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Evaluation of image reconstruction algorithms in cone-beam computed tomography technique

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Abstract Cone-beam computed tomography (CBCT) technique is largely used in medical diagnostic imaging and nondestructive materials testing, especially in cases which require fast times and high accuracy level. In this paper, the pros and cons of Feldkamp-Davis-Kress (FDK) and simultaneous iterative reconstruction technique (SIRT) algorithms used in CBCT technique is studied. The method of simulating CBCT systems is also used to provide richer projection data, which helps the research to evaluate many aspects of algorithms.

Keywords: *CT, cone beam, reconstruction algorithm, FDK, SIRT.*

I. INTRODUCTION

Computed Tomography (CT) was first employed in Medical Imaging Diagnosis in the early 1970s. It has been improved with seven commercial generations in the past 50 years. Today, CT became popular not only in medical applications but also in material analysis and non-destructive testing (NDT). Especially, the latest CT generation so-called Cone Beam CT (CBCT) can produce three-dimensional (3D) imaging with high-resolution to makes CT now more suitable for observing the inner structure of materials and detecting material defects. The most advantages of using cone-beam geometry are reducing data acquisition time and increasing spatial resolution. By employing cone-beam geometry, whole 3D information inside the sample could be gathered in a short time and could be used in reconstruction process to obtain 3D imaging or cross-section of any sample's part. Recent, development of radiation detector technology especially Flat Panel Detector (FPD) allowed CBCT is being widely studied and utilized in diversified applications [1-3].

Together with the development of hardware, CBCT reconstruction algorithms are also researched and improved. Practical CBCT system employs two major algorithms to reconstruct the image from projections. They are Filtered Back Projection (FBP) so called a convolution method and series expansion method which includes Algebraic Reconstruction Technique (ART), Simultaneous Iterative Reconstruction Technique (SIRT), Iterative Least-Squares Technique (ILST). Series expansion method is the most accurate reconstruction method, but it requires a very high level of hardware. This method only can be implemented when all projections are collected so that it slows the reconstruction period. Although the reconstructed image has poorer accuracy, convolution method is still widely used because of their flexibility and having higher processing speed. FBP is one of the important algorithms for practical CBCT due to their simplicity and parallel computing capability, FBP may produce a high-quality image if step angle between two adjacent projections is small enough [1, 3-6].

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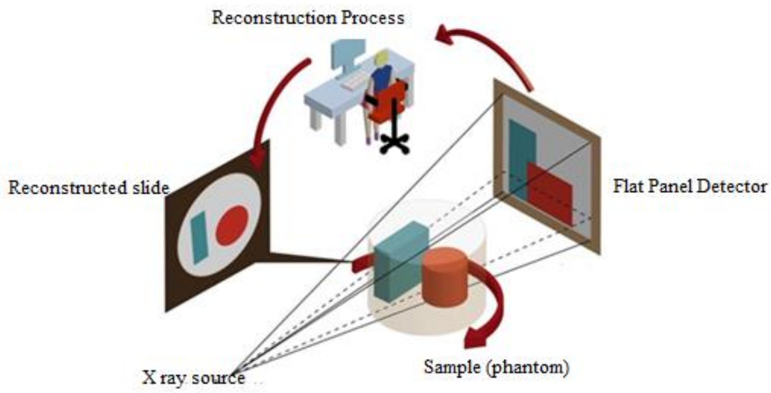


Fig. 1. CBCT configuration

In this paper, standard Back projection method is Feldkamp-Davis-Kress algorithm (FDK) and standard series expansion method is SIRT will be evaluated . This paper will show results and evaluations of image quality when applying difference filter mask in reconstruction process. Thereby it can show that FDK algorithm is the most appropriate algorithm for industrial CBCT in Vietnam.

