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TITLE OF THESIS

DESIGN OF CT PICTURES FROM 2D TO 3D

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Abstract

Volume visualization is one important part of scientific visualization. It has developed basing on absorbing the relative knowledge of computer delineation, computer visualization and computer image disposal. The knowledge of this branch is of much importance in computer application. Since it deals with contents with deeper meaning and it is more theoretic, having more arithmetic means, it generally stands for the level of computer application. The study and application of volume visualization is like a raging fire. My country started comparatively later in this field.

This thesis gives systematic representation and discuss in the field of tomography image 3D reconstruction. It mainly discusses after rotation, translation, filtering, interpolation and sharpening a series of 2D CT scanning images, get the boundary data of different object to form 3D volume data and actualize the 3D reconstruction of the object, and at the same time implement the function of display, translation, rotation, scaling and projection the volume data. Basing on the implementation of these functions according to software programming, this thesis gives a sum up to each algorithm of 3D volume visualization processing.

The method to actualize the 3D reconstruction of the tomography image is mainly about the image processing, image transformation, the way to actualize 3D reconstruction and image compression, etc. In image processing, it talks about getting the anchor points in the tomography image, the geometric transformation of the image, getting the boundary of the target, cross section display and the smoothing and sharpening of the image. In the transformation of the image, this thesis deals with the algorithm and implementation principle of the geometric transformation (transition, rotation, and scaling) of the 2D image, the three-dimensionalization of the planar data, construction of the stereo mode, geometric transformation of the 3D graph, curve-fitting, the processing of hidden line and hidden surface, color processing. It also introduces the thoughts of using OpenGL to develop and actualize tomography image 3D reconstruction system, including using OpenGL to transform the coordinate, solid model building, to actualize 3D rotation and projection.

Recently, the methods of applying chemotherapy to deal with cancer in hospitals of our country are different. Hospital with great fund takes import software to design while most of the hospitals take domestic software. These kinds of software are designed by DAHENG Company in BeiJing, WEIDA Company in ShenZhen. The programs in the software these two hospitals' doctors use to treat are images fielding in the plane not making radiation design under the mode of omnibearing cubic display. Under this circumstance the judgment of the key part can not remain precise, and this part is the most important part that the doctors need. The above problem is the aim of this project. This thesis mainly deals with the subject that after calibrating and sharpening the series of 2D CT images, extract the boundary data of different bodies to form a 3D volume data and actualize 3D reconstruction and at the same time actualize the function of display, translation, rotation, scaling and projection.

Mostly basing on the application of medical area, this thesis aims at making further research on computer graphics, computer vision and computer image processing through the study and application of volume visualization in this field. By the study and

development of the volume visualization technology in this project, it can provide simulation and display functions to the observer before the operation and the radiotherapy as well as providing the chance to simulate the real teaching and practicing link to the medical school in the teaching process, and increase the clinic level and teaching level of medical area.

Keywords: volume visualization, volume data, tomography image, 3D reconstruction, anchor point, boundary data, periphery boundary, OpenGL.

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Thanks for my parents. They are so kind and active. They cause me feel so happy in every days.

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LIST OF ACRONYMS

3D	Three-Dimensional
2D	Two-Dimensional
CAM	Computer Aided Manage
MRI	Magnetic Resonance Imaging
CT	Computed Tomography
SNR	Signal Noise Ratio
HSV	Hue Saturation Value
RGB	Red Green Blue

CHAPTER 1

INTRODUCTION

1.1 The Aim and Application of the research on Volume Visualization Technology

In the real world, there are many objects, natural phenomena and some calculation models that can be described by volume data. The research on volume data's expression, analysis, operation, object reconstruction and display has formed into an independent subject—Volume Visualization. The assignment of volume visualization is to reveal the object inside's complex structure; make us see the object's inside structure that cannot be seen in common situations. The application range of volume visualization becomes larger and larger. Volume visualization has played a very important role. The applications can be summarized as follows:

(1) Medical imaging: diagnosis, operational scheme and simulation, plastic operation, mapping, detection and analysis. [11]

(2) Industrial non-surgery: use industrial CT to carry out the quality detection on machinery or castings.

(3) Biology: display and analyze the macro and micro structure of animals and plants.

(4) Visualization of the calculation model: analyze the complex calculation models and some hidden mathematical functions.

(5) Geology: use the measurement data obtained by various detecting instruments to reconstruct the stratum's structure; analyze the geological composition.

(6) Physical and chemical research: carry out the disposal analysis on the various

experimental data such as the fluid dynamics analysis.

(7) modeling design: the computer assisted design based on volume data display model.

(8) Meteorology: analyze such 3D volume data as the atmospheric pressure, circumfluence graph, etc.; do the weather forecast.

Volume visualization is the earliest and most extensively used in the medical science field. In the medical treatment diagnosis, to observe the patient's one group of two-dimensional tomography images is the conventional way for the observer to diagnose the illness state. To ascertain the target's (pathological changes) spatial location, size, geometric shape and the spatial relation with the around biological tissues accurately, it is quite difficult for the observer solely to reconstruct in his head [11]. Therefore one effective tool is urgently needed to complete the three-dimensional reconstruction and three-dimensional display of the clay apparatus, parenchyma and the pathological changes. Volume visualization is such an effective instrument, which increase the medical diagnosis' accuracy and scientific quality. On the one hand, it enhances the quality of medical diagnosis; on the other hand it plays an important role in operational scheme and simulation, and medical research. The applications can be summarized as follows:

(1) Provide the 3D structural information of the apparatus and tissue in order to make an accurate judgment to the illness state.

(2) Do the operational scheme and simulation of the operational course; increase the reliability and security of the operation.

(3) On grounds of the geometric description obtained by 3D reconstruction, use the CAM system to manufacture the clay apparatus (such as artificial limb) automatically.

(4) As the tools for medical research.

(5) As the tools for medical teaching.

(6) Structural analysis, the finite element analysis on the temperature and stress of various

apparatus and tissues. [7]

1.2 Volume visualization's framework

Major processes of 3D Volume visualization are as follows:

1) Sampling data. Volume data can be made by way of image reconstruction from a series of 2D projection data. Such tomography scanning equipment as CT, etc. is used to fulfill image reconstruction and produce a series of tomography images.

2) 2D image filtering. There are some noises in the tomography images commonly. In order to make the image clear and easy to extract the boundary, implementing the filtering to enhance the SNR is needed.

3) Interpolation. When the distance between tomography images are much larger than the distance between the pixels in the tomography images, it is necessary that in the original tomography images there will generate some other medial tomography images by interpolation.

4) To form the 3D volume data.

5) Transfer, rotate and zoom.

6) The classification of volume data after rotation.

7) The object's 3D reconstruction.

8) The object's geometric description refers to the display of volume data and the 3D reconstruction of objects. Use the computer graphics' displaying technology to show the reconstructed surface.

1.3 The relation of volume visualization and other scientific fields

Volume visualization has developed basing on absorbing the relative knowledge of computer graphics, computer vision and computer image processing. It was an attention getting new science rising at the later 1980s. Nowadays, the study on volume visualization in and outside China is like a raging fire. It can be used in medicine, geology, industrial detecting, aviation as well as other fields. At the same time, these are branches very important to computer application, since it deals with contents with deeper meaning and it is more theoretic, having more arithmetic means, therefore it generally stands for the level of computer application.

Image processing mainly studies the transform from image to image. Normally it is to change one image into another. It includes image enhancement, feature extraction and segmentation technique, as well as correction. For example, the method of image filtering and image transform will be borrowed be used to filter the noises in the volume data and the aberrance generated in the correction process. The technique of image enhancement is mainly used for strengthening and stressing the feature of the images. The commonly adopted manner is to operate from dot to dot directly on pixel, and on partial operation on pixel region. Dot operation includes gray scale transform, histogram modification and partial statistics. Partial regional operation it to smooth and sharpen the image, including the median filter, lowpass filter and the highpass filter. Feature extraction technique mainly includes the spatial feature extraction of the gray scale amplitude. It adopts boundary recognition, using boundary extraction of boundary tracking and geometrical figure identification. Volume data is the spatial sampling to some physical attribution. Since different substance has different physical attributions. Therefore using image segmentation technique can distinguish different substances from each other.

Computer graphics is the way that through geometrical basis , such as line, circle, free curve and free curved surface to generate images. It studies the descriptive method of substances and the method that can generate and show images through geometrical descriptions. Volume visualization succeeds some displaying technique of computer graphics, such as visibility arithmetic and illumination model. The mapping method provided by computer graphics can basically meet the need of model protracting in volume visualization technology.

Computer vision is to give explanation to images, which is giving every image element a sign description. The segmentation and classification can be used to distinguish different kinds of substances in the volume data [28]. The classification of volume data is an essential process of volume visualization. The validity and veracity of the classification have a direction relationship to the analysis and display of the object in volume data.

1.4 The status quo of volume visualization research in China and overseas

1. The research work of volume visualization in developed countries is extremely active. The famous productions are as follows.

1) Clay visualization.

A series of 2D CT image or the nuclear magnetic resonance image (MRI) is reconstructed 3D clay structure. It enables the humanity to know own internal structure possibly. In 1991 the Colorado University medical school built the database of a man and a woman's whole dissection structure. From head to foot made the CT scanning, and the distance of piece spacing is 1mm. It provides the huge data for studying the clay's different structure to 3D reconstruct. [19]

2) Human embryo visualization.

It may realize a 7 weeklong human embryos interactive 3D display.

3) CT data of dog's heart dynamic display.

It can Display the dynamic image of a cycle of a dog's heart beating.

2. Medical image visualization system

In overseas, it already has had the commercialized system that can display the 3D medical image. For example, according to the user's need, Canada's Allegro system can connect with the CT scanning equipment or the nuclear magnetic resonance of different factories. After inputting the multilayer CT scanning image into computer, this system may display the input image by the frame along x, y, z three directions. It may construct 3D object. It is possible to the 3D image translation, rotation, zoom in and zoom out.

The research and application in China appears later. At present, the methods of applying chemotherapy to deal with cancer in hospitals of our country are different. Hospital with great fund takes import software to design while most of the hospitals take domestic software. These kinds of software are designed by DAHENG Company in Beijing, WEIDA Company in Shenzhen. The programs in the software these two hospitals' doctors use to treat are images fielding in the plane not making radiation design under the mode of omnibearing cubic display. Under this circumstance the judgment of the key part can not remain precise, and this part is the most important part that the doctors need. The above problem is the aim of this project.

1.5 Significance of the research

The study and application of volume visualization is like a raging fire. My country started comparatively later in this field. This project mostly discusses the principles, implementing arithmetic and method of implement as well as the application of spatial 3D volume visualization. Basing on its application in medicine, through the study and application of volume visualization in medicine, this project will certainly make a great contribution on the further study of computer graphics, computer vision, computer image processing, and at the same time advance the level of computer application of my country and the level of clinic and teaching in medicinal application area.

Presently, hospitals do not have complete CT image 3D reconstruction software which can display solid distribution spatial of radials. Making use of radials as a medical treatment has become the common method of painless operation. Yet, tasks such as the solid distribution of radial, the figure of sections, the intensity of the radial, the time of irradiation, the angle of radial, the orientation of bedstead need a great deal of calculation, it would be not totally objective through only human subjective judgments. Through the study and development of volume visualization in this project, it will solve these clinic problems for doctors. At the same time, it will provide simulative demonstration to the observer before their operation and radicalization treatment. Finally, it will provide simulation teaching and experimental approach to medicinal school.

This project is based on the background of medicinal application, discussing the principles, implementing arithmetic, implementing method as well as applications of spatial 3D volume visualization. Doing this study is not only because it is the urgent need of medicinal observer, but also because it is highly representative. It can be used in other areas after slight change. All in all, the study and development of this thesis has great practicability and broad foreground in application.

1.6 Thesis work and innovation

1. Thesis work.

1) Basing on the earlier period experimental work, I summarize the method of 2D tomography images to 3D extensively and scientifically. And finally I accomplish the system design.

2) I discuss the algorithm and theory of 2D tomography images to 3D reconstruction.

3) In the image processing experiment, I carry on each kind of processing to the CT images, including the image sharpening, the transformation, and the boundary extraction and so on. And I summarize the characteristics of each algorithm in the image processing.

4) In the image processing, I discuss using two methods (graphics technology and OpenGL) to realize the 2D tomography images to 3D reconstruction.

2. Thesis innovations.

I have realized the tomography image 3D reconstruction system with OpenGL. It includes realizing the 3D rotation, the projection, and internal object transparent display with OpenGL. The user can ensure the rotating angle of the range through keyboard inputting and mouse clicking, and output the objects section picture under the target irradiation through polishing, thus the section picture of the target under different angles will be acquired, and the basis of irradiation treatment will be provided.

1.7 Thesis contents

This thesis mainly discusses after rotation, translation, filtering, interpolation and sharpening a series of 2D CT scanning images, get the boundary data of different object to form 3D volume data and actualize the 3D reconstruction of the object, and at the same time implement the function of display, translation, rotation, scaling and projection the volume data. Basing on the implementation of these functions according to software programming, this thesis consists of 6 parts which are shown as follows:

- Part one introduces the original tomography image processing.

1. Target boundary extraction of original tomography images. Inputting many images into

computer, operate as follows:

(1) Anchor point extraction. There are three anchor points in every picture, the coordinates X, Y is to estimate whether the image excurses or deflects.

(2) The geometrical changes of the images, including the displaying of the translation, rotation, magnification, and deflation of the images, and as well as the correction.

(3) Extraction of target boundary. Since it is hard to estimate the pathological changes boundary precisely, it is due to the observer to estimate and orient the pathological changes boundary.

2. The arithmetic of the display of image section plane both vertically and horizontally.

(1) The extraction of image section plane vertically and horizontally.

(2) Interpolation between 2D images.

The function of this part is to display the section plane just like cutting an apple. It is propitious to the observation of the inner change of the target.

3. Deals with the pretreatment of the tomography images. It is to provide conditions to computer automatic recognizing boundary, and make the images clearer and projecting in boundaries as well as reduce the noise.

(1) Image smoothing. Release the noise generated in the process of image transmission.

(2) Image sharpening. On the basis of the improved images and make the boundary of the image more projecting.

4. Edge detection and edge extraction method. It includes the extracting methods of the human body boundary and protective tissue boundary. Among these, the human body boundary has achieved the level of automatic recognition and protraction.

- Part two introduces the arithmetic of geometrical transform to the boundary data of each level.

1. Taking the first anchor point as benchmark, adjust every anchor point in very tomography image, thus make coordinate value has the same benchmark. In order to make every anchor point has the same coordinate, it is essential to give geometrical transform to the anchor point in every layer.

2. Giving geometrical transform to the boundary data in each layer. Giving arithmetic to the translation, rotation, and zoom of the datum mark.

- Part three concentrates on reconstruction 3D object from serial 2D contours, discussing the way of implementing 3D reconstruction.

Dealing with discrete data of object boundary in different layers as follows:

1. Built solid model, and connect the object boundary point in different layers to form a 3D object

2. Giving geometrical transform to 3D images, including 3D translating transformation, proportional transform, rotation of the dimension, projection transform

3. Curve-fitting to object boundary point in different layers

4. Giving computer solid display to 3D images, including the management of hidden lines and hidden surface and the coloring of them.

This part mainly discusses plane representation of the solid model, the normal vector and equation of plane, depth inspection, removal algorithm and staining of solid plane.

- Part four deals with the designing method of the implementation of tomography images 3D reconstruction system. Including the following aspects:

1. The function of Open GL in tomography images 3D reconstruction display system.

2. Plan data coordinate three-dimensionalization.

3. Implementation of coordinate transformation by Open GL

4. Implementation of 3D rotation by Open GL

5. Projection

- Part five discusses the result of 3D reconstruction

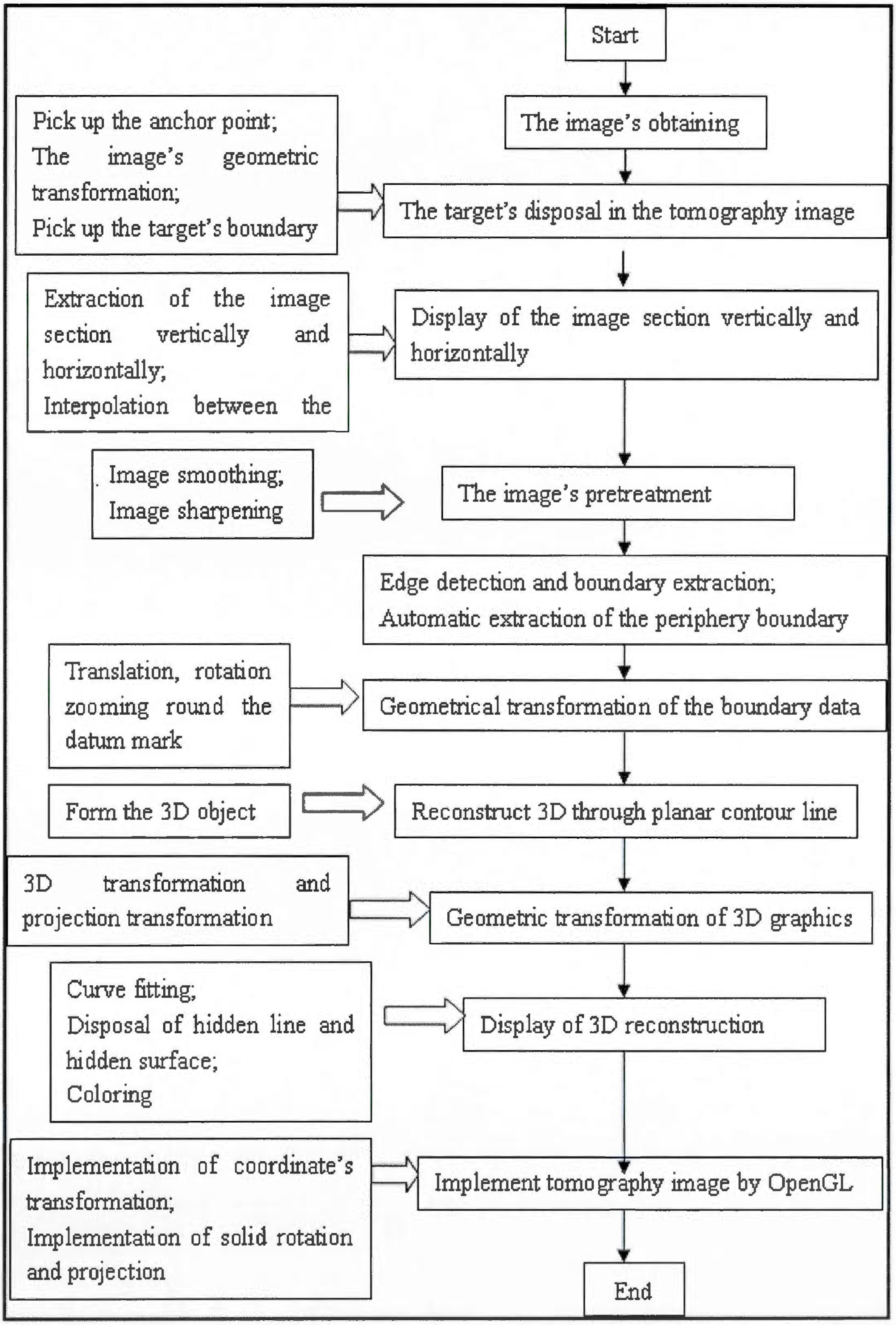
This part summarizes the above two ways of 3D reconstruction, and makes a comparison of the results.

