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3D imaging using combined neutron-photon fan-beam tomography: A Monte Carlo study

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HIGHLIGHTS

- Evaluation of fan-beam combined neutron and photon tomography.
- Neutron and photon transport was simulated using MCNP5.
- Results show that this imaging technique reveals both shape and material composition of objects.

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ABSTRACT

The application of combined neutron-photon tomography for 3D imaging is examined using MCNP5 simulations for objects of simple shapes and different materials. Two-dimensional transmission projections were simulated for fan-beam scans using 2.5 MeV deuterium-deuterium and 14 MeV deuterium-tritium neutron sources, and high-energy X-ray sources, such as 1 MeV, 6 MeV and 9 MeV. Photons enable assessment of electron density and related mass density, neutrons aid in estimating the product of density and material-specific microscopic cross section- the ratio between the two provides the composition, while CT allows shape evaluation. Using a developed imaging technique, objects and their material compositions have been visualized.

1. Introduction

The evaluation of objects' shape and material composition is a central goal of nondestructive testing. Photon radiography (Reimers et al., 1984) enables determining the density, shape and size of the objects being examined. Although this is effective in finding hidden items of specific shapes such as knives, guns, etc., or predetermined profiles in industrial settings, it does little to reveal the difference between materials of similar density, making their identification difficult. Photon-based methods are also less effective in imaging low-*Z* materials. Neutron methods, on the other hand, are more sensitive to low-*Z* materials, especially to hydrogen-rich compounds, and to materials with high neutron reaction cross-sections.

Combining photon and neutron imaging has the potential of better visualization of objects of different mass attenuation, simultaneously providing both density and composition information. Sowerby et al. (2009) showed that combination of fast neutron and photon radiographies have a potential to outperform current X-ray cargo scanners, if 'multiple view' capabilities are added. Computed tomography (CT) is employed to provide sectional and 3D images, but is currently limited to X-ray imaging (Goldman, 2007; Toriwaki and Yoshida, 2009). Due to the lack of high-yield neutron sources, CT methods for combined neutron-photon imaging were not comprehensively investigated. As intense neutron generators are beginning to emerge, offering a neutron output on the order of 10^{11} n/s (DD) and 10^{13} n/s (DT) (Phoenix Nuclear Laboratories), neutron computer tomography within a short scanning time becomes promising. In this paper, Monte Carlo simulations are used to examine the application of combined neutron-photon CT of a model container to support the application of this technology for security inspection. We begin first with a description of the methods used in the study. This is followed with a discussion of the CT reconstruction and visualization, including calculated errors. Finally we address the conclusions for this study.

2. Methods

The layout of a tomography system of a combined neutron and photon transmission imaging is shown in Fig. 1, where idealized

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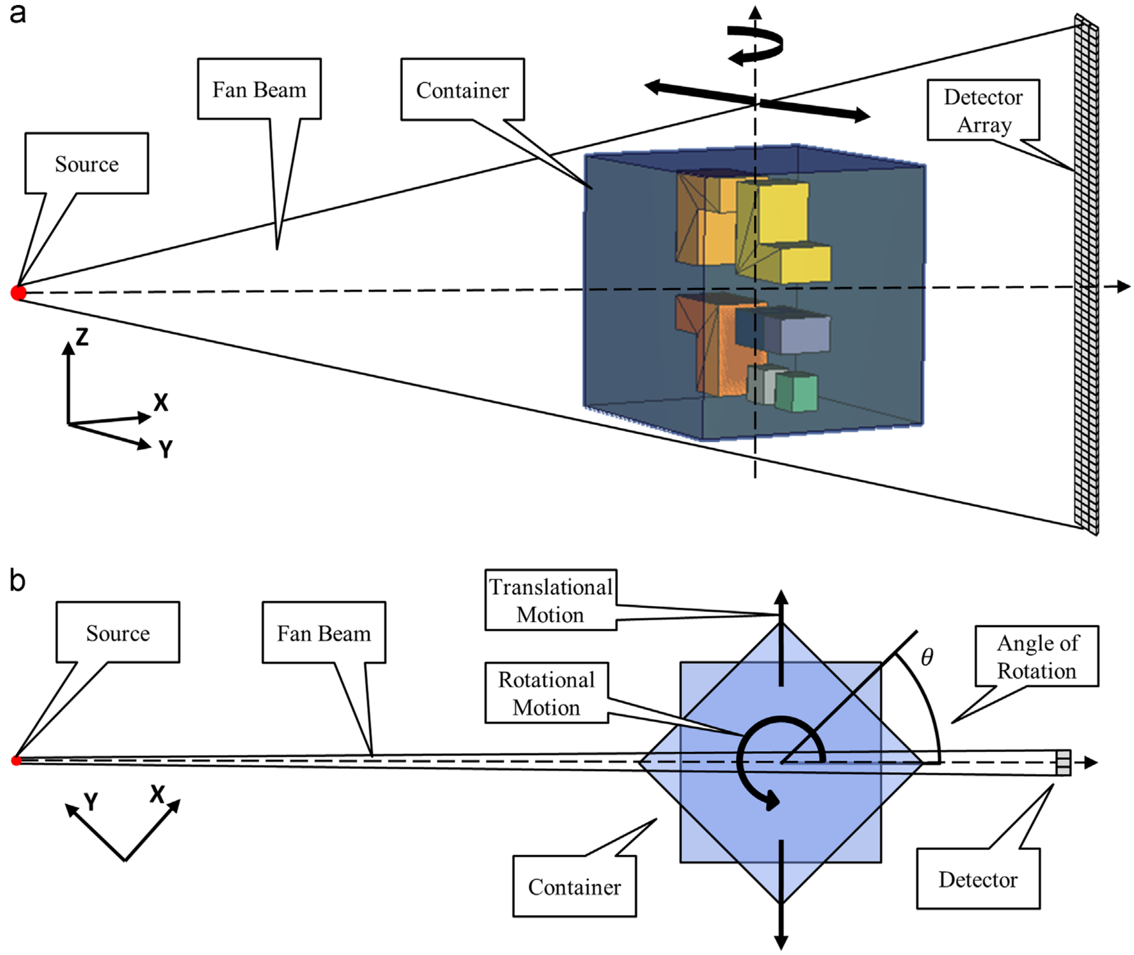