II. CONTENT

A. Subjects and methods

Today, the study of CBCT technique is still new in Vietnam. There is a national project (KC.05.18/16-20) which is being implemented in Hanoi University of Science and Technology. But hardware of system in this project has not finished yet. Hence, this research employed the Monte Carlo simulation to simulate CBCT system which has configuration is shown in Figure 1. In this configuration, detector and X-ray source have a fix position. The sample is rotated around the axis which is perpendicular to the line between X-ray source and center of detector array. With the configuration shown in figure 1, X-ray detector is Flat Panel Detector has 43x43.9 cm^2 effective area and 143μm×143μm pixel size, detector uses CsI(Tl) as scintillator with thickness is 0.3 mm. X-ray source in this simulation is cone-beam X-ray tube with cone angle is 30^o, the focal spot size is 4μm and maximum tube voltage is 240kV. Two samples (phantoms) are used to generate dataset of projections in this research have rectangular and cylindrical shape with dimensions of 2.5×2.5×6.0 cm (Length x Width x Height) and 10×8 cm (Diameter x Height) respectively. They are made by plastic and aluminum. F4 Tally combine with Fmesh Card are used in MCNP to get the result (average radiation flux in a cell), this allows a result has statistical error at single cell <3% and can meet requirement for good imaging quality in radiography. A two-dimensional matrix is a result of each simulation process in which contained flux value of cells, equivalent to the gray level of pixels. Data processing and imaging reconstruction are implemented by using Python language. Projection data obtained from simulation will be used to reconstruct 3D image of sample through FDK and SIRT algorithms, several filter masks are also applied to evaluate result. In this research, ASTRA Toolbox – an open-source tool will be used to integrate into MATLAB or PYTHON language to facilitate developing tomography system [7-9], this tool can well support imaging reconstruction process with reduction of coding work by using intuitive integrated library. The advantages and disadvantages of two algorithms will be analyzed in detail below.

B. Results

First, the quality of reconstructed images by using the FDK and SIRT algorithm via changing number of projections will be evaluated. Figure 2 displays reconstructed images of center slide of rectangular object (200×200 pixels) with difference projection database. The gray value distribution of pixels on a line of reconstructed image is shown in the figure 2. Reconstruction process is implemented on Workstation computer with the configuration: Intel® Xeon® CPU E5-2630 v4 @ 2.20GHz. For SIRT algorithm, all images are reconstructed with the number of iterations is 150. Reconstruction time performed by two algorithms for similar projection data set is recorded and shown in Figure 3.

