Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 12-13, 2016

Dual-gamma-source CT imaging system: Feasibility study with simulation and experiment

Sunhee Wi, Sunho Lim, and Seungryong Cho*
Dept. of Nuclear and Quantum Engineering, Korea Advanced Institute of Science and Technology, Daejeon, Korea
wi5425@kaist.ac.kr, **Corresponding author:* scho@kaist.ac.kr

1. Introduction

Polychromatic X-ray tube is used for imaging source of conventional CT system. However, conventional detector technique does not provide the capability to distinguish incident x-rays between different energy bins. Therefore, current reconstruction algorithms assumed and employed the mean values of the incident x-rays to reconstruct the 3D CT image. This assumption caused three main problems: formation of beam hardening, accuracy of quantitative CT imaging, and degradation of contrast, particularly for soft tissue. First, beam hardening causes cupping artifacts which can be observed as dark shades at the center of a CT image. Second, quantitative CT image refers to 3D image reconstructed by absolute value and conversion to Hounsfield units (HU). Quantitative CT is the active research field for normalized CT images and more accurate diagnosis. However, there are some limitations and difficulties to generate the quantitative CT image directly using polychromatic energy source. Third, polychromatic x-ray makes Compton scattering dominant and degrades the contrast of the soft tissue in CT images. To solve these problems, the use of monochromatic x-ray source is inevitable. However, low flux from radioisotope should be considered before using it for imaging source. In this work, we proposed dual-gamma-source CT imaging system to compensate low flux and developed an iterative image reconstruction approach accordingly. Our study demonstrated the feasibility of proposed CT imaging protocol and iterative reconstruction algorithm in both simulation and experimental studies.

2. Methods

2.1. Proposed iterative reconstruction approach

This study proposes an iterative dual-gamma-source CT reconstruction approach, as shown in Eq. 1. A constrained total-variation (TV) minimization algorithm was adopted and four constraints are considered. Our proposed reconstruction approach would minimize total variation of image corresponding to data fidelity, as shown in the first and second constraint terms. Weighting step to estimate each source sinogram should be considered before reconstruction. Accordingly, it provides the strict third constraint which represents the sum of two estimated data is equal to the measured data. The fourth constraint corresponds to the nonnegativity of the reconstructed image.

$$\vec{f} = argmin\|\vec{f}\|_{TV} \qquad (1)$$

, which satisfies four constraints

$$|M_1\vec{f} - \widetilde{g_1}| < \epsilon_1 : |M_2\vec{f} - \widetilde{g_2}| < \epsilon_2 : |\widetilde{I_1} + \widetilde{I_2} - I_m| = 0 : f_i \geq 0 \qquad (2)$$

, where $\tilde{g}$ is estimated data, f is image-space, M is the system matrix, i is the ith data element and TV means TV norm. ϵ can be selected for controllong the impact level of data fidelity on the image reconstruction.

Figure 1 would explain the detail process of our proposed approach. First, we initialize all value of image-space and then obtain each ray measurement, that is, forward projection or virtual projection, from each gamma source geometry. Weighting step separates measured sinogram into two estimated data using two virtual projection data. Estimated data would be utilized for reconstruction. Our proposed approach performs above process iteratively.

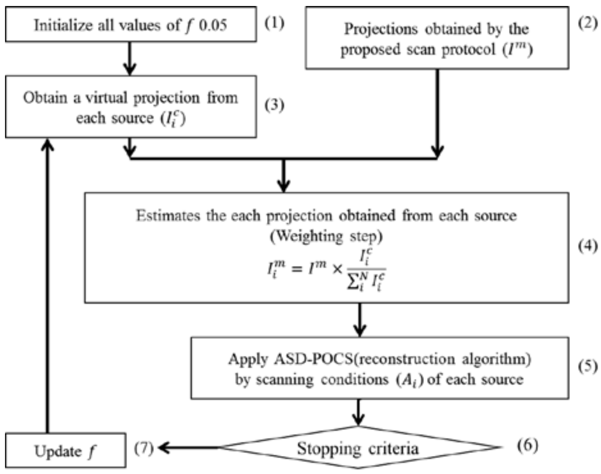

Fig. 1. Conceptual diagram of proposed reconstruction.

