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Research on CT System Parameter Calibration and Imaging

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ABSTRACT

The calibration of CT system parameters is of great significance to the research of CT imaging technology. In this paper, the parameters of CT system are calibrated with the help of the received information of geometry, and the corresponding mathematical model is established by using Iradon transform and filter back projection algorithm. The CT image is rebuilt and the location, geometry and other information of unknown medium are determined at the same time. Finally, the error and stability analysis of this model is given and a new template with clearer imaging is designed.

Keywords: *CT system parameter calibration, Iradon transformation, Filter back projection.*

1.INTRODUCTION

In order to obtain the internal structure information of the sample, CT images the samples of biological tissue and engineering materials by the absorption characteristics of the sample to the ray energy without destroying the sample. At present, with the characteristics of high-resolution, non-invasive and non-invasive X-ray CT imaging technology becomes an important detection method and has been widely used in non-destructive testing, medical imaging such as bone detection, vascular imaging, heart imaging, breast imaging, tooth imaging and other fields.

Since the development of CT scanning system, scholars have done a lot of research on CT imaging technology and its optimal design. Wang Zheng-kun et al [1] studied the attenuation law of X-ray passing through the uniform material vertically and the absorption efficiency of CT system detector for ray energy, which provided a strong theoretical basis for further research of CT imaging technology. Yu Jian [2] studied the geometric distortion correction of parallel beam CT system, CT reconstruction and image fusion by various information in diffraction enhanced imaging. And he proposed a method suitable for geometric distortion correction of parallel beam CT system. Wang Yanfei [3] studied the reconstruction simulation correction of cone beam X-ray industrial CT system image. Xu Xiaoru [4] studied the distortion of X-ray micro-CT images, and proposed an image distortion correction method suitable for micro-CT systems, which made CT be used in more fields. Focus on these results, there is little research on the improvement and accuracy of CT system parameter calibration however. The calibration of CT system parameters is the cornerstone of the research of CT system imaging technology, and the accuracy of CT system parameters calibration is of great significance to the optimal design of CT system imaging.

During the installation of the CT system, the center of rotation is often shifted, which affects the imaging quality. Therefore, the parameter calibration of the installed CT system needs to be performed. In this paper a filtered back-projection imaging model which inversely calculates the data measured by the CT system is established refers to the data and requirements of the A question of the National College Students Mathematical Modeling Contest 2017 of the Higher Education Society Cup [5]. The rotation center, rotation angle and the shape and position of the medium are studied and the parameter calibration of the CT system is effectively improved.

2. CALIBRATION OF CT SYSTEM PARAMETERS

A general two-dimensional CT system is shown in Figure. 1.

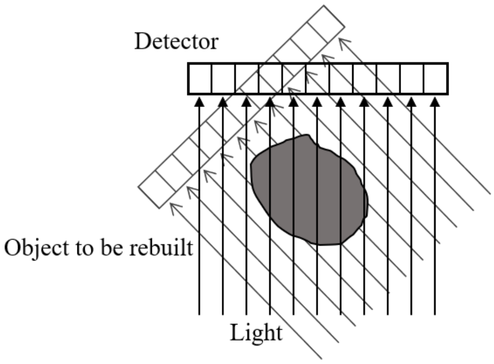


Figure. 1: CT system diagram

It can be known from Figure. 1 that the parallel incident X-rays are perpendicular to the plane of the detector, and each detector unit is regarded as a receiving point arranged at equal intervals. The relative position of the X-ray transmitter and detector is fixed, and the entire transmission-receiving system rotates counterclockwise 180 times around a fixed rotation center. On the detector with 512 equidistant units, each X-ray is measured to absorb and attenuate the ray energy after passing through a two-dimensional to-be-detected medium at a fixed position, and 180 groups of received information are obtained after gain processing.

This paper assumes:

(1)The absorption coefficient is a fixed value in a homogeneous substance, without considering the influence of photoelectric effect, Compton effect, electronic effect and other factors.

(2)The X-rays intensity of the CT system remains unchanged, with a gap and uniformity between the parallel beams.

(3)Ignore the effect of X-rays by shining on the material edge to the data.

(4)The effect of template thickness on the data is not considered.

2.1 Determination of The Detector Unit Distance

We import the data of Annex 2 into MATLAB and draw the thermodynamic diagram of absorbance value, as shown in Figure. 2.