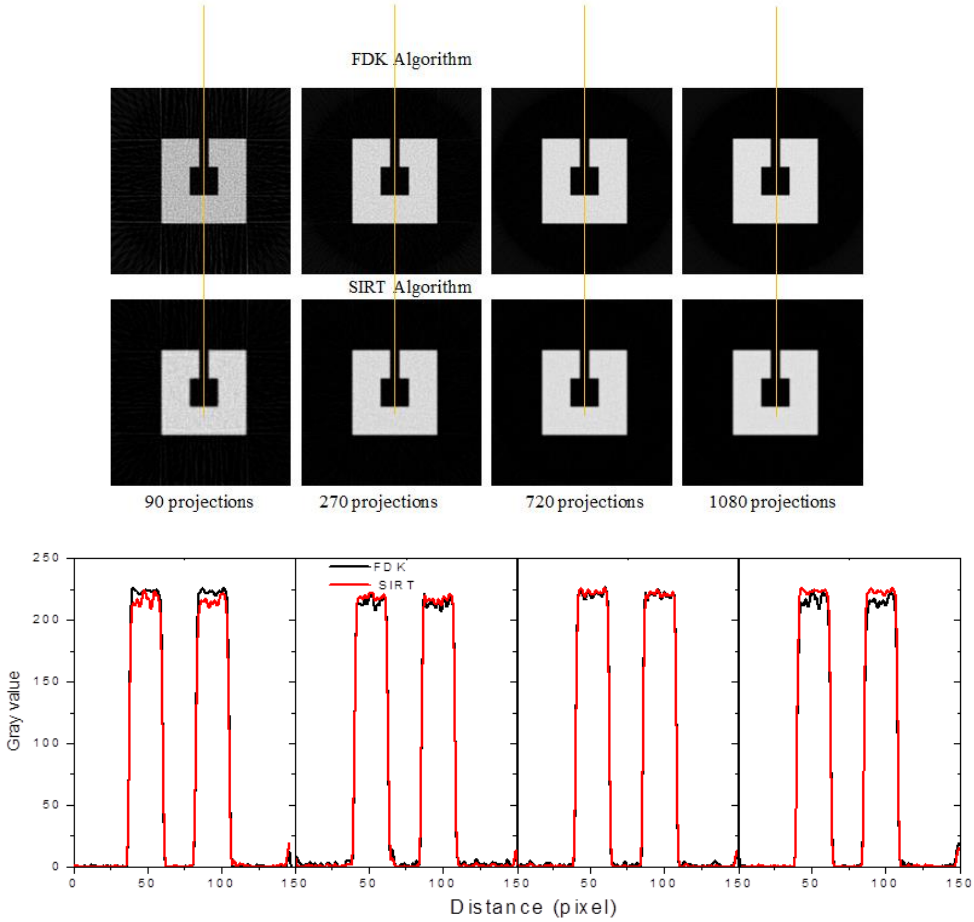


Fig. 2. Reconstructed images by FDK and SIRT with difference number of projections

In figure 4, a phantom with a two-dimensional image size of 500x500 pixels is used to investigate the quality of reproduced images by the SIRT algorithm with difference numbers of iteration. Figure 5a represents reconstructed images with 180 projections by using the FDK and the SIRT algorithms (with 400 iterations). Computational cost to reconstruct by the FDK algorithm is 43.18 seconds, and by the SIRT algorithm (with 400 iterations) is 1439.11 seconds (~23.9 minutes). In order to evaluate quality of an image, following criterial is concerned as gray-scale value and image noise. From figure 5b, one could realize that SIRT's image has higher gray value at interested peak and lower gray value in low-frequency noise range in comparison with FDK's image. It proves that SIRT algorithm allows to achieve higher quality of reconstructed image than FDK algorithm. With respect to images which require a larger number of pixels (higher resolution), image reconstruction process of the SIRT spend much more time than FDK. Therefore, SIRT is not suitable for applications which require short time for reconstructing image (less than 10 minutes). So, in this paper, FDK algorithm is recommended to reconstruct images of cone-beam computed tomography systems. In addition, three-dimensional image of the FDK algorithm also was performed. The results were shown in Figure 6, the dataset in this study consists of 720 projections in which intensity of radiation was increased gradually from left to right and from top to bottom with a ratio of 1: 4: 8: 10.

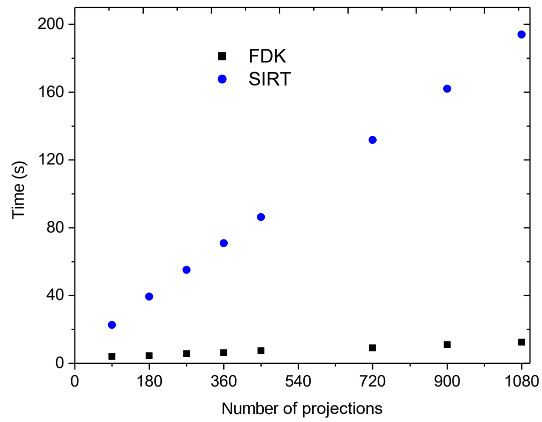
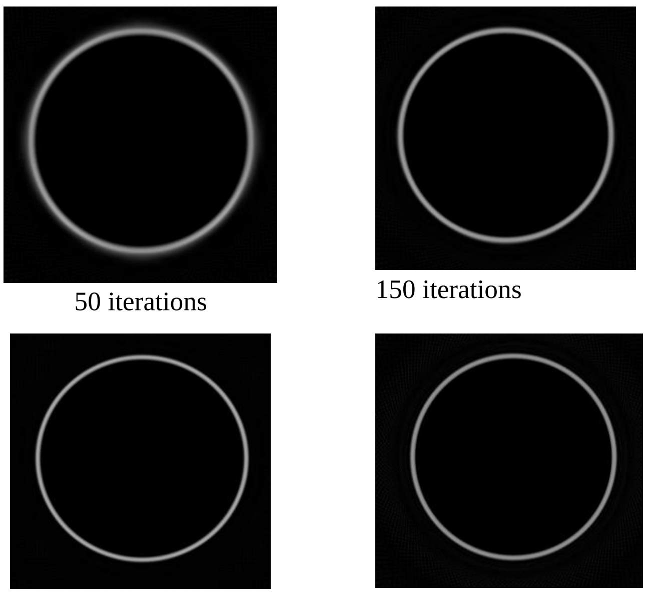


