Patient-specific scatter and beam-hardening estimation method in Cone-beam CT

Jonghwan Min[a], Seungryong Cho[b] and Sung-Joon Ye [c*]
[a]*BK21PLUS Smart Humanity Convergence Center, Seoul National University, Suwon, Korea*
[b]*Department of Nuclear and Quantum Engineering,KAIST, Daejeon, Korea*
[c]*Department of Transdisciplinary Studies, Seoul National University, Suwon, Korea*
[*]*Corresponding author: sye@snu.ac.kr*

1. Introduction

The scatter and beam-hardening of the x-ray leads to the degradation of the image quality in cone-beam CT. The generation of scatter and beam-hardening occurs physically independent of each other, but it is difficult to estimate them separately because there are measured at the same time. In order to reduce the influence of x-ray scatter and beam-hardening effect, it is necessary to accurately assess the amount of those occurrences. We propose a novel method for individually measuring the amount of scatter and beam-hardening. We first estimated the scatter signal using a x-ray beam-blocker, and reconstructed scatter corrected data by rebinned backprojection filteration algorithm(rBPF)[1]. Then, we used a forward-projection to reconstructed image for estimation of beam-hardening by comparison with original raw data. We have conducted an experimental study to validate the proposed method and the results are shown in the follow section.

2. Methods and Results

In this section, we explain the method used for scatter and beam-hardening. The experiment was carried out in object-rotation cone-beam CT. The CATPHAN600 and anthropomorphic head phantom were used for imaged objects in this study.

2.1 Patient-specific scatter estimation

We used a x-ray beam-blocker to measure the scatter signal. The signal of the shadow region of blocker can be regarded as a scattered signal of x-ray because the beam-blocker blocks the primary signal of transmission x-ray. The unblocked region scatter signal also can be calculated by interpolation method from neighbor data since the scatter signal has low frequency characteristics. The scatter correction is performed by subtracting the scatter signal from the original data as follow equation:

$$I_p = I_0 - I_s,$$

where I_o is measured intensity data without object, I_s is scatter signal and I_p represents a primary signal, respectively.

We experimented with a beam-blocker that is consist of 10 blocker strips. Figure 1 shows results of scatter distribution and profile of CATPHAN600. The scatter corrected data is used for image reconstruction.

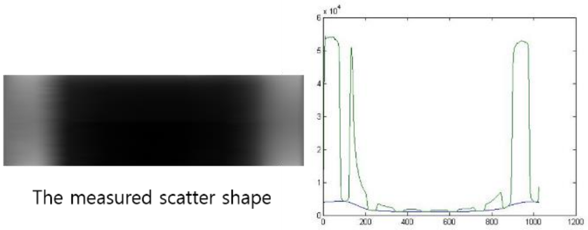

Fig. 1. The results of scatter distribution and profile of CATPHAN600. Left image is represent intensity shape of scatter. Right image shows the measured scatter signal (green line) and estimated scatter (blue line) using interpolation method.

2.2 Image reconstruction

To obtain a tomographic image, we used the rBPF algorithm to accurately image reconstruction from the partially blocked projection data[1]. The reconstructed image of the phantom is shown in the Fig 2.

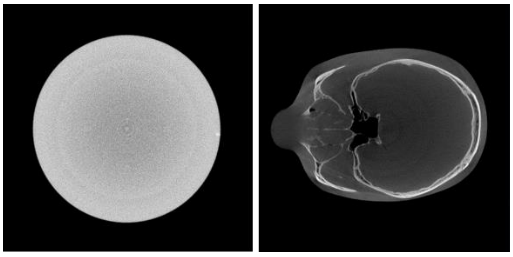

Fig. 2 Reconstructed image using rBPF algorithm from partially blocked data. Left image is results of CATPHAN and right is head phantom.

We can consider that image artifact are caused by beam-hardening after scatter correction process. The uncorrected CT image f_{ct} can be expressed as [2] :

$$f_{ct}(x) = f_{target}(x) + R^{-1}\left[P - Rf_{target}\right](x),$$

where f_{target} is unknown target image to be reconstructed, R^{-1} indicates reconstruction operator, P is projection data and Rf_{target} denotes radon transform. We assume that mismatch of $P - Rf_{target}$ cause a beam-hardening artifact. To calculate differences measured P and Rf_{target}, we used a forward projection technique for virtual radon transform.

