2005 International Nuclear Atlantic Conference - INAC 2005
Santos, SP, Brazil, August 28 to September 2, 2005
ASSOCIAÇÃO BRASILEIRA DE ENERGIA NUCLEAR - ABEN
ISBN: 85-99141-01-5

SIMULATED STUDY OF PARALLEL-BEAM GAMMA RAY TOMOGRAPHY AND IMAGE RECONSTRUCTION

Pablo A. Vásquez S.[2], Galo A. C. LeRoux[1] and Margarida M. Hamada[2]

[1] Departamento de Engenharia Química - Escola Politécnica
da Universidade São Paulo
Av. Prof. Luciano Gualberto, trav.3, 380
05508-900 São Paulo, SP
galoroux@usp.br

[2] Instituto de Pesquisas Energéticas e Nucleares (IPEN / CNEN - SP)
Av. Professor Lineu Prestes 2242
05508-000 São Paulo, SP
pavsalva@ipen.br
mmhamada@ipen.br

ABSTRACT

Transmission of gamma rays through a heterogeneous specific phantom was simulated using a Monte Carlo code for gamma diffusion simulation. Parallel beams transmission tomography arrangement using NaI(Tl) detectors and ^{60}Co sources were used to establishing the geometric conditions. The measurement of the attenuation data of the incident radiation provided a measure of the line integral of the local mass density distribution along the path traversed by the beam. Several such beams at different spatial and angular orientations with respect to the test section or volume, followed by an image reconstruction procedure using filtered back-projection algorithm, provided a density distribution of phases to a high degree of spatial resolution. The phantom used was a cylindrical object containing water and some small elements of different materials inside was studied. System proprieties just as dimensions, positions and attenuation coefficients were required as input data for the simulation software. Factors related with the sample spacing, number of projections, back-projection reconstruction filtering and interpolation were tested in order to simulate the influence on the reconstructed image.

1. INTRODUCTION

The transmission of gamma rays through a heterogeneous medium is accompanied by attenuation of the incident radiation, and the measurement of this attenuation quantifies the line integral of the local mass density distribution along the path traversed by the beam [2]. The measurement of several such beams at different spatial and angular orientations with respect to the test section or volume, followed by an image reconstruction procedure, provides a density distribution of phases to a high degree of spatial resolution [4]. Since the data collection is automated and the reconstruction process is performed using a computer, the process is referred to as computed tomography (CT) [4].

Scanners for transmission tomography employ radiation sources, such as an encapsulated gamma ray source, positioned on one side of the object to be scanned, and a set of collimated detectors arranged on the other side. Scanners of the second generation (parallel beam), an array of detectors, facing a single source, move around the object and provide a number of projections equal to the number of detectors. Sometimes, to reduce the scanning time, second-generation scanners using multiple radioactive sources can be employed [3]. Two main types of detectors depending on the principle are used in the detection process. In the detectors of the ionization chamber type, the sensors react to the ionization produced by the radiation. In the scintillation type, excitation or molecular dissociation induced by the radiation produces the measured effect.

The fidelity of a computed tomography (CT) image is very sensitive to the data acquisition and image reconstruction procedures. A thorough appreciation of many factors that limit the quality of the raw data and the accuracy of the reconstruction is essential to the development of an optimized CT system [6]. Simulation programs can be used to improve many parameters. Currently, there exist many kinds of Monte Carlo codes to simulate the radiation transport allowing to built specific geometries and to study different materials to obtain projection sets for image reconstruction. The mathematical coupling of various types of measurement errors to image artifacts in conventional computed tomography geometries is derived. The results can be used to establish a quantitative relationship between desired image quality and design tolerances on various components of the computed tomography scanner.

The basic problem in tomography is the inversion of the above integral equation along a linear path through a scalar field. The solution of this equation has been developed along different lines, and a good account of these is given in the review of Brooks and DiChiro (1976) and recently by Kumar and Dudukovic (1997). A very frequently used algorithm for reconstruction in commercial CT scanners is the filtered back-projection or its equivalent, the convolution back-projection system. Other algorithms of reconstruction such as the algebraic reconstruction technique (ART) and maximum likelihood based methods are described by Kumar and Dudukovic (1997).

