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Study of image reconstruction method for 2D gamma scan technique by anti-aliasing line "Xiaolin Wu" algorithm combined with simultaneous algebraic reconstruction algorithms and testing on MCNP simulation data

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Abstract: The traditional 1D gamma scanning technique is known as an effective and popular method for surveying the condition of distillation towers in oil refineries. The technique involves measuring the intensity of a gamma beam transmitted through the tower from a radioactive source arranged opposite the detector to obtain a density profile inside the tower along its height. From the obtained density profile, the internal condition of the tower can be determined, such as the physical condition of trays, the liquid level on trays, and abnormal phenomena of fluid above and below the trays, such as flooding, foam on the liquid, and rain under the trays, etc. This technique has many advantages in terms of fast, simplicity and accuracy regarding the physical condition of trays. However, interpreting fluid-related issues is quite complicated and requires experience, but the interpretation results are still qualitative. The 2D gamma scanning technique proposed in recent years worldwide is an improved solution that provides visual cross-sectional images, showing hardware details as well as the internal density distribution of the tower. The 2D gamma scanning technique can be seen as a supplementary solution to the 1D technique to enhance the effectiveness of tower surveys, meeting the increasingly diverse needs of oil refineries. Studies on the approach of 2D gamma scanning technique have been conducted at Centre for Applications of Nuclear Technique in Industry. This report presents the research results on the method of reconstructing 2D gamma scanning images using the Xiaolin Wu anti-aliasing algorithm combined with simultaneous algebraic reconstruction algorithms (SART) and validates the method using MCNP simulation data.

Keywords: *Gamma scanning technique, 2D gamma scanning, Xiaolin Wu's line drawing algorithm, SART.*

I. INTRODUCTION

The distillation column is a key component in oil refining plants that separates crude oil into various components based on their boiling points. The distillation column is typically a tall, vertical cylinder that contains a series of trays or plates stacked on top of each other. As the crude oil is heated and vaporized, the vapor rises through the trays and condenses into liquid form as it reaches a tray that is at a lower temperature. The distillation column is a critical piece of equipment in the oil refining process, as it enables the production of a wide range of valuable products, including gasoline, diesel, jet fuel, lubricants, and other chemicals. To ensure efficiency and safe operation, the distillation tower is regularly inspected and

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surveyed while the refinery plant is in operation. The 1D gamma scanning is a widely used technique for diagnosing the internal status of distillation columns. This technique can investigate the level of fluid on the tray and locate failures, foaming, or flooding inside the column when it is operating without shutting down or disassembling.

The traditional 1D gamma column scanning is based on the principle of gamma transmission, using gamma detectors and a gamma sealed source positioned on opposite sides of the column. Both are moved step by step along the elevation of the distillation column. The results are presented as a one-dimensional chart of transmission radiation counts according to column elevation. Experienced personnel are required to interpret the results, which can indicate important phenomena such as foaming, tray flooding, down-comer flooding due to tray malfunction, but the interpretation remains relatively qualitative. Similar to the traditional 1D gamma column scanning, the 2D gamma scan technique is also based on the principle of gamma transmission. The difference is the asymmetrical movement between gamma detectors and a gamma-sealed source, which means that the gamma beam per projection will fan out like a fan. The result of the 2D gamma scanning is a visual 2D image that clearly describes the inside of the distillation column using images instead of the 1D chart used in traditional gamma column scanning. Therefore, diagnosing the condition of the column based on 2D images will be more effective and reliable than using charts as in the traditional 1D gamma scan. The 2D gamma scanning method is a kind of computer tomography but with fewer projections, so the image reconstruction method needs a proper image reconstruction algorithm and techniques for anti-aliasing and noise reduction. This paper presents the results of studying the image reconstruction method for 2D gamma scan technique by anti-aliasing line "Xiaolin Wu" algorithm combined with simultaneous algebraic reconstruction algorithms and testing on MCNP simulation data.