2.2. Simulation condition

A simulation study was designed as summarized in Table 1 to demonstrate the feasibility of the proposed reconstruction approach. Circular trajectory and flat panel detector were employed to suppose that basic geometries are same with conventional CT imaging system. It is noticeable that we used a single flat panel detector with plural gamma ray sources. We conducted a study on dual-gamma-source CT system in this work with consideration of more sources in the future. In general, it would be difficult to recruit radioisotopes having exactly the same flux output. Therefore, we assumed that different gamma ray flux come from two radioisotopes. In addition, air intensity data should be necessary for dual-gamma-source CT reconstruction approach. One can obtain the air projection of each source using a radio-opaque blocker before taking the projection of an object as shown in Fig. 2. The human phantom, XCAT was employed in this simulation study. Other scanning conditions are given in Table 1.

Table I: Conditions for simulation study

Parameters	Value
Detector size	1024 × 1024 (550mm × 550mm)
Source to object distance	500mm
Source to detector distance	1000mm
Reconstructed image size	512x512
Angular separation bet. 2 sources	1°, 5°, 10°, 15°

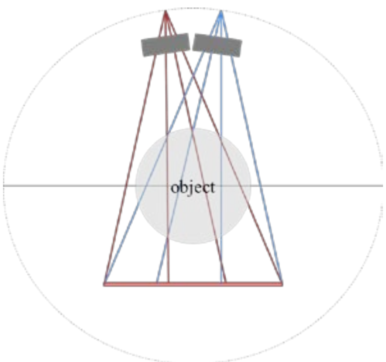

Fig. 2. Lead blockers of dual-gamma-source CT system.

2.3. Experimental setup

Tomosynthesis system in KERI was employed to demonstrate our reconstruction approach experimentally. There are some limitations of regulations to directly use radioisotopes in our laboratory. Therefore, preliminarily we performed the experiment study with x-ray imaging source system. X-ray tube which we could set at specific angular position, flat panel detector and object rotating system realized our proposed CT imaging system. Designed phantom is composed of various sizes and materials as shown in Fig. 3.

Fig. 3. Designed phantom and tomosynthesis system.

3. Results

3.1. Simulation study with Poisson noise

A 1° difference between the angular positions of the two gamma sources corresponds to 8.7mm in the proposed scanning geometry. Note that 8.7mm is way larger than a conventional x-ray focal spot size in CT imaging system. Therefore, a conventional CT image reconstruction algorithm that treats the two sources as a single source placed in the middle of them would lead to poor image quality as shown in Fig. 5(b). In spite of only 1 degree angular difference, degradation of image quality looks severe when using a conventional iterative algorithm that treats the two sources as a single entity.

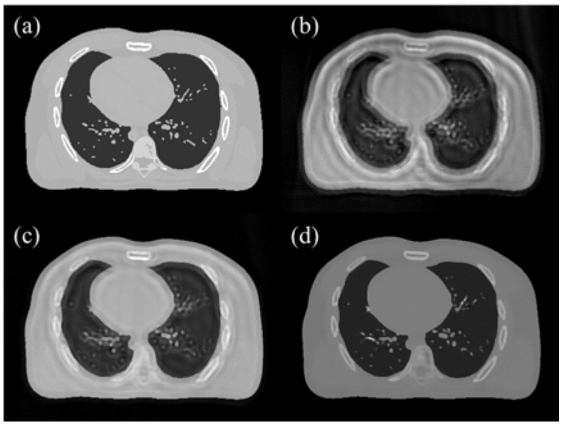

Fig. 4. Reconstructed images depending on iteration number of proposed approach. (Δθ=1°, (a) Reference, (b) 100, (c) 170, (d) 350)

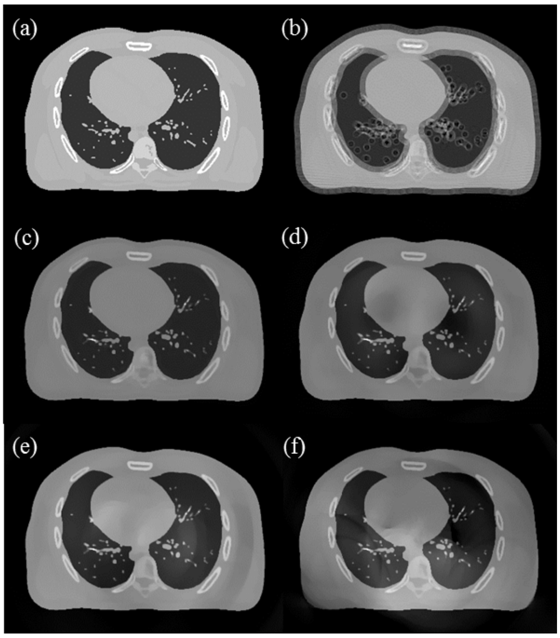

Fig. 5. Reconstructed images depending on angular separation. ((a) Reference, (b) Conventional method (Δθ=1°), (c) ~ (f): Proposed approach (Δθ=1°, 5°, 10°, 15°))

However, we could compensate the geometric errors and reconstruct CT image of better image quality with our reconstruction approach. Figure 4 shows more accurate reconstructed image as iteration number of proposed approach increases. Furthermore, we increased the angular separation between the two gamma sources, and the reconstructed images are shown in Fig. 5. The artifacts on the reconstructed image especially near heart become worse overall as angular separation increases. However, there exists a potential possibility to be improved through optimizing the parameters of the proposed iterative algorithm.

