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Parameter Calibration and Imaging of Computed Tomography System

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ABSTRACT

The paper based on the analysis of the working principle of Computed Tomography system and the geometric information in the question, the revolving center of Computed Tomography system, the space between detector units, the X-ray direction and the image back-projection reconstruction model are determined, and the maximum and minimum ray width of X-ray passing through ellipse are found. The width of light and the corresponding number of incident times. Then the image is reconstructed by Fourier transform algorithm. After obtaining the energy absorption rate of the image, the parallel projection is recorded as $p(t,\theta)$ and the original image is reconstructed by two-dimensional Fourier inverse transform. The geometric shape of the image is obtained by using MATLAB tool, and the position of the image is determined. The filtering function is used to modify the image. Finally, a clearer contrast image can be obtained by using inverse Fourier transform, which has a certain guiding role for the actual industrial Computed Tomography imaging inspection.

KEYWORDS: Computed Tomography System, Image reconstruction, Wave filter, Fourier transform.

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I. INTRODUCTION

With the progress of the industrial revolution, the quality and requirements of industrial products are increasing. In order to meet the quality requirements of industrial products, CT imaging technology is developing day by day. Computed Tomography can tomography the samples of biological tissues and engineering materials without destroying the samples, and obtain the structural information of the samples. A typical two-dimensional Computed Tomography system is shown in Fig 1. Parallel incident X-rays are perpendicular to the detector plane. Each detector unit is regarded as a receiving point and arranged equidistantly. The relative position of X-ray emitter and detector is fixed, and the whole transmitting-receiving system rotates counter-clockwise 180 times around a fixed rotating center. For each X-ray direction, the radiation energy absorbed and attenuated by the two-dimensional medium to be detected is measured on a detector with 512 isometric units, and 180 sets of received information are obtained after gain processing.There are often errors in the installation of Computed Tomography system, which affect the imaging quality. Therefore, it is necessary to calibrate the parameters of the installed CT system, that is, to calibrate the parameters of the Computed Tomography system with the help of the samples with known structures (called templates), and then to image the samples with unknown structures.

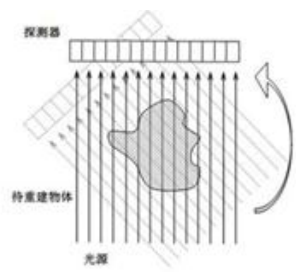


Fig1. CT system schematic diagram

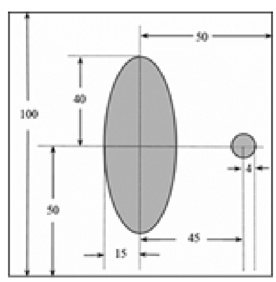


Fig2. Template schematic diagram (unit: mm)

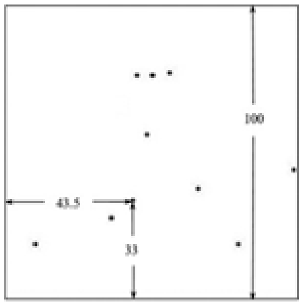


Fig 3. Ten position illustrations

1. The questions raised

1). A calibration template consisting of two uniform solid media is placed on a square tray. The geometric information of the template is shown in Fig2. As shown, the corresponding data are given, and the value of each point reflects the absorption intensity of the point, which is called "absorptivity". Based on this template and the received information, the position of the rotating center of the Computed Tomography system in the square tray, the distance between detector units and 180 directions of X-ray used in the Computed Tomography system will be determined.

2). The received information of an unknown medium obtained by the above-mentioned Computed Tomography system. Using the calibration parameters obtained, the position, geometry and absorptivity of the unknown medium in the square pallet are determined. In addition, the absorptivity at 10 locations given in Fig3 is also given.

3). The received information of another unknown medium obtained by the above-mentioned Computed Tomography system. In this paper, the relevant information of the unknown medium will be given by using the calibration parameters obtained. In addition, the absorptivity at 10 locations given in Fig3 will be given in detail.

II. PROBLEM ANALYSIS

To solve this problem, the maximum ray width (long axis length of ellipse) and minimum ray width of X-ray passing through ellipse are found from Fig. 1. When the maximum ray width is reached by MATLAB tool, it is the 61st incident, and when the minimum ray width is reached, it is the 151st incident. The number of detectors corresponding to the maximum light width and the minimum light width is obtained from the detected data. Because the distance between detectors is equidistant, the distance between detector units can be obtained by formulate. Let 512 light sources form a straight line of light sources, and find the maximum number of rows where the energy absorption and the maximum number of rows are located by MATLAB programming. In columns 61 and 151, the point m where the rows are located is found. Through this point, the intersection points of two X-rays l_1 and l_2, l_1 and l_2, are drawn, that is the center of rotation, Then a plane rectangular coordinate system is established as shown in the figure.