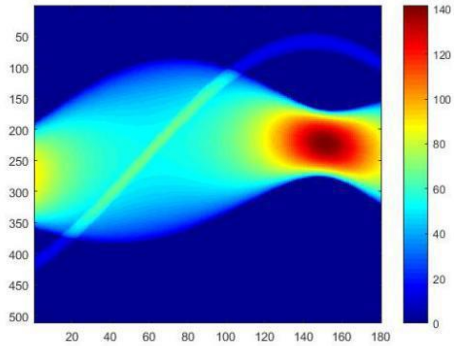


Figure. 2: Thermodynamic diagrams corresponding to the values in Annex 2

It can be known that the absorbance of the circle in the template is a light-colored arc as shown in Figure. 2. The data of 512 rows and 180 columns in Annex 2 corresponds to 512 values obtained by each rotation of the CT system in Annex 1. Each column in Annex 2 corresponds to the value of absorption on the detector once rotated. Then the column with the widest non-zero value in Figure. 2 is the data obtained by the detector when the X-rays are irradiated to the template diagram and the narrowest column of non-zero absorbance values is the data obtained by the detector when the X-ray level is irradiated onto the template schematic.

The data in Annex 2 with a narrow non-zero absorbance value was taken as the 180 ° rotation angle of the CT system. Because it rotates counterclockwise, the column with the widest non-zero value is used as the angle of the 90 ° rotation angle of the CT system, as shown in Figure. 3.

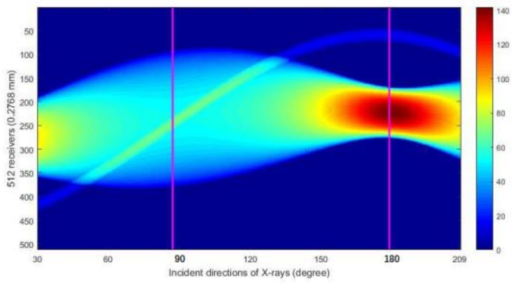
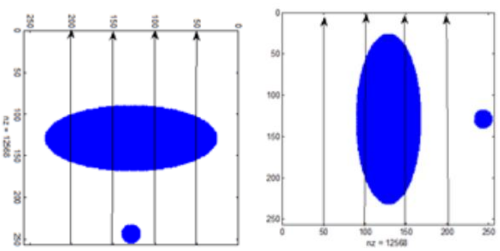


Figure. 3: Thermodynamic diagrams marked with special locations

The cross section of the ray position corresponding to the special angle of 90° and 180° is shown in Figure. 4.



90 ° ray position 180°ray position

Figure. 4: Ray position corresponding to special angles

By using MATLAB we get the conclusions: the number of rays passing through the major axis of the ellipse vertically at an angle of 90° is $N=298$ and the major axis length L of the ellipse is 80*mm*, then the spacing between the detection units is $d=L/N=0.2778$.

2.2 Determination of CT Rotation Center

In this paper, the exact center of the square tray in Annex 1[5] is set as the origin of the coordinates $(0,0)$ and the square tray is divided into small squares of 512 × 512 from the 512 absorbance values in Annex 2. According to the principle of the image rotation algorithm [6], let the rotation center be (X_0, Y_0), the rotation angle θ, R be the distance from the rotation center to the origin coordinate, as shown in Figure. 5.

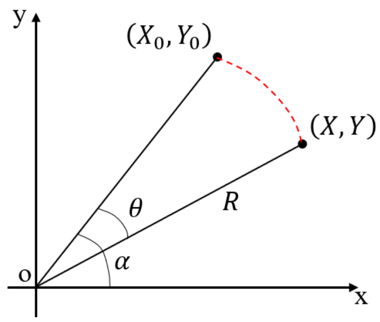


Figure. 5: Schematic diagram of rotation

According to the trigonometric function $X_0=R\cos\alpha$, $Y_0=R\sin\alpha$, after rotation θ, we have $X=R\cos(\alpha-\theta)$ and $Y=R\sin(\alpha-\theta)$. Suppose the width given in the template is W and the height is H, then we have:

$$X=X_0+0.5W \tag{1}$$

$$Y=-Y_0+0.5H \tag{2}$$

By inverse calculation from Eq. 1 and Eq.2 we get:

$$X_0=X\cos\theta-Y\sin\theta+dx \tag{3}$$

$$Y_0=X\sin\theta+Y\cos\theta+dy \tag{4}$$

$$dx=-0.5W'\cos\theta-0.5H'\sin\theta+0.5W \tag{5}$$

$$dy=0.5W'\sin\theta+0.5H'\cos\theta+0.5H \tag{6}$$

Therefore, the angle of the special position at θ=90° and θ=0° can be substituted into the above formula, and we get:

$$X_0=Y+0.5W-0.5H \tag{7}$$

$$Y_0=-X+0.5W+0.5H \tag{8}$$

Finally, calculating by MATLAB, the rotation center coordinate (X_0, Y_0) is gotten as $(-9.2734, 5.5363)$.

