Particle Swarm Optimization for Solving Medical Image Reconstruction Ill-conditioned Problems

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Abstract. Particle swarm algorithm applies to the field of computer neural networks a lot. In this paper, the medical image is used as an example to realize the modeling process based on the particle swarm algorithm. For the modeling and simulation analysis of medical images, the geometric model accuracy and physical model accuracy need to be solved. The mobile cube (MC) algorithm is used for surface reconstruction. At the same time, the quadratic error measurement (QEM) method is used to reduce and smooth the triangular patch. The Delaunay method is used to deduce the volume mesh model based on the surface mesh. and finally, the corresponding physical model is selected according to the target organization to use the finite element (FEM) method for analysis, and uses OpenGL to display the cloud chart of the equivalent stress. The analysis results show that the function and metabolism of human tissues and organs can be more accurately understood through the reconstruction of SPECT medical images.

Keywords: Image Segmentation, Three-dimensional Modeling, Visualization

1. Introduction
In order to improve the accuracy and scientificity of medical diagnosis and treatment planning, the two-dimensional tomographic image sequence needs to be transformed into an image with an intuitive stereoscopic effect. The biological modeling and simulation technology based on the three-dimensional visualization of medical images (SPECT, PET, CT, MRI, etc.) and computer virtual realities applied in various fields of modern medicine, such as virtual surgery, orthodontics, artificial femoral replacement, surgical plastic surgery, etc., showing good development prospects.

The research of biomedical modeling and simulation has very good theoretical significance and application value, so it has become a hot spot for relevant experts and scholars from various countries. At present, biomechanical simulation modeling based on medical image visualization has received more and more attention, and it has become one of the hot areas of biomechanical research. In recent years, many domestic universities and research institutes have successively carried out research on medical simulation-related issues, of which a lot of research has been done on geometric modeling of medical images and outstanding results have been achieved. However, the current virtual human
technology is still only in its infancy, and it will take more effort to realize various physiological processes that can completely simulate the human body[1]. In this paper, the medical image is used as an example to realize the modeling process based on the particle swarm optimization algorithm. The mobile cube (MC) algorithm is used for surface reconstruction. At the same time, the quadratic error measurement (QEM) method is used to reduce and smooth the triangular patch[2]. The Delaunay (Delaunay) is used to deduce the volume mesh model from the surface mesh, and finally the corresponding physical model is selected according to the target organization to use the finite element (FEM) method for analysis, and use OpenGL to display the cloud chart of equivalent stress.

2. Visualization of medical images

Compared with surface rendering, volume rendering method can not only display the surface information of volume data, but also reflect its internal information, so as to realize the realistic display of three-dimensional medical image data, which is conducive to the comprehensive understanding and analysis of doctors[3]. Diagnosis and treatment have a very important role. The medical image data read from the DICOM file is usually large, with hundreds of M, of which the information of the tissues and organs that the doctor is interested in is only a part of the image, but other background information still needs to be read, so rough segmentation can be done in advance to roughly mark the parts of interest in the form of cubes, and the image data is greatly reduced, which facilitates the subsequent image processing.

Figure 1 shows the block diagram of the level set segmentation of teeth.

![Figure 1. Program block diagram of level set segmentation](image-url)
Among them, the parameters defined by the middle initial layer using the level set method are defined in Table 1. Except for the different values of \( \nu \), the initial contour is set outside to be the same as the other parameters when it is set inside.

**Table 1. Initial layer profile parameter settings**

| \( \delta \) (Standard deviation) | \( \mu \) | \( \lambda \) | \( \lambda \) | \( t \) | \( \varepsilon \) | \( \tau \) (Number of iterations) |
|-----------------------------------|-----------|-------------|-------------|------|------|-----------------|
| 1.5                               | 0.04      | 3.0         | -2.0/2.0    | 5.0  | 1.5  | 300             |

From the existing research, it is relatively better to put the initial contour inside. If the initial contour is outside, as shown in Figure 2 (a), the gray value at the tip differs greatly from the gray value of the surrounding background, so the contour shrinks inward to find the boundary between the background and the tip area; the initial contour is inside, and the difference between the gray value of the tip and the gray value of the target inside is relatively large, so the boundary between the target and the tip can be found during the outward expansion of the contour.