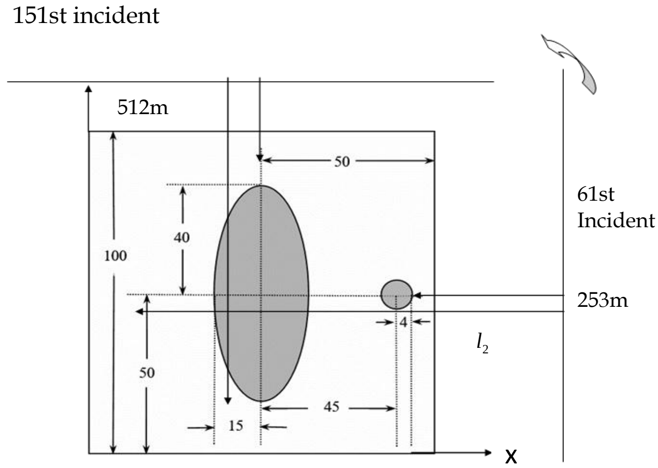


Fig 4: Twice incidence of X-ray

III. CALCULATING THE CENTER OF ROTATIONC

Step1：Calculate the distance between detectors

It is found that when X-ray is vertically injected at the 151th rotation, the ray width is elliptical short axis + small circle diameter. The number of detectors corresponding to the length of the shortest axis + small circle diameter can be obtained from the measured data. Then the distance model of the detector is established by using the formula.

$$d = \frac{a+r}{n}$$

Option: d is the space between detector units; a is the length of short axis; r is the radius of small circle.

Step2：Establishment of Rotation Center

The intersection point of the mid-vertical line of the two light sources is the center of rotation. Fig. 4 shows that the horizontal incidence of X-rays across the shortest axis is the 61st, and the vertical incidence across the longest axis is the 151st. The measured data show that the number of energy received by the 61st incident detector is the largest, that is, the width of light radiated on the ellipse is the widest. The 151st incident detector receives the least amount of energy, that is, the narrowest ray width on the ellipse. A rectangular coordinate system with the lowest left corner of the square pallet as coordinate origin o, the transverse axis of the square pallet as X axis and the number axis as y axis is established. Using MATLAB program, the most energy absorbed behavior m = 228 rows is obtained from the measured data. Two X-rays intersect at one point through m point.Vertical coordinates of the center of rotation: $y = d*(m-235)+50$;

The 150th incident is X-ray vertical incident, and the 222nd detector emits X-ray just over the ellipse length: Abscissa of the center of rotation: $x = 50 - d*(m-223)$;

Option: d represents the distance between the detector units, from which the coordinates of the rotation center can be obtained.

Step3：Determination of the direction of X-ray

Since the direction of the 61st incident X-ray is horizontal and the 151st incident X-ray is vertical, the direction of the two X-rays is 90 degrees, and the number of rotations is 90 times, so each counter-clockwise rotation is 1 degree. So the 61st incident indicates that the X-ray rotates counterclockwise 60 degrees from the starting position, so that the direction of the X-ray at the starting position and even at each post-rotation position can be obtained.

Step4：Solving the Center Point

Fig. 5 shows that the length of the short axis is 30 mm and the diameter of the small circle is 8 mm. The number of detectors corresponding to the shortest light width is 137 by means of Annex 2. The formula shows that:

$$d=\frac{30+8}{137}=0.2774(mm)$$

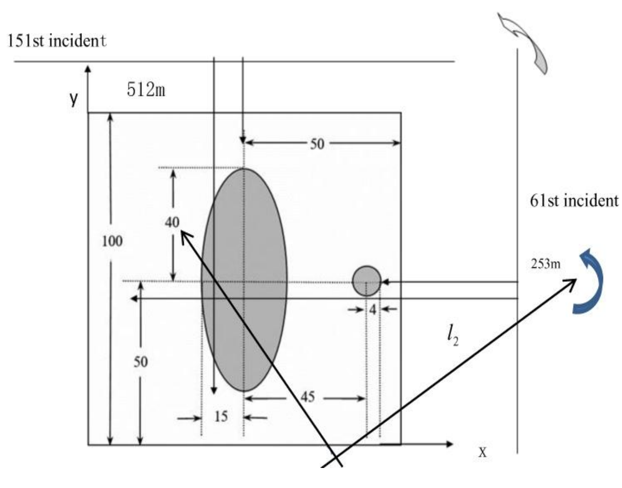
Therefore, the distance between detectors is 0.227 mm, and the total length of detectors is:

$$s=512*0.2774=142.0288(\ mm)$$

Vertical coordinates of the center of rotation: $y=d*(\ m-235)+50$ = 48.4082(mm)

Abscissa of the center of rotation: $x=50-d*(\ m-223)$ =48.8660(mm)

Solution of 180 directions of X-ray: Since the direction of X-ray is horizontal in the 60th incident direction and vertical in the 150th incident direction, the direction of the two X-rays is 90 degrees, and the number of rotations is 90 times, so each counter-clockwise rotation is 1 degree. So the 60th incidence indicates that the X-ray rotates counterclockwise from the starting position by 60 degrees, so that the angle between the X-ray source and the horizontal direction is 120 degrees. The X-ray is incident from the bottom to the top. Every subsequent counter-clockwise rotation, the step of the angle is 1 degree, until 180 counter-clockwise rotation. The figure is shown in Fig 2.



