

Laboratory Experiment on Non-invasive Investigation of Crude Oil Pipe by Industrial Gamma Computed Tomography

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Abstract: *With the inception applications for medical purpose, computed tomography (CT) is a rapidly developing technique that is also useful for measuring, imaging and troubleshooting multi-component and multi-phase processes in industry. Gamma ray CT can give two or three dimensional images to exploit density distribution of material in an opaque object. This research aims to utilize first generation Gamma ray scanning system to examine the liquid content and air-oil layer in a pipe line of petrochemical plant. The experimental investigations were carried out by using GORBIT gamma ray CT system with one source-one detector combination. The Cobalt-60 source of 50 mCi was used in the experiments and the transmitted gamma radiation was measured by 2-inch NaI(Tl) scintillation detector. The crude oil pipe phantom was created and scanned 64 projections for 180° to get cross-sectional images. The images were reconstructed from the measured data with filtered back projection method by using i-GORBIT and MATLAB software. The GORBIT system presented a good performance to apply in pipe scan at the refineries and petrochemical plants. The experimental gamma ray CT images have sufficient resolution to reveal the density distribution of air and crude oil inside the pipe phantom.*

Keywords: gamma ray CT, Cobalt-60 source, NaI(Tl) scintillation detector, crude oil pipe phantom, filtered back projection method

1. Introduction

The potentials of imaging with ionizing radiation were remarkably achieved for both medical and industrial applications. One of the imaging modality for industry is computed tomography (CT) which gives cross sectional imaging of parameters of industrial processes. The foundation of industrial process tomography is to conduct several measurements around the periphery of a multi-component or multiphase process, and use these measurements to unravel the cross sectional distribution of the process components in time and space [1]. This information is used in troubleshooting, design modification and optimization of industrial processes and process equipment, and improving accuracy of multiphase system measurements [1], [2], [3].

Industrial process tomography is a non-intrusive technique, which is capable of measuring the phase distribution inside multiphase equipment without disturbing normal operations. Multiphase mixtures have to be transported in pipes, mixed, separated and reacted in various columns, tanks and other reactors. Considerable savings in capital expenditures and in operating costs would result if these process units could be designed and operated more efficiently. Tomography provides unique technique for quantification of multiphase opaque flow fields, which cannot be accomplished by any other means [1], [4]. Tomography system could be applied in aggressive environment which contains superheated or corrosive material subjected to high internal column pressure. For industrial plant examination, gamma tomography which utilizes radioisotopes emitting more penetrating higher energy photons has greater advantages over X-ray CT which has a good spatial resolution for a small-scale object [4]-[6]. The industrial process gamma ray CT focuses on its

application to visualize failure equipment points in petrochemical and refinery industries [2], [3], [5], [7].

Several CT generations which refer to the geometrical arrangement of the source-detector combinations had been developed [1], [7]. In 2005, Pablo A. et al. made a simulated study on parallel beam gamma ray tomography through a heterogeneous phantom by using Monte Carlo code. In 2006, Jonbum Kim et al. published their study on industrial gamma ray CT with a single source-detector pair using 20 mCi Cesium-137 source and NaI detectors. Gamma ray tomography experiments in order to detect spatial patterns in the porosity in packed columns and to determine flow patterns in multiphase system were carried out in [2], [7] and [8]. Jonbum Kim et al. also carried out a simulation study to design clamp-on type portable gamma ray computed tomography system in 2012. Two kinds of algorithms, transformation based methods and iterative reconstruction methods, could be used to reconstruct an image from measurement data [1]-[7], [9]-[12]. The image reconstruction algorithms were implemented in LabView, MATLAB and Virtual Basic software platforms [1], [3], [12]. The influence of gamma ray energy, material density and counting time on reconstructed image quality were also investigated [1], [11].

During 2003 to 2007, the IAEA organized CT laboratories from different countries and implemented a Coordinated Research Project (CRP) on Industrial Process Gamma Tomography with the overall objective of testing and validating CT techniques for diagnosing industrial multiphase processes [1]. In 2013, cooperating with the IAEA, Myanmar established the project MYA1014 for building national capacity building to use radiotracer and sealed source techniques in industry. We conducted tomography experiments with first generation CT system to

study effect of density, intensity of radiation source and number of projection on reconstructed CT image [13].

This paper is organized as follow. Section 2 discusses the methodology of parallel beam gamma tomography and image reconstruction. Section 3 presents the gamma CT experiment on crude oil pipe phantom. Section 4 gives the results of the practical work and the discussion. Finally, section 6 states the conclusion remarks.

