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GAMMA RAY COMPUTED TOMOGRAPHY (CT) FOR THE INDUSTRIAL APPLICATION

Khin Ye Lwin[1], Moe Phyu Hlaing[2]

Abstract

Radioisotope Techniques have been used as diagnostic tools in various industrial sectors to improve production efficiency and to gain information that cannot be obtained in any other way. The gamma ray computed tomography (CT) is a radioisotope technique largely used for troubleshooting and optimization of the industrial process plants. The experimental research to investigate the interior distribution of density of the different density materials and the phase distribution inside the multiphase system have been carried out using GORBIT - the first generation gamma CT system at the Radioisotope Techniques Laboratory in the Division of Atomic Energy. The GORBIT CT system consists of one collimated radioactive source, one collimated detector, a radiation rate-meter, two servo motors and an electronic control system. The associated GORBIT software was used for controlling the hardware's operations and logging data. The objects were located in the middle of the gantry. The data were collected by measuring the radiation emitted from the radiation source moving around the objects. The radiation source was 50mCi of Co-60 gamma source and the detector was a 2″ × 2″ NaI (TI) gamma scintillation detector. Tomography images were reconstructed from the acquired gamma transmission data by Filter Back Projection (FBP) algorithm using the separate GORBIT software. The experimental results of two dimensional CT images interpreted the cross sectional profiles of the objects and multiphase system and also provided information on the internal structure of the objects including defects and their dimensions. Therefore the gamma computed tomography (CT) has proved a powerful non destructive testing and evaluation tool and has wide range of applications in the petrochemical and chemical process industries: distillation columns, packed beds, risers, fluidized beds and other multiphase processing units.

Keywords: Radioisotope Techniques, Industrial Process Gamma Tomography, Filtered Back Projection, Image Reconstruction, Petrochemical Industry

Introduction

The potentials of imaging with ionizing radiation were discovered almost at the same time as the ionizing radiation itself in the late 1890s.The imaging modality with high interesting is tomographic imaging which is cross-sectional imaging. The computerised tomography (CT) is used worldwide for a large number of applications in medicine as a diagnostic tool for different diseases and in industry for the development of modern engineering materials, a non destructive tool for determining the quality of the materials used in various industrial sectors. Gamma computed tomography for process visualization is a complementary advanced technology for optimizing industrial process design and operation, applicable for many industrial multiphase flow systems: distillation columns, packed beds with two phase flows, risers, fluidized beds, and other multiphase processing units. It is capable of measuring the phase distribution inside multiphase equipment without disturbing normal operations and it provides unique technique for quantification of multiphase opaque flow fields, which cannot be accomplished by any other means. The tomographic technique produces a two dimensional image of the cross-section of an object without physically sectioning and jeopardizing it. The indications revealed in CT images can be readily interpreted in terms of mass density. The CT images also provide information on

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[1] Dr, Principal Scientist, Division of Atomic Energy, Department of Research and Innovation
[2.] Director, Material Science and Research Division, Department of Research and Innovation

the internal structure of the object including defects and their dimensions[IAEA-TECDOC-1589, Ramamoorthy N. et al, Ashraf M. M. et al].

The gamma computed tomography experiments have been carried out at the Radioisotope Techniques Laboratory in the Division of Atomic Energy. The objectives of the experimental researches were to investigate the interior distribution of density of the different density materials, the internal structure of the object and the phase distribution inside the multiphase system using GORBIT-the first generation gamma CT system for the problem-solving application in industries.

Materials and Methods

Gamma Ray Computed Tomography

Computed tomography is a technique aimed to estimate the interior distribution of density of an object by measuring the radiation emitted from a radiation source moving around the object. Tomography refers to the cross-sectional imaging of an object from either transmission or reflection data collected by illuminating the object from many different directions. Gamma ray computed tomography methods measure the attenuation of an incident beam that travels in a straight path through an object. The incident beam is partially absorbed and scattered in the object of interest, with the remaining transmitted radiation traveling in a straight line to the detector. Figure 1 shows schematic principle of gamma computed tomography(CT) system. The amount of attenuation is related to the atomic number of the phases distributed in the object, as well as their density distributions [R. Abdul Rahim]. The data were collected by measuring the radiation emitted from the radiation source moving around the objects.

