New techniques of determining focus position in gamma knife operation using 3D image reconstruction

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ABSTRACT

In this paper, new techniques of determining focus of a disease position in gamma knife operation is presented. In these techniques, the transparent 3D color image of human body organ is reconstructed using a new three dimensional reconstruction method, and then the position, the area and the volume of focus of a disease such as cancer or tumour are calculated. They are used in gamma knife operation. The processes is following the CT pictures are inputted into digital image processing system. The useful information is extracted and the original data are obtained. Then the transparent 3D color image is reconstructed using these original data. By using this transparent 3D color image, the positions of human body organ and focus of a disease are determined in a coordinate system. While the 3D image is reconstructed, the area and the volume of human body organ and focus of a disease can be calculated at the same time. It is expressed through actual application that the positions of human body organ and focus of a disease can be determined exactly by using the transparent 3D color image. It is very useful in gamma knife operation or other surgical operation. The techniques presented in this paper has great application value.

Keywords: Y-knife, focus of a disease, focus position, CT picture, 3D stereo image, 3D reconstruction, transparent image

2. INTRODUCTION

As the development of medical techniques, some brain disease is treated by using Y-ray (or Y-knife). It provides a new efficient treatment method to deal with the difficult disease such as brain cancer or brain tumour.

During the treatment processes by using Y-knife, one of the key techniques is how to determine the positions of organizations and focus of a disease in human head, and the position relationship between organizations and focus of a disease, and the region size of focus of a disease. So that the focus of a disease can be cut exactly not to effect other normal organizations. In this paper, we use digital image processing method to determine the positions of organizations and focus of a disease.
and position relationship between them. The original basis is its CT pictures. We can set up a coordinate system and some control points in this coordinate system in advance. When we take the CT pictures, put them all together. Because the three dimensional coordinates of control points are known, we can set the relationship between organizations and focus of a disease inside human head and coordinate system by using these control points.

However, every CT image contains only two dimensional information. Here we need three dimensional coordinates of position of organizations and focus and relative three dimensional information. So we must combine these CT images and extract their three dimensional information. Using these information, we can calculate the three dimensional coordinates. So the problem of 3D stereo image reconstruction has arisen. It includes that extract useful information of every CT image, reconstruct 3D stereo image of human head and organizations inside it and the focus of a disease.

In order to determine the positions of organizations and the focus of a disease and the position relationship between them, a relative three dimensional reconstruction method is presented in this paper. In this method, first, input CT pictures into digital image processing system, make segment for these image using contour segment method, and extract the regions of organizations and focus of a disease. After giving color codes for organizations and focus, we can fill these regions, separate the useful information from useless information. Then, we organize the information into data files using Color Run-Length Encoding method. So that it can be used in later processing. At last, we can reconstructed 3D image. It includes projecting, moving, and rotating image. Using transparent techniques, we can make some organizations transparent, and other untransparent. So through the surface of human head, we can observe and measurement the shapes and sizes of organizations and focus of a disease. Using the 3D stereo image and the control points, we can calculate the coordinates of focus of a disease, and measurement the position relationship between organizations and focus of a disease. When we extract and fill the region of focus, we can calculate its area and volume. Using the three dimensional coordinates and size of focus, we can make the γ-knife surgical operation project.

In this paper, the computer program system is made according to the method above. It can be used conveniently on ordinary computer or work station for image processing. It is expressed through actual application that the method presented in this paper is correct, and the results are reliable. Using this method, we can determine the shapes and positions of organizations and focus exactly. At the same time, we can calculate the areas and volume of focus. The techniques of determine position and size of focus in γ-knife surgical operation has important application value.

3. THREE DIMENSIONAL STEREO IMAGE RECONSTRUCTION

Before we reconstruct 3D image for human head, we must get useful information from its CT pictures, and organize data files, and process them. The work includes that input original CT pic-
tures into digital image processing system, segment image, extract useful information, smooth data and create data files.

3.1 Get Information

3.1.1 Image Segmentation

After inputing the original CT picture into digital image processing system, we use mouse or track-ball to draw the regions of human head and the organizations inside it, and give color codes for each region. After filling these regions, we obtain color code images.

When filling regions, we use two-pass filling algorithm. First, all pixels are checked sequentially according to scanning line from top to bottom and one line to another. Every pixel on a scanning line is processed from left to right. According to the relationship between the pixel on last line that has just been classed and the pixel of this line, we set suitable class to the pixel that is processing. The pixels that are in same class are given same color code. This code is given by user interactively. At last, all pixels on whole image are processed. We obtain color code image. The second pass is that write the class codes of all pixels into suitable position of image array.