Fig. 3. Changing of reconstruction time according to number of projections for FDK and SIRT algorithm



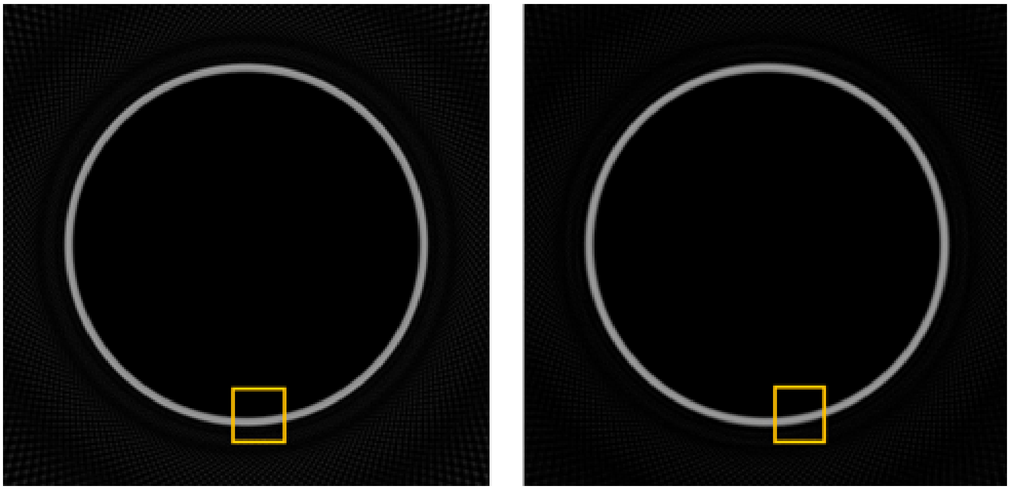
50 iterations

150 iterations

300 iterations

600 iterations

Fig. 4. Reconstructed images by the SIRT algorithm when increasing the number of iterations



FDK **SIRT**

Fig. 5a. Reconstructed images with 180 projections by FDK algorithm and SIRT algorithm

