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CT System Parameter Calibration and Imaging

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Abstract: According to annex 2 and the dimensioning of template schematic diagram, we take a circle as the research object, to calculate the detection unit interval approximation for d=0.2778 mm. We used in the physical problem of "met" train of thought for the initial Angle is 30 degrees of rotation (counterclockwise from straight and level Angle, is positive), step length for 1 degree even rotate it 180 times. Using spline function "smoothness" built a meter calculate Radon optimization mathematical model of inverse transformation, the absorption rate and make the unknown image, the image straight view shows the medium position in a square tray, medium geometry information, and we find requirements from the data after the inverse transformation of the absorption rate of 10 location.

Keywords: CT system parameter calibration; 2d radon transform; Spline function; Radon inverse transform

1. Introduction

Computed Tomography is a technique that USES the radiation energy absorption characteristics of samples to make Tomography images of biomaterials and engineering materials so as to obtain structural information within samples. However, the installation error of CT system will affect imaging to some extent. In order to improve the quality of reconstructed images and the precision and stability of the system, a mathematical model is established in this paper to solve these problems.

The position of the center of rotation of the CT system in the square tray, the distance between the detector units, and the 180 directions of the X-ray used by the CT system.

Using the calibration parameters obtained in the second paragraph, the position, geometric shape and absorbance of the unknown medium in the square tray are determined. In addition, please give the specific absorption rate at the 10 locations given in figure 3. See attachment 4 for the corresponding data files.

Attachment 5 is the receiving information of another unknown medium obtained by the above CT system. Using the calibration parameters obtained in the second paragraph, the relevant information of the unknown medium is given. In addition, please specify the absorbance at the 10 locations given in figure 3.

2. Determine the Model and Solution of the Rotating Center

CT reconstruction is the mathematical basis of Radon transform, the Radon transform is to point to a plane along different lines (straight line and the distance between the origin for s, direction Angle is q to do the line integral, $f(x,y)$, $F(s,q)$, (see figure 1)) by definition which has a two-dimensional Radon transform calculation formula that is:

$$F(s,q)=\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} f(x,y)d(x\cos q+y\sin q-s)\,dxdy \quad (1)$$

Where, $f(x,y)$ is the function of the object to be reconstructed[3], $F(s,q)$ is the Angle of view q, to reconstruct the object function $f(x,y)$ along the projection of line L, $p(s,q)$, s is the distance from the origin O to the line L.

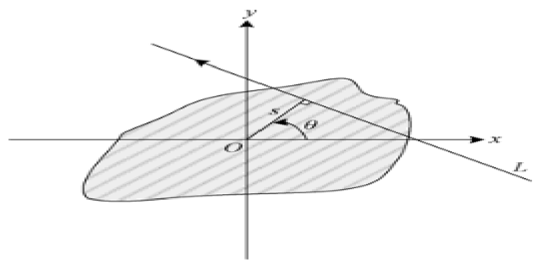

Figure 1. Geometric meaning of radon transform.

The centroid coordinate of the object is given as follows: for homogeneous solid media, the horizontal and vertical coordinates of the center of mass have the following formula:

$$x_c=\frac{\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} xf(x,y)dxdy}{\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} f(x,y)dxdy}$$

$$y_c = \frac{\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} yf(x,y)dxdy}{\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} f(x,y)dxdy} \qquad (2)$$

In order to simplify the calculation formula, the $\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} f(x,y)dxdy = M$, to a fixed point of view q , $p(s,q)$ is $p_q(s)$, and the integral calculation can prove $\int_{-\infty}^{+\infty} p_q(s)ds = M$.