3.1.2 Data Interpolating and Surface Fitting

For CT images, the size of pixel is much smaller than the distance between slices. We need to interpolate data and fit surface to obtain 3D stereo image accurately. Here two direction interpolations should be considered. They are weft and warp.

Actually the images which are segmented and extracted are a set of outlines. The weft interpolation is between two outlines. The frequency of interpolation depends on necessity. There are four situations in weft interpolation, coincidence, inclusion, intersection and separation. For each situation, we use different formula to interpolate the data. After weft interpolation, we can make warp interpolation\(^1\).

3.1.3 Calculate Area and Volume of Organizations

For each slice image, we can calculate the number of pixels in the region of organization. After inputing scale, we can calculate the area of this organization on this slice. When giving the distance between two slices, we can calculate the volume of whole organization.

3.1.4 Data Organization

In order to reconstruct 3D color image, we need a better data structure. In this process, we must compress the unuseful data and reserve useful data, so that it is convenient to be found for 3D reconstruction. Here, we use color Run-Length Encoding algorithm. The process as following.

We use different color code to express different organization on every CT picture and obtain slice data expressed by relative color code, and then use color run-length code to encode these slice data. At last, we gain slice data expressed by color run-length code. Here we define that background color is zero and the code of object is positive. After obtaining color run-length code, we use following method to organize data and save these data to files. Three data files, 3DMID, 3DRID, DAT consist of these data. Every line of object is expressed by coordinates of two end
points and color codes. All lines are written sequentially into data file DAT. When we process the
data of original CT pictures, we use follow method to obtain lines from left to right on every row
(i.e. we obtain run-length encode). The number of slices and pointers that have been processed
are given in the head of main index file 3DMID. These pointers provide relative information in later
processing. So all CT pictures can be processed in several times. The user can watch the middle
result if he wants when all slices have not been finished. The information of slices that have been
processed is saved in the other parts of main index file. This information includes the data blocks
of every slice, the lines that include object. Row index file 3DRID provides the number of lines in
every row and the information of pointer. It is very convenient to visit the data of every slice and
every row when this information combines with main index file. It is very useful for reading data
in any sequence by using this data structure. It is also very convenient to be use in remove hidden
algorithm BTF and FTB.

The start address of line in every slice and every row in file DAT is provided in following
means.

\[ \text{FDBRec} + \text{OFTPtr} + \text{FDRec} \]  

where,

FDBRec is provided by the recording of slice in main index file;
OFTPtr and FDRec is provided by file 3DRID. The position of row recording is provided by the
start address plus a displacement in file 3DRID.

3.2 Three dimensional reconstruction

As above, through processing for every CT picture, we gain useful information. After organizing
data using Color Run-Length algorithm, we can reconstruct 3D image of human head and organi-
zations inside it. As so far, there are some 3D reconstruction method. A large part of them gives
only black and white image. In some cases, it is very difficult to separate the organizations of organ.
Further more, we can only observe the surface of organ by using this black and white image. It is
difficult to meet the needs of actual medical image processing. In order to solve this problem, a new
three dimensional reconstruction method is presented in this paper using color 3D reconstruction
and transparent techniques. We display 3D surface of human head, at the same time display the or-
ganization inside it. So we can observe and measurement the sizes and shapes of the organizations
and the relationship between them.

3.2.1 The formation of three dimensional image

When we process every CT picture, we must draw the regions of human head and organizations
inside it, and give them suitable color codes, so that we can separate them each other. Now we can
repeat addition every slice from far to near or from near to far. So we can obtain a three dimensional
object. In order to display it on screen, first, we must transform it from object space to image space,
and then project it on 2D screen, at last gain stereo image. This process is called image transformation. It includes coordinate transformation, window transformation, vision port transformation and geometric transformation. The geometric transformation includes moving, scaling, and rotating.

3.2.2 Remove hidden

The stereo image obtained by transforming from object space to image space must be processed by removing hidden. Otherwise the image will be out of order. Here we use FBT algorithm to do this.

The main ideal of FBT algorithm is to process whole object from front to back. In this process, the distance to screen is increasing. First, write the projection of every voxel into a two dimensional array. Before this step, we must check whether the relative element of this two dimensional array has been written or not. If it has been written, this mean that this voxel is invisible, otherwise it is visible, and we must write it to the array. When the process has completed, the data in this array are the depth value of visible surface. This is depth image. However, this removing hidden algorithm has lower efficiency. The main cause is that we must check everytime before we write the projection of voxel into the array.