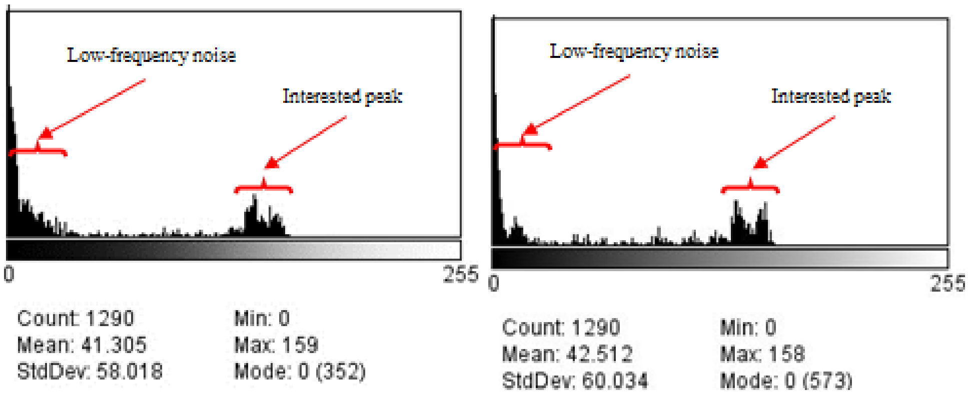


Fig. 5b. Histogram of a part of two above reconstructed images (FDK algorithm in the left and SIRT algorithm in the right)

Finally, reconstructed images of a data set were filtered with different filter functions as Ram-Lak, Shepp-Logan, Cosine, Hamming and Hann. These images were shown in Figure 7.

C. Discussion

From the obtained results, the quality of the image reconstructed by both two algorithms increases and its noise decreases as the number of projected images increases. However, with the same number of projections, contrast of reconstructed images using the SIRT are better than FDK (FDK) algorithm. With a small number of projections, it can still reconstruct images with required quality. The reconstruction time of both algorithms linearly increases according to the number of projections but the execution time of the SIRT algorithm increases more strongly than the one of FDK algorithm.

Figure 6 shows that when the projection intensity was increased, the 3D reconstructed image by using the FDK algorithm is more clearly. Thus, the quality of reconstructed image depends not only on projection data but also on intensity of X-ray source.

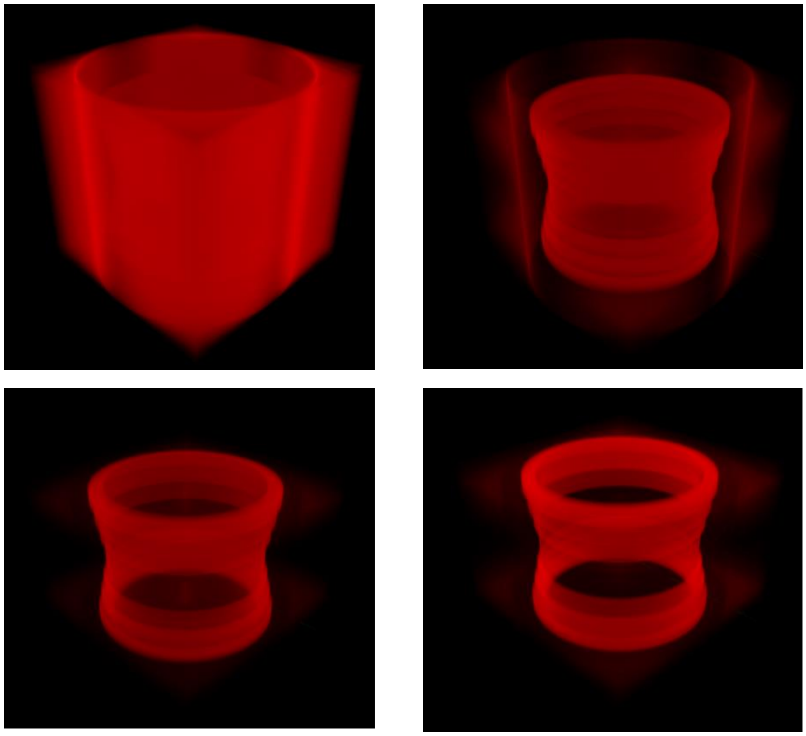


Fig. 6. A three-dimensional reconstructed image by the FDK algorithm as the dose level