Generally speaking, after making boundary extraction of the key objects in the multilayer planar section images, the 3D entity is formed by this system. Focusing on the centre of the target, this system makes objects rotate around the x, y, and z axis, thus the 360^0 rotation of the objects was implemented. Therefore the observers will be able to observe the shape of the objects under any angle. In observing the objects, they can know the solid shape, size, bearing of the target, and find the way to solve the problem, providing sound base for treating plan. In addition, since it can polish under any angle and provide the projection of the target section; this system can also implement the function of objects zooming.

The user can ensure the rotating angle of the range through keyboard inputting and mouse clicking, and output the objects section picture under the target irradiation through polishing, thus the section picture of the target under different angles will be acquired, and the basis of irradiation treatment will be provided.

- Part six introduces the function of CT tomography images 3D reconstruction software.

The whole disposal flow is shown by the next page.


Start
The image's obtaining
Pick up the anchor point;
The image's geometric transformation;
Pick up the target's boundary
The target's disposal in the tomography image
Extraction of the image section vertically and horizontally;
Interpolation between the
Display of the image section vertically and horizontally
Image smoothing;
Image sharpening
The image's pretreatment
Edge detection and boundary extraction;
Automatic extraction of the periphery boundary
Translation, rotation zooming round the datum mark
Geometrical transformation of the boundary data
Form the 3D object
Reconstruct 3D through planar contour line
3D transformation and projection transformation
Geometric transformation of 3D graphics
Curve fitting;
Disposal of hidden line and hidden surface;
Coloring
Display of 3D reconstruction
Implementation of coordinate's transformation;
Implementation of solid rotation and projection
Implement tomography image by OpenGL
End

CHAPTER 2

THE EDGE DETECTION AND EXTRACTION IN TOMOGRAPHY IMAGES

When inputting the images into the computer, the images will deflect because the influence of environment and subjective operational error. In order to implement the authentic 3D entity, first of all, the images shall be corrected, changing the images into standard ones. That is to standardize the position of the images and normalize the size of them. Thus, rectification methods such as rotation and move are needed. The base of the move and rotation of CT images is the set information CT images have - the anchor point. Every CT image has three anchor points: (x_1, y_1) (x_2, y_2),(x_3, y_3). The first and the third anchor point is stable, namely, they will not change according to the changes of the layers. But the second will. The length of x_2-x_1 is to distinguish and mark the numbers of different layers. If y_1=y_2=y_3, then the image does not deflect, or else it does. Just like Figure 2.1, the warp between point x_2 and x_1 gradually increase, indicating the different places of the image from low to high.

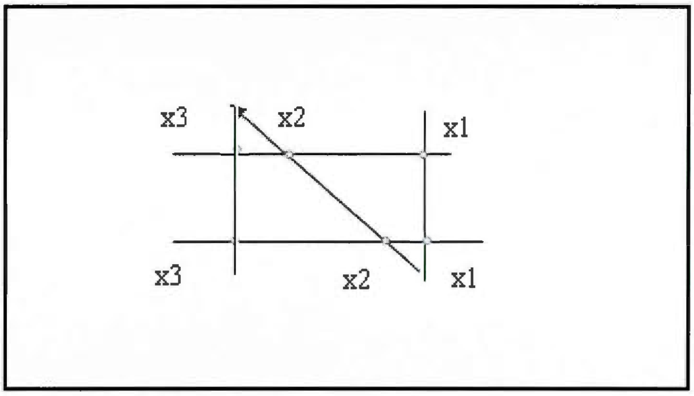


Figure 2.1 image of anchor point [11]

2.1 Anchor point extraction

After the input of the CT image through scanning, it is inevitable for the image to deflect. In the procedure, we have to correct the image according to the relative information of anchor frame in the CT image, making sure the angle between the connecting line of the three anchor point in the image and the horizontal direction, and other pixel will be made certain their coordinate relative to that connecting line. The first step of the process is to choose the anchor point. This is to provide data to the isochronous boundary correction. Just like Figure 2.3.

In the CT image, it can be observed that the anchor point is white, the value of the pixel is high, but the place round the pixel is dark, the value of the pixel is low. Just as what Figure 2.2 shows. Make a rectangular by the mouse near every anchor point, from left to right, from right to left, keeping an eye on the change of the chromatism. If there is a point whose chromatism is higher than a certain threshold from left to right, and the same from right to left, then the mean of the two points is the coordinate of anchor point x; under the same principle, if there are two points whose value are higher than the threshold, the mean is the coordinate of anchor point y. the advantage of this algorithm is its quickness. Not all the points have to be involved in calculating.

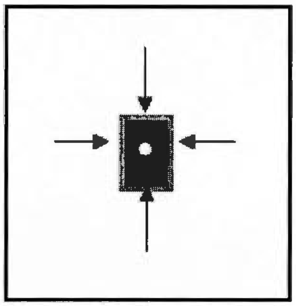


Figure 2.2 sketch map of anchor point extraction algorithm

Explain the task of the anchor point extraction using a figure in the following.

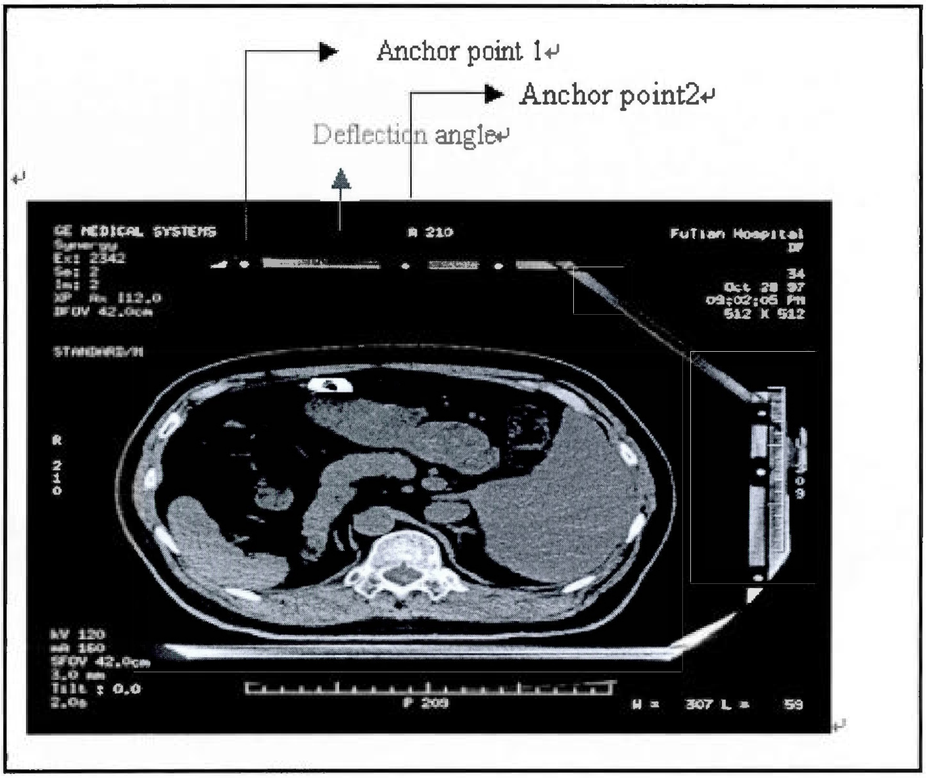


Figure 2.3 anchor point's schematic drawing

2.2 Geometrical transformation of images

The geometrical transformation of images includes the move, rotation, magnification, deflation of the image. Choose the central coordinates of three anchor points in every picture, making certain the angle between the connecting line of the three anchor points and the horizontal direction, emendating the image, the formula is as follows:

1) The angle between the anchor point and the horizontal direction is:

$$angle = atan((y_2-y_1)/(x_2-x_1))$$

(x_1, y_1)is the x, y coordinate of the first anchor point, (x_2, y_2)is the coordinate of the second anchor point. [16]

2) Translation

Translation is to add Δu and Δv to the coordinates of all the points in the image in plane uv, its transforming expression is: [16]

$$[x, y, 1] = [u, v, 1]\begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ \Delta u & \Delta v & 1 \end{pmatrix}$$

Translate the anchor point to the coordinate origin of the image uv plane, then the transformation expression of every point in the image is: [16]

$$x=x-x_1$$

$$y=y-y_1$$

3) Rotation

Rotate all the points in the image in uv plane counterclockwise for certain angle, the expression of transformation is: [16]

$$[x, y, 1] = [u, v, 1]\begin{pmatrix} \cos(angle) & \sin(angle) & 0 \\ -\sin(angle) & \cos(angle) & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

4) zoom

Zoom in or zoom out the image according to certain ratio. The transform expression is: [16]

$$[x, y, 1] = [u, v, 1]\begin{pmatrix} r_u & 0 & 0 \\ 0 & r_v & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$x=u*r_u$

$y=v*r_v$

r_u and r_v are the respectively scaling of the uv coordination axis direction, when they choose the value of different range, they will have different transforming results.

(1) When r_u, r_v are greater than 1, the images magnify.

(2) When r_u, r_v are less tan 1, the images deflate. [16]

2.3 Target boundary extraction

Medical image disposal is to extract the boundary of human being's important tissue and pathological changes, not all the boundaries. Target boundary is the boundary of pathological changes. The extraction of a pathological changes boundary has something to do with the knowledge of pathology, and have a close connection with the clinic experience of the doctor and their precise judgment. So for the boundary of pathological changes, it should not take the method of automatic boundary algorithm, but the interactive operation. It will make possible the operator control the boundary extraction process and its quality.

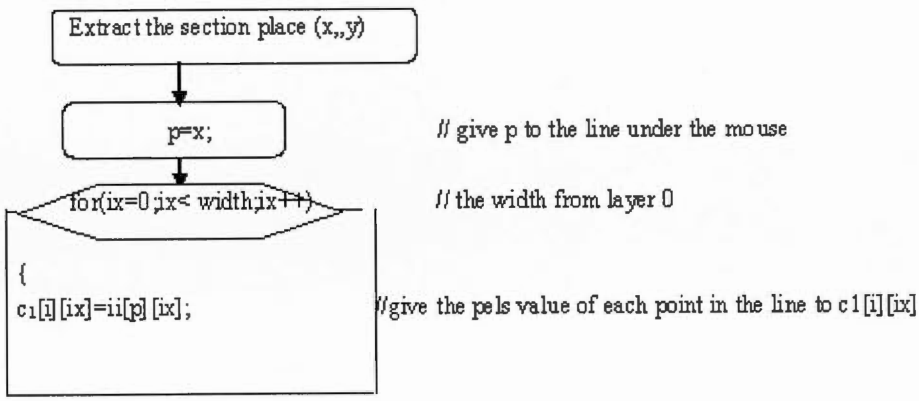
When circling the boundary, press the left mouse button and drag it, the state of coercive boundary circling. Under this state, it is not necessary to spot the mouse to every point in the boundary, but only pass several or dozens of points (according to the length of the boundary, the more points to pass, the more precise the boundary will be). This is to draw a polygon along the boundary. The points are the acme of the boundary. In the procedure, this polygon will be the initial contour for searching, and after working out the central point of these points, choose a point every other degree in the polygon as boundary point, altogether 360 boundary points. Therefore, the contour of the target is acquired.

2.4 Display of the image section vertically and horizontally

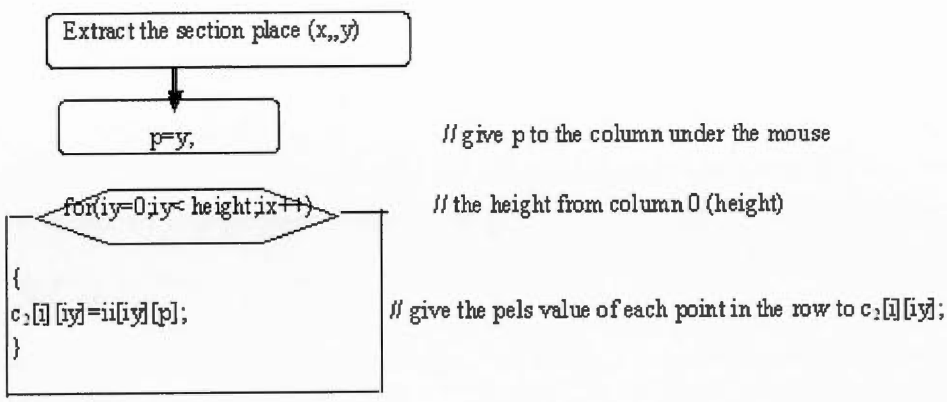
In order to observe the interior sections of the many pieces of tomography images effectively, in the screen, there should be two perpendiculars which will move along with the movement of the mouse. The horizontal line shows the location of the present section, while the vertical line shows the longitudinal section and near it, there will be the sectional view vertically as well as horizontally.

2.4.1 Extraction of the image section vertically and horizontally

In order to display the vertical and horizontal section image, set arrays c_1[40][width] and c_2[40][height]. c_1 [i][j] stores the horizontal section pixel value extracted from image layer i and row j, 0<i<41, 0<j<width; c_2[i][k] stores the vertical section extracted from image layer i and line, k 0<i<41,0<k< height. [2]



Under the same principle the extraction algorithm of the section in vertical direction can be obtained as follows:



2.4.2 The interpolation of 2D tomography images

When the distance between tomography images are much larger than the distance between the pixels in the tomography images, it is necessary that in the original tomography images there will generate some other medial tomography images by interpolation. But, image interpolation is a question with great randomicity. In order to make the image interpolation a certain, resoluble question, ordinarily we bring in the following three conditions:

1) the interpolation image shall be similar to the original tomography images;

2)the degree of the similarity the interpolation image and the two original tomography images shall be in inverse ratio with the distance between itself and the two tomography images respectively.

3) The interpolation sequence shall show a process of gradual change from one original tomography image to another original tomography images. [24]

The simple way of interpolation is to get the weighted average from the two tomography images of adjacency up and down, and a series of interpolation images will be acquired:

Suppose $s_k(i, j)$, $s_{k+1}(i, j)$ are the slicing images of layer k and layer k+1. According to the way to get the weighted average, their interpolation images shall be expressed as:

$$s_\lambda(i, j)=(1-\lambda)^* s_k(i, j)+\lambda^* s_{k+1}(i, j)$$

In this formula, λ=d1/(d1+d2), d1,d2 are the distances from the interpolation image to layer k and layer k+1.

When $\lambda=0$, $s_\lambda(i, j)= s_k(i, j)$

When $\lambda=1$, $s_\lambda(i, j)= s_{k+1}(i, j)$

After giving a group of $\{\lambda_i \mid \lambda_i \Sigma(0,1), I=1,2,\ldots,n\}$, accordingly, there are interpolation images amount to number n. in order to have the interpolation images of the same distances, the parameter sequence $\{\lambda_i \mid i=1,2,\ldots,n\}$ shall be $\lambda_i=i/(n+1)$. [24]

2.5 The pretreatment of the tomography images

In order to make the computer recognize the different boundaries of different objects in the CT, before the computer extracting the boundary automatically, we have to pretreat the images. Pretreatment of the images means after treating the original images, change them into images fit for feature extraction. When input the images into the computer, owing to the influence of inputting transforming parts as well as the surroundings, the images will have noises and distortion. In order to make the feature extraction steadily, the noise must be illuminated and the distortion must be corrected. Changing the images into images which are prone to observe and more portable to be handled by computers is called sharpening.

2.5.1 Images smoothing

Removing the noises in the images is called smoothing or filtering. The aims of filtering are two: first, it is to adjust to the need of computer disposal and eliminate the noise when numerating the images. Another is to extract the feature of the object and regard it as the feature mode of image reorganization. There are two conditions for filtering: one is not to damage important messages such as the contour and boundary of the original images. Second, making sure the images are clear and the visual effect is good. Therefore, the main contraction in smoothing is to eliminate the noise and at the same time keep the contour clear.

Image data is relative to space. The method of filtering includes spatial convolution method and spatial frequency domain filtering method. The window function for filtering is h(m , n), then the convolution operation to image data will be:

$$f_0(j,k)=\sum_{m=1}^{M}\sum_{n=1}^{N}(f(j-m,k-n)h(m,n))$$

In transform, the above formula is equal to:

$F_0=F*H$ (H is filtering transform function) [25]

2.5.1.1 Spatial convolution method

The window function used by spatial convolution is usually 2D. Using different sizes like 2*2 , 3*3 or 5*5, move the window function in the image following the order of from left to right, from the top down, then multiply every pixel in the domain with every element in the window function respectively. The sum of their arithmetic product is the new result of the pixel for the body in the domain center.

