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Development of GATE Simulation for X-ray Ghost Imaging

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1. Introduction

Unlike a traditional imaging technique via a multi-pixel photo detector, ghost imaging (GI) does collect the beam, which is reflected or transmitted from an object, with a single pixel photo detector. Not directly acquiring an image of the object GI carries out reconstructing a ghost image by means of the intensity correlation of two beams. A scheme of GI commonly has two different beam paths: in an object path the light is incident on the object and collected with the single pixel detector called a bucket detector; in a reference path the spatial distribution of the light is recorded by a camera such as CCD and CMOS. Due to its nonlocal property resulting from separating the detection and the imaging parts, GI can overcome limitation of the conventional imaging at the level of single-photon or in the strong turbulence [1]. Hence, GI has attracted the interest in many fields including remote sensing, biological imaging, and lensless imaging [2].

Recently, it was also applied with non-visible light source, namely the radiation such as x-ray, neutron, electrons and atoms. Since the first x-ray GI (XGI) was experimentally conducted in 2016 [3], many studies were reported as x-ray ghost attenuation contrast imaging with a table-top x-ray tube, x-ray ghost phase contrast imaging, and x-ray ghost tomography. Previous studies demonstrated that GI has a potential to reduce the dose while maintaining the good quality of image. In [4], it was founded that XGI outperformed the conventional x-ray imaging in terms of image quality at low dose. Nevertheless, there is still debate on whether XGI certainly achieves better performance or not [5].

In this study, we firstly developed a Geant4 application for emission tomography (GATE) simulation for XGI system. Over the past decades, GATE has been widely used for the preliminary design of a new radiation imaging system and optimization of parameters. Previous studies mostly examined the quality of ghost images, but did not quantitatively estimate the absorbed dose of a sample yet. Through a GATE simulation, the quantitative analysis on XGI with respect to both the image quality and the absorbed dose was conducted. We expect that development of GATE simulation can assist to solve the existing problems in XGI and make XGI more feasible for a practical application.

2. Methods

GI with Hanbury-Brown and Twiss interferometer was generally used to make intensity-correlated beams. Unfortunately, it is hard to split x-rays because of its high permeability, resulting in producing little flux of the separated x-ray. Hence, a computational GI scheme consisting of physical patterns or pre-recorded patterns was mainly applied in XGI. We simulated XGI system using such the pre-specified pattern in GATE as shown in Fig. 1. A coherent x-ray beam from a point source strikes on a scattering medium converting into pseudo thermal x-ray patterns called speckle patterns. A polychromatic 30 kVp spectrum of the x-ray was simulated. The emission spectrum was generated via the external software SpekPy. The scattering medium which is placed 5 cm away from the source was set up as a membrane structure composed of sphere-shaped CuSn powder. To create speckle patterns with different spatial distributions, we randomly changed the radius and center position of the CuSn spheres at each measurement.

Under these conditions, a set of patterns emitting from different membrane were initially recorded by a multi-pixel silicon detector. The pixel size of this photo sensor was 100 μm×100 μm and the total field of view was 10 mm×10 mm. On the other hand, we obtained the bucket intensity signal by reproducing the corresponding patterns in the same sequence of measurements. Several algorithms were exploited to reconstruct the ghost images: traditional GI (TGI), differential GI (DGI), normalized GI, uniformly weighted GI, uniformly weighted differential GI (UWDGI), and compressive GI (CGI). The total number of correlated data is ten thousand where the exposure time is 1 μsec at each frame. Lastly, to quantitatively analyze the absorbed dose of the object, a tool, named DoseActor was taken into account in GATE code.

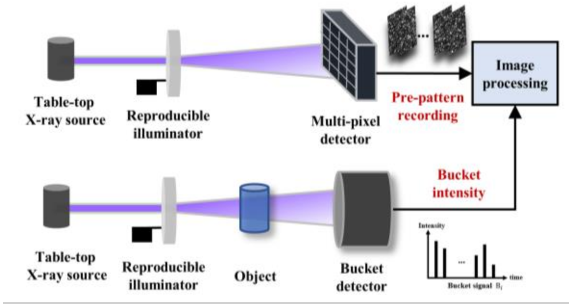

Fig. 1. A schematic of XGI based on pre-recording pattern system.