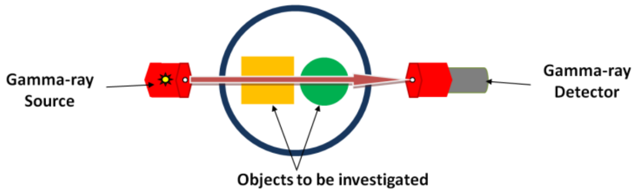


Figure 1 Schematic principle of gamma computed tomography(CT) system

Principle of Computed Tomography

To describe the principle of computed tomography technique, consider a well collimated beam of mono-energetic radiation passing through a homogeneous object. If the intensity of the incident beam of radiation is I_0 and the transmitted intensity through the object in the direction of beam is I, then the attenuation of a well collimated radiation beam through a homogeneous object is given by equation (1).

$$I = I_0 \, exp[-\mu(x,y)x] \; \dots\dots\dots\dots \; (1)$$

where x is the thickness of object traversed by the radiation and $\mu(x,y)$ is the linear attenuation coefficient within a cross sectional plane of the object. For an inhomogeneous material equation (1) can be rewritten as:

$$ln\frac{I_0}{I} = \int_L \mu(x,y)dx \dots\dots\dots\dots\dots (2)$$

The line integral over the path length L, known as the ray sum, is the Radon Transform of μ(x,y).The simplest arrangement for measuring the attenuation coefficients of the first generation transmission CT scanning system is shown in Figure 2.The source and the detector system allow a sequence of discrete transmitted measurements through a defined cross section as it traverses across the object with the source-detector coordinate frame (x, y) and rotated through an angle θ with respect to the object frame (x, y). Since μ (x, y) is a density function of (x, y), replacing μ (x, y) by f(x, y), equation (2) can be rewritten as

$$\ln\frac{I_0}{I} = \int f(x,y)ds \ldots\ldots\ldots\ldots (3)$$

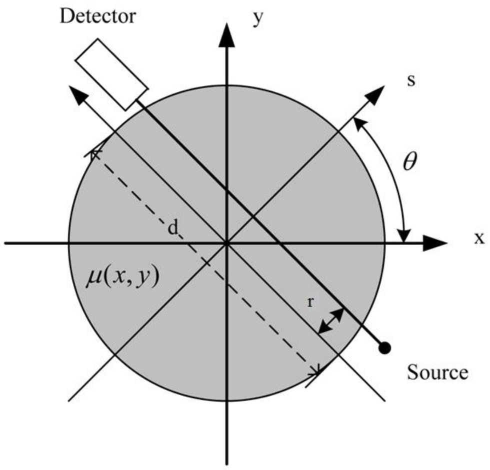


Figure 2 Arrangement of a transmission CT scanning system

Ray paths are described by an (r, S) coordinate system which is rotated by the same angle. Each ray is thus specified by coordinates (r, θ) where θis the angle of the ray with respect to x-axis and r is its distance from the origin. The coordinate S represents the path length along the ray.

$$P(r,\theta) = \int_{r,\theta} f(x,y)ds \ldots\ldots\ldots\ldots (4)$$

For imaging purposes with a radioisotope P(r, θ) , known as ray sum is directly proportional to the detector signal neglecting gamma ray attenuation and changes in the solid angle of the detector [Ashraf M. et al, Avinash C. Kak et al, IAEA-TECDOC-1589].

Image Reconstruction Methods

A number of methods are used for the reconstruction of images in computerized tomography. Two dimensional Fourier reconstruction and Filtered back projection reconstruction are the two analytical reconstruction methods used for image reconstruction. Analytical reconstruction is based on the direct solution of equation (4). The objective of CT algorithms is to inverse a set of equations relating the measurements to the image. The recorded data set are processed by dedicated computer software, which uses mathematic reconstruction algorithms, to generate the cross-sectional images of the object. The process tomography is to provide cross sectional information: spatial resolution, temporal resolution, contrast and linearity. Spatial resolution is strongly linked to the collimation of detectors, the number of steps per projection and the number of projections. Contrast is linked to the energy source, the activity and the detector type[Ashraf M. et al, IAEA-TECDOC-1589].