The main factors that determine the imaging capabilities of a CT scanner used in engineering applications are the spatial, temporal and density resolution. Spatial resolution is the minimal distance separating two high-contrast point objects; temporal resolution refers to the frequency with which the images can be obtained and density resolution refers to the smallest difference in mass attenuation coefficients that the system is able to distinguish [5].

2. PRINCIPLE

The goal of tomographic imaging in its simplest terms, is to reconstruct a two-dimensional array of linear attenuation coefficients from a series of one-dimensional transmission profiles. The initial data, which is acquired in the form of intensity measurements, must be converted to projection data, which approximate the line integral of the linear attenuation coefficients characterizing the material within the object. For an object surrounded by air, this is accomplished by taking the logarithm of the ratio between the incident intensity and the transmitted intensity (Fig.1). The projection data recorded for tomographic reconstruction of a single slice in case of parallel beam configuration is given by [1]:

$$P_\theta(t) = \int_{(t,\theta)line} \mu(x,y)ds = -\ln\left(\frac{I}{Io}\right) \quad (1)$$

Where θ (0≤θ≤π) is the projection angle and t is the distance in the detector plane from the projected rotation axis. I and Io are detected beam intensities with and without object in its path. CT obtains the object function *f(x,y)* from the set of projection measurements $P_\theta(t)$.

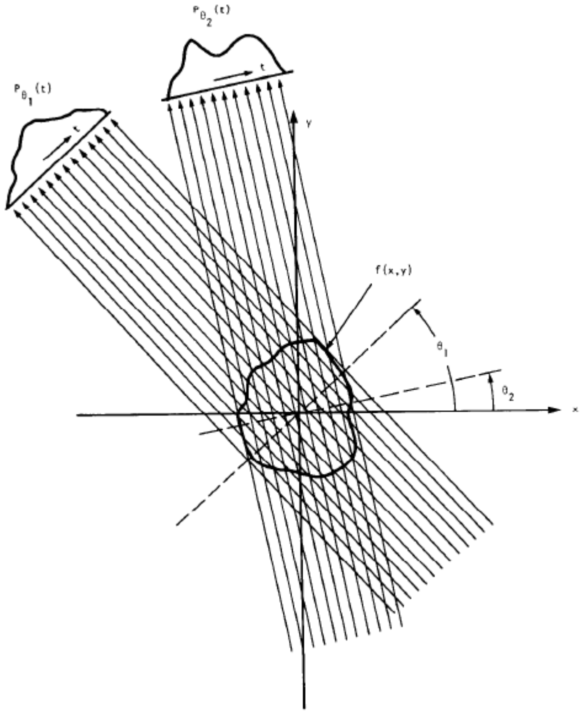

Figure 1. Parallel projections are taken by measuring a set of parallel rays for a number of angles.

The function *f(x,y)* is actually approximation of the distribution of $\mu(x,y,E_{eff})$, the linear absorption coefficients at the effective energy E_{eff} of the penetrating radiation. The energy dependence of $\mu(x,y)$ really causes problems in tomographic image reconstruction and the resulting artifact is known as cupping effect. If this is severe, the attempt to utilize non-linear projection data in any of the conventional reconstruction algorithms leads to inconsistent and spatially dependent reconstructions [2]. The complete set of projection data $P_\theta(t)$ over N_P projections with N_S rays per projections forms the discrete sinogram. The $N_P x N_S$ grid of projection data points should be equi-spaced for filtered back-projection algorithm.

3. SIMULATIONS

In the present work the tomography system was simulated using MCNP and MACALU software for radiation transport. The program calculates the gamma ray attenuation through the object cross section for all possible lateral and angular positions. The reconstruction algorithm used was the filtered back projection technique and was developed on MATLAB. The simulated system is shown in Fig.2. The phantom is composed by two little cylinders of different materials (alumina and polyethylene) into an other cylinder with water.

