Many-view under-sampling (MVUS) technique for low-dose CT: Dose versus image quality

Taewon Lee, Jonghwan Min, and Seungryong Cho, *Member, IEEE*

Abstract*–In computed tomography (CT) imaging, radiation dose delivered to the patient is one of the major concerns. Among many technical solutions to lowering radiation dose while preserving clinical utilities of the images, sparse-view CT is a promising technique. However, a fast power switching of an x-ray tube, which is needed for the sparse-view sampling, can be challenging in many CT systems. We have recently proposed a novel alternative approach to sparse-view circular CT that can be readily incorporated in the existing CT systems, and have successfully shown its feasibility. Instead of switching the x-ray tube power, one can place an oscillating multi-slit collimator between the x-ray tube and the patient to partially block the x-ray beam thereby reducing the radiation. In this study, we performed a preliminary study on the effects of dose reduction via using multi-slit collimators of varying sizes of slit-openings on the reconstructed image quality. MicroCT projection data of a mouse were used and a numerical collimation was applied in the form of multi-slits. We used a sinusoidal motion of the collimator to the perpendicular direction of the rotation axis for the purpose of obtaining more uniform spatial sampling of the image. For image reconstruction, we used a total-variation minimization (TV) algorithm which has shown its out-performance in many sparse-view CT applications. This study UQI value was calculated to investigate the dependence of image quality on slit-opening size. Additionally, a visual image quality assessment was made.

I. Introduction

CT has been widely used for many clinical applications. Dose reduction seems to be the most important issue to the CT developers and researchers. Among many technical solutions to lower radiation dose while preserving clinical utilities of the images, sparse-view CT is a promising technique. Sparse-view CT, which takes fewer projections, provides a viable option to reducing radiation dose. However it is technologically hard to implement in the current CT systems due to difficultis in fast tube power swiching. We have recently proposed a many-view under sampling (MVUS) techniques[1] as an alternatice to sparse-view CT. Instead of swiching the x-ray tube power, a multi-slit collimator is placed between the x-ray tube and the patient to partially block the x-ray beam thereby reducing the radiation. A sparse-view CT is realized by placing the oscillating multi-slit collimator between the x-ray tube and the patient. As a result, a kind of sparse-view CT is implemented as shown in Fig.1. In this study, we performed a preliminary study on the effects of dose reduction via using multi-slit collimators of varying sizes of slit-openings on the reconstructed image quality.

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T. Lee, J. Min, S. Cho are with the Korea Advanced Institute of Science and Technology, Daejeon, South Korea (telephone: + 82 42-350-5868, e-mail: leeto2000@kaist.ac.kr).

II. Material and Method

A. Micro-CT system

We used a circular cone-beam microCT projection data set of a mouse, which includes 720 projections per rotation and simulated MVUS scanning by using a numerical collimation. A detailed description of the simulation is given below with the image reconstruction Scanning parameters used in the data acquisition are summarized in table 1.

TABLE I. Scanning conditions

Parameter	Value
Tube voltage	90 kVp
Detector size	1232 ×1120, 100µm pitch
Scan range	360 °
Number of projections	720
Source to object distance	113 mm
Source to detector distance	220 mm

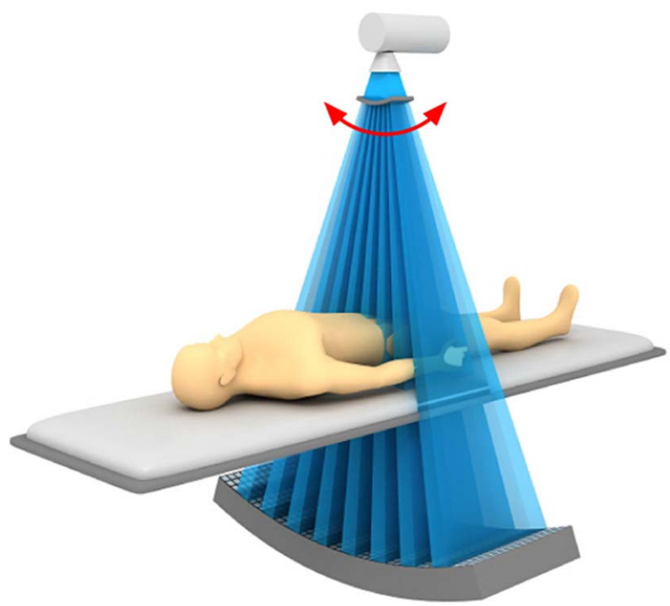

Fig. 1. Schematic of the proposed scanning configuration is illustrated. The arrow indicates a reciprocating motion of the collimator.

