



ELSEVIER

Contents lists available at ScienceDirect

Physica Medica

journal homepage: <http://www.physicamedica.com>

Technical Notes

Monte-Carlo simulation of a slot-scanning X-ray imaging system

Mayuresh Kulkarni ^a, Ronald Dendere ^a, Fred Nicolls ^b, Stef Steiner ^{a,c}, Tania S. Douglas ^{a,*}^a Division of Biomedical Engineering, University of Cape Town, Cape Town, Western Cape, South Africa^b Department of Electrical Engineering, University of Cape Town, Cape Town, Western Cape, South Africa^c Lodox Systems, Sandton, Johannesburg, Gauteng, South Africa

ARTICLE INFO

Article history:

Received 22 September 2014

Received in revised form 2 November 2015

Accepted 1 December 2015

Available online 22 December 2015

Keywords:

Monte-Carlo

Simulation

Slot-scanning

X-ray

ABSTRACT

We present a method for simulating slot-scanning X-ray imaging using the general-purpose Monte Carlo simulation package PENELOPE and penEasy Imaging. Different phantoms can be defined with the PENGEOM package, which defines bodies as combinations of volumes limited by quadric surfaces. The source-detector geometry, the position of the object, the collimator, the X-ray tube properties, the detector material and the pixel dimensions are defined. The output of the time-delay integration detector is simulated using sequential slot outputs derived from penEasy Imaging. The simulations are validated using tungsten and aluminium test objects, which are both simulated and imaged. The simulations are compared to the X-ray images using standard image quality metrics. The MTF, NPS and DQE curves show that the real and simulated X-ray images are comparable in terms of spatial resolution, noise and frequency information. The implementation can be modified to suit alterations in the system being simulated.

© 2015 Associazione Italiana di Fisica Medica. Published by Elsevier Ltd. All rights reserved.

Introduction

Several models have been developed to simulate the design and optimisation of X-ray imaging systems, but they either only simulate parts of the imaging chain like the X-ray energy spectrum [1] and scattered radiation [2], or are not sufficiently flexible to simulate different phantoms and imaging systems [3,4]. Furthermore, few simulation methods are available for slot-scanning imaging, and those that exist are application-specific and limited in their use. This paper describes a flexible and multi-purpose simulation tool for slot-scanning digital X-ray imaging using Monte-Carlo methods for radiation transfer with a flexible geometric setup.

Background

X-ray simulation tracks the path of X-ray photons from the source, through the test object to the detector, and is essentially a radiation transport problem. The Boltzmann equation was initially used to study radiation transport problems, but had considerable limitations for simple geometries [5]. In the early 1960s, with computing advances, Monte-Carlo (MC) simulations emerged as a powerful tool for radiation transport problems. Several MC implementations are available, such as ITS3 [6], EGS4 [7], EGS5 [8], GEANT3 [9], GEANT4 [10] and others.

* Corresponding author. Division of Biomedical Engineering, University of Cape Town, Cape Town, Western Cape, South Africa. Tel.: +27 214066633; fax: +27 21 4487226.

E-mail addresses: tania@ieee.org (T.S. Douglas), mayuresh87@gmail.com (M. Kulkarni), rdendere@gmail.com (R. Dendere), fred.nicolls@uct.ac.za (F. Nicolls).

XRaySim [3] is an open-source simulation package for industrial non-destructive testing and medical imaging applications. It uses C++ and open-source libraries to simulate X-rays. The input energy spectra are simulated using standard MC methods, while phantoms and their material properties are used to acquire simulated X-ray images on specified detectors. Phantom geometry can be modified using commercial CAD packages, custom materials can be defined and defects in test objects can be simulated. Detector characteristics can be defined and various scan geometries can be simulated. XRaySim does not support slot-scanning X-ray imaging and is not able to do high-resolution simulations (e.g., 50 microns/pixel).

The work done in [4] explains a simulation setup similar to XRaySim based on triangular mesh geometry, radiation transfer and ray-tracing, used with the X-ray attenuation law to simulate 3D phantoms for non-destructive testing (NDT). The imaging process comprises defining X-ray source, beam, test object and detector. The work has potential applications beyond NDT, but development is in the early stages and the code is not publicly available. The simulation does not currently have the flexibility for extension to slot-scanning X-ray imaging systems.

Hussein et al. [11] simulated a tissue-equivalent breast phantom image and compared it to X-ray images from a slot-scanning mammography system. The simulations were based on source models as well as empirical equations for pixel intensities, scattered radiation and other variables in the imaging chain. The simulated images were validated by comparison to real X-ray images of the phantom, using image contrast, contrast-to-noise ratio, noise power spectrum, modulation transfer function and detective quantum efficiency. The simulated images were found to be comparable to the real

images. Monte-Carlo methods and ray-tracing were not used. A limitation of this work is that it simulates the mammography imaging setup with one specific phantom and does not lend itself to modelling different phantoms, materials, geometries or X-ray sources.

Slot-scanning simulation methodology

This section describes the components of a generic X-ray imaging system and their simulation using PENELOPE and penEasy Imaging.