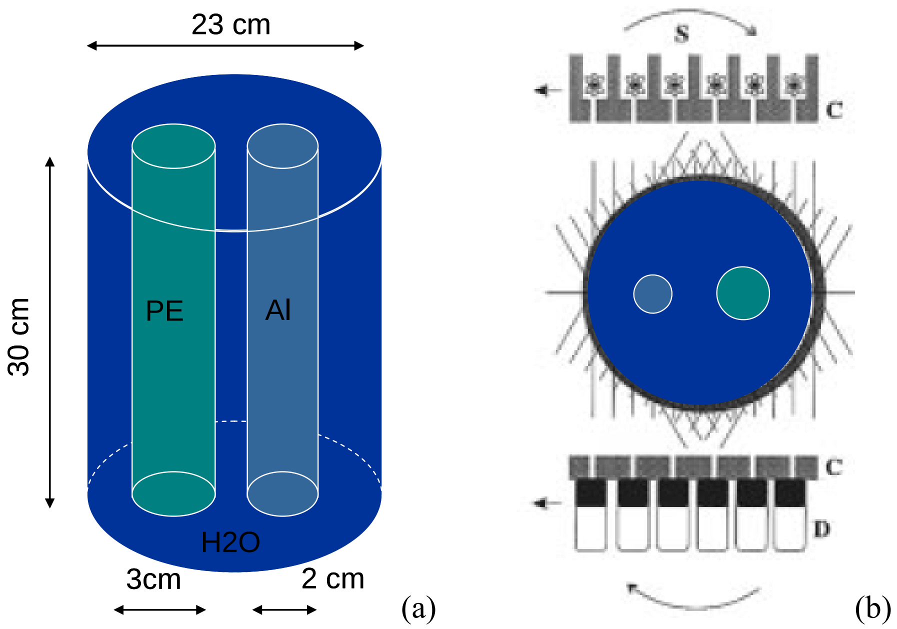

Figure 2. (a) Simulated system. (b) CT parallel beam scanning mode: S=source, D=detectors, C=collimator.

The tomography simulations were performed changing the sampling spacing (detection points) and modifying the number of projections (angles step). In order to improve the image reconstruction, back-projection filters as Ram-Lak, Shepp-Logan, Cosine, Hamming and Hann and interpolation methods like nearest neighbor , linear, spline, pchip (shape-preserving piecewise cubic) and cubic were tested [5]. The Ram-Lak is essentially the ramp function that is required to eliminate the blurring inherent to back-projection and sensitive to noise in the projections. The Shepp-Logan filter multiplies the Ram-Lak filter by a sinc function, slightly suppresses the high spatial frequencies. The cosine filter multiplies the Ram-Lak filter by a cosine function. The Hamming filter multiplies the Ram-Lak filter by a Hamming window. The Hann filter multiplies the Ram-Lak filter by a Hann window, emphasizes the intermediate spatial frequencies [2]. The images showed in the sections 4.1. and 4.2. were obtained using linear interpolation and Ram-Lak filter.

4. RESULTS AND DISCUSSION

4.1. Sample spacing

Images produced with sample spacing of 0.5, 0.67, 1.0 and 2.1 cm and 36 projections are shown in Fig.3. The scale represents the linear attenuation coefficient normalized that can be related with the density. A sample spacing equals to the 2.1cm and 1 cm beam width generated inferior spatial resolution were assumed. However, over sampling at a sample spacing of a 0.5 mm did not enhance the image noticeably.