3. Results

Fig. 2 shows the results of XGI simulated in GATE. As increasing the number of correlated data, the image quality of XGI was significantly improved with the naked eye. To quantitatively estimate the ghost images, both a peak signal-to-noise ratio (PSNR) and a structural similarity index (SSIM) were used in this work. As shown in Fig. 3, TGI and UWGI achieved relatively better results than the other methods in epecially when the number of data is little. Table I describes the simulated results of both a conventional x-ray imaging and the TGI at the same exposure time (1 ms). The retrieved image by TGI with 1000 measurements was considerably degraded than that of conventional imaging, while the absorbed dose of the object was reduced by about 30% in the TGI method.

4. Conclusions

In this study, we firstly proposed the GATE simulation for XGI to make it available to preliminarily design a proper system and estimate the image quality and radiation dose of the sample. A scheme of pre-recorded pattern was used to construct the XGI system. The simulated XGI reconstructed several ghost images where the PSNR and SSIM were up to 9.37 dB and 0.58 with 10000 measurements. Comparing with the direct imaging method, XGI showed the poor quality of images in the same exposure time, whereas the absorbed dose of the sample was slightly decreased. Further studies could enhance the image quality to the level of commercialization with reducing the absorbed dose by modifying the design-parameters such as x-ray energy, position, component, and radius of scattering material and employing an advanced algorithm.

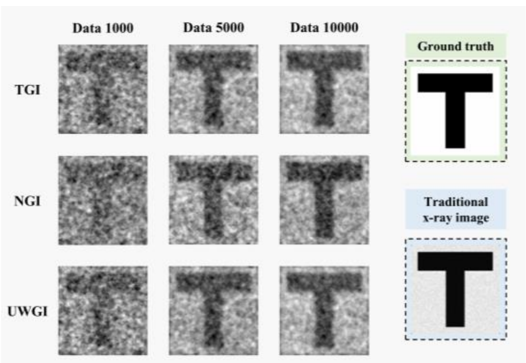

Fig. 2. Simulated ghost images depending on the number of measurements: the original image (ground truth) and a traditional x-ray image (Ex. time : 1 ms) were presented as reference.

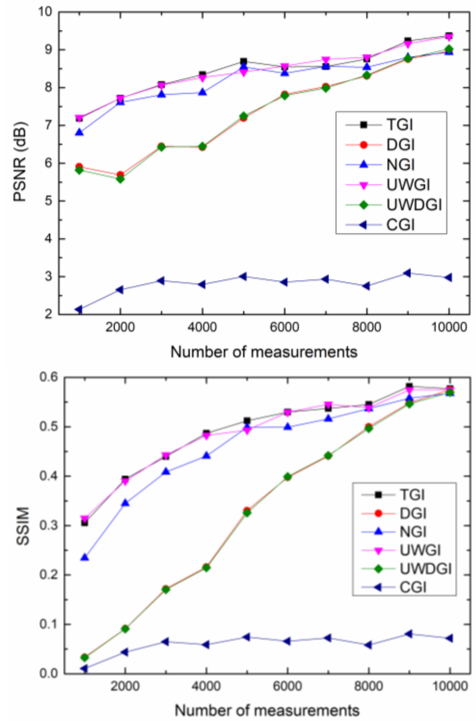

Fig. 3. Plot of the image quality (PSNR and SSIM) versus the number of measurements

Table I: Simulation results of the conventional imaging method and the TGI under the same exposure time (1 ms)

	PSNR (dB)	SSIM	Absorbed dose (mGy)
Conventional image	27.9	0.98	0.11
TGI	7.19	0.31	0.08

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