First Generation Gamma Computed Tomography System (GORBIT)

GORBIT is the first generation of gamma transmission computed tomography system based on the configuration of one source-one detector. The system is operated automatically based on the settings from computer. It consists of two main components: hardware and software. The hardware contains mechanical assembly, one collimated radioactive source and one collimated gamma detector, electronic part includes a radiation rate-meter, two servo motors and an electronic control system. The associated software is used for controlling the hardware's operations and logging data. Tomography images can be reconstructed from the acquired gamma transmission data by using a separate software designing based on Filter Back Projection(FBP), Algebraic Reconstruction Technique (ART) and Expectation Maximization (EM) algorithms.

The GORBIT system is designed to operate under control of an automatic control system (eGORBIT). Typical configuration of the control system would include 2 servo motors (1 for parallel motion, 1 for rotary motion) and their drivers, three photo micro sensors, a central control board and a computer program. Figure 3 illustrates the general arrangement of whole GORBIT system. There are GORBIT gantry, eGORBIT and a personal computer (laptop or desktop). The GORBIT gantry is a flexible design which can be fitted to some kind of object configurations. The Gantry can be set up horizontally, vertically or obliquely. The associated eGORBIT software was used for controlling the hardware's operations and logging data[User Manual of GORBIT].In the experimental research, GORBIT CT system which was provided by IAEA has been used to investigate the interior distribution of density of the objects.

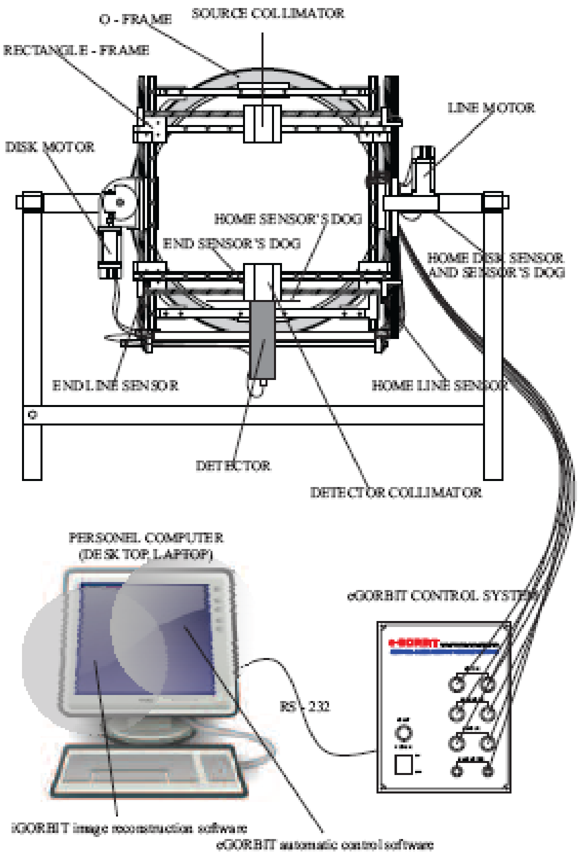


Figure 3 General arrangement of whole GORBIT system

Image Reconstruction

The iGORBIT is an image reconstruction program and used to reconstruct the images from the data set acquired by GORBIT system. The iGORBIT was designed based on four basic algorithms: Back Projection (BP), Filter Back Projection(FBP), Algebraic Reconstruction Technique (ART), and Expectation Maximization (EM). All of these algorithms used in this program to generate the images, which is 256x256 pixels of maximum resolution [User Manual of GORBIT].

Materials

In the gamma ray CT experiments, the blocks of different density materials of wood, polyethylene and concrete were used to investigate the interior distribution of density and a lead block was used to determine the internal structure of the object. 10 inches diameter polyvinyl Chloride (PVC) pipe was used to define the region of interest (ROI) for the CT measurement. For phase distribution experiment, 8 inches diameter of iron pipe partially-filled with crude oil and covered with plastic sheets at both ends was created as the multiphase system.