2. Methodology

The attenuation of a gamma ray beam of intensity I_0 when it traverses an absorber of thickness x and density ρ is described by the relationship [14] _

$$I = I_0 \exp(-\mu \rho x) \quad (1)$$

where μ is the mass absorbing coefficient and B is the build-up factor. The equation (1) can be rewritten as a reasonable approximation_

$$I = I_0 \exp(-\mu_{eff} \rho x) \quad (2)$$

where μ_{eff} is an effective mass absorption coefficient determined empirically.

2.1. Projections by Parallel Beams

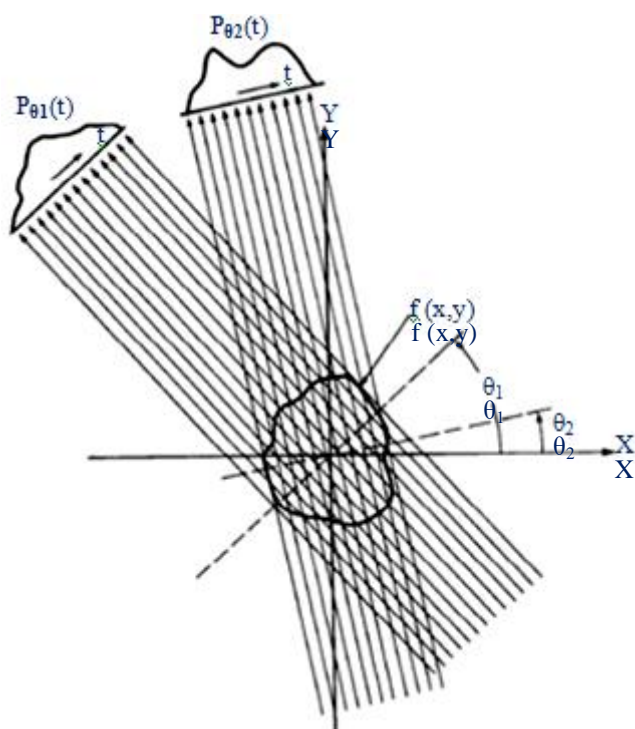


Figure 1: Parallel projections are taken by measuring a set of parallel rays for a number of angles [9], [10]

The process of tomographic imaging is to reconstruct a two-dimensional array of linear attenuation coefficients from a series of one-dimensional transmission profiles. The initial intensity measurements must be converted to projection data, which approximate the line integral of the linear attenuation coefficients characterizing the material within the object as illustrated in figure (1). For an object surrounded by air, the projection data recorded for tomographic reconstruction of a single slice in case of parallel beam configuration is given by [10]:

$$P_{\theta}(t) = \int_{(t,\theta)line} \mu(x, y) ds = -\ln(I / I_0) \quad (3)$$

where θ ($0 \leq \theta \leq \pi$) is the projection angle and t is the distance in the detector plane from the projected rotation axis. CT obtains the object function $f(x,y)$ from the set of projection measurements $P_{\theta}(t)$.

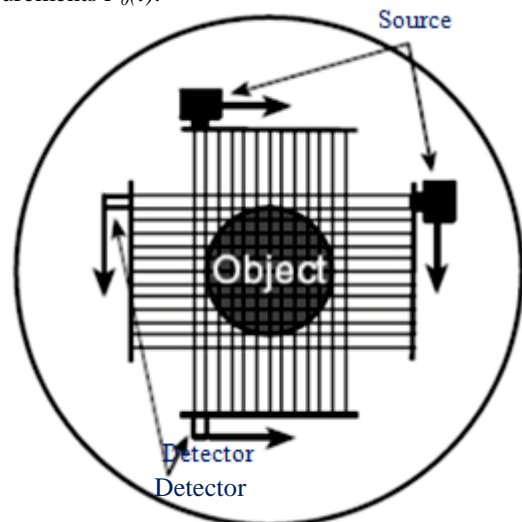


Figure 2: Measurement geometry for first generation gamma ray CT scanner [1], [7]

In first generation parallel scanning, figure (2), a source emitting a single pencil beam of gamma radiation and a detector are simultaneously translated to acquire individual projection. After the completion of the linear measurement, the source-detector assembly is rotated to the next angular position to acquire the next projection [1].