(The starting position of the light source)
Fig 5: Direction of X-ray

Note: The 180 directions of X-ray are shown in Fig 2. The angle between the X-ray and the x-axis is 120 degrees at the starting position, 1 degree at the counter-clockwise angle step per counter-clockwise rotation, 180 degrees at the 61 times, 270 degrees at the 151st incident, and 270 degrees at the last. The angle between sub-rotating X-ray and x-axis is 300 degrees.

IV. ESTABISHMENT OF GEOMETRIC SHAPE OF MEDIUM

Fourier transform [1] is used to reconstruct the image. First, the energy absorption rate of the image is calculated. The parallel projections collected from different angles are recorded as the complete Fourier transform of the object. Then, the object is reconstructed by inverse Fourier transform. That is, the original image is obtained by two-dimensional inverse Fourier transform. Using MATLAB program to get the geometric shape of the image and determine the position of the image, adding a filter function before the inverse Fourier transform can reduce the energy loss caused by the Fourier transform and result in artifacts and get a clearer image.

Step1: Determination of medium absorption rate

The absorptivity of the medium is set to $f(x,y)$. The parallel projection acquired at a certain angle is $p(t,\theta)$, p (u) can be obtained by Fourier transform. The two-dimensional Fourier transform of the original function f (x, y) can be done, and then the absorption rate of each point in f (x,y)can be obtained by using the inverse Fourier transform and MATLAB programming.

Step2: Determine the absorptivity of points in Fig3

After the whole geometric shape and the specific position of the pallet, the template schematic diagram as shown in Figure 3 is drawn, and the relative positions of the ten points given in the title in the geometric figure are observed.

$$\left|f(x,y)\right|\exists, M(x,y)\in R$$
$$f(x,y)=0,\ M(x,y)\notin R$$

The absorptivity at these ten locations can be obtained by substituting $f(x,y)$

Step3: Application of Bill's Theorem [2]

Let the linear attenuation coefficient (absorptivity) be the distribution function of u(x). When the incident intensity of X-ray is equal to I_0, the intensity after passing through the medium is I, and obeys the Bill's theorem.

$$I=I_{0e}-\int_L u(l)dl$$

The energy received by the medium is:

$$I^{'}=I_0-I=I_0\ (1-e^{-\int_L u(l)dl})$$

After transformation, it is obtained that:

$$P(l) = ln\frac{I_0 - I}{I} = \int_L u(l)\,dl$$

Option: p(l) is projection data. Then the problem is transformed into calculating u(l) from the projection data p(l) to obtain the absorptivity function u(l) of the medium.

V. FOURIER TRANSFORM RECONSTRUCTION ALGORITHM

1. Basic thought

The Fourier transform of each projection corresponds to a line in the Fourier transform of the medium [3], that is, there is a one-to-one correspondence between the projection and the medium. Firstly, the projections from different angles are combined into Fourier transform, and then the medium is reconstructed by inverse Fourier transform. When the detector rotates 180 degrees around the medium, the center piece of the two-dimensional Fourier transform of the medium corresponding to the direction of the detector can cover the entire Fourier space. The original image can be obtained by two-dimensional Fourier transform.

2. Central section method

Method 1: Assuming the objective function of reconstruction is f (x, y), the parallel projection acquired at a certain angle is $p(t,\theta)$, where t represents the distance between the isocenter of the projection line. In the case that the projection is parallel to the y axis [4], that is:

$$p(x,0) = \int_{-\infty}^{\infty} f(x,y)dy$$

Fourier transform of X is performed on both sides at the same time:

$$p(u) = p(x,\ 0) = \int_{-\infty}^{\infty} p(x,0)e^{-j2\pi ux} = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} p(x,\ 0)e^{-j2\pi ux}dxdy$$

Then the original function f (x, y) is transformed by two-dimensional Fourier transform to get its value at v=0:

$$F(u,v)|_{v=0} = \int_{-\infty}^{\infty}\int_{\infty}^{\infty} p(x,y)e^{-j2\pi(ux+vy)}dxdy\,|_{V=0} = \int_{-\infty}^{\infty}\int_{\infty}^{\infty} p(x,y)e^{-j2\pi(ux+vy)}dxdy$$

Option: This shows that the conclusion is valid at projection angle 0. Because the selection of coordinates is arbitrary, the above conclusions are also valid for every rotation angle.