Figure 4 The horizontal arrangement for the measurements of different density and internal structure of the objects

Figure 5 The vertical arrangement for the measurement of the phase distributionin the pipe

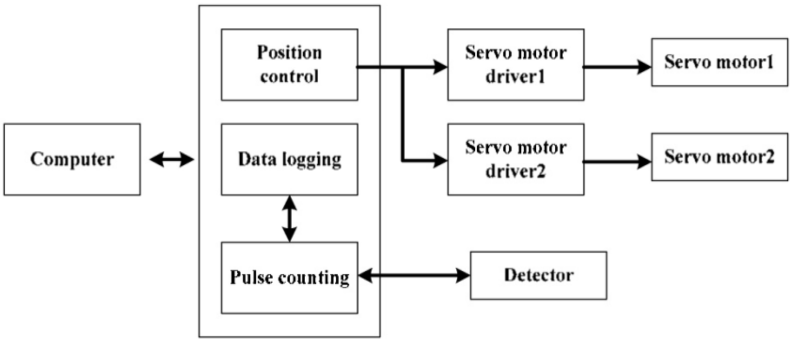


Figure 6 The block diagram of the operation of the CT system

When the experimental setting was completed, the gamma source and the detector were installed in respective containers. The radiation source was 50mCi of Co-60 gamma source and the detector was a 2″ × 2″ NaI (TI) gamma scintillation detector. After the objects to be imaged were located in the middle of gantry, the source and the detector were placed in the initial position. Then set up the parameters for automatic scan by using eGORBIT software installed in the computer.

The resolution of the image is linked to the number of projections and the number of steps per projection. In the experiment, therefore firstly, three different parameter sets of view (number of projections) and trays (number of steps per projection) were used to compare the resolution of the images. Table 1 shows the required parameters for three different scans of an object and figure 7 shows the parameters for automatic scan in eGORBIT software.

Table 1 Three different parameter sets for three scans of an object

Scan	Number of views	Number of rays
Scan 1	16	32
Scan 2	32	64
Scan 3	64	128

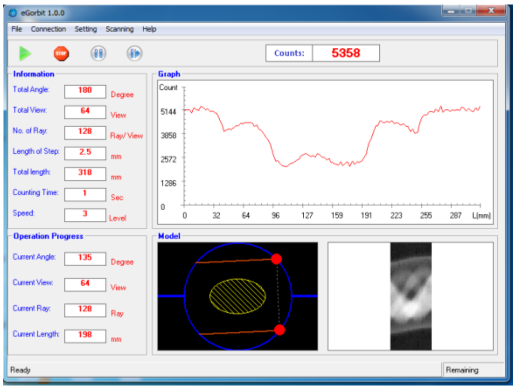
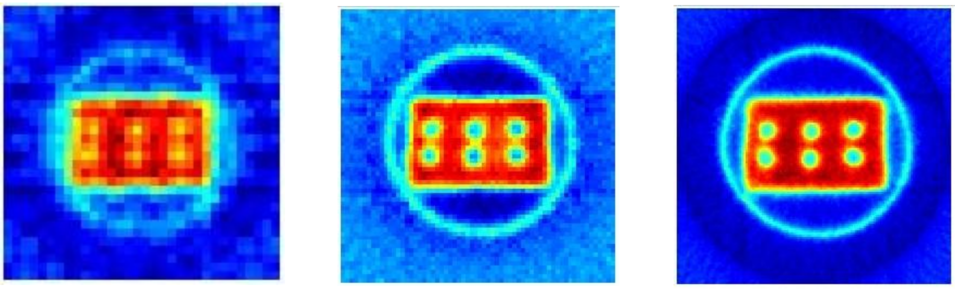


Figure 7 The parameters for automatic scan by using eGORBIT software

To scan the object, the source and the detector were moved according to preset steps simultaneously by one motor for a parallel beam scanning, whereas the other motor rotated the gantry at the preset projection angles within 180°. The motors were controlled through a driver linked to a data logger for PC control. The driver makes the motor finish the motion by the input pulses. The input pulse was generated from the data logger. The data logger transmitted the acquired data to a PC and controlled the two servo motor drivers for the rotating and scanning motions. It processed the measured radiation counts as two-dimensional data, the rows and columns which indicate the index for the location of a detector bin and the projection angle, respectively.

Tomography images were reconstructed from the acquired gamma transmission data by Filter Back Projection (FBP) algorithm using the separate iGORBIT software. The comparison of the reconstructed images of three different scans of an object are shown in figure 8.