II. CONTENT

A. Subject and methods

1. 2D gamma scan image reconstruction algorithms

To create a 2D gamma scanning image, it is necessary to obtain projections of the area of interest at many different angles. Because the 2D gamma ray imaging method is essentially a computed tomography imaging method that lacks projections, it is not possible to apply a back-projection algorithm to reconstruct the image. In addition, because of the lack of projections, image reconstruction is strongly affected by artifacts and noise due to geometric calculations. To overcome this problem, the project team has applied simultaneous algebraic reconstruction technique (SART) algorithm combined with Xiaolin Wu algorithm and image matrix from the design drawing to reconstruct images with appropriate quality that meet the technical requirements of 2D gamma ray imaging.

The procedure for reconstructing 2D gamma scan images from measured data is carried out in the following steps:

- Step 1: Convert the measured data (fan beam) to a parallel beam configuration data.

- Step 2: Calculate the position of the sources and the detectors for different projection angles.

- Step 3: Find the passing pixels and the weight of the ray's contribution to the pixel using Xiaolin Wu's line drawing algorithm.

- Step 4: Reconstruct the image using the simultaneous algebraic reconstruction algorithm.

The algorithms used in the above procedure include coordinate transformation, Xiaolin Wu's line drawing algorithm, and simultaneous algebraic reconstruction technique (SART).

To begin, the configuration of the 2D gamma scan data is first transformed into a parallel configuration. Then, the position of the sources and the detectors for different projections are calculated using the coordinate transformation formula as follows: [4, 5]:

$$[t\ s\ ] = [cos\ cos\ \theta \quad sin\ sin\ \theta \quad -sin\ sin\ \theta \quad cos\ cos\ \theta\ ][x\ y\ ] \quad (1)$$

$$\Leftrightarrow \{t = \ x.cos\ cos\ \theta + y.sin\ sin\ \theta \quad s = -x.sin\ sin\ \theta + y.\ cos\ cos\ \theta$$

The coordinate system (x, y) is rotated by an angle θ to obtain the (t, s) coordinate system. The (x, y) system represents pixel coordinates (in pixels), and the (t, θ) system represents rays and projection angles, respectively.

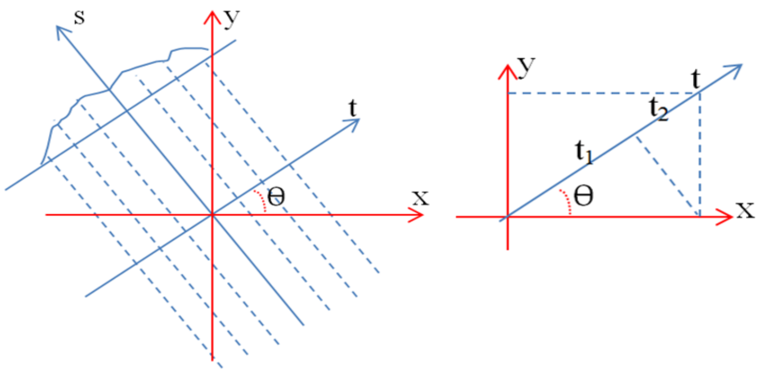


Fig. 1. Coordinate transformation formula

During the transformation of the fan beam data sets to the parallel configuration, some projections in the new data sets may lack beams. To solve this problem, an interpolation method is typically used. While it is possible to reconstruct the image using image reconstruction algorithms, the 2D gamma scan's missing projections and the errors involved in calculating gamma beam penetration through pixels can cause the resulting image to be incomplete. As a result, details of the object may not be accurately reconstructed. However, if Xiaolin Wu's line drawing algorithm is used during image reconstruction, there is no need for interpolation or error correction methods. This algorithm accurately determines the passing pixels and the weight of the ray's contribution to the pixel, resulting in more accurate image reconstruction. Therefore, the use of Xiaolin Wu's line drawing algorithm can improve the accuracy of image reconstruction and eliminate the need for interpolation and error correction methods when dealing with missing projections and errors values in the gamma beam penetrating the calculated pixel.

Xiaolin Wu’s line algorithm is characterized by the fact that each step of the calculation is carried out for the two closest to the line of pixels, and they are colored with different intensities, depending on the distance. Current intersection middle pixel intensity gives 100% if the pixel is within 0.9 pixel, the intensity will be 10%. In other words, one hundred percent of the intensity is divided between the pixels which limit the vector lines on both sides. To calculate the error, the floating point can be used, and the error value of the fractional part is taken.