2.2. Image Reconstruction Algorithm

The algorithm that is well-known analytical method of straight ray tomography is the filtered back projection algorithm. It has been shown to be extremely accurate and amenable to fast implementation and will be derived by using the Fourier Slice Theorem [1], [4], [9].

In practical application areas of computed tomography, projections are formed by measuring the attenuation of radiation that passes through a physical specimen at different angles. The intensity measurement data received from the detector can be organized in MATLAB in a matrix form $R(x,y)$ which represents the Radon transform of a cross section through the specimen. Then an internal image of the specimen is reconstructed by *iradon* function. The *iradon* uses the filtered back projection algorithm to compute the inverse Radon transform from projection data. The filter is designed directly in the frequency domain and then multiplied by the Fast Fourier transform of the projections. This algorithm forms an approximation of the original image based on the projections in the columns of R [15]. A more accurate approximation of the original image can be obtained by using more projections in the reconstruction [9], [15].

3. Experimental Procedure

The gamma scan investigations were carried out by first generation CT geometry with one source- one detector

combination. The scanning experiment was conducted using a 50 mCi Cobalt-60 source and 2-inch NaI(Tl) scintillation detector.

3.1 Crude Oil Pipe Phantom



Figure 3: Preparation of crude oil pipe phantom

The phantom was made by 8-inch diameter iron pipe which is 25 inches in length and 0.2 inch in wall thickness. The pipe was covered with plastic at both end and tied with rubber band. Then a hole was made at the upper portion of one end, and finally the phantom was prepared by filling half the volume of the pipe with crude oil.

3.2 Set up for Gamma Tomography

The GORBIT CT system shown in figure (4) consists of mechanical assembly, two servo motors, two collimators for source and detector, electronic control system and a computer. The system can be installed to fit with the horizontal, oblique or vertical pipes (or objects) with a maximum diameter of 24 inches [13]. The assembly of source and detector was adjusted to scan oil pipe phantom vertically for the simulation of pipe scanning in industrial field.

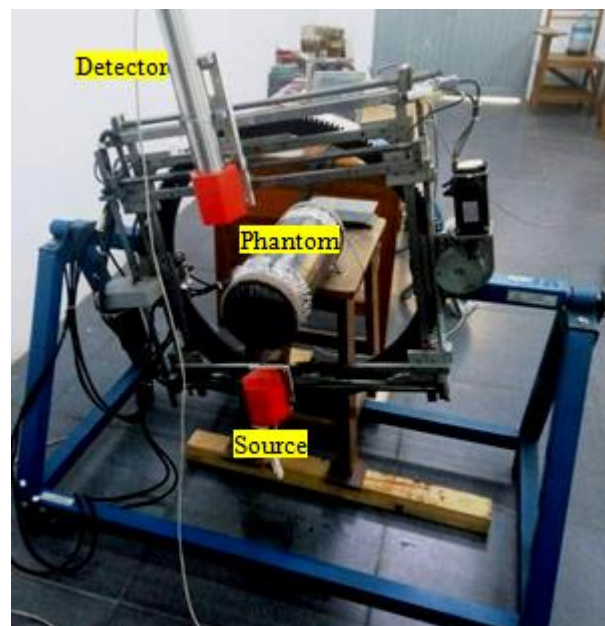


Figure 4: Experimental Set up for gamma tomography of crude oil pipe phantom

3.3 Taking Projections and Image Reconstruction

To make a compromise between reconstructed image quality and overall run time, the scanning parameters for the system were set to get 64 projections with 128 rays per view for 180° [13]. One motor in GORBIT system moves the source and the detector simultaneously for a parallel beam scanning. The translation of the mechanical assembly was delayed one second counting time for each ray. After a complete scanning of one projection, the other motor rotates the scan assembly at a preset projection angle as illustrated in figure (2). The associated e-GORBIT software was used for controlling the hardware's operations and logging data automatically. Then, the measured intensity values could be saved as a 64×128 matrix in a text file.

The i-GORBIT software can use the resulted text file to reconstruct the cross-sectional image of the phantom by different image reconstruction methods, such as, unfiltered and filtered back projection, algebraic reconstruction technique and estimation maximization technique. It is a well developed software package from Vietnam, and it has been currently utilizing for laboratory study as well as field inspection. And, one thing to be noted about i-GORBIT software is that it works only single image reconstruction process for one file at a time.

