Simulation on a limited angle beam gamma ray tomography

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1. Introduction

Limited angle beam tomography was introduced in the medical field more than two decades ago, where it was mainly used for cardiovascular diagnostics [1]. Later, it was also used to trace multiphase flows [2]. In these studies, the detection systems were fixed and a scanning electron beam was rapidly swept across an x-ray target using deflection coils. Thus very fast scanning was possible in these studies, but their geometry resulted in a heavy and bulky system because of a complex control system and vacuum tube. Because of its heavy hardware, limited angle beam tomography has remained as indoor equipment.

If the source section is replaced by a gamma ray source, limited angle beam tomography will have a very light source device. In addition, limited angle beam tomography with a gamma ray source can be designed using an open type portable gantry because it does not need a vacuum guide for an electron beam.

There is a lot of need for a portable tomographic system but so far no definitive solution has been created. The inspection of industrial on-line pipes, wood telephone poles, and cultural assets are some application areas [3]. This study introduces limited angle beam gamma ray tomography, its simulation, and image reconstruction results. Image reconstruction was performed on the virtual experimental data from a Monte Carlo simulation. Image reconstruction algorithms that are known to be useful for limited angle data were applied and their results compared.

2. Limited angle beam geometry and its Monte Carlo simulation

A Monte Carlo code can simulate photon detection in a manner quite similar to real situations. We can estimate the results prior to designing a real system. To simulate the limited angle beam geometry, detectors and a source were positioned as shown in Fig.1. The object is simulated as a 50cm steel pipe which is commonly used in industry. In simulation setup, the pipe includes objects of different sizes, material, and densities. By including this kind of phantom, we can evaluate the resolution and contrast for objects screened by a steel wall. This is the most common situation in industries. The source was simulated as ^{137}Cs (662 keV) for the gamma emitter. ^{137}Cs emits mono energy of 662MeV.

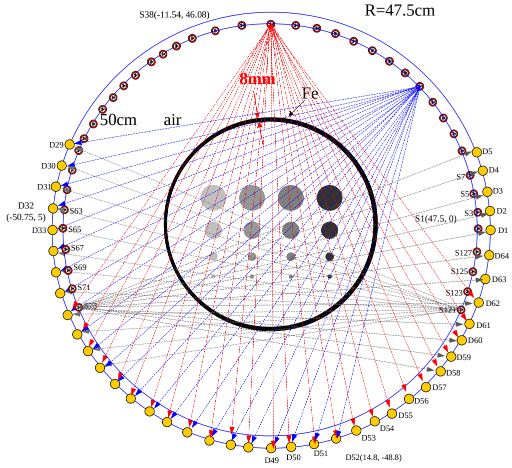

Fig. 1. Simulation geometry.

Table 1. Material information for Monte Carlo simulation

	Chemical form	Density (g/cm^3)	dimension
detector	NaI	3.67	1.2 cm dia×2.5 cm long
Source	CsO	1.47	3×3mm
Vessel	Fe	7.9	1cm thick
Material 1	CH2	0.9	1,2,4,6cm (dia.)
Material 2	CH2	1.5	1,2,4,6cm (dia.)
Material 3	Al	2.5	1,2,4,6cm (dia.)
Material 4	Fe	7.8	1,2,4,6cm (dia.)

3. Image reconstruction algorithm

While conventional tomography data are measured from all direction, simulation data are limited angle data in which data from a certain angle do not exist. For data from a limited angle, it is known that iterative algorithms are suitable for image reconstruction. The simulation data from a limited angle geometry were reconstructed using ML-EM (Maximum Likelihood Expectation Maximization) and TV (Total Variation).

3.1 Expectation Maximization algorithm

The first method of solving the likelihood function was known as Expectation Maximization (EM) [4]. In transmission EM, the updating equation is denoted as eq (1). M_{ij} and N_{ij} are the number of photons entering and exiting the j_{th} pixel, respectively, in the i_{th} measurement. Eq (1) is an approximate equation in the second term of the Taylor series [4]. This algorithm has been widely used in spite of its slow convergence and computational inefficiency.

$$\mu_j^{(n+1)} = \frac{\sum_{i=1}^{N_y} (M_{ij}^{(n)} - N_{ij}^{(n)})}{1/2 \sum_{i=1}^{N_y} (M_{ij}^{(n)} + N_{ij}^{(n)}) h_{ij}} \quad (1)$$