1. Lowpass filter: the smooth and blur

The basic principle of lowpass filtering is to keep the low-frequency part in the image spatial frequency, and reduce the high frequency part, making the low-frequency part in the image which is inconspicuous more distinguishable.

Lowpass filter has characteristics as follows:

1) The number of rows and columns of the convolution kernel is in odd number, usually 3;

2) The convolution coefficient is point symmetric with the central point as its center;

3) The convolution coefficients far from the center are relatively small or stable.

4) All the convolution coefficients are positive number. [16] [24]

2. Filtering arithmetic

$$H=\begin{pmatrix} a1 & a2 & a3 \\ a8 & a0 & a4 \\ a7 & a6 & a5 \end{pmatrix}$$

```
for(x=1;x<row-1;y++)
{
for(y=1;y<col-1;x++)
{
f0(x,y)=a0*f(x,y)+a1*f(x-1,y-1)+a2*f(x,k-1)+a3*f(x+1,k-1)
+a4*f(x+1,y)+a5*f(x+1,y+1)+a6*f(x,y+1)+
   a7*f(x-1,y+1)+a8*f(x-1,y)
}
}
```

After the above calculation, there will be a image of the result of convolution, but its size shall be (M-2) *(N-2), then the next step is to give adjacent pixel value to all the boundary points. [16][24]

2.5.1.2 Median filtering

Median filtering is nonlinear spatial filter technique. This kind of noise filtering method can restrain the noise in the image effectively, and protect the contour boundary of the image. Median filtering handling is taking the median of gray scale in the part region as the output gray scale

3*3 the subprogram of median filtering is as follow:

Input the image: ii[row][col]

Output the image: oi[row][col]

Size of the window: n=3*3

Put all the pixel values in the 3*3 window in mado[9] array.

```
For(x=1;x<row-1;x++)
        For((y=1;y<col-1;y++)
        {
        m=0;
        for(xx=x-1;xx<=x+1;xx++)
        for(yy=y-1;yy<=y+1;yy++)
        {mado[m]=ii[xx][yy];
        m++
        }
```

Use bubble sort to classify the content of mado[m] according to the descending order.

```
        do
```

```
{
chg=0;
for(m=0;m<9-1;m++)
{
if(mado[m]<mado[m+1])
{
madom=mado[m];
mado[m]=mado[m+1];
mado[m+1]=madom;
chg=1;
}
}
}while(chg=1);

medi=mado[4];                // seek the median medi
oi[x][y]=medi;               //put the median into oi[x][y]
}
```

[16][24]

2.5.2 Image sharpening

The aim of image sharpening is to enhance the edge and details of the contour in the image. It is also called edge enhancement.

The function of highpass filter is to sharpen and clarify the image.

Highpass filter enhances the high-frequency part and hold up the low-frequency part. The basic features of highpass filter are:

1) The number of rows and columns of the convolution kernel is in odd number, usually 3;

2) The convolution coefficient is point symmetric with the central point as its center;

3) convolution coefficients around the center are usually negative or 0;

4) The convolution coefficients in the center are positive number.

5) The sum of the convolution coefficients is 1, with the brightness of the image unchanged [16].

$$h1=\begin{pmatrix} -1 & -1 & -1 \\ -1 & 9 & -1 \\ -1 & -1 & -1 \end{pmatrix} \quad h2=\begin{pmatrix} 0 & -1 & 0 \\ -1 & 5 & -1 \\ 0 & -1 & 0 \end{pmatrix}$$

In highpass filter, convolution coefficient in the center of the convolution kernel is the greatest, and it is crucial in the whole processing. When the convolution kernel passes the high-frequency part in the image, since its value is big, the multiplication product of itself and the pixel value is big. Therefore, after the convolution, the abrupt change of the pixel value in the image becomes more conspicuous, namely, the difference of the pixel value is enhanced. At the same time, the domain whose pixel value changes comparatively small is influenced lightly. Thus, highpass filter will sharpen the image, making it more striking, clear. The algorithm is the same as the lowpass filter. [2]

2.6 Edge detection

When displaying three-dimensionally the objects in the 2D tomography image, the boundary point of the 2D object must be extracted. After detecting the boundary of the curved surface object, line it up smoothly to form the edge of the object. The edge is the basic feature of the image. According to the configuration of the edge, it can be divided into step type and roofing type. The section of the boundary is to find out the points whose grey scale is in discontinuity, and make them the edge of the image. The edge points of the step type is the maximum points in the first derivative of the grey scale, or the zero-crossing of the second derivative; roofing type is the zero-crossing of the first derivative of the grey scale or the minimum points of the second derivative. As Figure 2.4 shows.

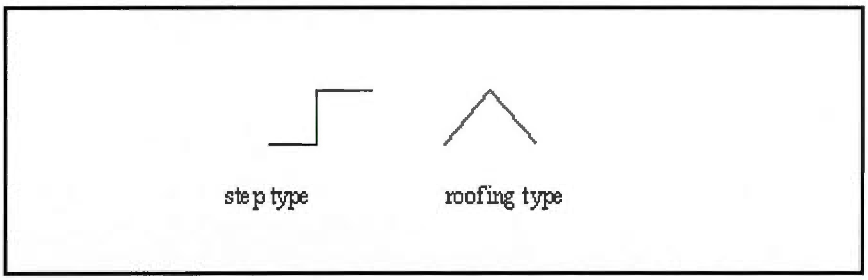


Figure 2.4 two kinds of edges

2.6.1 Edge extraction

2.6.1.1 Implementation of the gradient operator through convolution

Edge enhancement can also be implemented through convolution. Actually, highpass filter can implement one kind of edge enhancement. The basic feature of the convolution kernel using for edge enhancement are:

1) The number of rows and columns of the convolution kernel is in odd number, usually 3;

2) The convolution coefficients far from the center are relatively small or stable.

3) convolution coefficients around the center are usually negative or 0;

4) The convolution coefficients in the center are positive number.

5) The sum of the convolution coefficients is 0. [2]

$$h1=\begin{pmatrix} 0 & 0 & 0 \\ -1 & 1 & 0 \\ 0 & 0 & 0 \end{pmatrix} \quad h2=\begin{pmatrix} 0 & -1 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{pmatrix} \quad h3=\begin{pmatrix} -1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

Perpendicular edge plane edge plane and perpendicular edge

The basal principle of this method is to move the image for one pixel and minus this image with the original image. The result of the subtraction shows the rate of change of the original image. As for the unchanged the domain, the difference is 0, as for the domain which has an acute change, the rate of the change after the subtraction is bigger.

2.6.1.2 Sobel operator

Sobel edge detection is nonlinear edge detection arithmetic. It is highly efficient and with abroad use.

Its basic method is to use the two different convolution kernels along the x and y direction, that is:

$$\begin{pmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{pmatrix} \qquad \begin{pmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{pmatrix}$$

x direction y direction

After using the grads operator or Sobel operator, we need to choose a proper threshold T. if the image at the point (i, j) after filtering is more than the threshold T, then the point (i, j) is the edge point; otherwise it is not. [2]

2.6.2 Automatic extraction of periphery boundary

As what is shown in Figure 2.5, there is a domain outside the periphery boundary. The pixel value in this domain is low, smaller than 50. They surround the periphery boundary while the pixel value in the periphery boundary is great and bright. Therefore, it is possible to extract the periphery boundary points through gradient operator.

As we have seen there is a polygon surrounding the periphery boundary. The acme of this polygon can be defined, thus it is possible to define the rectangular which surrounds this polygon. Every point in the rectangular has a fixed coordinate x, y. calculate the center point of the polygon; circle the rectangular; extract one point every other degree from the rectangular. Move along with this point to the central point; estimate every pixel whether it is inside the polygon. If it is not, continue to move toward the central point until move inside the polygon. Get the gradient value of the pixel one by one. If the different value is greater then a certain threshold, then this point is the boundary point, or else, keep on moving toward the central point. Thus get a boundary every other degree. Altogether there will be 360 boundary points.

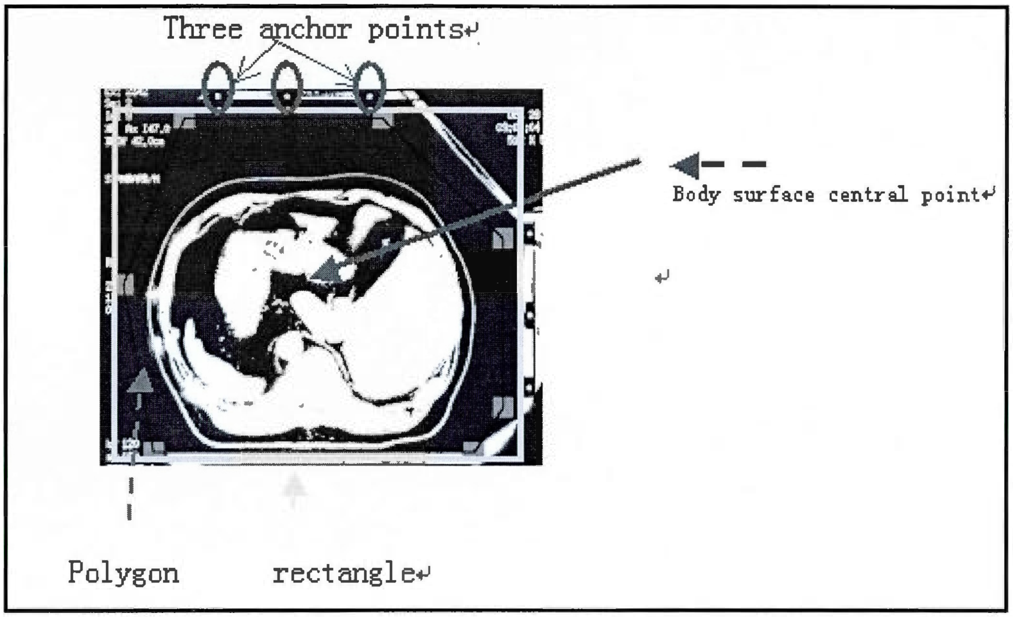


Figure 2.5 the figure of automatic extraction of the periphery boundary

Periphery boundary automatic detection. Computer automatic mapping, without manual intervention. As following Figure 2.6.

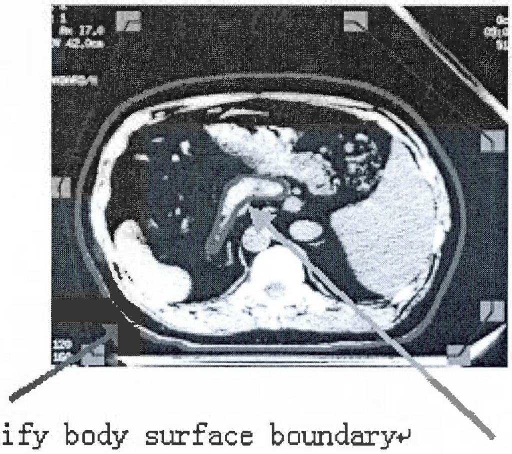


Figure 2.6 the figure of Periphery boundary automatic extraction

2.7 Summary

This chapter introduces the extraction of the anchor point: the transform of image geometry, including the display of image translation, circumrotating, enlarging and narrowing, and so on; the extraction of target boundary; the Display algorithm of the image section vertically and horizontally, including the extraction of the image section vertically and horizontally, and the interpolation among the 2D tomography images; the pretreatment of the tomography images, including the image smoothing to eliminate the noise in the process of imaging and transmitting, and the image sharpening, on the basis of the improved image, give more prominence to the edge feature of the objects in the image; the method of edge detection and edge extraction. Besides, it also introduces the extraction methods of boundary such as the boundary of human body and the protection tissue. And among them, the boundary of human body is completely automatically identified and mapped.

The whole flow frame of the program is shown in the following chart:

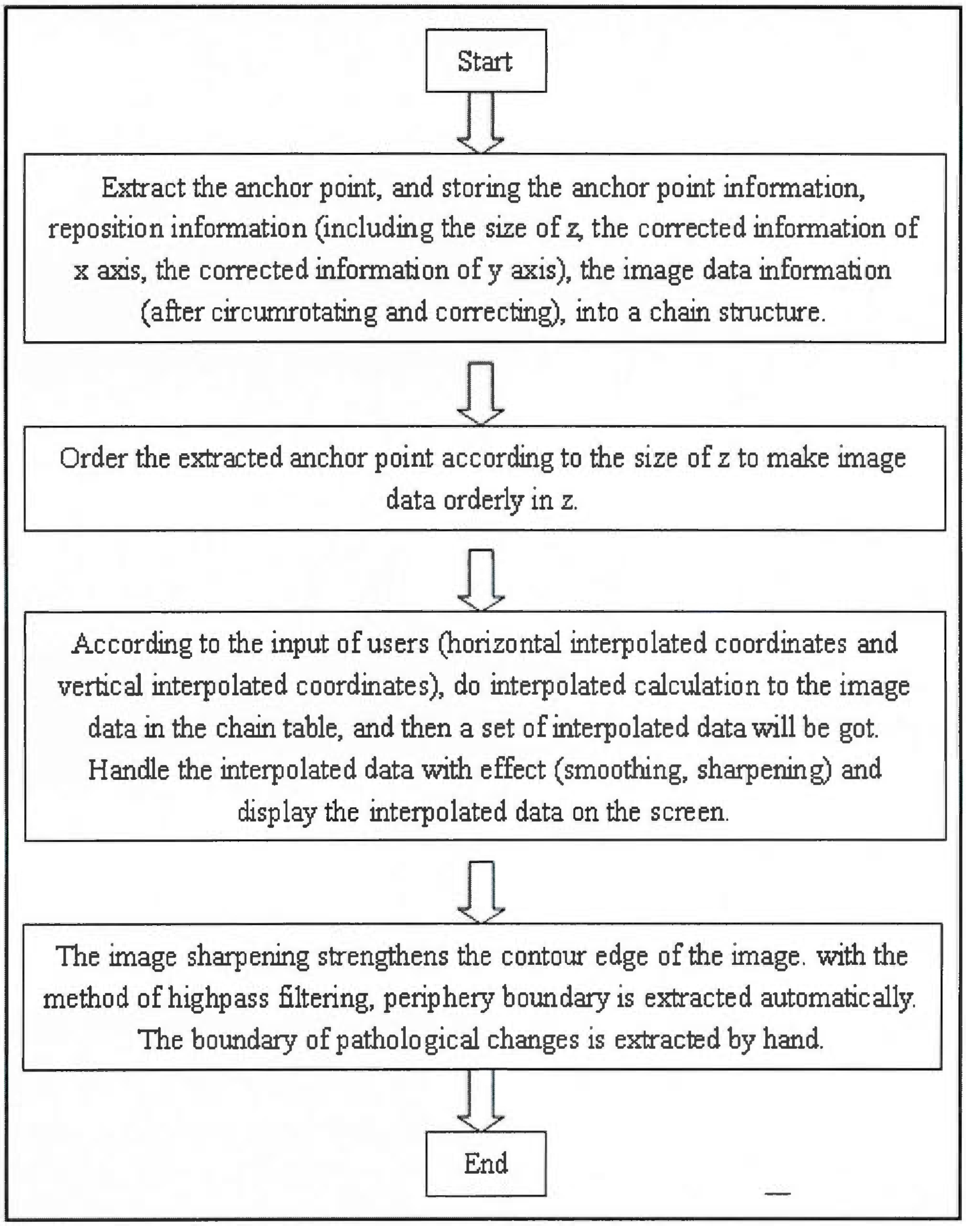


Figure 2.7 the whole flow chart of the program

The whole flow frame of the image interpolation is shown in the following chart:

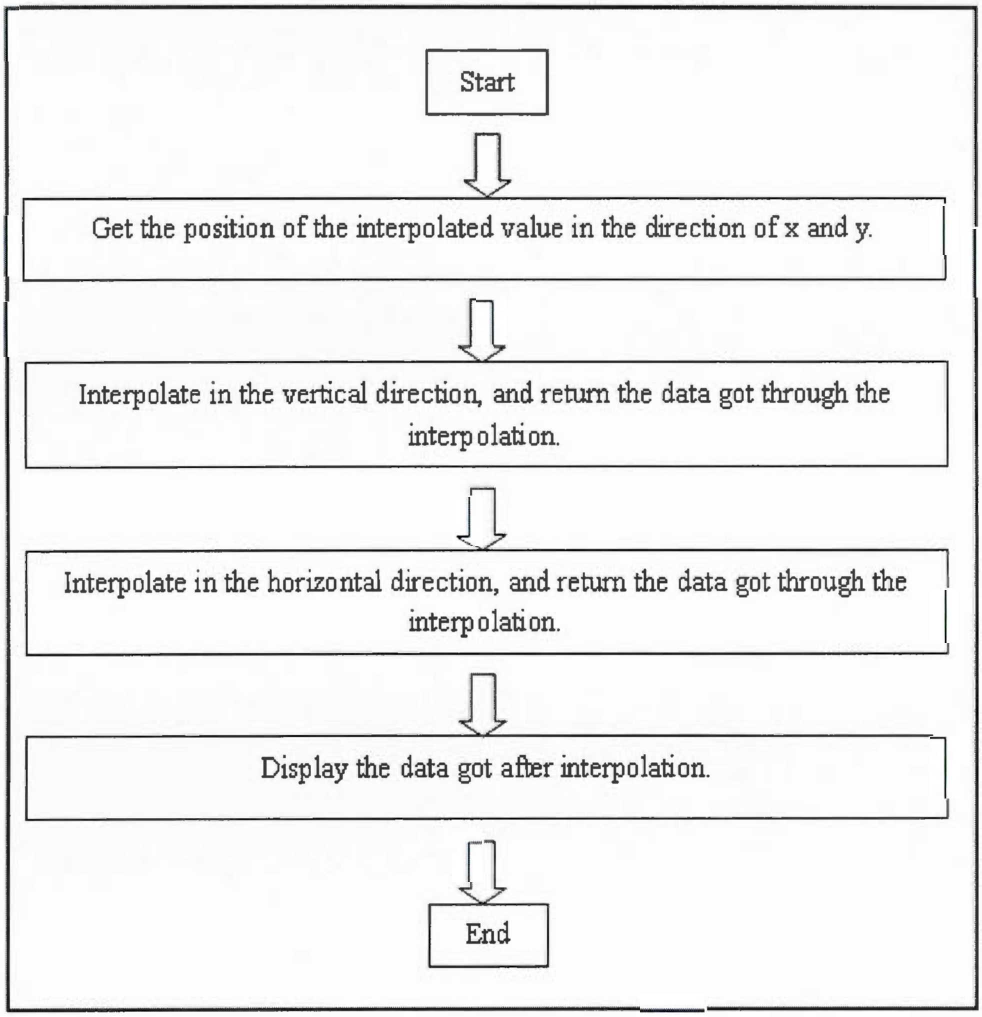


Figure 2.8 the whole flow chart of the image interpolation

CHAPTER 3

GEOMETRICAL TRANSFORM OF 2D IMAGES

3.1 Basic transform

In the previous geometrical transform of the images, there have been already three coordinates of the anchor points: (x1,y1) , (x2,y2) , (x3,y3), and at the same time, according to the coordinate value, the image has been corrected. Therefore, the boundary data of different objects in different layers are relative to the first anchor point. In order to reconstruct three-dimensionally all the boundary points in all the layers, all these points should have uniform relative coordinates. Basing on the first anchor point in the first layer, correct the anchor points in every tomography image, so that the coordinate values of the boundary points are relative to the same datum mark. In order to make the first anchor point in all the layers the same with each other, it is necessary to give translation calculation to the anchor point and the boundary point in every layer. Basing on the first anchor point in the first layer, implement the following 2D geometrical transform.