In fact, specific interpolation used in back projection and filter for frequency domain filtering might be chosen to get the best reconstructed image optimized for the components and phases in the scanned object. For example, nearest neighbor interpolation showed low resolution whereas linear interpolation improved the resolution. The Ram-Lak filter is preferred for small high contrast features and Hann filter for large low-contrast features [10].

Therefore, the MATLAB demo software was created to reconstructed images with different filtering and interpolation parameters to use in the inverse Radon transform for the selected file at a time. In the MATLAB platform, the resulted

file of intensity value needs to convert into 128×64 matrix which is appropriate form of the Radon transform R of the phantom. Then, the function $IMAGE = iradon(R, theta)$ reconstructs the cross sectional image of the phantom from the projections in the columns of the matrix R .

4. Results and Discussion

The unfiltered back projection image of the crude oil pipe phantom and the reconstructed images by means of filtered back projection method with i-GORBIT software were compared in figure (5). In the cases of reconstruction filtering with Ram-Lak filter, Shepp-Logan filter and Hamming filter, blurring images similar to unfiltered back projection image were resulted. The image in figure (5-f), which used Hann filter, was the poorest reconstruction with some artifacts. The

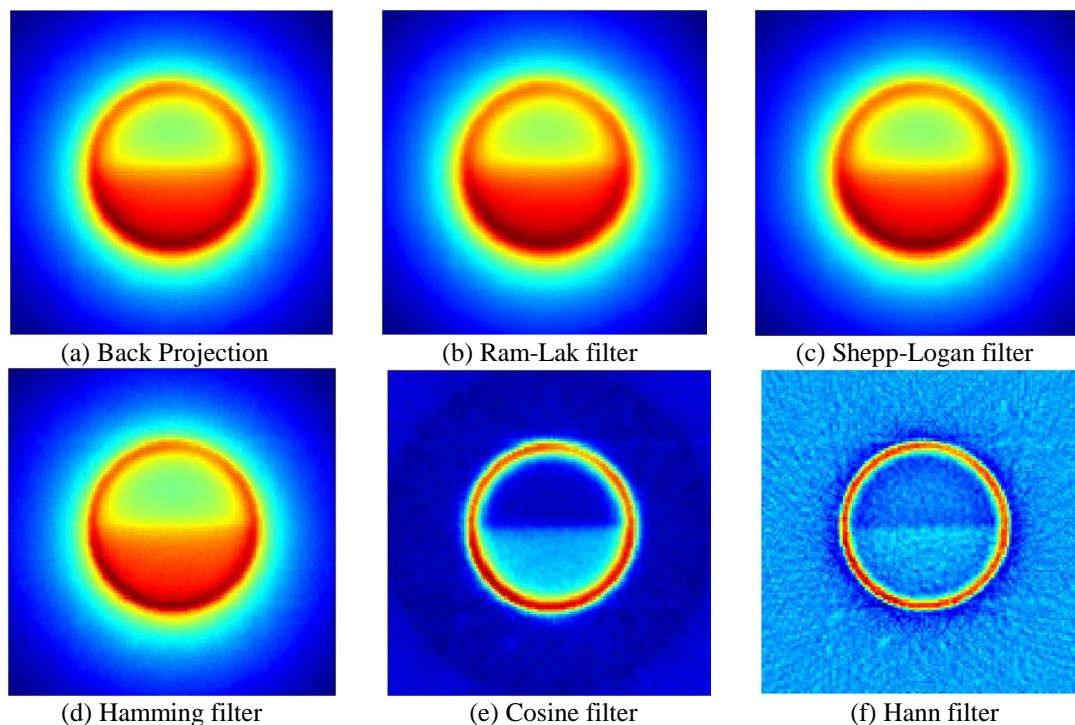


Figure 5: Reconstructed images by i-GORBIT software

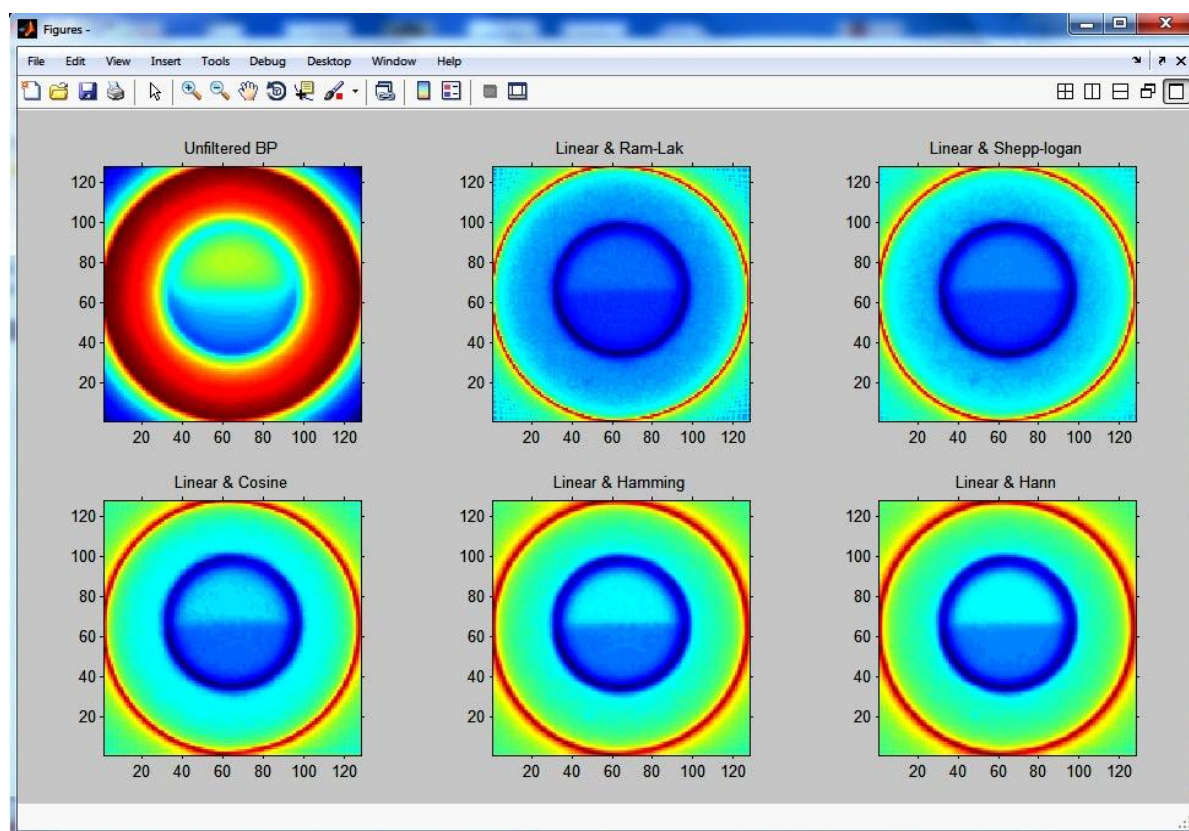


Figure 6: Reconstructed images on MATLAB platform

best image with great contrast between iron pipe and air-oil layer was resulted using consine filter. As shown in figure (5-e), the red coloured cycle represented the iron pipe which has the highest density. The sky blue semicycle at the lower half of red cycle represented the content of less density crude oil in the pipe whereas the dark blue colour represented air. The tomograhpy images of crude