B. Data sampling scheme

A numerical multi-slit collimators was realized via using a mask matrix of the same size with projection data. Numerical

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multi-slit collimator having varying sizes of slit-openings were used to simulate the beam blocking. The collimator is composed periodically of slit-openings and radio-opaque rectangular areas, and the length dimension of the slits is parallel to the rotation axis. In addition, we used a sinusoidal motion of the collimator to the perpendicular direction of the rotation axis for the purpose of more uniform spatial sampling of the image. For each projection data, we multiplied a mask matrix that can simulate the desired numerical collimation. In this study, we changed the relative size of slit-openings in each partition of the collimator from half to 1/16 as an attempt to achieve dose reduction at varying levels. Fig. 2 shows the sinograms of the simulated collimator conditions.

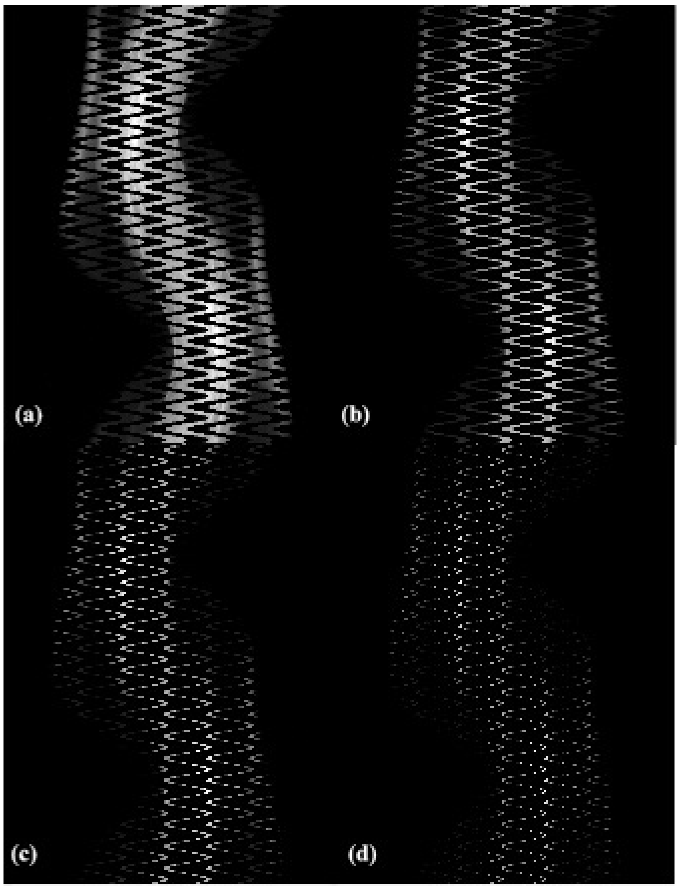

Fig. 2. The sinograms are shown corresponding to (a) one-half, (b) one-fourth, (c) one-eighth, and (d) one-sixteenth of the data used for image reconstruction according to the MVUS technique.

C. Total-Variation Minimization Algorithm

For image reconstruction, we used a total-variation minimization (TV) algorithm. The TV algorithm is based on the compressive sensing theory and its excellent performance in sparse-view CT applications has been reported [2]. We adopted the adaptive-steepest-descent projection-onto-convex-sets (ASD POCS) approach [3] and modified the POCS step so that only the measured data through the collimator slits are to be used in the computation.

The TV algorithm searches for a solution that minimizes the image total-variation.

$$f^0 = argmin\|\vec{f}\|_{TV} \quad such\ that\ \|Mf - g\| < \epsilon$$

Where f represents an image under iteration, f^0 the minimum image total-variation solution, M the system matrix, and g the measured data. $\| \quad \|_{TV}$ represents the total-variation of an image function. The system matrix was based on a ray-driven model, and ϵ could be emplically determined by the value of data distance of POCS steps.