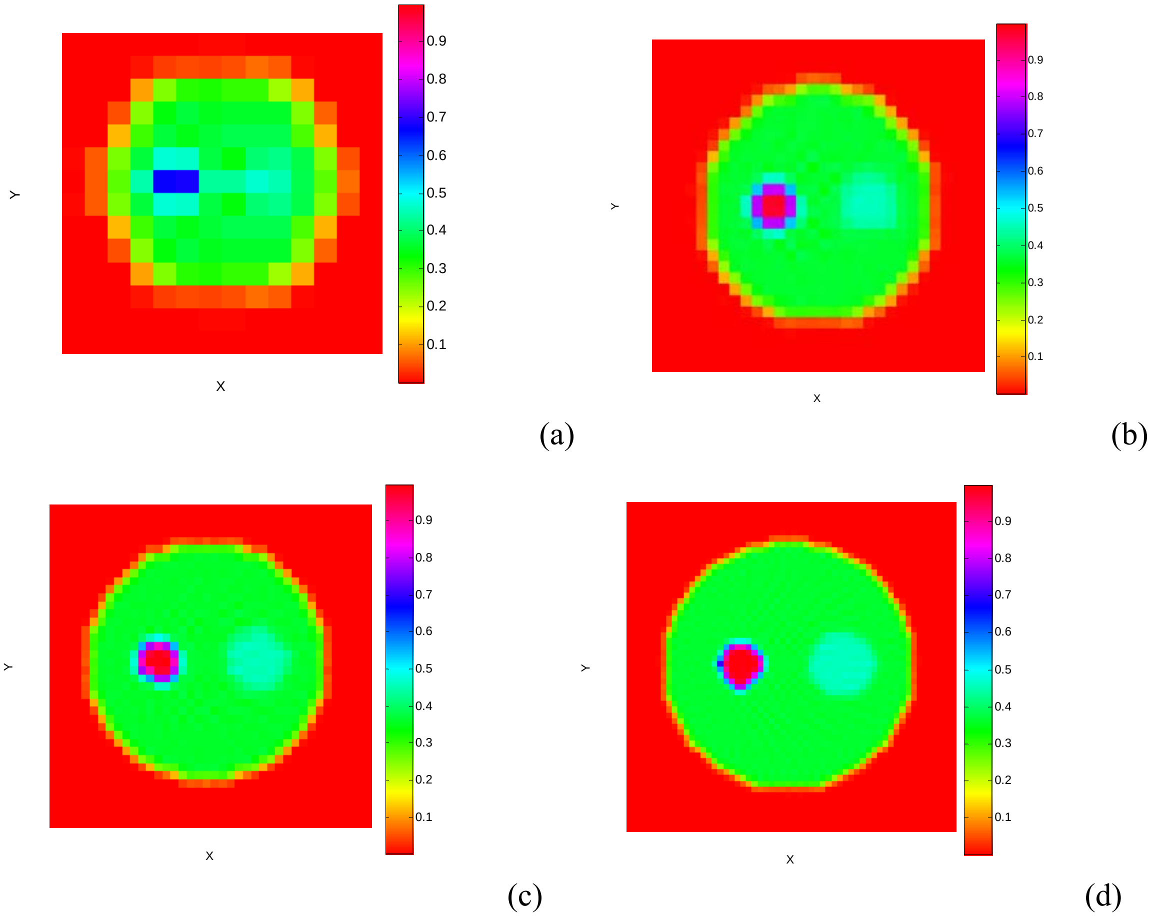

Figure 3. Images obtained with photon beams with sample spacing: (a) 2.1 cm, (b) 1.0 cm, (c) 0.67 cm and (d) 0.5 cm.

4.2. Number of projections

Fig.4 shows images obtained with 180, 45, 22 and 11 projections using sample spacing of 0.67 cm. The anticipated artifactual streaks are clearly visible in the 22 and 11 projections images. Forty-five projections appear to be sufficient to suppress the streak artifacts in this case. However, the test object used here probably does not provide a very stringent test of the system's sensitivity to streaking. For the most case of practical interest, 90 is an adequate ratio, the only advantage of fewer projections is a reduction in the reconstruction time [2] .