3.1.1 Translation

Calculate the difference between the first anchor point in every layer and the first anchor point in the first layer repeatingly.

anchor[40][3][3]

-----denoting there are altogether 40 layers, in every layer there are three coordinate points, and every point has coordinate (x, y, z).

tx[i]=anchor[i][0][0]-anchor[0][0][0]

-----denoting the difference between the first anchor point coordinate x in the first layer and first anchor point in the layer i.

ty[i]=anchor[i][0][1]-anchor[0][0][1]

-----denoting the difference between the first anchor point coordinate y in the first layer and first anchor point in the layer i.

To translate transform every boundary point, the algorithm is as follows:

$$\begin{pmatrix} x' \\ y' \\ 1 \end{pmatrix} = \begin{pmatrix} 1 & 0 & tx \\ 0 & 1 & ty \\ 0 & 0 & 1 \end{pmatrix} * \begin{pmatrix} x \\ y \\ 1 \end{pmatrix}$$

[32]

3.1.2 Rotation

If the horizon line of the anchor point in layer i has an angle θ with the horizon line of the anchor point in the first layer, then the rotation translation equation for circling around the origin of coordinates shall be:

$$\begin{pmatrix} x' \\ y' \\ 1 \end{pmatrix} = \begin{pmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{pmatrix} * \begin{pmatrix} x \\ y \\ 1 \end{pmatrix}$$

[32]

3.1.3 Zoom

Zooming translation equation concerning the origin of coordinates is:

$$\begin{bmatrix} x' \\ y' \\ 1 \end{bmatrix} = \begin{pmatrix} s_x & 0 & 0 \\ 0 & s_y & 0 \\ 0 & 0 & 1 \end{pmatrix} * \begin{bmatrix} x \\ y \\ 1 \end{bmatrix}$$

s_x, s_y are zooming coefficients, it can be allocated with any positive numbers. If the number is smaller than 1 then deflect the size of the object, if larger then magnify it. [32]

3.2 The rotation of general benchmark point

Through the sequence of translation—rotation—translation, to implement rotate around the datum mark (x, y).

1) Translate the objects so that the location of the datum mark can be moved to the origin of the coordinates.

2) rotate around the origin of coordinates

3) translate the object so that the datum mark will move back to its original location.

The compound transform matrix is :

$$\begin{bmatrix} x' \\ \\ \\ \end{bmatrix} \begin{pmatrix} 1 & 0 & tx \\ & & \\ & & \end{pmatrix} \begin{pmatrix} \cos\theta & -\sin\theta & 0 \\ & & \\ & & \end{pmatrix} \begin{pmatrix} 1 & 0 & -tx \\ & & \\ & & \end{pmatrix}$$

$$\begin{array}{cccccccccccc} y' = & 0 & 1 & ty & * & \sin\theta & \cos\theta & 0 & * & 0 & 1 & -ty \\ 1 & 0 & 0 & 1 & & 0 & 0 & 1 & & 0 & 0 & 1 \end{array}$$

[32]

3.3 Summery

This chapter mainly introduces the algorithm of 2D transform to the boundary data in each layer.

1. The main contents are as following:

1) Take the first anchor point in the first layer as benchmark, and adjust the anchor points in each tomography image in order to make the coordinates of the boundary points be comparative to the same datum mark. In order to make the first anchor point in all layers be the same, the anchor points in each layer must be handled with the transform of the geometric transform.

2) Handle boundary data of each layer with the geometric transform and the algorithm such as translation, rotation, narrowing and enlarging, and so on along the datum mark.

2. The program flow chart of the anchor point adjusting is as following:

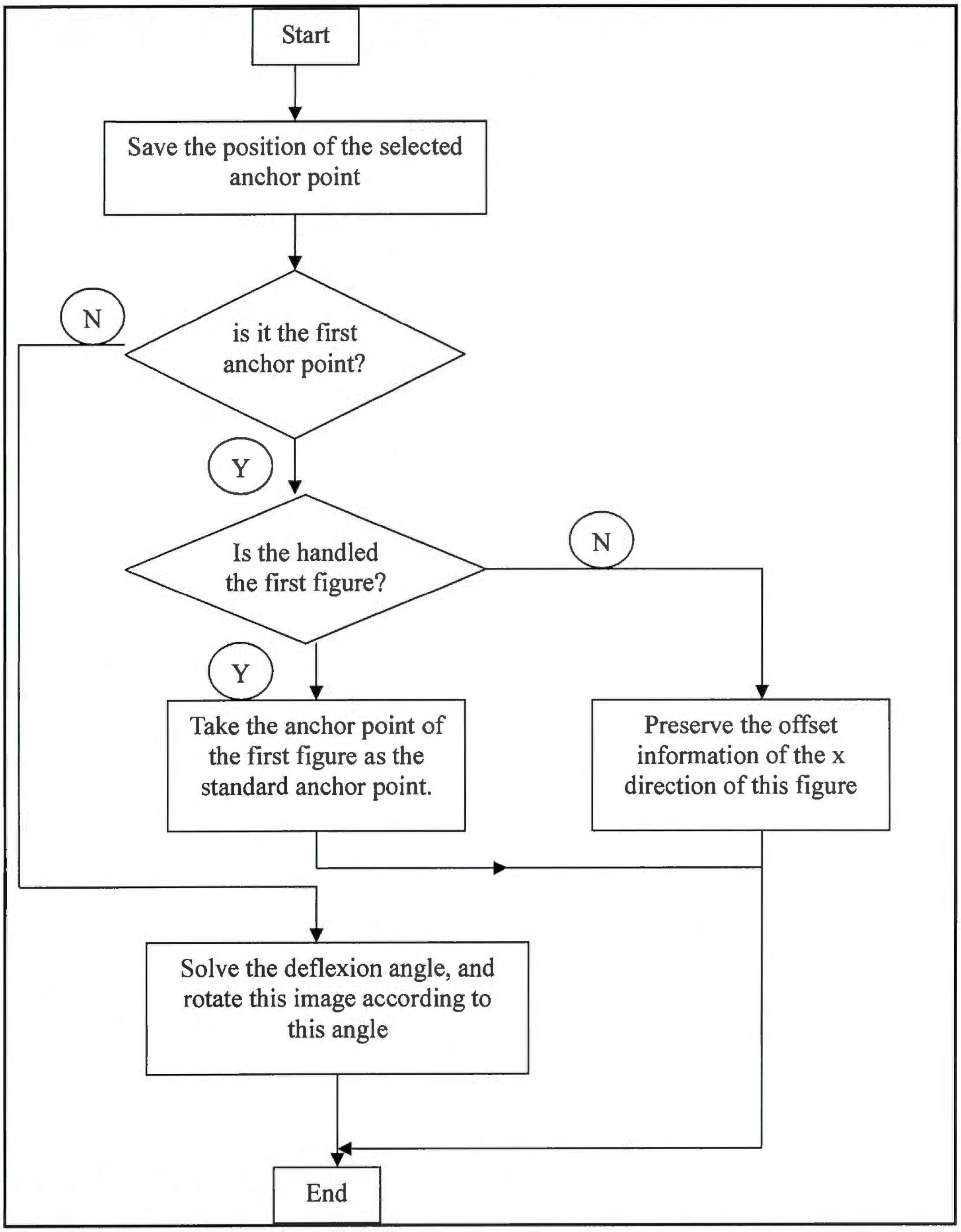


Figure 3.1 the program flow chart of the anchor point adjusting

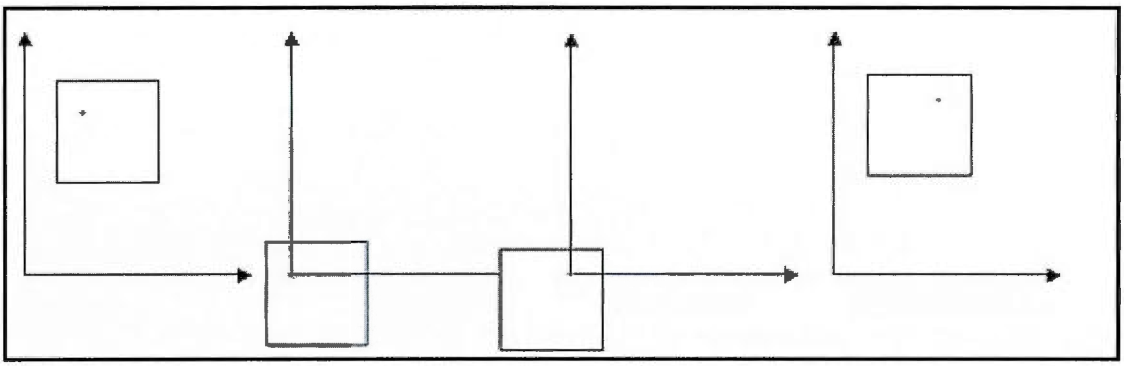
3. There are three steps of the image rotation:

1) Translate the rotation center of the bitmap to be superposition with the origin of the coordinate system.

2) Do circumrotating calculation.

3) Translate the bitmap to the original position.

For example, circumrotate 90^0 with the method shown in the following figure:



①   ②   ③   ④

Figure 3.2 circumrotate 90^0

① original state

② tranlate the circumrotating center to the centre of a circle

③ circumrotate 90^0 deasil

④ translate to the original posision

The program flow chart of the image rotation:

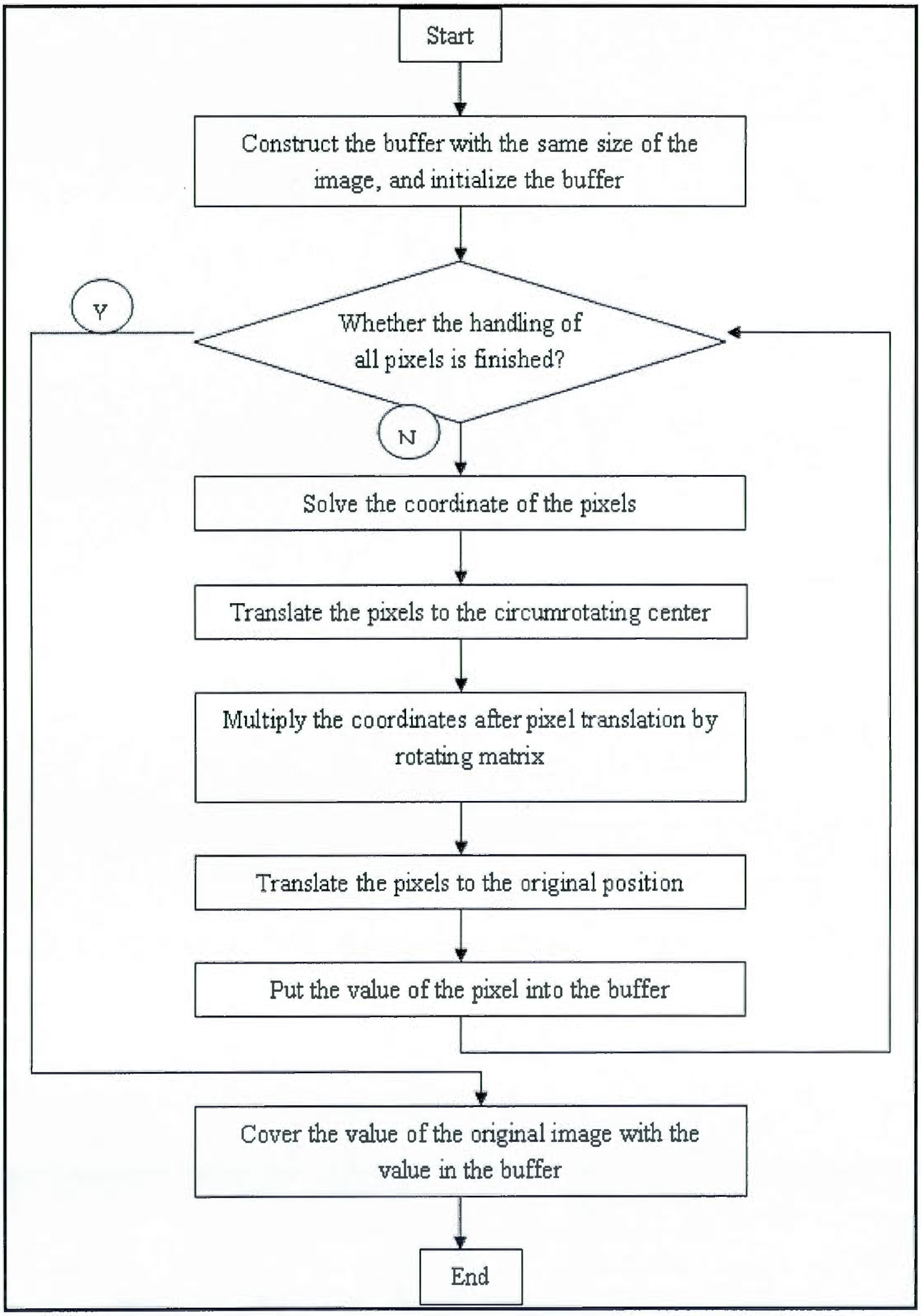


Figure 3.3 the program flow chart of the image rotation

Chapter 4

CONSTRUCT 3D OBJECT FROM 2D CONTOURS

(SOLID RECONSTRUCTION)

4.1 Input data

After the extraction of the different object boundary data from the 2D tomography image in every layers and the above mentioned correction, all the boundary points are build in unified coordinate system. The data of solid reconstruction comes from the object's boundary data of these 2D tomography images. After input data, the boundary data of every object is saved in the data base, including:

1) The information of the solid—including the file mark, the number of the object and the number of the layers.

2) The data of CT anchor point—since every CT is relatively separate from each other, in the process of CT perspective view, the anchor point is added, and used to make certain the mutual alignment of every layer.

3) The information of every object—number of the starting layer of the object's CT, characteristics (periphery, pathologic changes, protection and etc.)

4) The boundary data of the object—using the centre point of the object and the 360 polar lengths (taking one polar length every one degree). That is using the form of polar coordinates to express the boundary point data of the object. It can use one number to express one point with this

record method, but it needs two numbers to express one point with the x, y coordinate system. So, using polar coordinates can simplify the algorithm and save the storing space and memory space.

4.2 The three-dimensionalization of the 2D data

The coordinate x and y of every point in the space can be determined by its polar angle and its polar length, and be rectified by the place of the object central point and the anchor point. Coordinate z can be derivate by the layer number of this point. The calculation formula is

$$X_i = L \times \cos\alpha$$
$$Y_i = L \times \sin\alpha$$
$$Z_i = N \times 5$$

L is the length of the boundary polar axis of polar angle a. N is the layer number of this point [18]. For example: assume that there are 5mm between every two layers, in the control of circulation, use this formula to calculate all the extracted boundary data, transform many tomography plane polar coordinates data into three-dimensional coordinate in the form of (x, y, z), then the 360 points of the three-dimensional coordinates of every object can be figured out.

The algorithm for regulating the coordinate is:

Suppose the physical center of the solid model is $A(X_0,Y_0,Z_0)$, the physical center of layer i of the CT image is (X_i,Y_i) and a certain boundary data is (X_n,Y_n) then its calculation formula is:

$$X=X_n-X_0+X_i \qquad Y=Y_n-Y_0+Y_i \qquad Z=5*i$$

After the correction, the coordinates of all the points are relative coordinates in unification. For the sake of calculating convenience as well as implementation of the anticipating aim, the center point (0 , 0 , 0) is the physical center of the object [18].

4.3 The problem of contour correspondence

Every tomography image has many different objects, extract the contour of these objects and generate the boundary data of every object. At the same time, save the data into file, therefore in the file the following content is saved orderly:

1) The coordinate of anchor point. The sequential layer used for judging the image.

2) The boundary data of the object in each layer, including:

① Mark position, used for judging which object this boundary belongs to.

② The x, y coordinates of the boundary central point of the object.

③ The polar length of the 360 points sequentially ordered in the object boundary.

Read the boundary data from the file, and according to the difference of the anchor point, confirm the layer that the boundary data in.

According to mark position, calculate the sum of the objects, the layer of every object, the number of the first layer and the ending layer, the number of the central layer, the distance between every layer and the central layer [17][18].

4.4 Construction of the solid model

After the three-dimensionalization of the planar data, we will change the data into a series of discrete space points. These points can be operated through zooming, and rotation. But they can not output the solid image in the display equipment. It is necessary to have a proper algorithm to model build these points. The simplest and most audio-visual way is to compose these points into lines, then compose these lines into plane, then from planes the solid is obtained. This needs to regard the associative point as a small plane, and then there will be many planes to form the solid polyhedron

[18].