The center of mass of the projection $p_q(s)$ is C_p, and its coordinates on the s axis are s_p .The determination of the centroid coordinates of the object and according to $p_q(s) = \int_{-\infty}^{+\infty} f(s,t)dt$ has the following formula:

$$s_p = \frac{\int_{-\infty}^{+\infty} s\cdot p_q(s)ds}{\int_{-\infty}^{+\infty} p_q(s)ds} \qquad (3)$$

Because the xOy of the reconstructed coordinate system and the sOt of the detection coordinate system can be transformed into each other, the transformation relationship is as follows. Now we use s,t to represent x,y .

$$\begin{cases} x = s\cos q - t\sin q \\ y = s\sin q + t\cos q \end{cases} \qquad (4)$$

Due to the jacobian value is equal to 1, so after integral variable substitution:

$$s_p = \frac{1}{M}\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty}(xcosq + y\sin q)f(x,y)dxdy \qquad (5)$$
$$= x_c\cos q + y_c\sin q$$

The geometrical meaning of formula (5) is: the projection of C the centroid of the object on the detector must coincide with the centroid C_p of the projection $p_q(s)$, and refer to the geometrical model of figure 2.

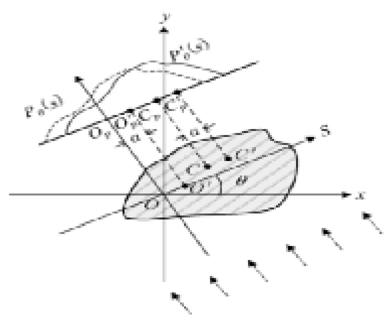

Figure 2 schematic diagram of the geometric model of centroid relation

2.1. Determination of rotation center coordinates.

Assumes that the center of rotation O migration to O', they are in the detector of projection O_p and O_p', respectively, after the migration of the projection of $p_q'(s)$ center of mass of C_p' , it is not difficult to get the $C_pC_p' = O_pO_p' = a$ (see Figure 2), so the center of rotation of the fixed offset solving into 0 perspective projection function of center of mass migration problem, when the center of rotation of the offset is zero, then find out the center of rotation of A specific:

The center of rotation is (9.4452, 5.6949).

2.2. Probe unit spacing is solved

A square tray with two homogeneous solid media is placed in the detection system, and the geometric information of the calibration template is known, as shown in figure 3. The concrete geometry information of the two graphs is:

1. Ellipse, long and semi-axis b=40mm, and short half axis a=15mm;
2. Circle, radius r=3mm, and the square edge is 100mm.

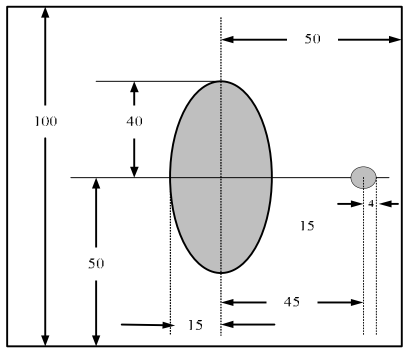

Figure 3. Schematic diagram of calibration template (unit: mm)

A lot of literatures, found that CT system can be rotated 180 degrees usually determine the shape of the medium under test, the size and the relative position of each medium, so this article assumes that the CT machine a total of 180 times rotated 180 degrees. The detector is known to have 512 equidistant detection units, which are numbered 1~512 counterclockwise for each probe unit.

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Run the CT system, the 180 X ray direction, get the matrix, the matrix size is 512 * 180 on each column represents a direction of X ray detection unit receives the information, the receiving information can be understood as the attenuation of X-ray through different path length, if radiation has been detected by the detection unit directly without through the medium, the attenuation is 0, the opposite is 1. According to the data in annex 2, the image function of Matlab can be obtained as follows:

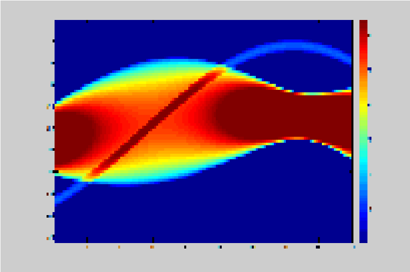

Figure 4. Attenuation variation

Can be clearly observed from above two ribbon, a ribbon (a finer and approximate width) portrayed in the drawing is round medium attenuation change, we can check it from attachment 2 ribbon width information, take the ribbon part column of the data collected in the table below:

Table 1. Partial Data of Color Band.