2.2 Polychromatic forward projection

The beam-hardening depend on the energy dependency of f_{target} and the spectrum of the x-ray beam. We used an inverse transform technique to model the x-ray spectrum [3]. The total spectrum can be represented by a combination of basis spectra. Zhao proposed a method of determining the weight of basis functions by using optimization techniques[3]. The spectrum $\Omega(\mathrm{E})$ is expressed as a weighted summation of a set of model spectra $\Omega_i(E)$,

$$\Omega(\mathrm{E}) = \sum_{i=1}^{M} c_i \Omega_i(E)$$

where c_i is the weight value and M is the number of the model spectrum, respectively.
The polychromatic projection data can be expressed as :

$$\mathrm{p} = \log\left(\frac{I_0}{I_p}\right) = \log\left(\frac{\int_0^{E_{max}} dE\Omega(E)\eta(E)}{\int_0^{E_{max}} dE\Omega(E)\eta(E)\exp\left[-\int_0^{l}\mu(E,s)ds\right]}\right)$$

where E_{max} is the maximum photon energy of the spectrum, $\eta(E)$ is the energy dependent response of the detector, $\mu(E,s)$ is the linear attenuation coefficient depend on energy and l is path length of each ray.
We set the value of $\eta(E)$ to 1 for convenience. In addition, instead of calculating the weight c_i, we used the value previously calculated in SRS78. The siddon ray tracing algorithm were used for forward projection[4].
Figure 3 shows the flowchart of the proposed method and Table 1 lists the experimental condition.

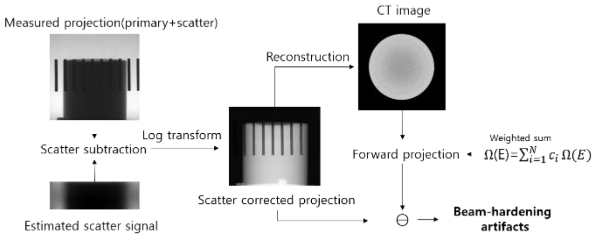

Fig. 3. Flowchart of the proposed scatter and beam-hardening estimation method.

Table I: Imaging system geometry

Parameter	Value
x-ray energy	100 kVp
x-ray tube current	7mA
Source to object distance	1000 mm
Source to detector distance	1500 mm
Source to beam-blocker distance	585 mm
Detector array size (pixel size)	1024 × 1024 (0.4mm)
Scan mode	Circular, 360 degree
Number of view	720

2.3 Beam-hardening estimation

Figure 4 shows the intensity difference due to beam-hardening. The upper images are the log-converted projection of head phantom, (a) is side view image and (b) is a front view image. The bottom images are the profiles of upper image. The red line represents a measured projection data, and black line indicates the forward projection data. In the experimental results, we can confirm that the beam-hardening phenomenon appears at a specific view.

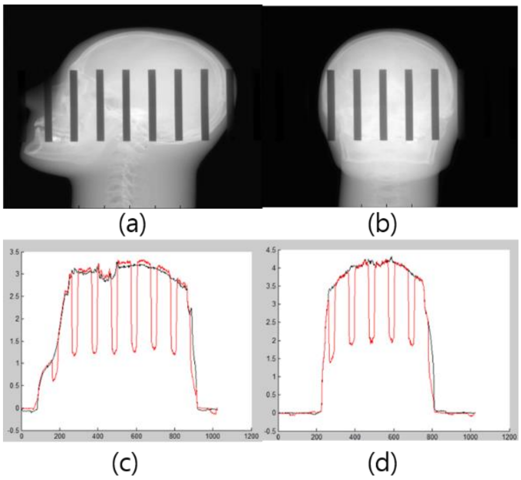

Fig. 4 Results of beam-hardening estimation. (a) is side view of head phantom, (b) is front view. The upper images are the log-converted projection of head phantom. The bottom images (c, d) are the profiles of upper image. The red line represent a measured projection data, and black line indicates the forward projection data.

3. Conclusions

We have proposed a novel method for scatter and beam-hardening estimation scheme. The scatter correction method based on beam-blocker that provides scatter corrected partial-beam data for image reconstruction is not affected by beam-hardening. After removing scatter effect, the accuracy of beam-hardening estimation process can be improved by eliminating each interference. These feature were well appeared from the results. We have demonstrated that the proposed method accurately estimates the scatter and beam-hardening through the experiments. This study is expected to contribute to beam-hardening correction and spectrum estimation research in the future.

REFERENCES

[1] Min, J., Pua, R., Kim, I., Han, B., & Cho, S. Analytic image reconstruction from partial data for a single-scan cone-beam CT with scatter correction. Medical physics, 42(11), 6625-6640, 2015.

[2] Park, H. S., Hwang, D., & Seo, J. K. Metal artifact reduction for polychromatic x-ray CT based on a beam-hardening corrector. IEEE transactions on medical imaging, 35(2), 480-487. 2016.

[3] Zhao, W., Niu, K., Schafer, S., & Royalty, K. An indirect transmission measurement-based spectrum estimation method for computed tomography. Physics in medicine and biology, 60(1), 339, 2014.
[4] Siddon, R. L. Fast calculation of the exact radiological path for a three-dimensional CT array. Medical physics, 12(2), 252-255, 1985.