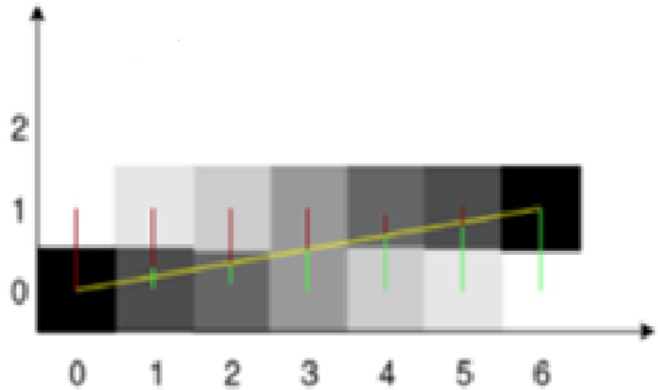


Fig. 2. Xiaolin Wu's line drawing algorithm [4, 5]

After using Xiaolin Wu's line algorithm to determine the passing pixels and the weight fraction of the ray's contribution to the pixel. The final step is applied of Simultaneous Algebraic Reconstruction Technique (SART) to reconstructed images.

The Simultaneous Algebraic Reconstruction Technique (SART) is a good algorithm for reconstructing a less number of projection data sets. It combines the Simultaneous Repeat Reconstruction (SIRT) algorithm with the Algebraic Reconstruction Technique (ART). Although the SIRT algorithm can incorrectly reconstruct noisy data, it can produce a smoothing effect for a high-quality image. However, SIRT takes a long time to achieve a relatively high-precision image. In contrast, ART is a fast-converging process but may produce low-quality images. Due to its useful properties, the SART algorithm is well-suited for 2D gamma scan. The formula for SART is represented by the equation below:

$$f_j^{(k+1)} = f_j^{(k)} + \lambda \frac{1}{\sum_{i \epsilon I_\theta} w_{ij}} \cdot \sum \frac{p_i - \sum_{l=1}^{N} w_{il} f_l^{(k)}}{\sum_{l=1}^{N} w_{il}} \cdot w_{ij} \quad (2)$$

Where p_i is the projected data from the measurement result; f_j represents a value at position j on the pixel; w_{ij} is the weight fraction of the ith ray passes contributed to the jth pixel; k is the number of repetitions; λ is the relaxation factor

The process calculation of the SART algorithm is then performed as follows steps:

1. Estimate and predict the original matrix.
2. Determine the number of iterations
3. Calculate the value of the projection data from the previous iteration data, which is the estimated data in the initial iteration.
4. Calculate the correction factor from the difference projection data.
5. Update matrix data
6. Repeat steps 3-5 based on the number of repetitions.
7. Show the results of images from the last updated matrices.

2. 2D gamma scanning configuration

In this study, the 2D gamma scanning configuration is simulated by MCNP5 to create the raw data sets for researching noise processing and image reconstruction algorithms. The simulation configuration includes the distillation column, which has the shape of a rectangular cuboid with a thickness of 0.5 cm on each side. The height, length, and width of the column are 200 cm, 50 cm, and 50 cm, respectively. Each steel tray inside the column has dimensions of 45 cm x 35 cm x 0.5

cm and is placed 30 cm apart along the height of the column with liquid above. The location and density of the liquid inside the column depend on the experimental purpose.