That is, the Fourier transform of the projection of the target medium at any angle is equal to the line of its two-dimensional Fourier transform in the same direction.

Method 2: Make a rotating coordinate system so that the s axis is parallel to the projection direction and the objective function f (x, y). In the new coordinate system, f'(t, s) is used to express the relationship between the two coordinate systems.

$$t = xcos\theta + ysin\theta$$

$$s = -xsin\theta + ycos\theta$$

Projection $p(t,\theta)$ is the line integral of function f'(t, s) along the s axis:

$$p(t,\theta) = \int_{-\infty}^{\infty} f^{'}(t,s)ds$$

The projection $p(t,\theta)$ calculates the Fourier transform of the variable t:

$$p(w,\theta) = \int_{-\infty}^{\infty} e^{-j2\pi wt}dt \int_{-\infty}^{\infty} f^{'}(t,s)ds$$

By integral theory: dsdt= J ∗ dxdy

$$p(w,\theta) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} e^{-j2\pi wt(x\cos\theta + y\sin\theta)} f^{'}(t,s)dxdy$$

The projection Fourier transform $p(w,\theta)$ is connected with the Fourier transform of the original function f(x,y). It can be obtained that:

$$F(u,v) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} p(x,0)e^{-j2\pi wt(ux+yv)}dxdy$$

Let $u = w\cos\theta$ and $v = w\sin\theta$,
bring $F(w\cos\theta, w\sin\theta) = p(w,\theta)$.

In Fourier space, variables $u = w\cos\theta$ and $v = w\sin\theta$ definitions are a straight line that passes through the origin and the U-axis is angled. That is to say, the Fourier transform of the parallel projection is a slice of the Fourier transform of the original function, and the angle of the slice is the same as that of the projection.

VI. DETERMAINATION OF MEDIUM ABSORPTIVITY

The absorptivity of the medium is set to f (x, y)_. The parallel projection acquired at a certain angle is $p(t,\theta)$ p(u) can be obtained by Fourier transform. The two-dimensional Fourier transform of the original function f (x, y) can be done. Then the absorption rate of each point in f (x,y) can be obtained by using MATLAB programming. The correlation between p(l) and u(l) can be obtained by using Schoeber' s [5] law Department:

$$p(l) = \ln\frac{I_0 - I}{I_0} = \int_L u(l)dl$$

The absorptivity of the medium is set to f (x, y), and the parallel projection is marked $p(t,\theta)$. t denotes the distance between the projection line and the isocenter. Order:

$$t = x\cos\theta + y\sin\theta$$

$$s = -x\sin\theta + y\cos\theta$$

After determining the whole geometric shape and the specific position of the pallet, make the template schematic diagram as shown in Fig 3, and observe the relative position of the ten points given in the title in the geometric figure.

$$\left| f(x,y) \right| \exists, M(x,y) \in R$$
$$f(x,y) = 0,\ M(x,y) \notin R$$

The absorptivity of these ten locations can be obtained by substituting $f(x,y)$

The coordinates of the ten positions are:(10，18)（34.5,25）(43.5,33)（45,75.5）(48.5,55.5) (50,75.5)（56,76.5）(65.5,37)（79.5,18）(98.5,43.5）;

The absorptivities at ten locations were as follows: 2010.6627,7399.9407,13603.5480,7617.103,15183.15,7652.0500, 7146.1150,13734.2100,5122.7390,4074.7130 .

VII. CONCLUSION

In this paper, aiming at the problem of industrial CT imaging, through the analysis of specific problems, a suitable mathematical model is established and the idea of energy absorption and maximum always passing through the rotating center is used. The intersection point is the rotating center, which can effectively reduce the error of the rotating center and make the model more practical. The model is also used in Fourier transform. On the basis of image reconstruction algorithm, filter function is added to reduce artifacts, and the resulting image is clearer and more accurate. Secondly, the back projection method estimates the absorption coefficient of a certain pixel by using the projection values of all the rays of the pixel. The filter back projection method is a convolution method. First, the back projection function is modified, and then the image is reconstructed by back projection. Convolutional back projection is a method of correcting the projection by using a special filter function. Convolutional back projection can filter artifacts produced by simple back projection, which increases the contrast of CT imaging. Fourier image reconstruction algorithm is indispensable in the process of reconstructing image for digitizing and visualizing the information conveyed by the energy signal of CT machine. But because the image generated by Fourier image reconstruction algorithm is usually accompanied by artifact generation, it is usually combined with filtering function to get a clearer image. In this paper, specific solutions and methods are given in such specific problems, which can play a guiding role in industrial product quality detection methods.

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