Column-number	A	B	C	D	E	F	I	J	K
Number of data	29	29	29	29	29	29	29	28	29

Statistics all the data we found that more than 90% of the detector unit number 29, to detect the distance between the single yuan are d, the diameter of the circle is known for d = 8 mm, approximate detector unit number is 28.8, get the equation: $28.8\times d = D$ $d = 0.2778mm$.

2.3. The gamma rays are determined in 180 directions.

CT system after a total of 180 degrees, we use the solution to "meet" problems in the physical thought computed CT system initial Angle of 30 degrees of rotation (counterclockwise from straight and level Angle, is positive), and 1 degree as the step even rotate it 180 times.

3. The position and absorption of unknown medium in square pallet are solved

3.1. The calculation of Radon inverse transformation

According to the principle of work and CT imaging of CT system known CT system fault image is actually a scatterplot absorption rate.

So, then we have to settle the problem is how to the reading value of detector Radon inverse transformation, the absorption rate of the data obtained, the image of the section, and the medium to be detected to determine the geometric shape and the absorption rate of the medium.

Build the spline function.

The following k-order spline function $B_k(t)$ is defined by recursive convolution.

$$\begin{cases} B_k(t) = B_{k-1}(t) * B_0(t), k = 1, 2, \ldots \\ B_0(t) = \begin{cases} 1, |t| \le \frac{1}{2} \\ 0, else \end{cases} \end{cases} \quad (6)$$

$*$ represents the convolution of two functions.

calculation of Radon inverse transformation.

The Fourier transform of Radon inverse transform is expressed as follows:

$$f(x,y) = \frac{1}{4p^2}\int_0^p dq \int_{-\infty}^{+\infty} Rf_q(w) e^{w(x\cos q + y\sin q)} |w| dw \quad (7)$$

Among them, $Rf_q(w)$ represents the Fourier transform of the projection function $Rf(t,q)$ on T. Therefore, if $f(x,y)$ is required to know $Rf_q(w)$, the construction principle of spline function can be deduced:

$$Rf_q(w) = \text{sinc}^4(w)\sum_{n=0}^{N-1} a_q(n) e^{-nw} \quad (8)$$

The respective variables are expressed as follows:

$$\begin{cases} a_q = \left(E^T E\right)^{-1} E^T Rf(q) \\ Rf(q) = \left[Rf(0,q), Rf(1,q), \ldots, Rf(N-1,q)\right]^T \\ a_q(n) = \left[a_q(0), a_q(1), \ldots, a_q(N-1)\right]^T \end{cases} \quad (9)$$

Substitute in (7), and finally get the function of the object:

$$f(x,y) = \frac{1}{4p^2}\int_0^p dq \sum_{n=0}^{N-1}\left(\int_{-\infty}^{+\infty} a_q(n) e^{w(x\cos q + y\sin q - n)} |w| \sin c^4(w) dw\right) \quad (10)$$

Confirmation of information.

Calculation for the unknown data, using data from drawing discover the unknown medium in question 2 Whole is an ellipse, on both sides of the axis of the ellipse is deducted two small ellipse, in the oval short axis of the upper two there is a large and a small oval region of large and uniform density.

The xOy right Angle coordinate system for your reference, that is, to the origin of the reference frame at the center of the square tray, dielectric properties of the ellipse center coordinates (0.8334, 0.8334), half shaft 82.2288 mm long, short half shaft 43.4368 mm, of which the semi-major axis and x axis Angle is 80 °, the specific geometry and media in the tray in a unknown place as shown in figure 5.

Find the absorption rate of the 10 positions required in the obtained data, and the data is shown in the table below.

In the same way, we get the data in attachment 5 Radon inverse transform, and make figure 6.