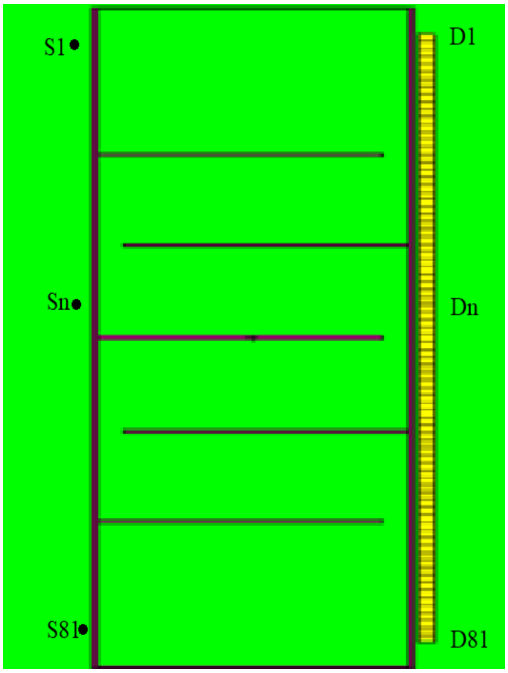


Fig. 3. Simulation configuration of the distillation column

The simulation experiment is designed as follows: There are 81 Cs-137 point of sources arranged in a straight line along the height of a column (represented by symbols S1, S2,… Sn,…, S81), with a distance of 2.5cm between each source. On the opposite side of each source, there is 81 cylindrical detector measuring 2.5x2.5cm (represented by symbols D1, D2,... D81). Both the sources and detectors are symmetrically placed along the vertical axis of the distillation column. This setup allows for the creation of a network of gamma rays that can pass through the column and trays without missing any positions.

The simulation will begin from the S1 source, and the D1 to D81 detectors will record the radiation emit from S1. Then, the simulation will continue at the S2 source, and the radiation emitted from the S2 source will be recorded by the D1 to D81 detectors. Similarly, the simulation for the S3 to S81 sources will be repeated as above. The results from the MCNP simulation are the matrix with 81 rows and 81 columns corresponding to 81 sources (from S1 to S81) and 81 detectors (from D1 to D81).

B. Results

Based on the simulation configurations in Figure 1, the project team simulated various hypothetical situations that could occur inside the distillation column. These include trays without liquid on tray (shown in Figure 4a), bending trays with a 11^0 angle (Figure 5a), 10cm water on trays (Figure 6a), and the vapor above the liquid phase with a 10 cm water level, 10 cm vapor level, and vapor densities is 50% compared to the liquid (Figure 7a). After running the simulation, the resulting dataset, which consists of a matrix with 81 rows and 81 columns corresponding to 81 detectors and 81 sources located, is extracted into an Excel file and colored according to density conditions (as shown in Figure 4).

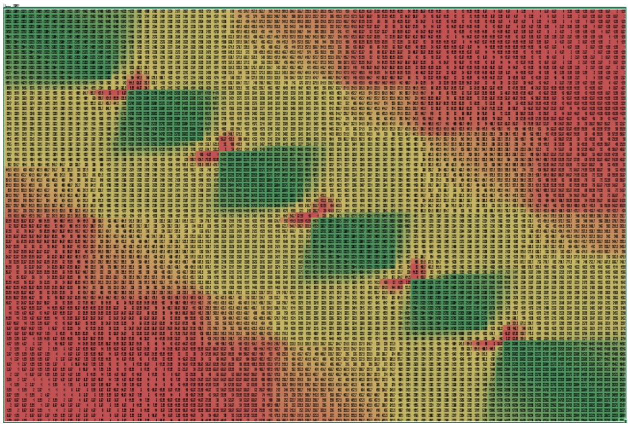
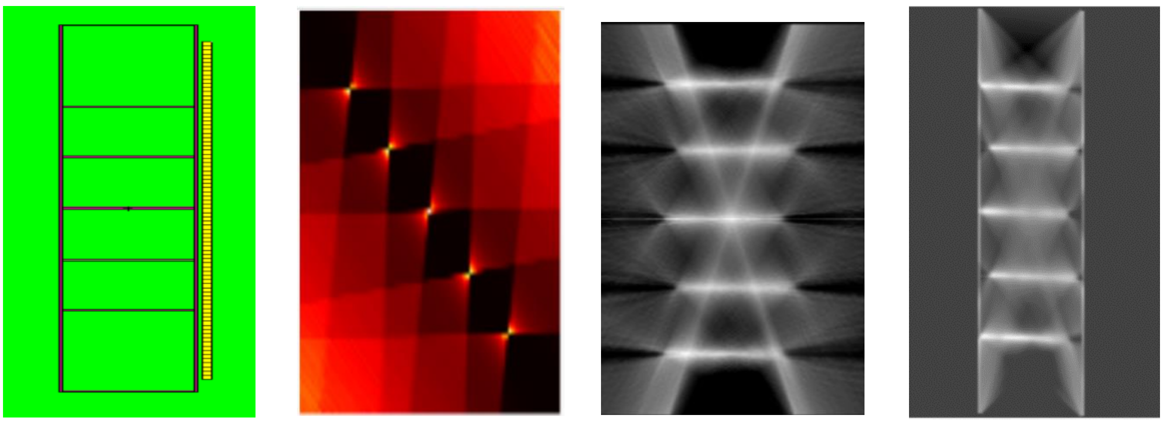


