected by the panel detector and information about the detected particles were recorded in phase-space-files for future analysis.

2.2. Monte Carlo simulation of x-ray spectra

Using the Monte Carlo method to simulate radiation transport has become the most accurate method of predicting the x-ray spectra even in complex geometries.[15,16] Moreover, the method tracks the evolution of all secondary particles (and their descendants) generated by primary electrons and enables one to simulate the interaction between electrons and photons within the target and filters.

Geometry of the x-ray tube has been realized accurately in the simulation according to the tube used in a real CBCT system, which is shown in Fig. 1. The anode is made of tungsten with an angle of 55° with respect to the incident electron beam. The inherent filter is of 0.2-mm beryllium and the added filter is of 0.3-mm aluminum. When the electron beam with specified energy hits the target, both bremsstrahlung and characteristic x-ray photons were produced.

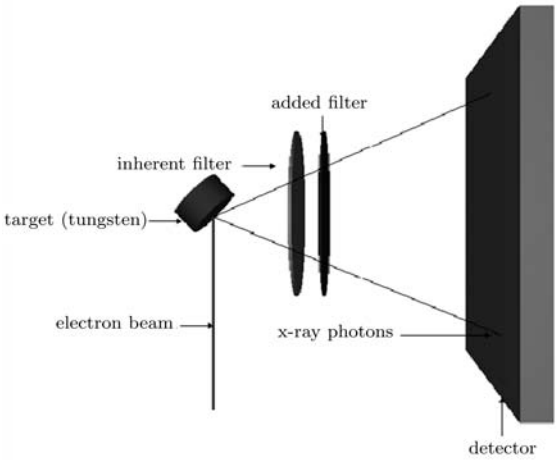


Fig. 1. Monte Carlo simulation model of x-ray tube.

Three simulations were performed by varying the peak tube voltage. For each simulation, 1×10^{10} electrons with specified kilovolt peak (kVp) bombarded the target. Figure 2 shows the MC simulated x-ray spectra for different peak tube voltages (40, 60, and 120 kVp). These results will be used as input parameters in the following MC simulations.

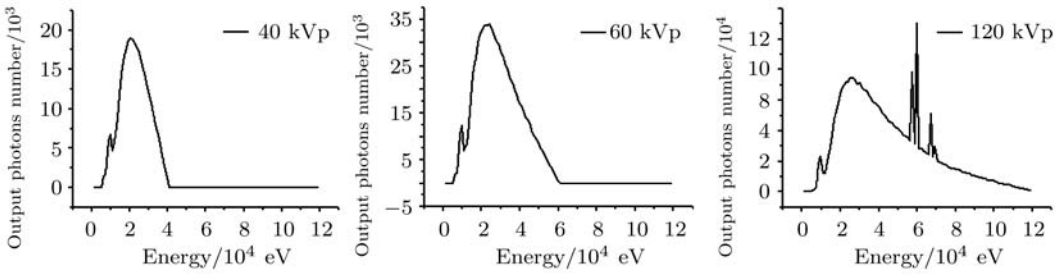


Fig. 2. Monte Carlo simulation results of x-ray spectra.

For a real x-ray tube, the energy of emitted electrons is not absolutely equal to the product of electron charge and peak tube voltage but jittered around it. We assume that the jitter energy is of a Gaussian distribution in order to discuss the influence of the jitter on the resulting x-ray spectra. In MC simulation input files, we set the emitted electron energy to be of a Gaussian distribution with a mean value of 60 kV and jitter energies to be 1.2 keV and 3 keV separately. Figure 3 shows a comparison of x-ray spectrum between

different jitter energies, and we can conclude that the influence of the jitter energy on the resulting x-ray spectrum is negligible and the previous simulation results are credible.

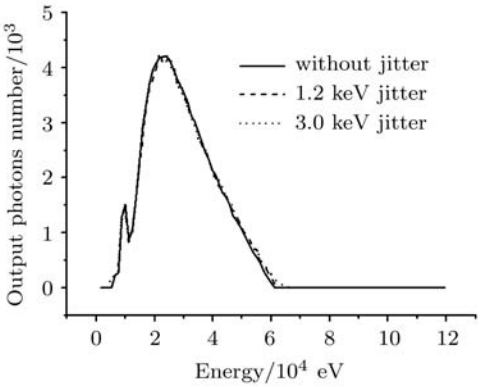


Fig. 3. Comparison of x-ray spectrum between different jitter energies.