According to the characteristics of the data—every point is extracted from the layer, for the same organ, the number of the points in every layer is approximately relative to the polar angle. Therefore, it is possible to joint the two points between the adjacent layers and the adjacent point in the same layer together to form a plane. Get a series of this kind of planes together and the solid graph will be obtained. As the following Figure 4.1 shows

After obtaining the plane, it is possible to do the planar vector calculation and implement hidden and coloring.

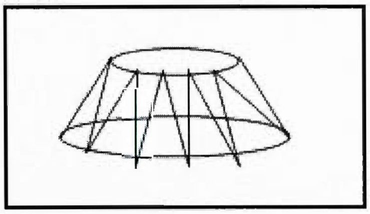


Figure 4.1 Scheme of solid model [18]

4.5 The geometrical transformation of the 3D image

Even after the formation of the solid graph, the reflection of this object in the screen is just one flank of the object. The figure of the rear face is eliminated due to hidden. To know the figure of the object in detail, it must be observed from each flank, thus there is the geometrical transform of the 3D image—the functions of solid rotation and zooming.

4.5.1 Basic transform of the three-dimension

The geometrical transform of the 3D image is implemented through transforming the essential element (3D point) in 3D space. And the 3D point (x , y , z) can also be expressed by homogeneous coordinate (x ,y ,z ,1), so, all the geometrical transform can be expressed by the multiplication of the matrix. Suppose the homogeneous coordinate of the 3D point before transform is (x , y , z , 1), and the coordinate after transform is (x' , y' , z' , 1), then the geometrical transform can be expressed as:

$$(x' , y' , z' , 1) = (x , y , z , 1) \begin{pmatrix} A & B & C & 0 \\ D & E & F & 0 \\ G & H & I & 0 \\ L & M & N & 1 \end{pmatrix}$$

$$T = \begin{array}{c} \begin{array}{cc} (\square) & (\square) \end{array} \\ \left(\begin{array}{ccc:c} A & B & C & 0 \\ D & E & F & 0 \\ G & H & I & 0 \\ \hdashline L & M & N & 1 \end{array}\right) \\ (\square) \end{array}$$

Partial matrix I expresses the ratio, reflection and the rotation of the 3D image;

Partial matrix II expresses the translation transform of the 3D image;

Partial matrix III expresses the perspective projection transform of the 3D image [32];

4.5.1.1 3D translation transformation

Implement through changing the three elements (L , M , N) in partial matrix II

$$\begin{pmatrix} x' \\ y' \\ \\ \end{pmatrix} = \begin{pmatrix} x \\ y \\ \\ \end{pmatrix} * \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ & & & \\ & & & \end{pmatrix}$$

$$\begin{matrix} z & z & 0 & 0 & 1 & 0 \\ 1 & 1 & L & M & N & 1 \end{matrix}$$

x'=x+L

y'=y+M

z'=z+N

4.5.1.2 3D scaling transformation

Implement through changing the three elements (A , E , I) in partial matrix II

$$\begin{pmatrix} x' \\ y' \\ z' \\ 1 \end{pmatrix} = \begin{pmatrix} x \\ y \\ z \\ 1 \end{pmatrix} * \begin{pmatrix} A & 0 & 0 & 0 \\ 0 & E & 0 & 0 \\ 0 & 0 & I & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

x'=x*A

y'=y*E

z'=z*I

when A=E=I , implement equal ratio transformation

when A=E=I>1 , implement magnified transformation when A=E=I 〈1 , implement deflating transformation [32]

4.5.1.3 3D rotation transformation

The equation of rotation around z axis is :

$$\begin{bmatrix} x' \\ y' \\ z' \\ 1 \end{bmatrix} = \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} * \begin{pmatrix} \cos\theta & -\sin\theta & 0 & 0 \\ \sin\theta & \cos\theta & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

The equation of rotating around x axis is :

$$\begin{bmatrix} x' \\ y' \\ z' \\ 1 \end{bmatrix} = \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} * \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta & -\sin\theta & 0 \\ 0 & \sin\theta & \cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

The equation of rotating around y axis is :

$$\begin{bmatrix} x' \\ y' \\ z' \\ 1 \end{bmatrix} = \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} * \begin{pmatrix} \cos\theta & 0 & \sin\theta & 0 \\ 0 & 1 & 0 & 0 \\ -\sin\theta & 0 & \cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

[32]

The calculation of rotating lines and planes is highly complicated calculation. But it is easy for the point to rotate in space. Therefore, it is possible to do rotating calculation only to the point.

When acquiring the coordinate of the point after rotation, the solid after rotation can be obtained through model building, hidden, and coloring. In order to simplify the calculation, it is better to define a certain point as the center of rotation, and then the coordinate of each point is the relative coordinates based on this point. Therefore it is possible to rotate round (0, 0, 0) and to use the previous formula directly. Because of the approximation of the algorithm as well as the circumference ratio, after the accumulation and the rotation algorithm, the precision of the data will decrease. After several rotations, because of the accumulation of the error, there will be great distinctness between the image and the original one. Therefore, it is highly necessary to correct the data timely. Comparatively speaking, the superposition of the angle does not have the above mentioned error, so this procedure will save the 3D data as the original data. After each rotation, the original data will be extracted for once, and then based on the original data, calculate through the super imposed angle to ensure the accuracy of the image when the user sees.

Since the multiplication of the matrix does not have the characteristics of commutative law, so though the degrees of the angle around the rotating axis are the same, yet their sequences are different, therefore the graphs acquired are different. This brings troubles to the users, and they can not get the one and only graph through the data by screen presentation. It also brings inconvenience to the next step of calculation.

To solve this problem, the angle of rotating around each coordinate axis is provided by the program. The flow chart is shown by Figure 4.2.

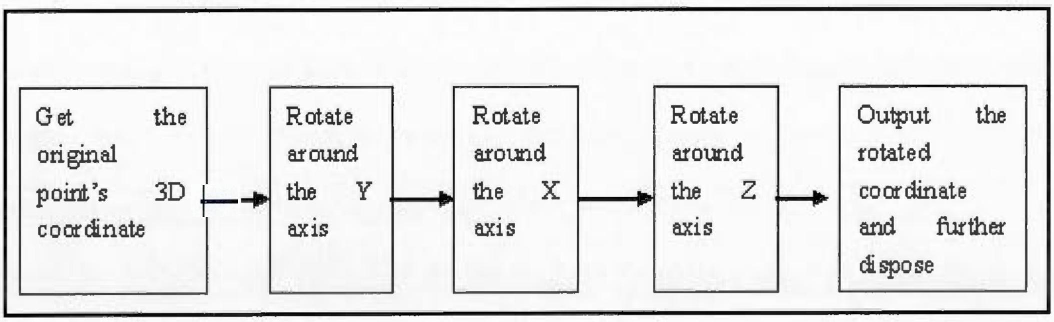


Figure 4.2 the flow chart of rotating around the coordinate axis

4.5.2 3D Projection Transform

Usually, the figure output equipments are 2D. When using these 2D equipments to display the 3D figure with third dimension, it needs to transform the coordinates of each point in the figure of the 3D coordinate system into the 2D icon in some horizontal coordinate system, that is, transforming (x, y, z) into (x', y') or (x', z') or (y', z') . There are many kinds of transform methods. In reality, according to different aim, it needs to use different transform method. It is generally divided into orthographic projection, axonometric projection and perspective projection.

4.5.2.1 Orthographic projection

In engineering, the three coordinate planes of 3D coordinate system 0XYZ are respectively called H plane (XOY), V plane (XOZ) and W plane (YOZ).

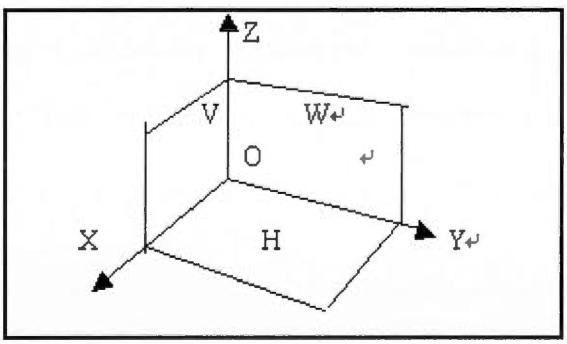


Figure 4.3 the sketch map of the three coordinate planes [18]

The orthographic projection is to make a vertical line respectively from each point in the 3D figure to some coordinate plane. The foot of perpendicular is called the orthographic projection point of this 3D point in this plane. Join all the orthographic projection points one by one according to the relationship between the point and point in the original 3D figure, and then we can get a planar figure. This planar figure is the orthographic projection of the 3D figure in this plane.

1. H plane orthographic projection

H plane (XOY) is the plane seen in the computer display screen. Its transform matrix is as the following:

$$TH = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

Then,

$$(x' \quad y' \quad z' \quad 1) = (x \quad y \quad z \quad 1) * TH = (x \quad y \quad z \quad 1) * \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

Then,

$x' = x, \qquad y' = y, \qquad z' = 0$ [18]

2. V plane orthographic projection

V plane (XOZ) projection transform matrix is as the following:

$$TV = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

Then,

$$(x' \quad y' \quad z' \quad 1) = (x \quad y \quad z \quad 1) * TV = (x \quad y \quad z \quad 1) * \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

Then,

$x' = x, \qquad y' = 0, \qquad z' = z$ [18]

3. W plane orthographic projection

W plane (YOZ) projection transform matrix is as the following:

$$TW = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

Then,

$$(x' \quad y' \quad z' \quad 1) = (x \quad y \quad z \quad 1) * TW = (x \quad y \quad z \quad 1) * \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

Then,

$x' = 0, \qquad y' = y, \qquad z' = z$ [18]

4.5.2.2 Axonometric projection

Axonometric projection is a kind of method the most commonly used to get the 3D figure with the third dimension. It is divided into two kinds: the normal axonometric projection and oblique axonometric projection. Here, the normal axonometric projection is mainly introduced.

The normal axonometric projection means to rotate the 3D objects certain angle respectively along two coordinate axis, and then make the orthographic Projection to the coordinate plane decided by these two coordinate axis.

For example:

1) rotate the 3D object α angle along Z axis;
2) rotate the 3D object β angle along X axis;
3) Make an orthographic projection to the plane XOZ.

The transform matrix is as following:

$$T = \begin{pmatrix} \cos\alpha & \sin\alpha & 0 & 0 \\ -\sin\alpha & \cos\alpha & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} * \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\beta & -\sin\beta & 0 \\ 0 & \sin\beta & \cos\beta & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} * \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

$$\begin{pmatrix} \cos\alpha & 0 & -\sin\alpha\sin\beta & 0 \\ -\sin\alpha & 0 & -\cos\alpha\sin\beta & 0 \end{pmatrix}$$

$$
\begin{array}{ccccc}
= & 0 & 0 & \cos\beta & 0 \\
 & 0 & 0 & 0 & 1
\end{array}
$$

[18]

4.6 Curve fitting

4.6.1 The cubic spline curve

The cubic spline function can express the complex curve with several less splines. The cubic slpine function has been widely applied into computer graphics. The cubic spline has enough degree of freedom to approach the position and direction the edge section. The cubic spline is a sequence constituted by the cubic curve section p_0 (u), p_1 (u)... p_n (u). This sequence is defined in the continuous interval [0, 1], [1, 2] ... [n-1, n]. join the ends in order to make $p_i(u) = p_{i+1}(u)$, as is shown in the Figure 4.4 [18].

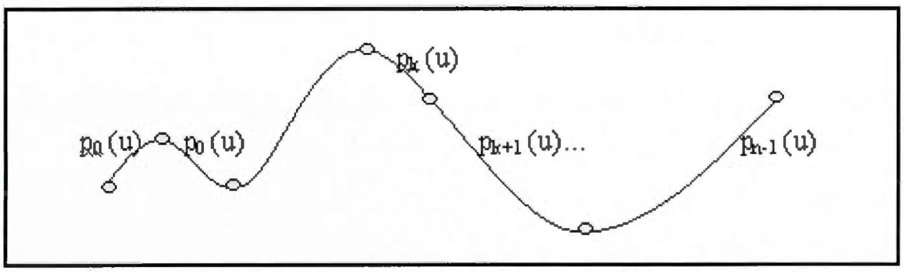


Figure.4.4 the cubic curve section [18]

Each cubic curve section in the spline is called spline section, and the point joining the two ends of the spline section is called node. Supposing the i^{th} node joins the $i-1^{th}$ section and the i^{th} section. This node is expressed by $p_{i-1}(1)$ or $p_i(0)$.

4.6.2 The cubic B-spline curve

B-spline curve is the gradual-section polynomial curve directed by the nodes, and is a kind of smooth and interpolated technology. B-spline curve is not necessary through the node (this kind of node is called the directing node). The cubic polynomial of B-spline curve is used most commonly, because the continuous degree of these spline curve rate is the lowest.

It is known that the sequence of the directing node is v_0, v_1 … v_{m+n}, m+n+1 nodes in total. The polynomial of the cubic B-slpine is as following:

$p_i(t) = B0\,(t)\,v_{i-1} + B_1(t)\,v_i + B_2(t)\,v_{i+1} + B_3(t)\,v_{i+2}$

$B_0(t) = (1-t)^3/6$

$B_1(t) = (3t^3-6t^2+4)/6$

$B_2(t) = (-3t^3+3t^2+3t+1)/6$

$B_3(t) = t^3/6$

Comprehensively, the expression of the i^{th} matrix is as following:

$$p_{i,3}(t) = [t_3 \quad t_2 \quad t_1] * 1/6 * \begin{pmatrix} -1 & 3 & 3 & 1 \\ 3 & -6 & 3 & 0 \\ -3 & 0 & 3 & 0 \\ 1 & 4 & 1 & 0 \end{pmatrix} * \begin{pmatrix} v_{i-1} \\ v_i \\ v_{i+1} \\ v_{i+2} \end{pmatrix} \quad , \quad 0 \leq t \leq 1$$

Then the position of the two ends of $p_{i,3}(t)$ is as following:

$p_{i,3}(0) = (v_{i-1} + 4v_i + v_{i+1})/6$

$p_{i,3}(1) = (v_i + 4v_{i+1} + v_{i+2})/6$

Take the condition of the free ends into consideration, i.e.:

$P''_{0,3}(0) = v_{-1} - 2v_{0} + v_1 = 0$

$P''_{m-1,3}(1) = v_{m-1} - 2v_{m} + v_{m-1} = 0$

Then we can get the two artificial points through calculation.

$v_{-1} = 2v_0 - v_1$

$v_{m+1} = 2v_m - v_{m-1}$

In this way, the B-spline curve with m sections is completely determined by m+1 points adding two artificial points v_{-1}, v_{m+1}, m+3 points in total.

To those closed equidistant B-spline that is easy to seen, there is the following:

$v_{-1} = v_m$, $\quad v_{m+1} = v_0$

Then

$p_i(0) = (v_{i-1} + 4v_i + v_{i+1})/6$

The corresponding matrix is as following:

$$1/6 * \begin{pmatrix} 4 & 1 & & & 1 \\ 1 & 4 & 1 & & \\ & \vdots & \vdots & \vdots & \\ & 1 & 4 & 1 & \\ 1 & & & 1 & 4 \end{pmatrix} * \begin{pmatrix} v_0 \\ v_1 \\ \vdots \\ v_{m-1} \\ v_n \end{pmatrix} = \begin{pmatrix} p_0(0) \\ p_1(0) \\ \vdots \\ p_{m-1}(0) \\ p_n(0) \end{pmatrix}$$

The algorithm of B-spline curve is as following:

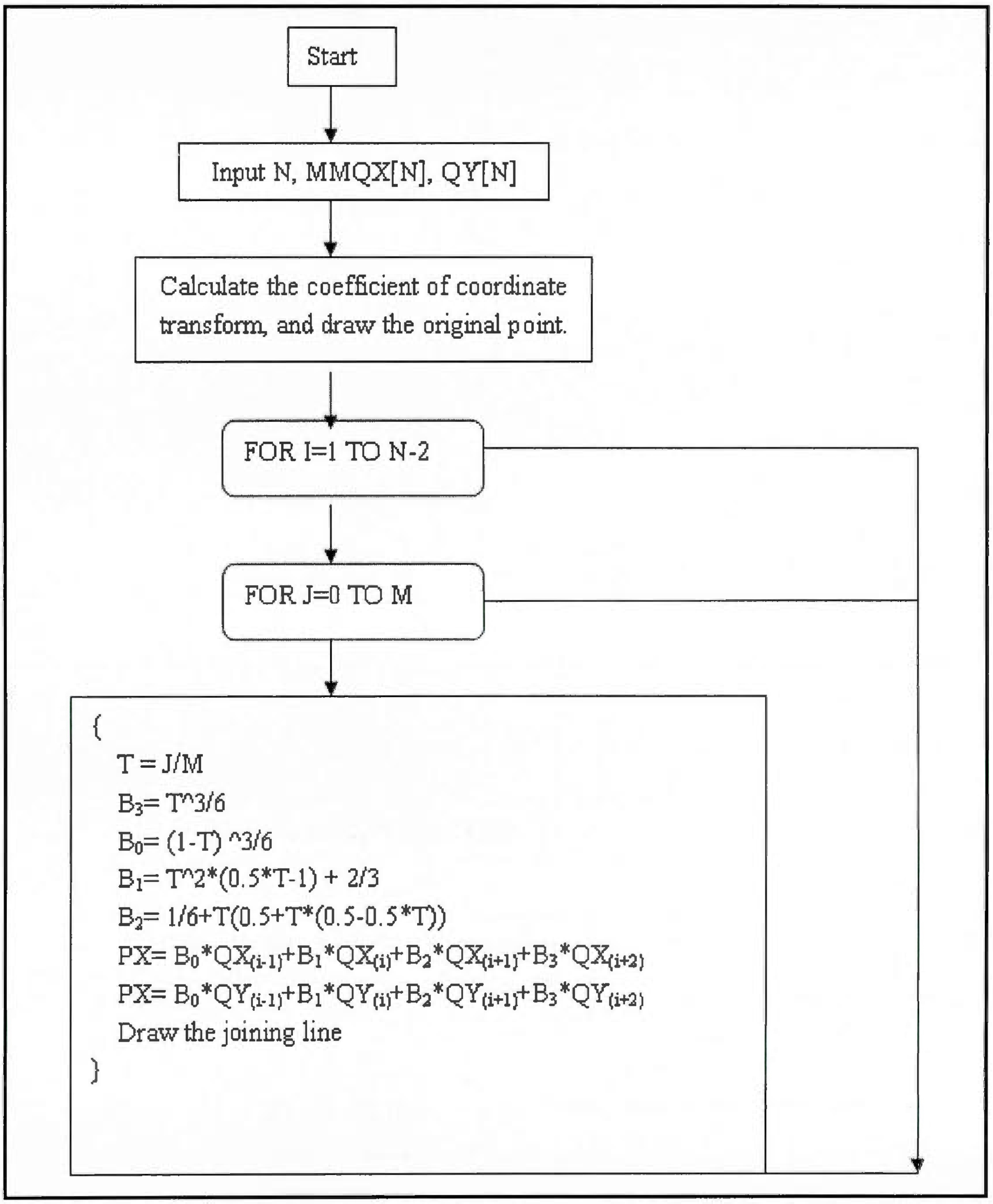


Figure.4.5 the algorithm of B-spline curve [18]

4.7 The Handling of the Hidden Line and the Hidden Surface

When people observe the opaque object in the space, there is only some parts of surface that can be reflected into human vision to become the part that are visible; the other parts is invisible because it is covered. The computer itself cannot automatically instinct the visible and the invisible parts. If this does not be handled specially, then, in the object figure produced by the computer, all parts of the object will be expressed. If it is like this, the shape will not be clear, even indefinite. Therefore, to draw definite cubic figure with strong the third dimension, it must eliminate the invisible parts of the object. This is the problem of 'hidden'.