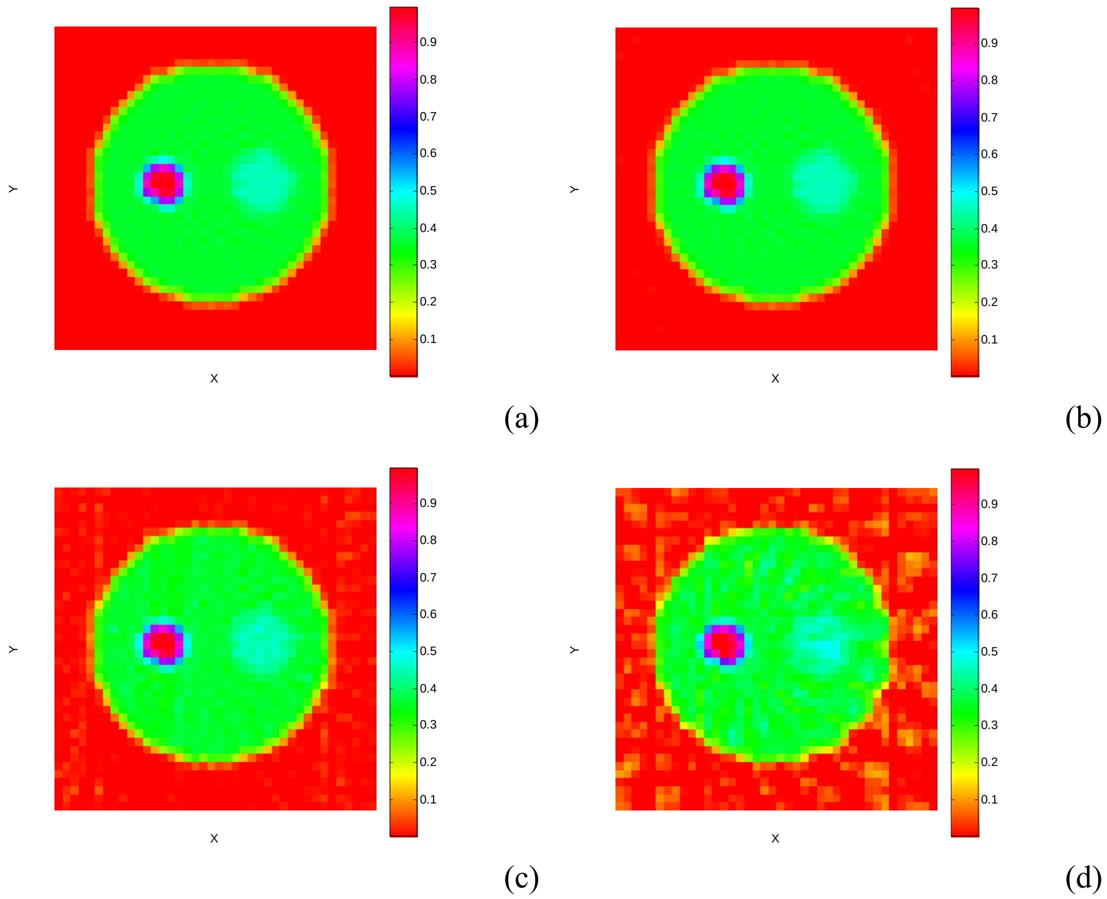

Figure 4. Images generated by (a) 180 projections, (b) 45 projections, (c) 22 projections and (d) 11 projections.

4.3. Back-projection reconstruction interpolation

Similar results were found using the methods presented in section 3 for this specific system for all interpolation methods. Nearest neighbor interpolation showed low resolution. The linear interpolation may be allowed improve the resolution (neither images nor analysis are presented here).

4.4. Back-projection reconstruction filter

Images generated with the Shepp-Logan, Cosine, Hamming and Hann filter are shown in Fig.5. If large low-contrast the features are required, the Hann filter is preferable. However, the Ram-Lak filter enhances the detectability for small high contrast features.