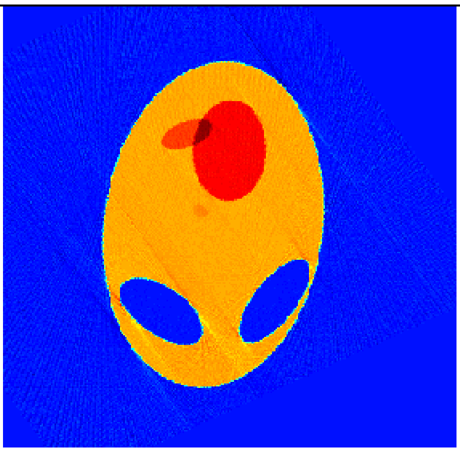

Figure 5. Question 2 medium position in the square

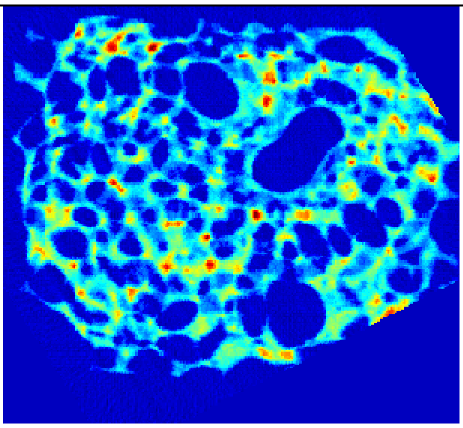

Figure 6. Question 3 the position of the medium in the square tray.

Table 2. The Absorption Rate of Unknown Medium.

Item	1	2	3	4	5
Coordinates	(10, 18)	(34.5, 25)	(43.5, 33)	(45, 75.5)	(48.5, 55.5)
Absorption rate	0.0000	0.7055	0.0000	1.1277	1.0064
Item	6	7	8	9	10
Coordinates	(50, 75.5)	(56, 76.5)	(65.5, 37)	(79.5, 18)	(98.5, 43.5)
Absorption rate	0.0000	2.4980	0.0000	1.3944	0.0000

Table 3. The Absorption Rate of Unknown Medium.

Item	1	2	3	4	5
Coordinates	(10, 18)	(34.5, 25)	(43.5, 33)	(45, 75.5)	(48.5, 55.5)
Absorption rate	0.0000	0.9851	1.0187	1.0125	0.9967
Item	6	7	8	9	10
Coordinates	(50, 75.5)	(56,76.5)	(65.5, 37)	(79.5, 18)	(98.5, 43.5)
Absorption rate	0.9665	1.2558	0.9914	0.0000	0.0000

The medium for irregular geometric shape, the whole is square, almost cover the whole square tray, and the uneven medium density, containing multiple small hole, half hole smooth round, oval, and half hole irregular shape.

The absorption rate of the medium at 10 locations is shown in the following table:

4. Conclusion

Using Radon transform and mass center method, obtained about the center of rotation, the object between the projection center of mass and the center of mass of a contains three equations of an unknown quantity, with less volume projection data that calculate the CT center of rotation square tray in the position coordinates (9.4452, 9.4452). Then, the image is made from the data in annex 2, and the color band I, which represents the circle, is taken as the research object. Then, according to the size labeling of the template sketch, the approximate value of the detection unit interval is d=0.2778mm. Finally determine the CT system a total of 180 degrees, we use the solution of the thought of "met" to calculate the CT system initial Angle of 30 degrees of rotation (and straight and level Angle, take counterclockwise for positive), and 1 degree as the step even rotate it 180 times.

According to the working principle of the CT system, we know that the data in the receiving information represents the integral of the absorption rate of the medium micro-element to the corresponding path diameter, which is essentially Radon transform. In order to make the media section of the image to be detected, determine the geometric shape of unknown medium and absorption rate, we use of spline function "smoothness" built a meter calculate Radon optimization mathematical model of inverse transformation, the absorption rate and make the unknown image, the image straight view shows the medium position in a square tray, medium geometry information, and we find out from data after the inverse transformation for the absorption rate of 10 location.

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