2.3 Determination of 180 Rotation Angles of CT System

This paper assumes that each rotation angle of the CT system is equal. When the X-ray is parallel to the short axis of the ellipse, the X-ray passes through both the short axis of the ellipse and the small circle diameter and the maximum value is 67.3529. This group of data is the 61st group in Annex 2. That is, the angle between the X-ray used by the CT system and the horizontal direction is 61°. When the X-ray is parallel to the long axis of the ellipse, the value of the received information corresponding to the ray at this time is the maximum value in the near range, and the set of data is the 151st group in Annex 2. Each set of data in Annex 2 is the data obtained after one rotation. The difference between the two rotations is 90 times and the angle of rotation is 90°. Therefore, the angle of each rotation of the CT system is 1°. From the sum of the number of columns before the absorptance value when the X-rays are parallel to the short axis of the ellipse, the CT rotation angle is 30° to 209°.

2.4 The Establishment of Filtered Back-projection Reconstruction Imaging Model

In applications, if we know the received information and given calibration parameters of an unknown medium and the information such as the position, geometry and absorption rate of the medium needs to be determined, a filtered back-projection reconstruction algorithm and image scaling can be used to construct a filtered back. The projection imaging model uses the received information of the given medium to restore images within the size range of the detection board [7, 8]. This method is most widely used in CT systems with very high reconstruction efficiency.

The filtered back-projection method, also known as the synthesis method, performs back-projection on the original data and distributes the corresponding approximate data copied in a two-dimensional space. The basic principle is to distribute the measured projection values evenly to each point according to its original path. After the projection values in all directions are back-projected, they are superimposed on the image to infer the original image, as shown in Figure. 6.

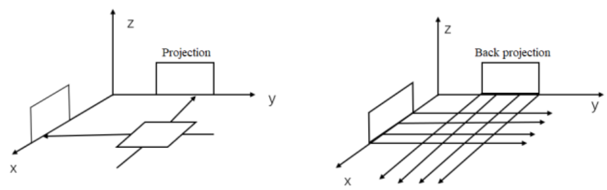


Figure. 6: How back projection works

The central slice theorem is the theoretical basis for back-projection reconstruction. The central slice theorem states: when the projection angle of a one-dimensional space is θ, the projection function $f(x, y)$ is equal to a slice of two-dimensional Fourier transform function $F(w_x, w_y)$ at angle θ [9] by Fourier transform, as shown in Figure. 7.

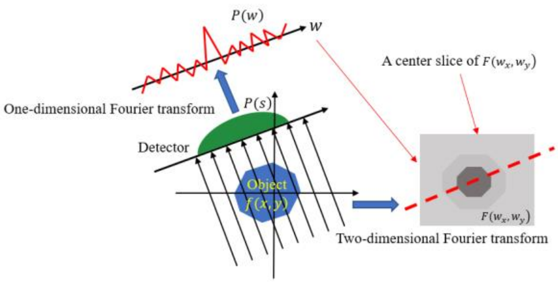


Figure. 7: Central slice theorem schematic

In this part, by adjusting the direction of the projection to obtain specific sections of the Fourier transform in each direction, the Fourier transform of the entire two-dimensional plane can be obtained, and the reconstructed image can be gotten by the Fourier transform. The Fourier slice theorem only provides a relatively simple conceptual model. Based on the central slice theorem, this paper uses a filtered back-projection algorithm [10] and inverse Fourier transform to transform polar coordinates to re-determines the integral limit for reconstruction of parallel projections. The flowchart is shown in Figure. 8.

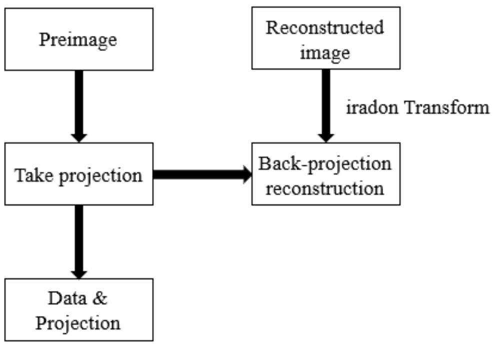
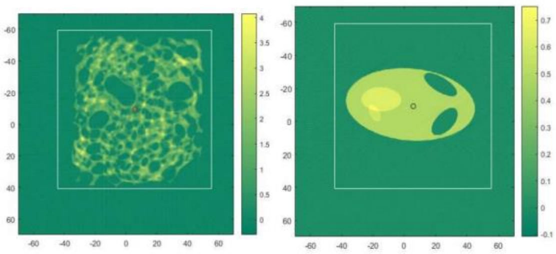


Figure. 8: Model solution diagram

The back projection reconstruction process is implemented by the Iradon function in MATLAB [11], and the back projection image of the original material has been obtained, as shown in Figure. 9.