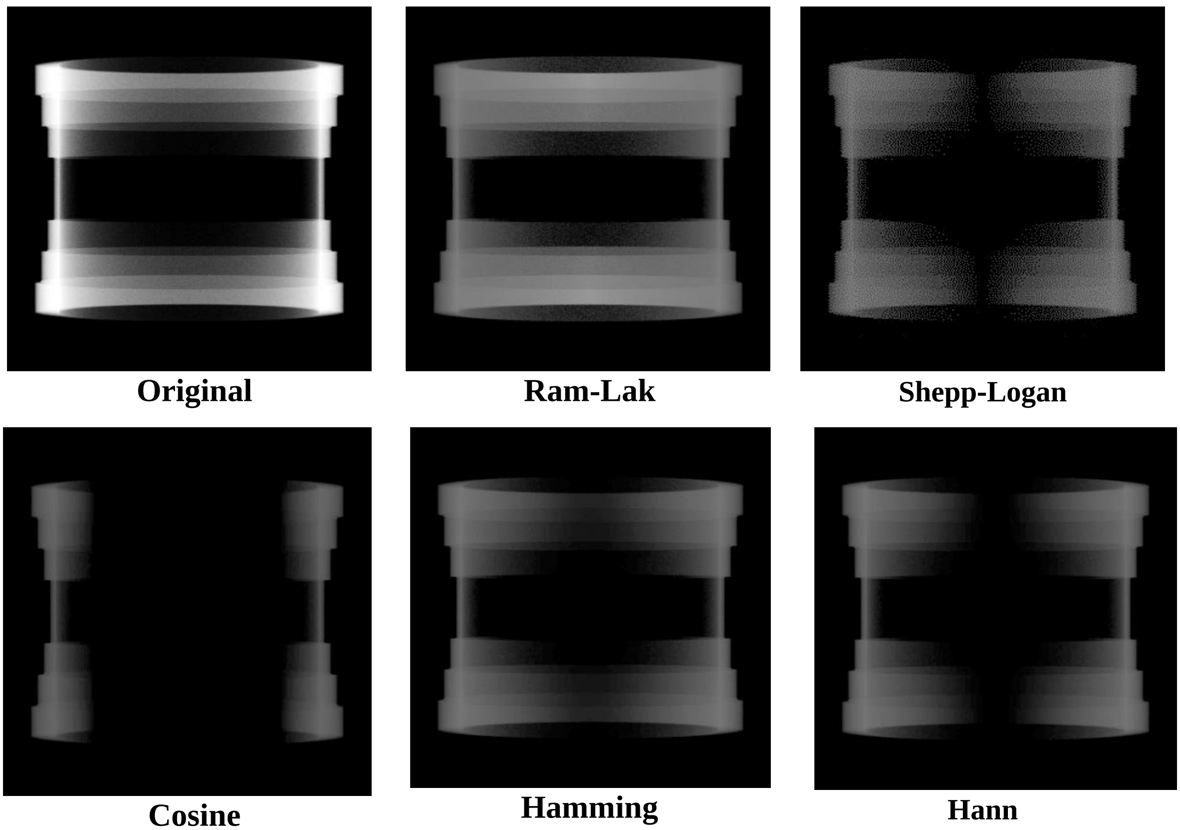


Fig. 7. Image before and after using the filtering function of the reconstructed image

Figure 7 shows the differences between images with different filter functions. Because each filter function has different frequency domain responses, it affects different parts of the image. For this image, the Ram-Lak filter function improves the image best. Depending on the specific case, an appropriate filter can be chosen to achieve the best quality of reconstructed image.

III. CONCLUSIONS

In this paper, some properties of the FDK and SIRT algorithm used for cone-beam computed tomography systems have investigated. The results show that the reconstructed image quality of the SIRT algorithm is better than the FDK algorithm. However, when the number of pixels increases, to achieve the same image quality, the SIRT algorithm takes a longer time than FDK algorithm. Therefore, FDK algorithm is recommended to reconstruct images in industrial-used CBCT systems with fast speed requirements. In addition, the quality of reconstructed image by FDK algorithm was investigated when changing intensity of X-ray source and when using additional image filtering functions. Our results are consistent with other studies in the world [1, 3-6].

ACKNOWLEDGMENTS

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