4.7.1 The Planar Expression of the Cubic Model

The 3D point can only be displayed in the planar display. Even there are the cubic data, when displaying, it still needs transform the projection.

The method of projection transform is as following:

Taking the projection centre Oe(x, y, z) as view position, similar to the position coordinates of the observer's eyes, it can observe the shape from different angle by changing the coordinates of the projection centre; The normal vector of the observed plane is generally decided by Z axis of the observed coordinate system. And then, the formula of the 2D coordinates transformed from the 3D coordinates is as following:

$X' = X * (L-Z) + L$

$Y' = Y * (L-Z) + L$

L is the distance of view position in this layer. And (X, Y, Z) are the coordinates of some point in the object, and (X', Y') is the projection position in the screen. This process will be repeated in each display. Therefore, this function is realized by function OnDraw() of C++ of the kind of CView.

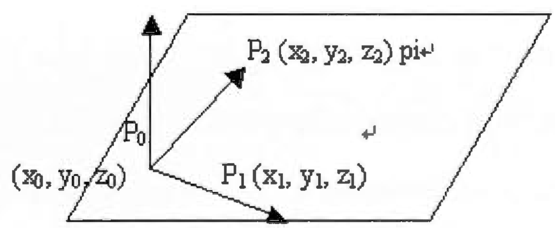
4.7.2 Solving the Normal vector and the Equation of the Plane

Once the display position is decided, the next problem to solve is the plane hidden. The outside normal vector of each cubic surface of the computer and its equation coefficient are the key parameter to judge whether this plane is 'forward' or 'backward' in the 'hidden'. The comparison of the depth through solving the intersection of the view line and the plane can determine the hiding relation.

There is a known plane π in the right-hand coordinate system.

$P_0(x_0, y_0, z_0)$, $p_1(x_1, y_1, z_1)$, $p_2(x_2, y_2, z_2)$ are three points not in the same line in the plane π. Then p_0p_1 and p_0p_2 are the normal vector in the plane π. Solving the cross product of these two normal vectors can get the normal vector N of the plane π as is shown in the figure:

Solving the normal vector of the plane:



$$P_0 P_1 = (x_1\text{-}x_0)\, i + (y_1\text{-}y_0)\, j + (z_1 - z_0)\, k$$

$$P_0 P_2 = (x_2\text{-}x_0)\, i + (y_2\text{-}y_0)\, j + (z_2 - z_0)\, k$$

$$N = P_0 P_1 * P_0 P_1$$

$$= \begin{pmatrix} i & j & k \\ x_1\text{-}x_0 & y_1\text{-}y_0 & z_1 - z_0 \\ x_2\text{-}x_0 & y_2\text{-}y_0 & z_2\text{-}z_0 \end{pmatrix} = Ai + Bj + Ck$$

Thereinto:

$$A=\begin{pmatrix} y_1-y_0 & z_1-z_0 \\ y_2-y_0 & z_2-z_0 \end{pmatrix}$$

$$B=\begin{pmatrix} z_1-z_0 & x_f-x_0 \\ z_2-z_0 & x_2-x_0 \end{pmatrix}$$

$$C=\begin{pmatrix} x_1-x_0 & y_1-y_0 \\ x_2-x_0 & y_2-y_0 \end{pmatrix}$$

Input the coordinate value of any point P in the plane π, and then we can get the equation of the plane π. For example, put the coordinates (x_0, y_0, z_0) of the point P_0 into the above formula, the equation we get is:

$$A(x-x_0)+B(y-y_0)+C(z-z_0)=0$$

Simplifying it into: $Ax+By+Cz+D=0$

Thereinto: $D=-(Ax_0+By_0+Cz_0)$ [6]

4.7.3 The Depth testing

When two graphs are mutually overlapped in the projection plane, they two must have the relation of mutual hiding. The one near the view position will cover the one far away from the view position. In order to judge the hiding relation between them accurately, it only can compare their respective distance from the view position. In the following, take the point and the plane polygon for example to explain how to judge the hiding relation between them.

Supposing the projection of the plane polygon in the projection plane contains the projection of the point P. It must be definite that whether the point P is in front of the polygon plane or in the back of the polygon plane (comparing with the view position). If point P is in back of the polygon, then it will be covered; otherwise, it will not be covered.

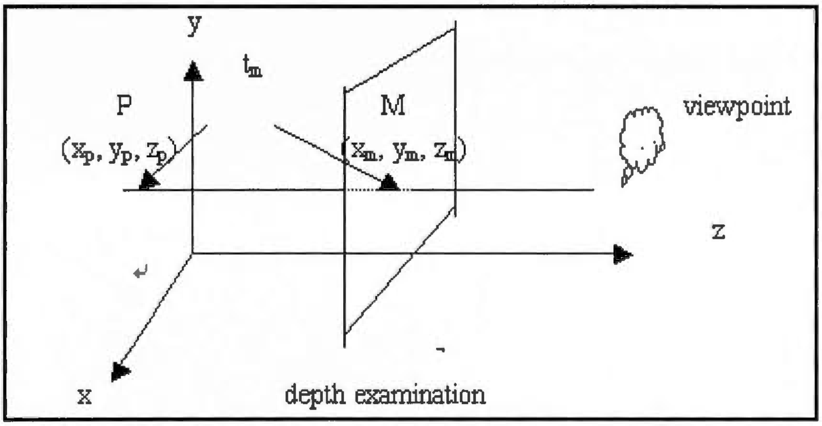


Figure.4.6 depth examination [6]

Draw a straight line L through the point P (x_p, y_p, z_p) to the direction of the view position. In order to handle conveniently, draw straight line L parallel to depth coordinate axis z, as the figure shows. This straight line L and the plane intersect at the point M (x_m, y_m, z_m). The equation of the straight line L's is:

$x=x_p$

$y=y_p$

$z=z_p+ t_m$

Then solve the equations of the straight line and the plane, and the value of the parameter t_m at M can be got:

$$t_m = -\frac{Axp + Byp + C * zp + D}{C}$$

When $t_m>0$, it means that the point P is in back of plane, and it is hidden by the plane;

When $t_m<0$, it means that the point P is in front of plane, and it is not hidden by the plane [6].

4.7.4 The Hidden Algorithm of the Cubic Plane

3D is encircled by many plane polygons. There is the normal in the plane which each polygon is in. People stipulate that the direction of the normal is from the inside of the 3D to outside. We call it outer normal.

Take x-y coordinate plane (V plane) in the computer screen as projection plane, the z axis as the depth coordinate axis. Now we need to output the cubic orthographic projection of the plane in this projection plane. At this time, the projection line (or the view line) must be parallel to depth coordinate axis z. Therefore, the angle between outer normal and the z axis is also the angle with the view line. According to the size of this angle, it is possible to judge the visibility of this normal in the plane.

1. Relationship between β angle and visibility

Supposing the included angle between outer normal and the z-axis is β. In the following, take the triangular pyramid for instance to explain the relationship between β angle and visibility, as the Figure 4.7 shows.

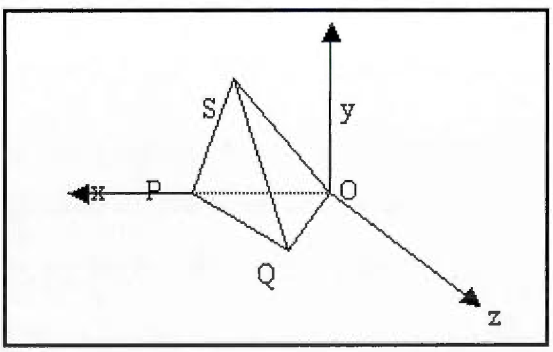


Figure 4.7 triangular pyramid [27]

1) When $0^0 \leq \beta < 90^0$, then $\cos\beta > 0$, here the projection of the outer normal of the plane in z axis has the same direction as the positive direction of z axis. Reflecting this to the space indicates that the outside surface of the polyhedron which is represented by this normal is toward to the viewer. We call this outside surface the forward surface, as □ SPQ and □ SQO in the figure.

2) When $\beta = 90^0$, then $\cos\beta = 0$, here the projection of the outer normal of the plane in z axis is zero. Reflecting this to the space indicates that the plane which this normal represents is parallel to the z axis, and the vertical projection is in the projection plane x-y. Therefore, projection in the projection plane gathers into a straight line, as □ OPQ in the figure.

3) When $90^0 < \beta < 180^0$, then $\cos\beta < 0$, here the projection of the outer normal of the plane in z axis has the same direction as the negative direction of z axis. Reflecting this to the space indicates that the outside surface which is represented by this normal is back to the viewer. We call this outside surface the backward surface, as □ SOP in the figure [27].

From the above three situations, we can see that the backward surface is invisible to the viewer, covered by the forward surface. Therefore it is invisible surface. And only if there is no other forward surface covering the forward face, it is visible to the viewer. Regarding the second situation, here the plane gathers into a straight line in the projection plane. We regard this as invisible.

So, the above three situations may be induced into two kinds of possibilities:

① When $90^0 \leq \beta \leq 180^0$, then $\cos\beta \leq 0$, the surface which the normal represents is invisible surface.

② When $0^0 \leq \beta < 90^0$, then $\cos\beta > 0$, the surface which the normal represents is visible surface.[27]

2. The calculating method of included angle β between outer normal and z axis

Supposing the outer normal of the surface

$$N= A_i +B_j+C_k,$$

Then $$\cos\beta=C/|N|$$

Because |N| is permanently positive, the sign of cosβ can be decided by the sign of C. Therefore, it will be OK to calculate the C and judge the sign of it.

Then the calculating formula of C as mentioned above is:

$$C= \begin{pmatrix} x_1-x_0 & y_1-y_0 \\ x_2-x_0 & y_2-y_0 \end{pmatrix}$$

Take three points not in the same line in each surface, and calculate the value C. if C>0, then this surface is visible; Otherwise, it is invisible. [27]

In the process of program, give the 3D coordinates of three points according to certain order (anti clockwise), and solve their normal vectors. Then judge whether the included angle between the vector of the view line and them is smaller than 90^0. If it is, then it is visible; otherwise, it is invisible. It can be seen that after the above transformation, the visibility can also be judged by (X, Y) coordinates, and the algorithm is as following:

```
sp=0;
sp1= x1-x0;
sp2= y2-y0;
sp=sp1 * sp2;
sp1= y1-y0;
sp2= x2-x0;
sp=sp-sp1 * sp2;
if (sp<0) return (TRUE);
else return (FALSE);
```

Among them, P_0 (x_0, y_0, z_0), P_1 (x_1, y_1, z_1), P_2 (x_2, y_2, z_2) are three points in a facet. sp, sp1, sp2 is the temporary variables. When sp is greater than 0, then it is visible surface; Otherwise, it is invisible surface. [27]

4.8 Coloring

For the sake of the stereo perception of the image, it is necessary to color the visible facets. In view of the specific information, considering the need of the HSV color model for large quantity of graphic library, this procedure adopts the RGB color model and most part of the development tool support this display modes directly. Here the vector method is used. Making use of three points, calculate the normal vector of this plane. According to Lambert cosine law, the luminance value of this plane can be calculated.

$A=y_1*(z_2-z_3)+y_2*(z_3-z_1)+y_3*(z_1-z_2);$

$B=z_1*(x_2-x_3)+z_2*(x_3-x_1)+z_3*(x_1-x_2);$

$C=x_1*(y_2-y_3)+x_2*(y_3-y_1)+x_3*(y_1-y_2);$

jiao=sqrt(C*C/(A*A+B*B+C*C)); [27]

in this formula ,(x_1 , y_1 , z_1)、(x_2 , y_2 , z_2)、(x_3 , y_3 , z_3) are the 3D coordinates of these three points. jiao is the cosine value of the normal vector of this plane.

According to Lambert cosine law, I=Ka*Ia+Ks*Il*cosα , Ka*Ia can be a definite value. So the cosα value can determine the intensity of this plane.

The formula of this procedure:

RGB(145+jiao*110,145+jiao*110,145+jiao*110); [27]

4.9 Summary

This chapter introduces the method of constructing 3D object from 2D contours. Making use of the principle of computer graphics, handle the discrete data of object boundary in different layer as following:

1) Constructing the 3D model. Dock the boundary points of the object in different layer to form the 3D object;

2) The geometry transformation of 3D figure. Including the 3D translating transformation, the 3D scaling transformation, the 3D rotating transformation, and the 3D projecting transformation;

3) Curve fitting to the boundary points of the objects in the different layer;

4) Handling the 3D display of 3D graph computer, including the handling of hidden line and hidden surface, and the handling of coloring. The chapter mainly introduces the planar expression of 3D model, solving the normal vector of the plane and the equation of the plane, the depth testing, the hidden algorithm of 3D plane and the handling of coloring.

The flow chart of the 3D reconstruction is as following:

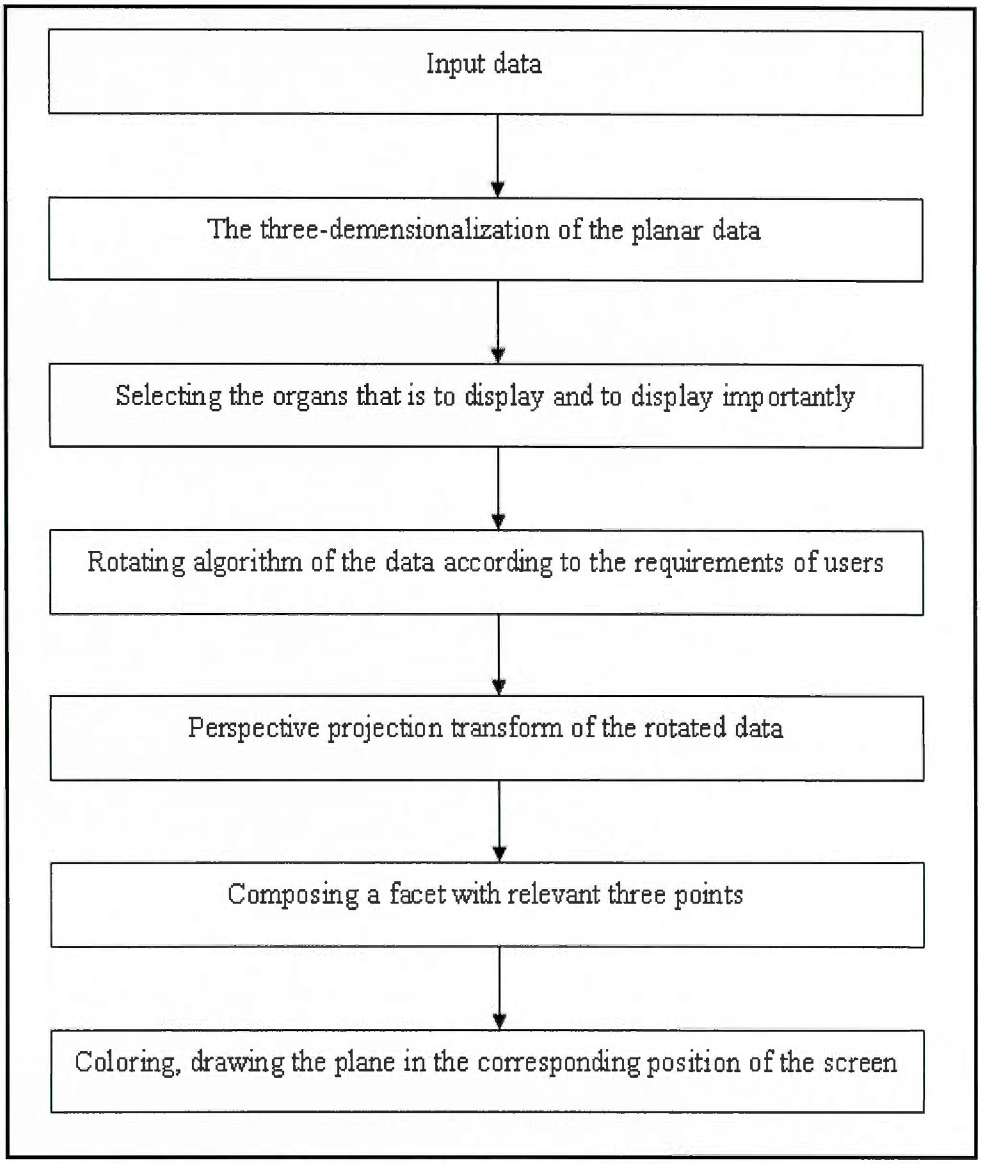


Figure 4.8 the flow chart of the 3D reconstruction

CHAPTER 5

DESIGN THE THREE-DIMENSIONAL RECONSTRUCTION SYSTEM OF TOMOGRAPHY IMAGE WITH OpenGL

5.1 The function of OpenGL in tomography image three-dimensional reconstruction display system

Along with the development of the computer technology, computer graphics has entered into the era of third dimension image. OpenGL is one of the main tools of making use of the computer to generate third dimension image. It is a 3D graphic library. The set of functions in this library becomes the complicated computer graphics algorithm such as all the curved surface model, image transformation, illumination, material, texture, pixel operation, anti-out of shape, etc [26].