Message receiving image Primary material geometry

Figure. 9: Schematic diagram of the original material geometry

The left image in Figure. 9 is an image reconstructed by using the Iradon inverse transform to the received information of Annex 5. The absorption rate of the green part is 0, which means that there is no substance or the medium is hollow inside, that is, the inside of the medium is uneven. The right image shows the geometry of the unknown medium, which is consistent with the acceptance information on the left. Among them, the circle in the center represents the center calibration position, and the image surrounded by the white line is a 50 × 50 square template. Then the distance can be obtained according to the square origin coordinates and the center coordinates of the obtained substance, and the geometric position of the substance at the center position of the square tray and the position of the unknown medium, and the absorption rate of each position.

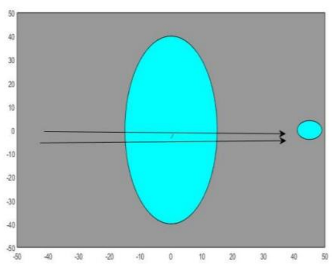
3. MODEL ERROR AND ATABILITY ANALYSIS

3.1 Form of Error

For different objects with different ideal rotation centers, the deviation of the rotation center may affect the image quality obtained by the CT system. Therefore, the accuracy analysis of the model can be discussed in terms of sampling and fuzzy edges.

(1) Error caused by sampling: the information obtained by the detector is discrete but projection is a process of continuously extracting information. When θ=90° and θ=0° are determined in the parameter calibration, the ray selected by default passes through the centroid of the template, but it may not actually be centroid, so an error may occur, which does not exceed the distance $d = 0.2778$ of a detector unit. Therefore, when the center point is established, the position of the center point becomes (-9.27 ± 0.2778, 5.53 ± 0.2778).

(2) Fuzzy edges: In the process of back-projection image reconstruction, when X-rays pass through the edge of the template, the rays may not be exactly tangent. They may not touch or pass through the template. The re-created image is inconsistent to the original, as shown in Figure. 10.



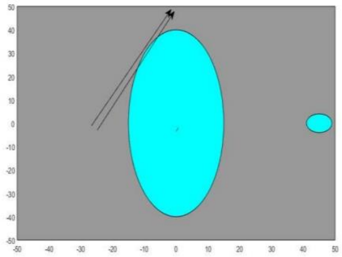


Figure. 10: Back-projected rays

3.2 Stability Calculation

The back-projection model established by the reconstructed image is used to back-project the image by the data in Annex 2 and a matrix of the image is obtained. The data in Annex 1 has two distributions, 0 and 1. 0 means that X-rays pass through the area without any substance, and the absorption rate is 0. 1 means that there is some substance here and the absorption rate is 1. The stability is the ratio of the sum of the non-zero data in Annex 3 to the sum of the non-zero data in the data obtained after back projection by Annex 3. The stability calculated by MATLAB is 0.973, which is close to 1. It indicates that the model has a better stability because the data obtained after back projection are close to the original data.

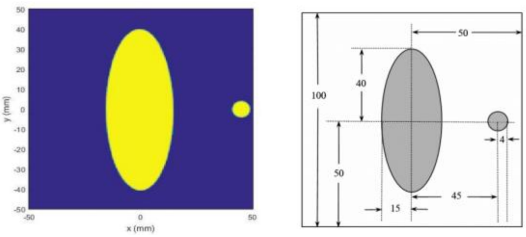
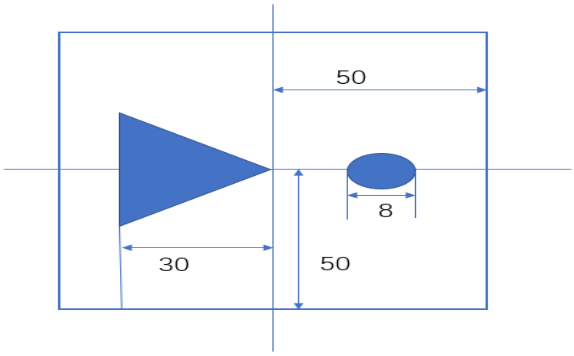