3.2. Experimental study

We obtained full-view projection data at 0 and 3 degree of x-ray tube angular position and simply combined both data sets to generate virtually projection from dual x-ray tube sources as shown in Fig. 7. Reference CT image was provided from only projection data obtained at 0 degree position. Figure 8 shows that our proposed approach can reconstruct CT image from dual-source projection as the image quality maintains similar to reference CT image. In this experimental study, we confirmed the feasibility of our dual-gamma-source CT reconstruction approach

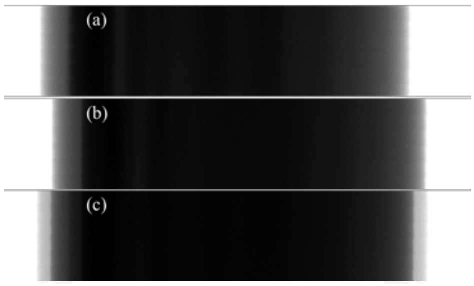

Fig. 7. Projection data from x-ray tube position at (a) 0degree, (b) 3degree, (c) Combined data(Virtually from dual sources).

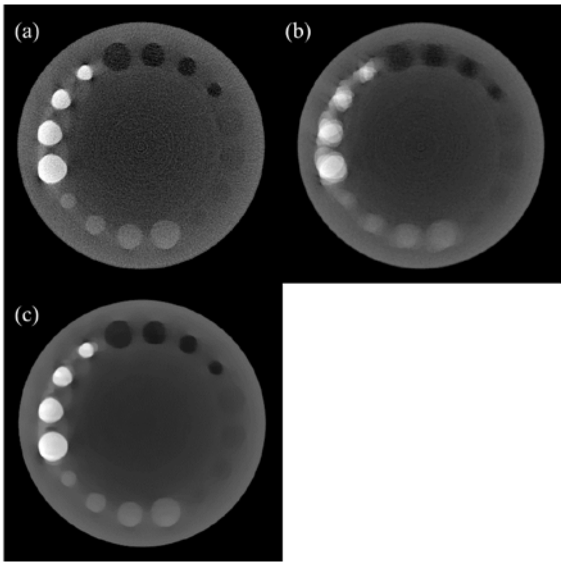

Fig. 8. (a) Reference image from only 0degree projection data, reconstructed images from combined projection data using (b) conventional algorithm, (c) proposed reconstruction approach.

4. Conclusions

We proposed a CT imaging protocol using multi-gamma-sources. We accordingly developed an iterative image reconstruction algorithm and validated it through both numerical and experimental studies. Our preliminary study demonstrated a feasibility of using multi-gamma-sources for CT imaging. The developed reconstruction approach would find applications in a high-resolution imaging with a large-focal-spot x-ray source or in a fast-scan x-ray CT imaging.

ACKNOWLEDGEMENT

This experimental study was supported by the Korea Electrotechnology Research Institute (KERI).

REFERENCES

[1] Sidky E. Y., and Pan X, "Image reconstruction in circular cone-beam computed tomography by constrained, total-variation minimization," Phys. Med. Biol., 53, pp. 4777-4907, 2008.

[2] J. Hsieh, "Computed tomography: principles, design, artifacts, and recent advances," SPIE Bellingham, WA, 2009.
[3] W. Segars, M. Mahesh, T. Beck, E. Frey, and B. Tsui, "Realistic CT simulation using the 4D XCAT phantom," Medical physics, vol. 35, no. 8, pp. 3800-3808, 2008.
[4] S. Abbas, T. Lee, S. Shin, R. Lee, and S. Cho, "Effects of sparse sampling schemes on image quality in low-dose CT," Med. Phy., vol. 40, p. 111915, 2013.
[5] Z. Wang, A. C. Bovik, H. R. Sheikh, and E. P. Simoncelli, "Image quality assessment: From error visibility to structural similarity," IEEE Trans. Imag, vol. 13, pp. 600-612, 2004.