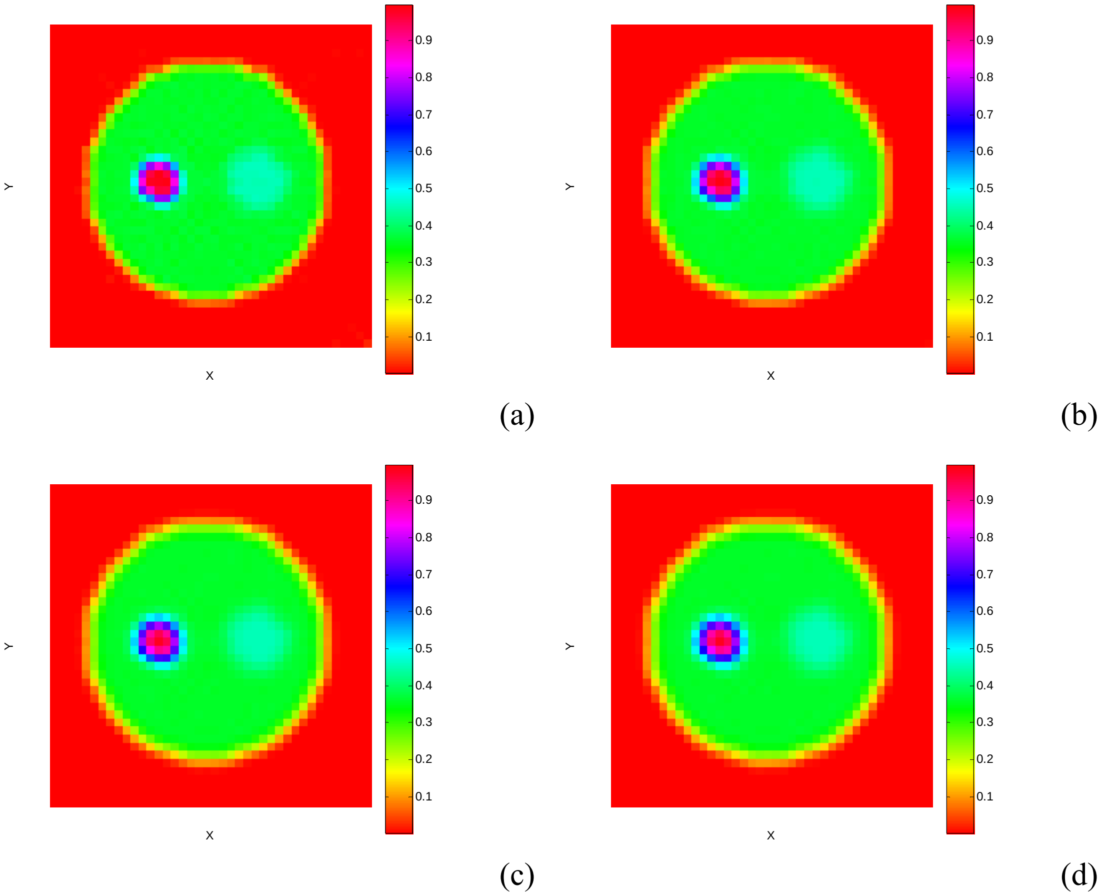

Figure 5. Images generated by (a) Shepp-Logan filter, (b) Cosine filter, (c) Hamming filter and (d) Hann filter.

5. CONCLUSIONS

Simulate studies present valuable data to start the design and optimization of real tomographic systems with respective limitations like the sampling spacing and the number of projections. Monte Carlo code provides a precision way for measuring photon attenuation coefficients. A number of firm guidelines have been deduced. The sample spacing of the photon beam should be equal to the desired resolution. The projections should number 45 times the amount of samples per projection and should span 180°. For reconstruction effects, the pixel width should be equal to the sample spacing. The Ram-Lak filter is preferred for small high-contrast features and the Hann filter for large low-contrast features while Shepp-Logan filter provides a useful compromise.

ACKNOWLEDGMENTS

The authors would like to thank Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for the financial support.

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