The functions of OpenGL in CT image 3D reconstruction display system are as follows:

(1) Draw 3D object. OpenGL regards the acme as primitive, making up lines through the points, and constructing polygon through the lines and the topological structure. It uses the basic geometric graphs such as the point, line, and the polygon to draw the object figure needed in the CT observation.

(2)View the object. Making use of the OpenGL can establish personal view, and assign the observational angle, orientation and the size of the observational range. It is also possible to view every facet of the pathologic object and do the magnification and the deflation of the transformation.

(3)Appoint the color model. OpenGL uses specialized function and structure to appoint the color model.

(4)Illumination. The object drew through OpenGL can also be added lighting. This makes the drawn object resembles the real object very much.

(5)Enhance the effect of the image. OpenGL provides a series of functions to enhance the effect of the image. It can provide the subtransparent effect, thus bestow transparency on every tissue surface. Therefore makes possible to observe and measure the 3D figure of human organ surface and interior texture from different angles and different directions, offering great convenience to the study of the pathologic changes of human organ texture [23][24].

5.2 Planar data coordinates three-dimensionalization

The boundary of every object is composed of 360 points, which is to choose one point every other degree around the object center. These points are expressed by polar coordinates. The x and y coordinate of every point in the space can be determined by the polar angle and the polar length of this point, and can be corrected by physical center and the location of the anchor point. The formula is:

$$X_i = L_i * \cos\alpha_i$$

$$Y_i = Li * \sin\alpha_i$$

Z_i = the distance from that layer to the central layer

i is the number of the point, L_i is the polar length of boundary point correspondent to the polar angle α_i. [18]

5.3 Implement coordinate transformation with OpenGL

The coordinates system of windows is to take the top left corner of the window as the coordinate origin. The positive axis of axis x stretches to the right along with the horizontal direction while the positive axis of axis y stretches downwards vertically. But the coordinates system in the OpenGL is different. It takes the center of the window as coordinate origin. The positive axis of axis x stretches to the right along with the horizontal direction while the positive axis of axis y stretches upwards vertically, and the positive axis of axis z is normal to screen stretching outwardly [20]. The extraction of the Boundary data uses the coordinate system of windows operational system. In order to make the position displayed by 3D solid conform to the result observed from the CT image, the coordinates system must be transformed. That is to transform the object center coordinate from the position relative to that of in the windows coordinates system to the one relative to the central point in the OpenGL. Translate all the boundary points through the command - glTranslatef, and make the coordinate of the pathological changes center identical to the coordinate origin of OpenGL. [20]

5.4 Solid model building

After transforming the 2D coordinate of the planar data into 3D ones, the data will be changed into a series of discrete space points. These points can be operated through zooming, and rotation. But they cannot output the solid image in the display equipment. It is necessary to have a proper algorithm to model build these points. The simplest and most audio-visual way is to compose these points into lines, then compose these lines into plane, then from planes we get solid. I will divide the solid top surface and flank and draw them out respectively, thus ultimately the solid display is achieved.

5.4.1 Flank

The boundary of the object is extracted from layers. For the same object, the number of the point in every layer is the same, are all relative to the polar angle. So it is possible to joint the couple of points between adjacent layers and another couple of point's correspondent to the next angle together to form a quadrangle or a triangular. The rest may be deduced by analogy as what is shown in Figure 5.1: v_0~v_1~v_2~v_3 form a quadrangle and v_2~v_3~v_4~v_5、v_4~v_5~v_6~v_7...... etc. It can be deduced under the same principle. A loop of this kind of quadrangles are connected together to form banding circle. The adjacent circle is connected to form the flank of the solid. As shown in Figure 5.2.

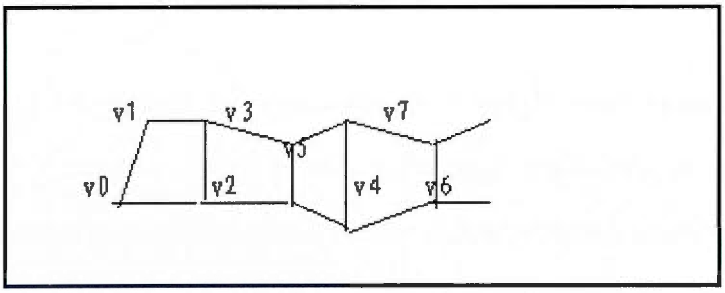


Figure 5.1 joint the points in the adjacent layers to form the quadrangle [26]

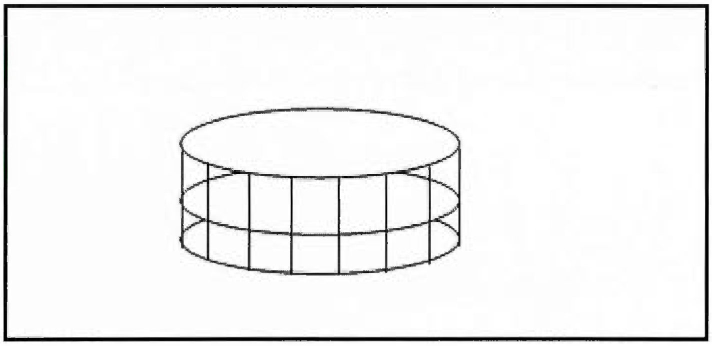


Figure 5.2 the graph of solid flank [26]

5.4.2 Top surface

For the convenience of observation, the top surface and the back surface of the object surface in the outermost layer are not displayed. In the pathologic changes and protection tissue, the boundary data of every layer is composed of three parts: center point, polar angle and polar length of the corresponding point. Jointing the center point and the two adjacent polar points in the boundary together to form a triangular, connecting the continuous triangles, approximately, there will be a sector. Use the command - glBegin (GL_QUAD_STRIP) in the OpenGL to draw 360 triangles, as what is shown in Figure 5.3.

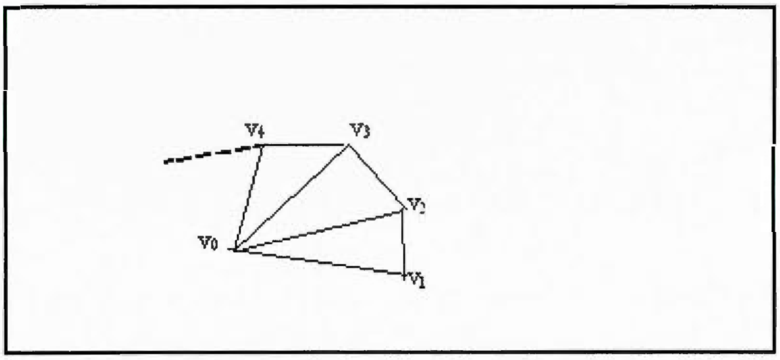


Figure 5.3 360 sectors [26]

5.5 Implement solid rotation with OpenGL

Though the solid image is formed, the display in the screen is just one flank of this object. The figure of the rear face is eliminated due to hidden. In order to make the doctor know the figure of the object in detail, the object must be observed from each flank, thus there is the solid rotation.

in this system, three variable: are defined α、β、γ represent respectively the angles rotating round axes x, y, and z. In the initialization, give initial value to α、β、γ,

$\alpha=225$ $\beta=0$ $\gamma=0$

It is to agree with the visual habit to suppose the initial value of α is 225^0. Complete the rotation transformation through the command - glRotate in OpenGL. This step must be completed before the drawing of the graph.

There are four parameters in function - glRotate: the first one stands for the angle of rotation; the other three can be set as 1 or 0. If the second parameter is 1, it means rotating around axis x; if the third parameter is set as 1, it means rotating around axis y. If the fourth parameter is set as 1, it means rotating around axis z. [23]

5.6 Projections

In the process of radiate therapy, the doctors must get the projection graph of ray exposing pathological changes in order to master the shape of pathological changes from different direction. In order to realize this function, inaugurate a space in the window to draw the projection graph of object with pathological changes. The projection of pathological changes is vertical with the screen which enables the doctors to master the shape of the projection.

Solve the projection graph along some direction using the method of coordinate rotating the object with pathological changes. First, rotate the object with pathological changes in order to make the ground of the object with pathological changes parallel to the x-y plane as the Figure 5.4 shows. α is the included angle between the incidence line in the anticlockwise direction and the positive direction of x axis. Rotate the cubic certain angle to make the plane that is vertical with α incidence direction parallel to the screen. And then we can see the projection graph. The steps of rotation are as following:

1) Rotate the coordinates of the boundary point of the pathological changes $90\text{-}\alpha^0$ along z axis anticlockwise to make the projected plane parallel to x axis.

2) Rotate the coordinates of the boundary point of the pathological changes 90^0 along x axis anticlockwise.

In the Figure 5.4, the round stands for the underside of the solid, and α stands for the incidence line, and AB stands for the plane vertical to α.

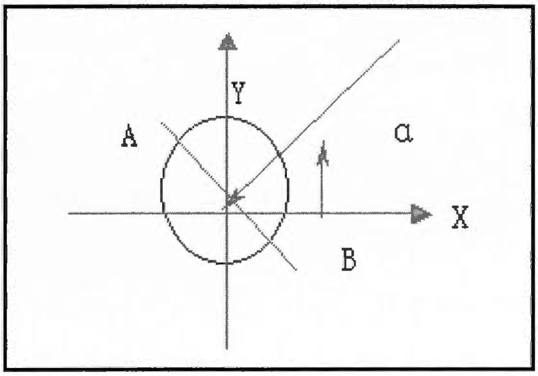


Figure 5.4 the Projection Algorithm [7]

5.7 Summery

This chapter introduces the design method to realize the 3D reconstruction system of tomography image with OpenGL. The contents include:

1) The function of OpenGL in the 3D reconstruction system of tomography image.

2) The three-dimensionaliztion of the planar data coordinates.

3) Realizing coordinate transform with OpenGL.

4) Realizing solid rotation with OpenGL.

5) Projection.

CHAPTER 6

THE RESULTS OF 3D RECONSTRUCTION

6.1 Flow of 3D reconstruction

1) Input data
2) 2D data's three-dimensionalization
3) selective display and pivot display apparatus
4) carry out the rotation operation on data according to user's demands
5) carry out the perspective projection transformation on the rotated data
6) correlated three points form a facet
7) coloring; draw the facet on the screen's corresponding location
8) take the next apparatus' data

6.2 The results of 3D reconstruction

Practically, using computer graphics can implement all kinds of functions in this project. But to implement tomography images 3D reconstruction with OpenGL provides method of high efficiency, high quality and high performance. The effect is significant. As what is shown in Figure 7.10, 7.11 and 7.13. Along with the development of the computer technology, computer graphics has entered into the era of third dimension image. OpenGL is one of the main tools of making use of the computer to generate third dimension image. It is a 3D graphic library. The set of functions in this library becomes the complicated computer graphics algorithm such as all the curved surface model, image transformation, illumination, material, texture, pixel operation, etc. from drawing any simple 3D object to mutual dynamic scene, OpenGL can help the programmer complete these tasks in high efficiency and help the programmer get rid of the tedious cockamamie programming with a better result.

CHAPTER 7

INTRODUCTION OF THE FUNCTION OF CT TOMOGRAPHY IMAGE 3D RECONSTRUCTION SOFTWARE

7.1 Boundary extraction

1. New case history

The main function of new case history system:

Collect image→spread image→ get the anchor point→collate image→calibrate image →extract periphery boundary→extract target boundary→save boundary data→cross section image

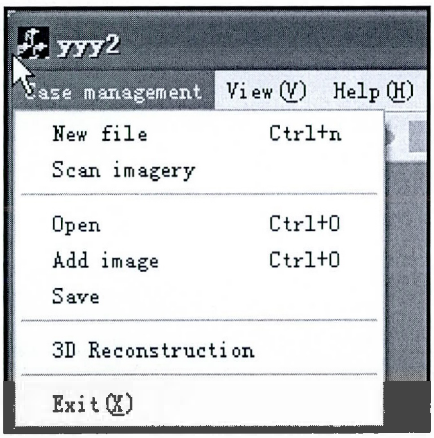


Figure 7.1 case history management menus

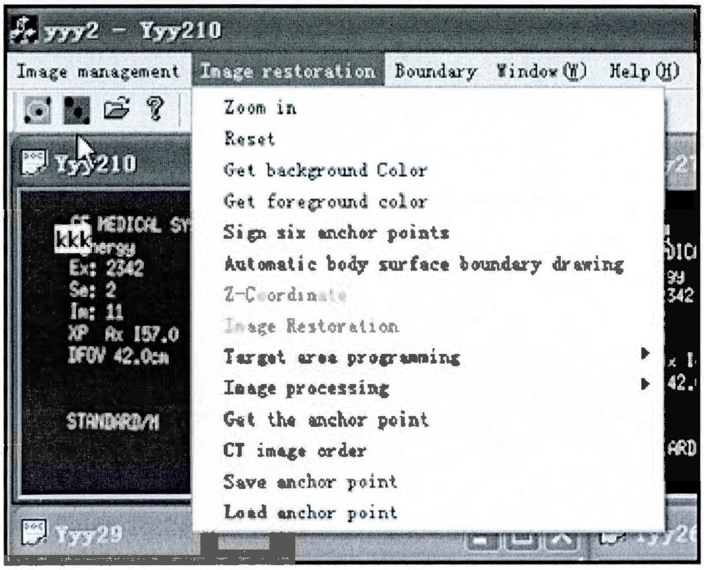


Figure 7.2 boundary extraction system menu

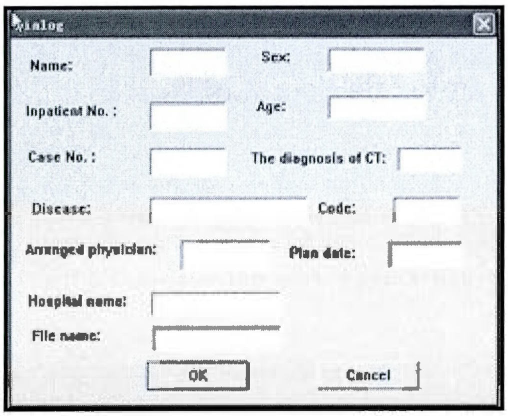


Figure 7.3 dialog block of inputting case information

1. The function of new case history system menu is displayed as Figure 7.1 and 7.2.

2. Input information such the name of the case into the new case history dialog block Figure 7.3, the system will create file for that case automatically. Every case will have the file as Figure 7.4 shows, and the file will be named by the name of the case with five sub-files inside.

Figure 7.4 the file generated by each case

1)original CT image catalog c:\\name\\CTBMP

2)ct image catalog whose boundary has been circled c:\\name\\BMP

3)boundary data catalogue c:\\name\\ctdata

3. Input all the ct images of the case into c:\\name\\CTBMP by scanning instrument

4. Create 9*4 windows; spread the image by 9*4 or 10*4 every row and line. Under the resolution factor of 800*600, suppose every window is 90*90, as shown in Figure 7.5.

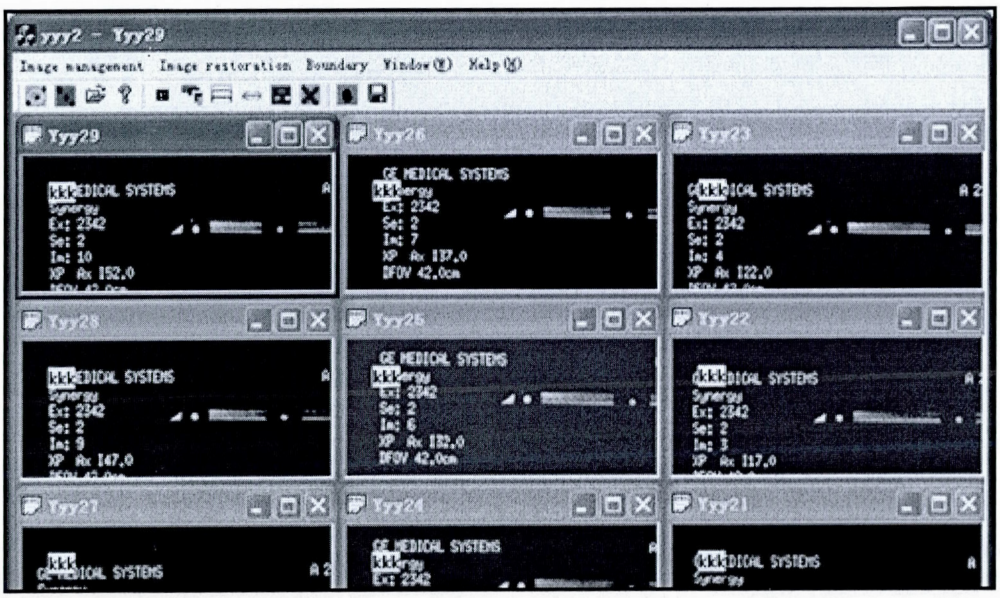


Figure 7.5 spread the image on the screen

5. Display an image in every window.

6. Single click the window can enlarge the window to 480*500

7. After inputting the information of the case into the computer then choose the case and deal with the 2D tomography image.

Choose the ct image of a certain case to deal with. As shown in Figure 7.6.