PENELOPE and penEasy imaging

A typical MC X-ray implementation consists of modelling the physics of the imaging process and tracking the geometry of the rays. PENetration and Energy LOSS of Positrons and Electrons (PENELOPE) [5], developed by the Nuclear Energy Agency (NEA), is a set of Fortran subroutines that model the transport of photons through different media. The interaction between media and radiation, in the energy range from 50 eV to 1 GeV, is simulated. PenGEOM defines the geometry of the system using either voxel geometry or quadrics. The RITA (Rational Inverse Transform with Aliasing) algorithm is used to simulate coherent and incoherent scattering of photons in PENELOPE. PENELOPE and its various subroutines have been widely used to develop tools to simulate complex geometries and phantoms. The basic simulation of an X-ray image using PENELOPE is defined in penEasy Imaging [12]. General-purpose Monte-Carlo simulations of radiation transport using PENELOPE are combined with a flexible geometric setup based on triangular meshes in penMesh [13]. These were used to define anthropomorphic phantoms to simulate X-ray images in [14]. The tools have been used to generate clinically-realistic projection images and computed tomography scans of the Duke phantom of the human body [15].

X-ray source and collimation

A 90 kV–100 mA rectangular beam source, also known as a fan-beam, is defined using penEasy Imaging. It provides a collimated beam, beam width 6 mm, of radiation that produces a rectangular radiation field on the detector, to resemble a cone beam emitted from a point focal spot; the beam is collimated using lead as an ideal collimator with total absorption and no scatter radiation. The source-to-detector distance is 1296 mm, with an inherent 1 mm aluminium filter. Variables like the polar and azimuthal apertures, the direction of the fan-beam and the source location in the overall geometry enable modification of the source to match the physical one. Different energy spectra may be used.

Post-collimation filters are frequently used to improve scatter or reduce X-ray dose. They can be modelled by altering the energy spectra. Adding the filter to the geometry, at the desired location and with the desired material properties, is another way of modelling filters. A filter of a specific thickness and material is incorporated into the simulation as a plane in the geometric system. Photon transport is followed through the filter to the detector.

Imaging geometry

Fig. 1 displays a typical slot scanning system, showing the effect of collimation and the relationship between collimator width and beam width. An image is formed as the source moves with respect to the detector in the scan direction, which is perpendicular to the slot direction.

The imaging geometry can be divided into two parts, namely the object geometry and the system geometry. The object geometry defines the shape and size of the object being scanned. PENGEOM splits an object into its quadric components (surfaces of varying 3D

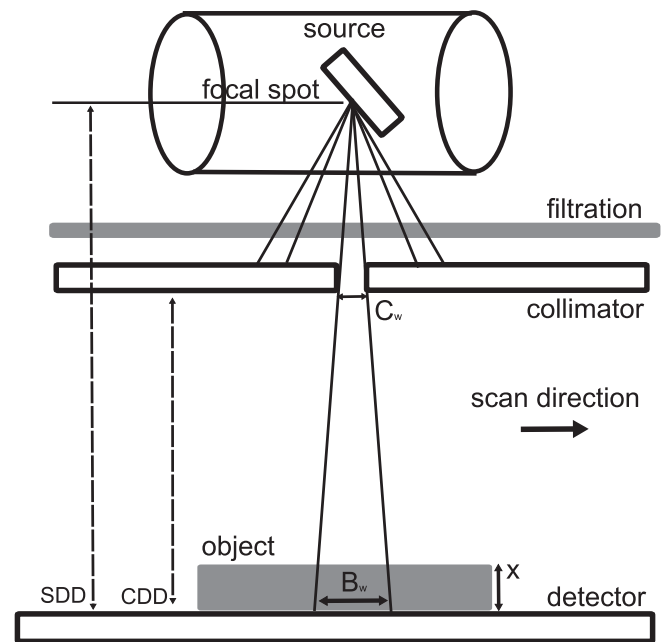


Figure 1. Typical slot scanning X-ray system. SDD: source-to-detector distance, CDD: collimator to detector distance, x : thickness of the object to be scanned, C_w : collimator width, B_w : beam-width at the detector. The slot direction is coming out of the page and the scan direction is from left to right.

shapes) and assigns them material properties using the PENELOPE material database, which covers over 200 materials including elements, compounds and mixtures.

The system geometry contains information about the locations of the source, the detector and the object. The apertures of the source and the source-detector distance determine the detector size to be used. The number of pixels on the detector, and hence the resolution, can be set.

The penEasy Imaging package provides tools to obtain the X-ray image output from PENELOPE [12]. Thus PENELOPE handles the physics of photon travel, RITA provides scatter modelling, PENGEOM contains the geometrical information, and penEasy Imaging converts the detector signal into output. The system geometry shown in Fig. 1 is defined using the PENGEOM package.

TDI detector

The time delay integration (TDI) read-out technique, also known as drift scanning, divides the detector into columns or slots representing the collimated beam. The distance between two slots can be defined. The slots generally overlap to ensure that a certain area on the detector occurs in many slots. Combining the slots averages the output at the detector, reducing the noise and scattered radiation. Over the period of a scan, each slot is exposed to X-rays and is clocked out of the detector. All the individual scans are integrated to produce the final X-ray image. Fig. 2 shows two consecutive slots in the detector.

The step is the distance between the beginnings of consecutive slots. The step width can be set for simulation. A larger step size reduces the run time.

Image acquisition and simulation

This work uses the subroutines in PENELOPE to model the Lodox Statscan (Sandton, South Africa) slot-scanning X-ray system. The basic implementation has been modified to perform iterative slot

Download English Version:

<https://daneshyari.com/en/article/10731025>

Download Persian Version:

<https://daneshyari.com/article/10731025>

[Daneshyari.com](https://daneshyari.com)