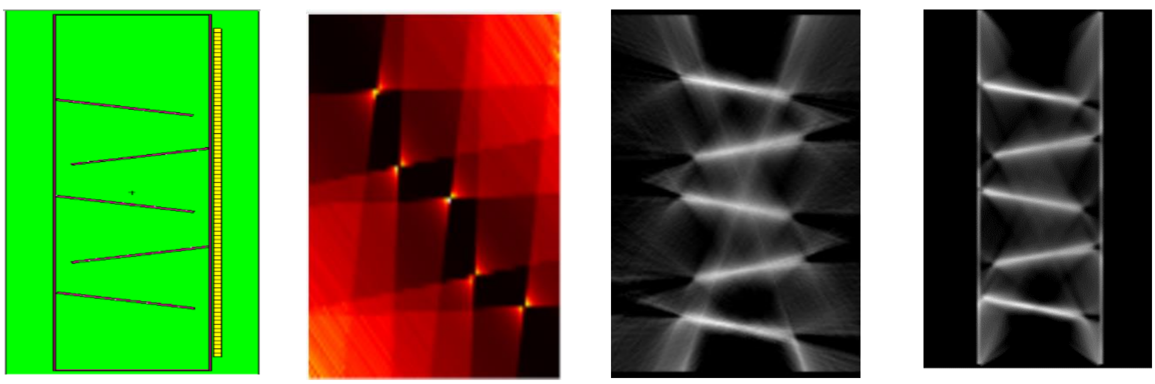
Fig. 4. Example of data set obtained from simulation of distillation column

The images showing the status inside the simulation column will be calculated using the coordinate transformation formula and reconstructed using a combination of the Xiaolin Wu and SART algorithms after obtaining the simulation data. The resulting images are shown in the Figures 5, 6, 7, 8 below:



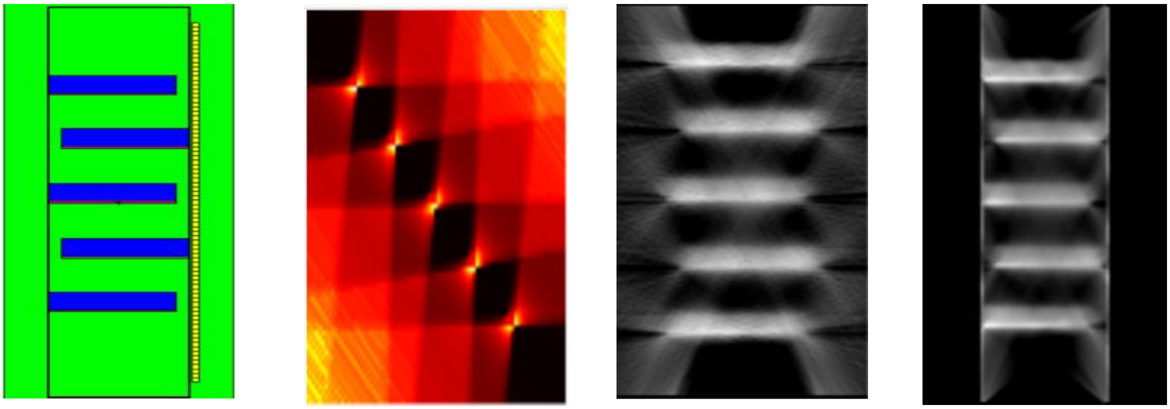
(a) (b) (c) (d)

Figure 5: Trays without liquid on tray configuration simulation (a); Sinogram (b); 2D reconstruction image using SART algorithm without Xiaolin Wu's line drawing algorithm (c); and 2D reconstruction image using the combination of Xiaolin Wu with SART algorithms (d).