2.3. Monte Carlo simulation of scattered photon distribution

An MC scattering simulation model was built according to scanned objects and real CBCT system specialities in this paper. The model includes: generation of x-ray photons, attenuation of photons in filters and scanned objects, detection of transmitted and scattered photons on the panel detector. Figure 4 shows the scattered photon distribution of a hypothetic scanned object simulated by the MC model. Figure 5 shows the Gaussian fitting result for scattered photon distribution, where A is the area below the curve, ω is the half width, x_c is the axis position, y_0 is the background scattered photon number and R^2 is the relation coefficient. With R^2 equal to 0.97781, it is demonstrated that Gaussian function is applicable for describing the scattered photon distribution. In the MC simulation model, after x-ray photons irradiate the scanned object, scattered photon distribution and Gaussian fitting result were recorded in a database. With formula (1) and Gaussian function parameters, we can obtain the scattering correction matrix for the projection image with the same value as the MC simulated one.

$$y = y_0 + \left(\frac{A}{\omega \times \sqrt{\frac{\pi}{2}}}\right) \times \exp\left(-2 \times \left(\frac{x - x_c}{\omega}\right)^2\right), \quad (1)$$

where y is the number of scattered photons, x is the distance from the matrix element to the Gaussian axis.

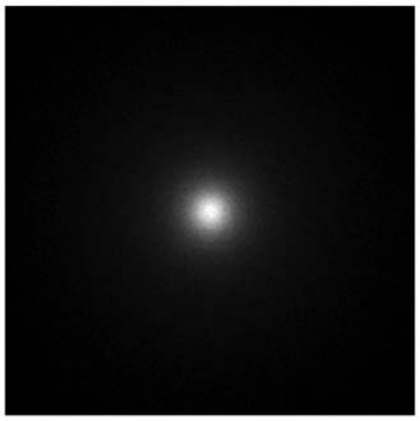


Fig. 4. Scattered photon distribution obtained from MC simulation.

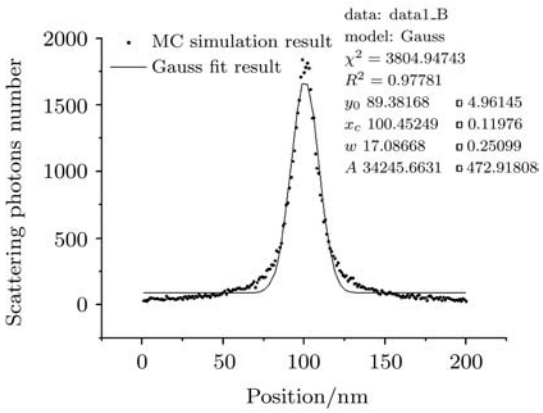


Fig. 5. Gaussian fitting results of scattered photon distribution.

After scanning the object with a real CBCT system, we choose appropriate scattering correction matrixes from the database for each projection image according to pixel values of the projection image, and then remove the scattered photons from it.

3. Results and discussion

We scanned an object with the real CBCT system and obtained the scattering correction database by using the MC simulation model. Table 1 shows the relationship between pixel values and scattered photon distribution parameters obtained from MC simulation.

With the database, we can obtain the scattering correction matrixes for pixels in projection image according to pixel values. Figure 6 shows the projection image of the scanned object and the scattered photon distribution that is calculated according to pixel values by using the results from the scattering correction database.

For each projection, we calculated the scattered photon distribution and removed scattered photons from the original image to obtain the scattering corrected projection image. Using these corrected images, we reconstructed the object and obtained better results as shown in Fig. 7. We can find that the reconstruction images after scattering correction are more distinguishable and have less noise or artifacts. It is demonstrated that the method used in this paper is effective and applicable for scattering correction.

For a scanned object with different materials and complicated structures, simulation for all the components is time consuming and impracticable. The analysis method of obtaining the scattered photon distribution based on MC simulation results needs to be developed. The influence of x-ray energy on detective quantum efficiency (DQE) is not considered in this paper. These subjects would need more discussion in future work.