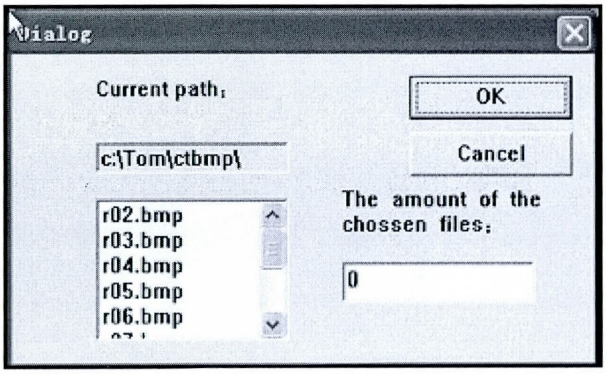


Figure 7.6 choose the ct image to deal with

8. Choose the anchor point; give every picture a centre of the three anchor points. Calculate the coordinate of z.

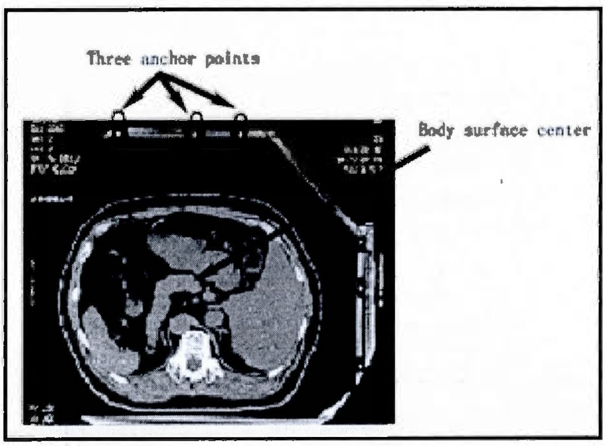


Figure 7.7 body surface boundary automatic extraction schematic diagram

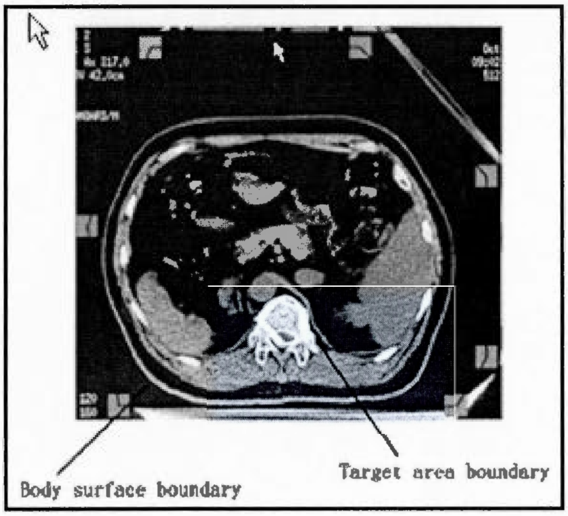


Figure 7.8 body surface boundary automatic extraction display image

9. Automatic body surface boundary detection. Computer draws automatically without manual work as what are shown in figure 7.7 and 7.8.

10. The display of image section plane both vertically and horizontally

Get the pels of the cross section of the image, display the horizontal and vertical section after the 2D tomography image interpolation.

7.2 Construct 3D object from 2D contours with OpenGL

The menu function of this part is shown by Figure 7.9. The main function include giving 3D reconstruction display to the boundary data of every layer, displaying the 3D object inside transparently through the body surface, rotating the 3D object around axles x, y and z round the center of the target, giving 360^0 projection to the target under any angle.

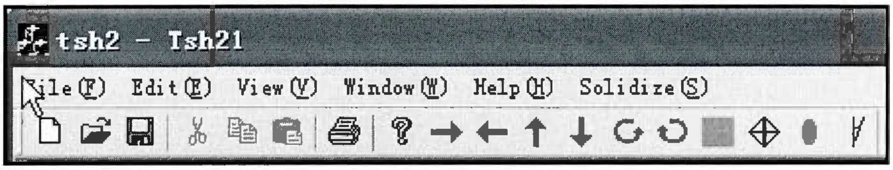


Figure 7.9 the menu of reconstructing 3D object with OpenGL

1. 3D reconstruction display as shown in Figure 7.10, 7.11 and 7.13

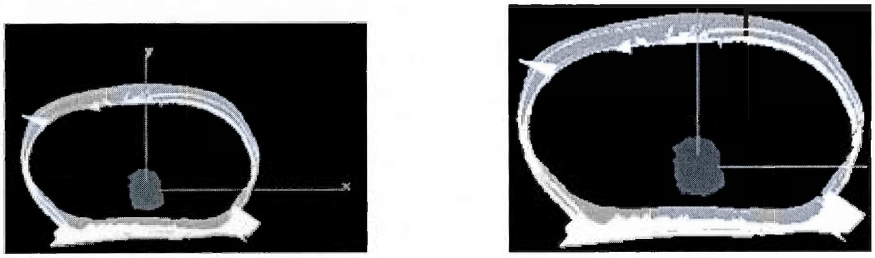


Figure 7.10 3Dreconstruction display image

2. Rotate round axles x, y and z under any angle as shown in Figure 7.11.

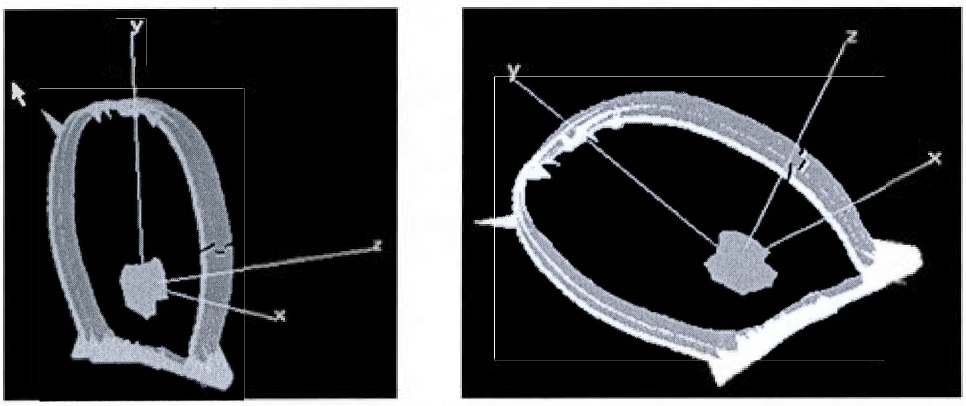


Figure 7.11 solid rotatiion display image

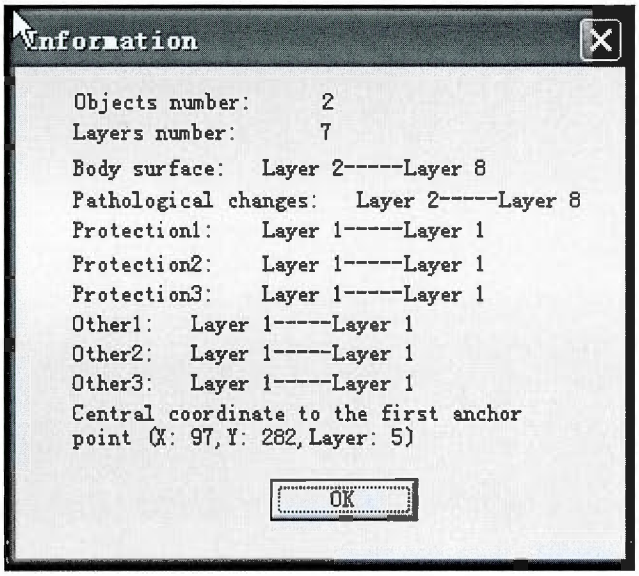


Figure 7.12 3D reconstruction information dialog box

3. Give a 0 to 360^0 domain projection to the target around axle z as shown in Figure 7.13.

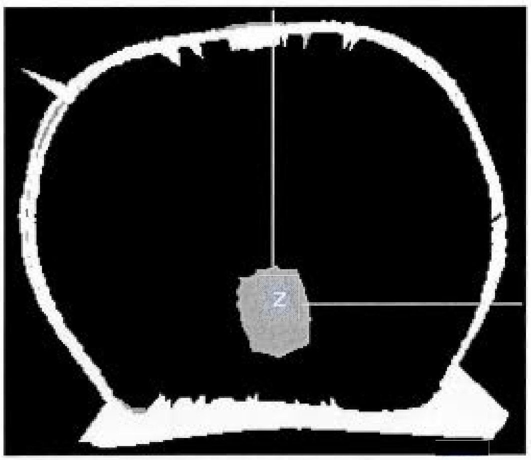


Figure 7.13 display of projection to the target area

4. It is possible to display the rotation of the object around axles x, y, and z.

7.3 Reconstruct 3D object from 2D contours with computer graphics

The main functions of this part are:

Geometric transformation of 3D graphics includes 3D translation transformation, 3D scale transformation, dimension rotation transformation, 3D projection transformation. Actualize 3D reconstruction by 2D contours through computer graphics application.

1. The function of systematic menu is displayed by Figure 7.14.

Figure 7.14 the menu function of computer graphics 3D reconstruction

3. Choose tomography image, as what is shown in Figure 7.15.

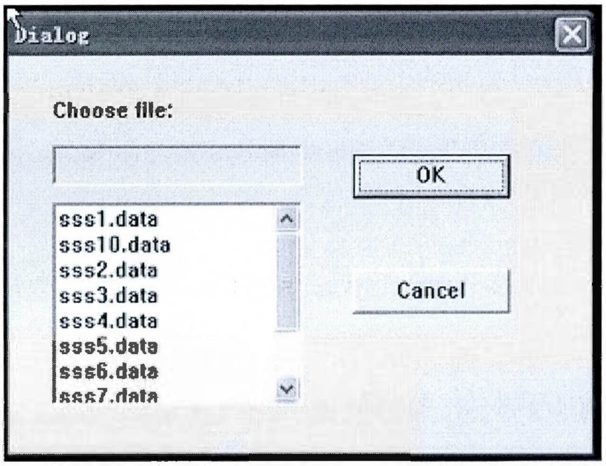


Figure 7.15 choose tomography iamges

4. 3D reconstruction display, as what is shown in Figure 7.16,7.17

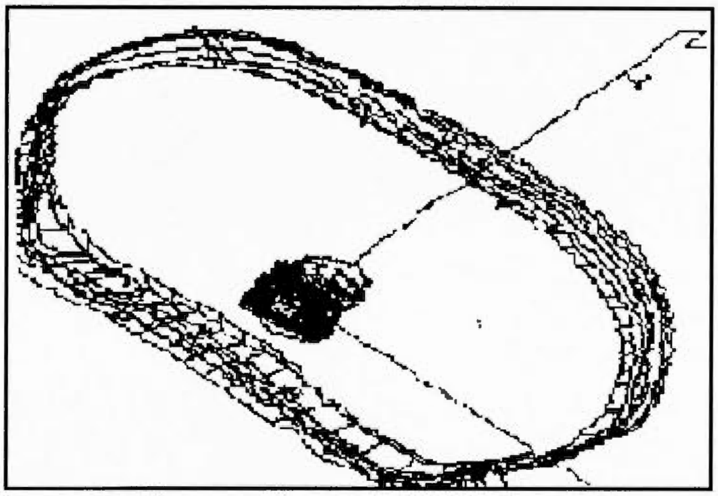


Figure 7.16 the solid display of the periphery and pathologic changes

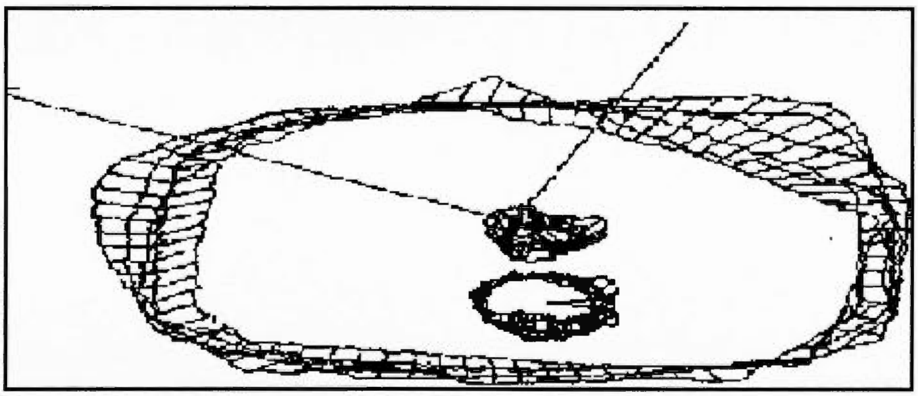


Figure 7.17 the solid display of periphery, pathologic changes and protective tissue

7.4 Conclusion

This system get the boundary data of the key object in the 2D tomography image of many layers and use two ways (computer graphics and OpenGL) to form the 3D entity. It makes the object able to circle around the x, y and z axles round the centre of the target. And at the same time it also actualize the function of object projection, which can irradiation under any angle, get the sectional projection image of the target and observe the shape of the object in the target at any position precisely so that make the observer able to observe the object under any angle and know the solid shape, size and position of the target, which will help to find the solution and provide base to the radiotherapy.

CHAPTER 8

CONCLUSION AND PROSPECTS

8.1 Thesis Conclusion

The study of this research refers to image processing programming, graph processing programming and all kinds of algorithm. Under the developing circumstances of visual c++, I first of all actualize the boundary extraction of 2D tomography image. Then I use two methods to actualize 3D reconstruction. One is to us visual c++ simply to carry out the graphic processing algorithms; another is to use the ready graphic processing function provided by OpenGL to actualize the graphic processing algorithms. The reason why I use OpenGL to implement 3D reconstruction is because of the powerful graphic processing function of it. And at the same time, I also sense that it is not perfect to use visual c++ simply to handle all the graphic processing algorithms since it is a heavy task and the result is not ideal.

After the comparison of these two results it can be known that using visual c++ to actualize every algorithms of graphic processing simply is better for the x ray enveloping of the target and statistical distribution calculation situation; the result is better when using the ready graphic processing function of the OpenGL to actualize the graphic processing algorithms.

Through the development of this project, the ability of image and graphic processing increases, so does my computer programming ability.

8.2 Next work and expectation

The technology of volume visualization develops greatly in the recent 10 years and has a compelling accomplishment. But it still remains in the stage of developing. With many questions requiring further study, I still have a lot of work to do.

1) Keep on doing research in the area of image and graphics disposal.
2) Doing further study in edge distribution and edge description.
3) Doing further study in volume visualization technology.

REFERENCE

[1] Chen Jianchun. *Visual C++ Higher Program Technology—the Analysis of the Developing Cases.* Electronics Industry Press, 1999.

[2] Cui Yi. *The Technology and Application of the Digital Image processing.* Electronics Industry Press, 1997.

[3] Donald Hearn, M. Pauline Baker. *Computer Graphics.* Electronics Industry Press, 1998.

[4] D.W.Townsend. *Image Reconstruction for Medical Application.* Advances in Computer Graphics 4 Spring-Verlag. 1991.

[5] G.T.Herman. *Three-Dimensional Display of Human Organs from Computed Tomograms.* Computer Graphics Image Processing. Vol.9.1979.

[6] Guan Weiguang. *The Technology and Application of the Volume Visualization.* Electronics Industry Press, 1998.

[7] Guan Weiguang. *The Visualization of Volume Data and its Application in Medical Field.* The fourth volume. The thesis of doctor's degree in China science Chinese Academy of Sciences Institute of Automation.

[8] Guan Weiguang, Ma Desong. *The Visualization Technology of 3D Volume Data. CT Theory and the Application Research.* The fourth volume. The first periodical, 1995.

[9] Jia Yunde. *The machine vision.* Science Press, 2000.

[10] Li Jiegu. *The Theory and Application of the Computer Vision.* Traffic University Press, 1991.

[11] Lv Weixue. *The Medical Image processing.* Higher Education Press, 1989.

[12] M. Frubauf. *Combing Volume Rendering with Line and Surface Rendering.* EUROGRAPHICS' 91.

[13] Peng Xiaoming. *Open GL Deep Program and the Secret of the Case.* Electronics Industry

Press, 1999.

[14] R.C.Gonzalez, R.E.Woods. *Digital Image Processing.* Addison-Wesley(1992).

[15] R.C.Gonzalea, R.E.Woods, S.L.Eddins. *Digital Image Processing Using MATLAB.* Prentice Hall (2003).

[16] Rong Guan'ao. *The Computer Image processing.* Tsinghua University Press, 2000.

[17] Shi Jiaoying, Can Wenli. *The Algorithm and the System of the Visualization of Science Calculation.* Science Press, 1996.

[18] Tang Zesheng. *The Visualization of the 3D Data.* Tsinghua University Press, 1999.

[19] Tang Zesheng. *The application of the Visualization of Science Calculation.* www.ccw.com.cn (computer world network).

[20] The Creative Group of Moonlight in Lotus Pond. *How to Use OpenGL Developing Program.* Beijing Institute of Technology Press, 1999.

[21] Wang Jifen, Zhang Xinrong. *Computer Image Recognition.* China Railway Press, 1988.

[22] Wang Xufa, Zhuang Zhenquan, Wang Dongsheng. *The Design of C Language Image processing Procedure.* China Science and Technology University Press, 1994.

[23] Wu Bin, Bi Liyun. *The Case and Technique of Open GL Program.* People Post and Telecommunications News Press, 1999.

[24] Wu Jiankang. *The Analysis of Digital Image.* People Post and Telecommunications News Press, 1989.

[25] Xia Liangzheng. *Digital Image processing.* Southeast University Press, 1999.

[26] Xiang Shiming. *Open GL Program and the Case.* Electronics Industry Press, 1999.

[27] Xu Longwen. *Computer Drawing.* Machinery Industry Press, 1989.

[28] Yang Shuying, You Zheqing. *Research Construction of 3D Model Based on CT Images, First International Conference on Image and Graphics* August, 16-18, 2000:p512-515.

[29] Zhang Minjin. *The Image Understanding and the Computer Vision.* Tsinghua University Press, 2000.

[30] Zhong Yuzhuo, Qiao Bingxin, Li Shuqing. *The Visual Technology of the Robot.* The defense Year Press, 1994.

[31] Zhou Changfa. *Master Visual C++ Image Program.* Electronics Industry Press, 2000.

[32] Zou Beiji. *The Principle and Application of the Computer Graphics.* Hunan University Press, 1989.