3.2 Total Variation Algorithm

Sidky et al (2006) introduced an iterative image reconstruction algorithm based on the minimization of the total image variation. Total variation of an image is defined as eq (2)

$$\| f_{s,t} \|_{TV} = \sum_{s,t} \left| \vec{\nabla} f_{s,t} \right| = \sum_{s,t} \sqrt{(f_{s,t} - f_{s-1,t})^2 + (f_{s,t} - f_{s,t-1})^2} \quad (2)$$

TV has been utilized in image processing for reducing image noise while preserving the edges. Sidky used POCS to enforce the projection data constraint. If the step size of the gradient descent is too large, the image becomes uniform and inconsistent with the projection data. On the other hand, if the step size of the gradient descent is too small, the algorithm reduces to a standard ART with the positivity constraint included. In their studies, Sidky et al described the TV algorithm as being suitable for a limited-angle problem. This is why TV was chosen as the image reconstruction algorithm of this study.

4. Results and conclusion

Fig.2 shows the image reconstruction results for a simulation geometry. In the TV algorithm, the gradient step of the total variation is controlled by two factors, which are α and Ngrd. See ref [5] for more details on these factors, Ngrd=20, α = 2.

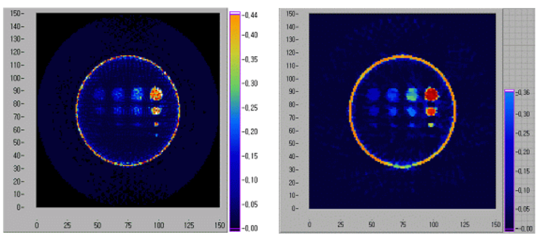

Fig. 2. Image reconstruction results by EM(left) and TV(right).

Table 2. Reconstruction conditions.

Reconstruction conditions	Value
Photon emission from source at each projection	10^9
N# of Detector	41
N# of projection	81
Energy bin	0.6~1MeV
Coverage angle	227 deg

It looks like trade between noise reduction and sharpness because a larger α value is selected, the reconstructed image becomes smooth. In this study, the TV image reconstruction results are not much better than the ML-EM results, while Sidky et al showed that TV result is superior to ML-EM and ART result in their studies. But both results from ML-EM and TV algorithm show that they can discriminate the object successfully in this paper. Here is another example of Fig. 3. Deposit of inner scale attached to vessel wall as in Fig. 3 is difficult to find by other method such as gamma scanning and gamma radiography. This is example that is showing where limited-angle tomography can be applied to.

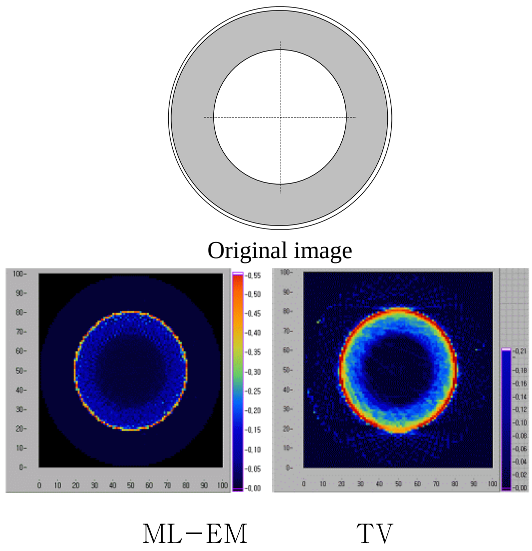

Fig. 3. Image reconstruction results

Acknowledgement

This research has been carried out under the Nuclear R&D program by MOST.

REFERENCES

[1] Boyd D P and Lipton M J , "Cardiac computed tomography," Proce. IEEE 71, 298-307, 1983.
[2] F Fischer, D Hoppe, E Schleicher, G Mattausch, H Flaske, R Bartel and Hampel, "An ultra fast electron beam x-ray tomography scanner", Meas. Sci. Technol. 19, 11-19,2008
[3] IAEA tecdoc-1589, "Industrial gamma process tomography", 2008.
[4] Kenneth Lange and Richard Carson,"EM Reconstruction Algorithms for Emission and Transmission Tomography," Journal of Computer Assisted Tomography, vol 8, no 2, pp. 306-316, 1984
[5] Emil Y. Sidky, Chien-Min Kao, and Xiaochuan Pan, "Accurate image reconstruction from few-views and limited-angle data in adivergent-beam CT", Journal of X-ray Scinece and Technology 14,119-139, 2006