D. Universal Quality Index

Universal quality index (UQI) is used to evaluate the quality of reconstruction images [4]-[5]. UQI is used to measure the degree of similarity between the reconstructed image using MVUS technique data and reference image. The UQI is defined as following equation.

$$\bar{f}_j = \sum_{n=1}^{N} (f_{jn})/N$$

$$\sigma_j^2 = \sum_{n=1}^{N} (f_{jn} - \bar{f}_j)^2/(N-1)$$

$$Cov\{f_1, f_0\} = \sum_{n=1}^{N} (f_{0n} - \bar{f}_0)(f_{1n} - \bar{f}_1)/(N-1)$$

$$UQI = \frac{2cov\{f_1, f_0\}}{\sigma_1^2 + \sigma_0^2} \frac{2\bar{f}_1\bar{f}_0}{\bar{f}_1^2 + \bar{f}_0^2}$$

UQI measures the pixel-to-pixel similarity between the reconstructed and reference images, and its value ranges between 0 and 1. The closer to 1, the more similar the two images are.

III. Results

Fig. 3. shows the reconstruction images of a transverse slice of mouse. Image reconstructed by the FBP algorithm from the uncollimated 720 projections is shown in Fig. 3 (a) as a reference image. Image reconstructed by the total-variation minimization algorithm from the uncollimated 180 projections that are equally separated from each other in view angles is shown in Fig.3.(b). The reconstructed images by use of the total-variation minimization algorithm from the collimated 720 projections according to half, 1/4, 1/8, and 1/16 collimation ratio are shown in Fig.3 (c)-(f). A visual comparison shows that the anatomical structures are clearly reconstructed.

Additionally, we calculated an image similarity index, UQI to quantitatively assess the image quality. The ROI was selected as show in Fig. 4.

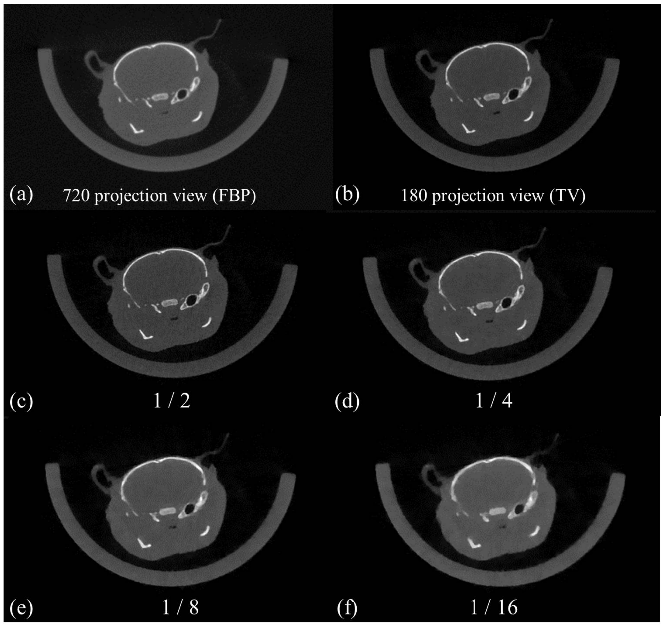

Fig. 3. The reconstruction images of a mouse are shown. The images were reconstructed (a) by the FBP algorithm from 720 projections. The images were reconstructed (b) by the TV algorithm from 180 projections, (c) one-second of the total area collimated 720 projections, (d) one-fourth of the total area collimated 720 projections, (e) one-eighth of the total area collimated 720 projections, and (f) one-sixteenth of the total area collimated 720 projections.

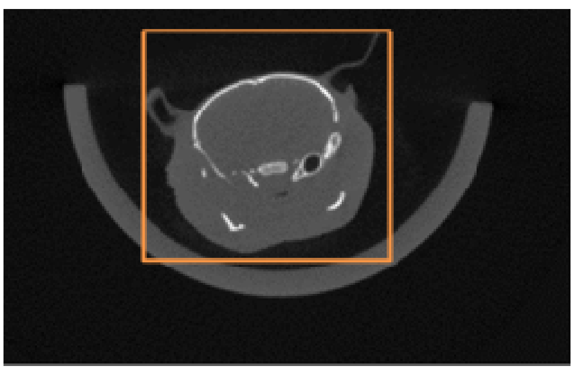

Fig. 4. Selected ROI in reference image

The corresponding UQI values are summeraized in Table 2.

TABLE II. UQI VALUE OF EACH EXPERIMENT CONDITION

	Sparse view	1/2	1/4	1/8	1/16
UQI(FBP)	0.990	0.984	0.988	0.989	0.985

IV. CONCLUSION

In our study, we have performed a preliminary study of the effects of dose-reduction on the image quality in the MVUS approach. In terms of UQI value, the dependence of image quality on slit-opening size was very weak. However, visual image quality assessment reveals that the images obtained by use of larger opening have higher spatial resolution. More investigation is under work to compare image quality using a standard phantom, and an experiment is also in progress.

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