3. Three-dimensional modelling of medical images based on particle swarm optimization

3.1. Surface rendering-moving cube algorithm

The establishment of geometric models for medical images is the basis of simulation analysis using finite elements[4]. The surface of the model is actually a continuous isosurface. Assuming that the pixel value of a data point of a voxel in medical volume data is less than a given threshold, the data point is marked as 1, and the data point is considered to be outside the isosurface; on the contrary, if the pixel value is greater than (or equal to) the threshold of the isosurface, the data point shall be marked as 0, and the data point is considered to be inside the isosurface. If in a voxel, one endpoint of one of its edges is inside the isosurface and the other endpoint is outside the isosurface, then the edge must intersect the isosurface. Therefore, according to the judgment result of the data point mark in the voxel, you can know whether the voxel intersects the isosurface, and you can also know which edge of the voxel has the intersection point. In fact, it only needs to process the voxels that intersect with the isosurface to complete the drawing of the medical three-dimensional model, so as to reduce the amount of data calculation as much as possible[5].

In order to use graphics hardware to display the isosurface image, the normal direction (or the normal direction of the triangle vertices) of each triangle forming the isosurface must be given, and the appropriate lighting model and material should be selected to perform the lighting calculation before the realistic graphical display of the third dimension can be generated. For each point on the isosurface, the gradient component along the tangent direction of the surface should be zero. Therefore, the direction of the gradient vector at that point also represents the normal direction of the isosurface at that point. Let the pixel value of a data point with a spatial coordinate of \((i, j, k)\) in the medical volume data be represented by \(I(i, j, k)\), then the gradient value at the data point is \(\mathbf{g} = (g_x, g_y, g_z)\). The central difference method is used to calculate the gradient at this data point in the voxel:

\[
\begin{align*}
g_x &= \frac{I(i-1, j, k) - I(i+1, j, k)}{2} \\
g_y &= \frac{I(i, j-1, k) - I(i, j+1, k)}{2} \\
g_z &= \frac{I(i, j, k-1) - I(i, j, k+1)}{2}
\end{align*}
\]  

(1)

Perform a normalized calculation on \(\mathbf{g}\) to obtain the unit normal vector at this data point as:

\[
N = \frac{\mathbf{g}}{|\mathbf{g}|}
\]  

(2)

Similarly, by using linear interpolation, the normal vector of the intersection points of the triangle patch forming the isosurface on a voxel edge, that is, the normal vector of each vertex of the triangle patch can be obtained:

\[
N = N_i + (value - V_i) \times (N_2 - N_i)/(V_2 - V_i)
\]  

(3)

\[
N_i + (value - V_i) \times (N_2 - N_i)/(V_2 - V_i)
\]
Among them, N1 and N2 are the normal vectors of the two ends of the side where the triangle vertex is located, V1 and V2 are the pixel values of the two ends, and value is the threshold of the isosurface[6]. Finally, the normal vectors of the three vertices of the triangular patch can be used to realize the real drawing of the isosurface.

It can be seen from the results that compared with the results without considering ambiguity, the results obtained when considering ambiguity are indistinguishable from the display alone, but the number of triangular surfaces and the vertexes generated by the two are different. The MC results is not smoothed here, so there are obvious edges and corners from the display effect.

3.2. Modelling algorithm based on Delaunay criterion
In the process of modeling, considering the execution efficiency of the Delaunay algorithm, the data with the triangle patch reduced by 98% is selected. In order to detect whether the point is inside the polyhedron, for the detection point Q, rays of different directions are randomly generated. If a ray that does not intersect the polyhedron is found, it means that the point is outside the polyhedron. Based on this idea, the centroid ray method can well solve the problem of internal redundant grids. Taking the center of gravity of the triangle patch as the end point of the ray, as long as there is a ray that does not intersect other patches in the triangle mesh except the triangle patch itself, you can know that the triangle patch is superficial, otherwise the triangle patch is inside. The left image in Figure 2 is the result before the reconfiguration of the surface, and the right image is after reconfiguration of the surface.

![Figure 2. Comparison between before and after surface reconstruction](image)

Both the results obtained by MC and the simplified results are stored as a V-F table, that is, a vertex-face table, so the point set in the V-F table is used as an input, and a three-dimensional Delaunay incremental algorithm is used to perform tetrahedral segmentation. In this step, the Standard Template Library (STL) container class operation is used. In the Delaunay incremental algorithm, a lot of insertion and deletion operations are used, and the container happens to be more suitable for a large number of insertion and deletion steps.