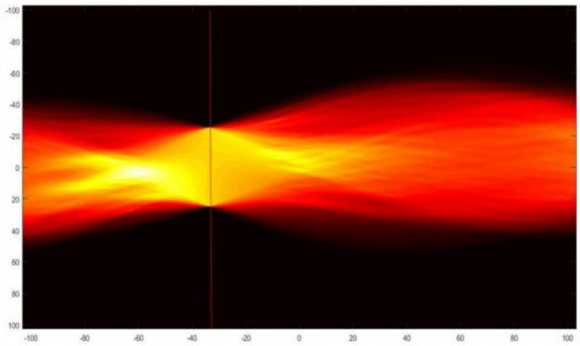
Figure. 11. Schematic diagram of stability calculation

3.3 New Template Design

According to the error analysis and stability calculation of the model, a new template is designed in this paper, as shown in Figure. 12 (a). Compared with the original template, the new one can reduce the error caused by fuzzy edges. We rotate and project the new template data from $\theta=30^{\circ}$ to $\theta=210^{\circ}$, project and draw the corresponding thermodynamic diagram of the absorbance value, as shown in Figure. 12 (b). Then we find the column vector of the least non-zero elements in the matrix corresponding to the image, corresponding angle is $\theta=0^{\circ}$, that is, when the X-ray is parallel to the long axis of the ellipse in the template, the special position of the original template is more accurately determined and the imaging is more obvious.



(a)New template diagram



(b) Thermodynamic plot of absorbance values or the new template

Figure. 12: Schematic diagram of the new template and corresponding thermodynamic diagrams of absorbance values

4. CONCLUSION

Aiming at the parameter calibration and imaging of the CT system, this paper build a model by the iradon transform function and back-projection reconstruction algorithm, which can not only determine the parameter calibration error of the CT system, but also enable the CT system to accurately estimate the position, geometry and absorption rate of the unknown medium. Moreover, it can calculate the model error and stability, which is conducive to the further precision of the model results. Compared with the traditional Fourier transform algorithm, the filtered back-projection reconstruction algorithm avoids complex operations when processing actual data, thus the calculation amount and storage space are reduced, and the operation efficiency is improved. The new template increases the probability of rays passing through the center of rotation while avoiding fuzzy edges. This paper only simulates and analyzes the CT parameter calibration and unknown medium reconstruction in the case of parallel beams. For other beam shapes and conditions, further research and analysis are needed.

REFERENCES

[1] Wang Zhengkun, Wang Peng, Xu Haohao, Principles of CT system imaging, Shandong University of Science and Technology, 2018.

[2] Yu Jian, Hard X-ray diffraction enhanced imaging CT. Dalian University of Technology, 2006.

[3] Wang Yanfei, Cone-beam X-ray industrial CT system image reconstruction simulation correction,. Lanzhou University, 2014.

[4] Xu Xiaoru, Study on the distortion correction of X-ray micro-CT images. Tianjin University, 2016.

[5] The 2017 National College Students Mathematical ModelingContestA.http://www.mcm.edu.cn/html_cn/node/460baf68ab0ed0e1e557a0c79b1c4648.html

[6] Principle of image rotation algorithm, http://blog.csdn.net/liyuan02/article/details/6750828

[7] Sun Chaoming, Tang Guangping, Wang Zengyong, Li Qiang, Analysis and experiment of 2D CT image reconstruction method, Institute of Mechanical Manufacturing Technology, China Academy of Engineering Physics, 2012.

[8] Wang Hui, CT parameter calibration method based on filtered back-projection reconstruction algorithm, Journal of Pingdingshan University, 2018.

[9] P. Xu,Y, Su, Design and Implementation of landscape system for East and West Huashi Street in Beijing based on virtual reality technology, Applied Mechanics and Materials, 263(2012)1849-1852.

[10] Gao Xin, Theoretical research and implementation of a new iterative image reconstruction algorithm. Zhejiang University, 2004.

[11] Zhang Shunli, Li Weibin, Tang Gaofeng, Research on filtered back-projection image reconstruction algorithm, Journal of Xianyang Normal University, 2008.

[12]Back-projection reconstruction algorithm, https://cn.mathworks.com/help/images/ref/iradon.html

[13]P. Xu; N. Na; S. Gao; C. Geng, Determination of sodium alginate in algae by near-infrared spectroscopy, Desalination and Water Treatment, 168(2019)117-122.

[14] Geng C., Zhao Z., Xue Z.; Xu P., Xia, Y., Preparation of Ion-Exchanged TEMPO-Oxidized Celluloses as Flame Retardant Products, Molecules, 24(2019)947.