oil pipe phantom produced on MATLAB platform was presented in figure (6). Although a demo software, it gave reliable image results with good resolution and contrast. The first CT image which was severely blurred due to overlapping of the Fourier transformed images around the low frequency region was porduced by unfiltered back projection method. In the rest CT images with different filtering, the contrasting features (high frequencies) were accentuated, while blurring (low frequencies) was minimized. To interpret those images, the dark blue cycle represented the iron pipe, the blue coloured semicycle represented crude oil and the sky blue colour represented the air medium.

Additionally, MATLAB Image Processing Toolbox provides a comprehensive set of reference-standard algorithms and graphical tools for image processing, analysis, visualization, and algorithm development. Better tomography images could be produced by performing image enhancement, image deblurring, noise reduction and color management. Graphical tools let the user explore an image, examine a region of pixels, adjust the contrast, create contours or histograms, and manipulate regions of interest (ROIs) [16].

5. Conclusion

Laboratory experiment on crude oil pipe phantom presented the reliability of GORBIT system and filtered back projection image reconstruction method in order to inspect multiphase equipments in refinery and petrochemical plant. The mechanical assembly of the CT system presented good performance in terms of strength, rigidity, accuracy and repeatability to be applied in field inspection. The i-GORBIT is completely developed software to reconstruct the cross sectional image of the specimen from tomograhpic projections. Although MATLAB demo software has room to improve, it also showed applicability to industrial process diagnosis. The future works should be focused on improving the MATLAB software to a version with graphical user interphase for measuring data and greater quality image processing.

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