Table 1. Pixel values and corresponding scattered photon distribution parameters.

pixel value	ω	y_0	A	H
5	52.39	1.80	384	5.86
15	52.56	4.61	882	13.40
51	55.68	13.76	2880	41.26
217	50.49	33.04	5444	86.02
504	55.25	50.40	17100	246.97
912	60.13	51.30	16467	218.51
3010	73.18	63.00	18339	199.94
3269	73.73	71.82	19602	106.07

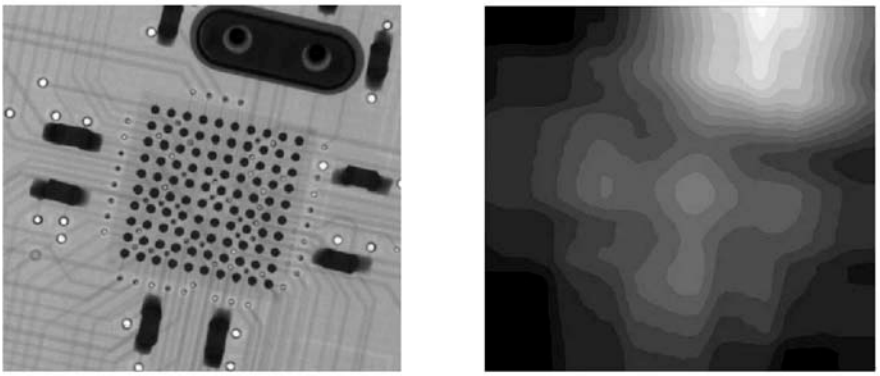


Fig. 6. Projection image and scattered photon distribution.

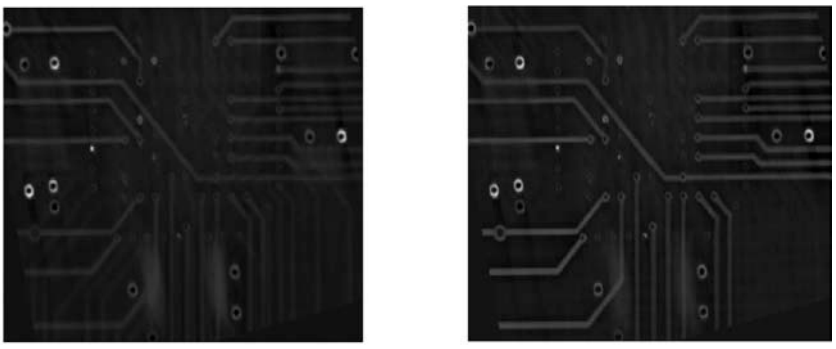


Fig. 7. Reconstruction image before and after scattering correction.

References

[1] Rinkel J, Gerfault L, Esteve F and Dinten J M 2007 *Phys. Med. Biol.* **52** 4633

[2] Siewerdsen J and Jeffray D 2001 *Med. Phys.* **28** 220

[3] Zhu L, Bennett N R and Fahrig R 2006 *IEEE Transactions on Medical Imaging* **25** 1573

[4] Ning R and Tang X 2004 *Med. Phys.* **31** 1195

[5] Neitzel U 1992 *Med. Phys.* **19** 475

[6] Lo J Y, Floyd C E, Baker J A and Ravin C E 1994 *Med. Phys.* **21** 435

[7] Naimuddin S, Hasegawa B and Mistretta C A 1987 *Med. Phys.* **14** 330

[8] Seibert J A and Boone J M 1988 *Med. Phys.* **15** 567
[9] Wiegert J, Bertram M, Rose G and Aach T 2005 *Proc. SPIE* **5745** 271
[10] Jarry G, Graham S A and Moseley D J 2006 *Med. Phys.* **33** 4320
[11] Kriakou Y, Deak P, Riedel T, Smekall L V and Kalender W A 2005 *Eur. Radiol.* **15** 306
[12] Watanabe M, Yamada R, Watanabe M, Gao F and Liu H F 2009 *Chin. Phys.* B **18** 3066
[13] Siewerdsen J H, Daly M J, Bakhtiar B, Richard S, Keller H and Jaffray D A 2006 *Med. Phys.* **33** 187
[14] Salvat F, Fernandez-Varea J M and Sempau J 2006 *PENELOPE-2006:* a code system for Monte Carlo simulation of electron and photon transport (Spain: Workshop Proceedings) p. 2
[15] Xu H B, Peng X K and Chen C B 2010 *Chin. Phys.* B **19** 062901
[16] Zhang T, Liu Y B, Yang B, Wu H X and Gu J H 2009 *Chin. Phys.* B **18** 2217