Fig. 1. The schematic of the neutron-photon CT system: (a) 3D view showing the position of the source, scanned object and detector array; (b) top view showing rotation and translation of the scanned object.

Table 1
Transmission ratios for low-Z and High-Z Materials.

Material	Photons and neutrons, 3 MeV X-rays/ 2.5 MeV neutrons	Dual-energy X-rays, 3 MeV/6 MeV
Polyethylene	0.1415	1.4656
Water	0.1985	1.4329
Aluminum	0.4970	1.3337
Iron	0.8966	1.1845
Lead	1.9615	0.9643

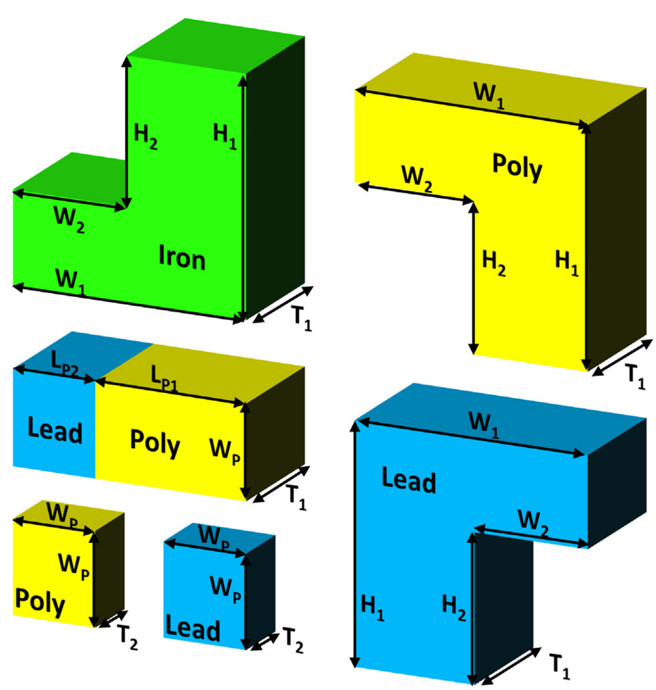

Fig. 2. Objects placed in the container.

isotropic point radiation sources (neutrons and photons) are collimated to produce fan beams. A linear detector array is aligned with the fan beam. A container representing a target scene is positioned between the source and the detector on a frame with rotational and translational degrees of freedom. The translational motion of the frame enables generating the 2D transmission image by merging the vertical 'columns' recorded by pixels of the linear detector array. The rotation of the table about the vertical axis through the center of the scanned object provides projections taken at different angles, with a step of 5°.

Photon transmittance $T_p(x)$, through a material of thickness x and the average density ρ is evaluated as follows:

$$T_p(x) = -\ln\left(\frac{I_p(x)}{I_p(0)}\right) = \mu\rho x \tag{1}$$