In order to improve the original FBT algorithm, we combine dynamic chain table with original FBT algorithm. After using dynamic chain table, an object segment that is composed of several voxels need only to compare two end points with the content of relevant scanning line chain table. The more the object segment, the higher the efficiency of this algorithm compared with the old, and as the pixel is written in image, the segment of image is reduced, and the checking times are reduced.

3.2.3 Shading for 3D image

For a realistic 3D image, an image of hidden removed should be shaded. First, we must set up lighting mode.

There are many lighting models. Here we use the one as following

\[ I = (I_1 - I_\ast)(\cos \theta)(1 - d/D) + I_\ast \]  

(2)

where

\[ I \] is reflecting intensity;
\[ I_1 \] is the intensity of light point;
\[ I_\ast \] is diffuse reflection intensity;
\[ \theta \] is angle between the point on object surface and light point;
\[ D \] is the distance when intensity is zero (not consider \( I_\ast \));
\[ P \] is a constant.

From the lighting model, we know that for shading 3D image, we must calculate the normal-vector of object surface at first, we use image space method to do this.

After removing hidden surface, we obtain a depth image. The grey value of each pixel corresponds to a Z value of point on visible surface in image space. We use \( Z = Z(x, y) \) to express the visible surface. \( x, y, z \) are the coordinates of visible surface in image space. Through calculating \( \frac{\partial Z}{\partial x} \),

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\( \frac{\partial z}{\partial y} \), we can obtain the normal-vector by using following formula

\[
\mathbf{\hat{N}} = (\frac{\partial z}{\partial x}, \frac{\partial z}{\partial y}, -1)
\]  

so we can get

\[
\cos \theta = \frac{\mathbf{\hat{L}} \cdot \mathbf{\hat{N}}}{\| \mathbf{\hat{L}} \| \cdot \| \mathbf{\hat{N}} \|}
\]

where

\( \theta \) is the angle between light point vector and normal-vector;
\( \mathbf{\hat{L}} \) is the light point vector;
\( \mathbf{\hat{N}} \) the normal-vector.

We can calculate the grey value of pixel with formula (2).

Because we have not the exact formula of \( Z = Z(x, y) \), we only have discrete data, so we must use finite-difference approximations to calculate \( \frac{\partial z}{\partial x}, \frac{\partial z}{\partial y} \).

3.2.4 Transparent processing

As above, we suppose that all organizations inside the head are visible. We calculate the grey of every visible surface. In transparent processing, we calculate the grey of every pixel using following formula.

\[
I = K I_1 + (1 - K) I_2
\]

where

\( K \) is "Transparent Degree" of surface, \( 0 \leq K \leq 1 \), when \( K = 0 \), the surface is transparent, when \( k = 1 \), the surface is not transparent;
\( I_1 \) is the intensity of a point on surface;
\( I_2 \) is the intensity of a point on organization inside organ;
\( I \) is the intensity of a pixel displayed on screen.

3.3 Display color image

After shading, we gain a mono-color 3D image. Using this 3D image, the grey and color code of every pixel, we can calculate the color intensity of relative pixel. We give the color code to the relative color, and then we can calculate all intensity of a color. The intensity of all colors are reserved in a look up table (this table is composed of three tables, luto R, luto G and luto B. The corresponding color is red, green, and blue). Through this process, we can display transparent color 3D image of human body organ and the organization inside it.

4. DETERMINING POSITION OF FOCUS

Because we set up a three dimensional coordinate system and some central points inside it be-
forehand, we can calculate the distance between the centre point of focus of disease to control point using the 3D stereo image reconstructed above. So we can calculate the three dimensional coordinates of focus of a disease in coordinate system. At the same time, we can observe and measurement the organizations and focus of disease in every direction by using the 3D transparent stereo image. So we can determine the position relationship between organizations in human head and the focus of disease. At last, we can make the project which $\gamma$-ray irradiates, determine the orientation of $\gamma$-ray, so that other organizations are not hurted.

5. CONCLUSION

New techniques of determining position of focus of a disease in gamma knife surgical operation is presented in this paper. We use CT images as original data, and extract useful information from them. After some processing, we reconstruct 3D transparent stereo image using transparent techniques. So we can observe and measurement human body organ and organizations inside it. By calculating the coordinates of focus of a disease, we can determine the position of focus of a disease and determine the position relationship between organizations and focus of a disease, so we can make the project of gamma knife surgical operation. The techniques of determining position of focus of a disease presented in this paper has important application value.

6. REFERENCES