After the operation of the Delaunay incremental algorithm, the result is shown in Figure 3 (a). It is obvious that the difference between Figure 3 (a) and Figure 2 is too large, and the original surface has not been restored. The solution is to delete the tetrahedron whose center of gravity is outside the reconstructed surface. In view of the fact that a surface with no internal redundant mesh has been obtained, the reconstructed surface can be regarded as a general polyhedron. In this paper, the method of judging the point in the general polyhedron: the end point of the ray is at the detection point Q, the direction of the ray is d (1,0,0), and the intersection point of the ray and the polyhedron is calculated. Assuming that the ray only intersects the polyhedron at the inner point of the plane, the parity of the number of intersection points indicates whether the point is inside or outside the polyhedron. If it is an odd number of points, the point is inside; if it is an even number of points, the point is outside. After deleting the tetrahedron of the center of gravity outside the reconstructed surface, it is shown in the right panel of Figure 3.
Figure 3. Comparison of before and after removing the center of gravity outside the tetrahedron of the reconstructed surface

4. Quality evaluation and simulation analysis

4.1. Model quality evaluation

A high-quality tetrahedral mesh can improve the accuracy and efficiency of finite element numerical calculation. If there are many inferior elements, it will seriously affect the performance of the calculation and may even cause the calculation to lose meaning. Therefore, it is very necessary to evaluate the quality of the tetrahedral mesh. For a long time, there is no universally accepted standard for measuring the quality of tetrahedral units. In this paper, a standard that is simple to calculate and often used is also used:

\[ \beta = \frac{3r}{R} \] (4)

Where, \( r \) and \( R \) are the radius (0,1) of the tangent and circumscribed spheres in the tetrahedron, respectively. If a tetrahedron is a regular tetrahedron, its quality parameter is 1, if the tetrahedron is coplanar at four points, its quality parameter is 0. If the mass parameter of a tetrahedral element is less than 0.01, the tetrahedral element can be regarded as a thin element, that is, a tetrahedral model of poor quality. The distribution of the mass coefficient after the tetrahedron is divided is shown in Table 2.

| Table 2. Mass coefficient of tetrahedron |
|-----------------------------------------|
| \( \beta \)  | \(<0.01\) | \(0.01<\beta<0.1\) | \(0.1<\beta<0.5\) | \(0.5<\beta<1\) | Recovery rate |
| Number     | 1/806   | 9/806  | 297/806 | 499/806 | 98.39% |
| %          | 0.12%   | 1.11%  | 36.71% | 61.91% | 98.39% |

It can be seen from the table that the number of triangles and vertices after 98% reduction are small. After Delaunay tetrahedralization, most of the tetrahedral mass coefficients are concentrated between 0.5 and 1, which shows that the quality of generated tetrahedral mesh is relatively high. The recovery rate reflects how much of the reconstructed surface triangles exist in the tetrahedral mesh structure. This article also uses the above steps to reduce the data by 90%. As a result, the overall quality of the tetrahedron is not high, most of which are between 0.1 and 0.5. This requires the use of space decomposition to add points internally to improve the overall quality. After adding the internal points, the data with the quality between 0.5 and 1 reaches more than 65%, showing that the quality is improved, but the recovery rate drops slightly, which is still around 97%.

4.2. Simulation analysis of the model

It is difficult to study the soft tissue model of the human body. Usually, physical parameters such as elastic modulus, damping coefficient and density of soft tissue are used to characterize the viscoelasticity, anisotropy and non-uniformity of soft tissue. In this paper, a physical model of linear elasticity is selected for the material and properties of teeth, and the relevant parameters of the model are set as follows: the elastic modulus is \( 1.86e10 \) pa and the Poisson's ratio is 0.31. Here, the load is applied to the crown surface in the negative direction along the Z axis of the coordinate axis, and the
size is 50N. This value is the size of the tooth when it is chewed normally. The set boundary conditions are displacement boundary conditions, and the displacement vectors of the nodes at the roots of the teeth are all zero. The basic finite element analysis process of the model is realized through the steps of structural discretization, element analysis, overall analysis, introduction of boundary conditions and equation solving. In the drawing of a cloud image, it is very important how to choose the mapping method from physical quantity to color mode. Straightforward color mapping This directly affects the quality of image generation, and also affects the continuous change of physical information. The cloud image display method used in this article first constructs a color table, dividing the equivalent stress into partitions according to the size, with each partition represented by a different color value.

5. Conclusion
The purpose of this article is to further realize the degree of visualization of medical imaging technology, and then based on particle swarm algorithm for modeling simulation analysis of medical images, the modeling process and the analysis process are integrated into a platform. The MC algorithm in surface rendering is used to reconstruct and display the three-dimensional surface, and the tetrahedral mesh is established based on the incremental method of Delaunay criterion. The finite element method is applied to the tooth data, and the equivalent stress finally obtained is displayed using OpenGL to display its distribution cloud.

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