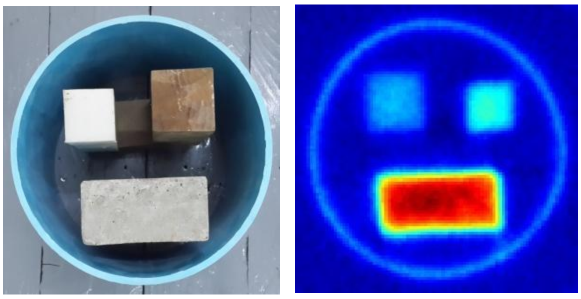
(a) Scan 1 (16x32) (b) Scan 2 (32x64) (c) Scan 3 (64x128)

Figure 8 The comparison of reconstructed images of three different scans of an object

These images can be determined that the image of Scan 3 with the parameters 64x128 is with the highest resolution. Therefore the gamma ray computed tomography automatics cans for the different density materials (wood, polyethylene and concrete), the lead block and the multiphase system pipe performed with 64 projections and 128 rays (64 x 128 pixels)for 180°.

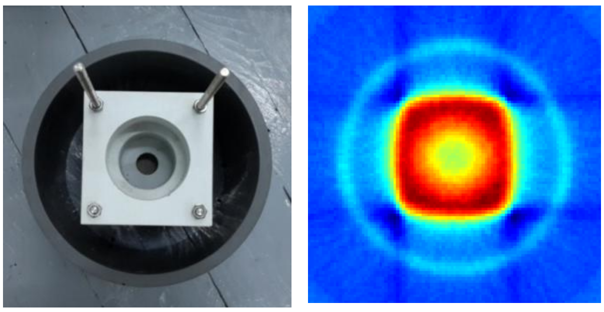
Results and Discussion

Tomography images of the blocks of different density materials of wood, polyethylene and concrete, the lead block and the multiphase system pipe were reconstructed from the acquired gamma transmission data by Filter Back Projection (FBP) algorithm using the separate iGORBIT software. The reconstructed cross-sectional images were compared with the optical camera images. The comparison for the interior density distribution of different density objects is shown in figure 9, for the internal structure of lead block is shown in figure 10 and for the phase distribution in the pipe is shown in figure 11.



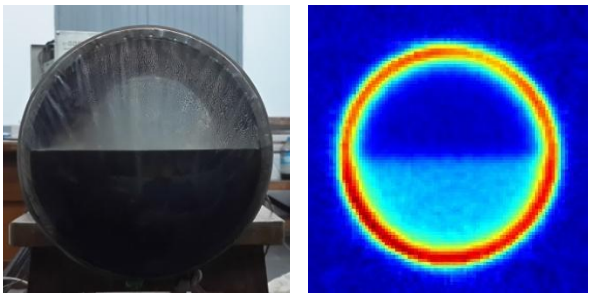
(a) (b)

Figure 9 The comparison of(a) the optical camera image and (b) the reconstructed cross-sectional image of the interior density distribution of different density objects



(a) (b)

Figure 10 The comparison of (a) the optical camera image and (b) the reconstructed cross-sectional image of the internal structure of the lead block



(a) (b)

Figure 11 The comparison of (a) the optical camera image and (b) the reconstructed cross-sectional image of the phase distribution in the pipe

The reconstructed images measured by the different scan parameters can be compared the resolution of the images. The resolution of the tomography image scanned with the highest number of parameters (64x128) is the highest resolution. The experimental results of two dimensional CT images revealed the cross sectional profiles of the objects and multiphase system. The reconstructed images also provided information on the internal structure of the objects including defects and their dimensions. The tomography images can be determined the dimension of the object and the attenuation coefficient of materials by using reconstructed software.

Conclusion

Gamma ray computed tomography system was used to look the interior of the different density materials, the lead block and the multiphase pipe. The experimental results of two dimensional CT images interpreted the cross sectional profiles of the objects and multiphase system and also provided information on the internal structure of the objects including defects and their dimensions. The resolution of the image is linked to the scan parameters. The higher the number of parameters (projections and steps) was used, the higher the resolution of the reconstructed image can be got.

Gamma transmission tomography allows measuring spatial distributions of material based on its attenuation properties. The attenuation properties take into account the nature of material (atomic number) and the density. It means that transmission CT can distinguish phases with significant different attenuation properties due to density (liquid-gas or solid-gas) and/or atomic number. Therefore the gamma computed tomography (CT) has proved a powerful non-destructive testing and evaluation tool and has wide range of applications in the petrochemical and chemical process industries. The success of radioisotope industrial application is due to primarily to the ability, conferred by the unique properties of radioactive materials, to collect data which cannot be obtained by other investigative techniques.

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