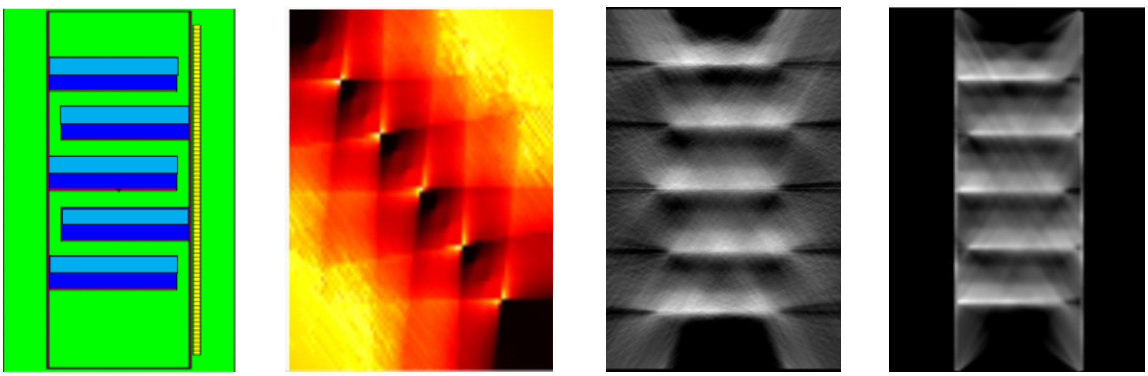
(a) (b) (c) (d)

Figure 6: Bending trays configuration simulation (a); sinogram (b); 2D reconstruction image using SART algorithm without Xiaolin Wu's line drawing algorithm (c); and 2D reconstruction image using the combination of Xiaolin Wu with SART algorithms (d).



(a) (b) (c) (d)

Fig. 7. 10 cm water on trays configuration simulation (a); Sinogram (b); 2D reconstruction image using SART algorithm without Xiaolin Wu's line drawing algorithm (c);
and 2D reconstruction image using combination of Xiaolin Wu with SART algorithms (d)



(a) (b) (c) (d)

Fig. 8. Vapor on the liquid phase configuration simulation (a); Sinogram (b); 2D reconstruction image using SART algorithm without Xiaolin Wu's line drawing algorithm (c);
and 2D reconstruction image using combination of Xiaolin Wu with SART algorithms (d)

C. Discussion

In general, each simulation case produces reconstructed images with different shapes and colors that represent the density of the materials, but they still clearly show the structure inside the simulation column, including the 5 trays and the phases of liquid on the trays. The reconstructed images using the 2D gamma scan technique after applying geometric calculations and noise treatment are quite good, as they clearly show the shape, spatial position, and level of the fluid and vapor in the column. The combination of Xiaolin Wu and SART algorithms produces even better images (Figures 5d, 6d, 7d, 8d) than using only the SART algorithm without applying noise treatment algorithms (Figures 5c, 6c, 7c, 8c).

As shown in the images above, it is possible to distinguish between bending trays and common trays and to determine the composition of materials on each tray (vapor and liquid). The positions of the objects inside the simulation column and the reconstructed images are similar, so any changes in position will be easily noticeable. However, this assessment is only qualitative, so the research team will develop software methods for a more quantitative assessment.

In summary, the reconstruction image algorithm for the 2D gamma technique, including geometric calculations, Xiaolin Wu noise treatment algorithm, and SART algorithm, has been successfully implemented. The reconstructed images from MCNP simulation data are of quite good quality.

III. CONCLUSION

The project team has conducted simulations of various scenarios inside the distillation column and reconstructed images to evaluate the effectiveness of noise treatment and image reconstruction algorithms for the 2D gamma scan technique. Moving forward, the team will continue their research to identify solutions that can enhance the quality of the reconstructed images while maintaining reasonable computational efficiency. Furthermore, the image reconstruction algorithms mentioned above will be applied to datasets obtained from actual laboratory experiments to evaluate their accuracy in reconstructing images

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