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Research on the Method for Smoothing Surface of 3D Model Reconstructed based on Octree

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Abstract: It has become one of the hot research subjects in the computer field that is how to reconstruct the 3D solid model of the part quickly and efficiently based on its multi-vision image sequence. The space carving method can realize to reconstruct 3D model of parts according to its 2D image information obtained from different angles of view. But the surface of 3D model reconstructed is seriously serrated. To get the better surface of 3D model reconstructed, a surface smoothing method based on Octree was proposed in this paper and it was used to smooth the rough surface of the 3D model reconstructed. It is analyzed that the value of n , which is the number of times a body was divided, how to effect on the surface roughness of the model. The results show that the surface smoothness of 3D model reconstructed can be improved by the method based on Octree proposed. The conclusion can provide theoretical reference for improving the surface smoothness of the model.

1. Introduction

In recent years, while developing of computer technology, the 3D reconstruction of object based on point-free data has been widely used in different industries such as industrial, medical, archaeology, geological exploration [1], bioresearch [2], material structure analysis [3] because of the contactless reconstruction of the object researched. There are many kinds of surface features for the reconstructed objects, so many scholars pay attention to how to reconstruct their 3D solid model of objects researched quickly and effectively. The data for 3D model reconstruction can be got by one[4] or two[5] or many cameras[6,7] Reference [8] has realized 3D reconstruction of object based on point-off data got by Lased scanner. Reference [9] has realized 3D reconstruction of object based on the data got by Lased scanner and camera. Reference [3] has done based on the data got by Focused ion beam scanning electron microscope (FIB-SEM).

Literature[10] proposed a voxel based space engraving method in 2000. In literature[11] based on the space engraving method, a probabilistic space engraving method is proposed. In literature[12] a three-dimensional reconstruction method of increasing voxel is proposed, which improves the accuracy and authenticity of the reconstruction model. Literature[13] used the calibrated digital camera from different viewpoints to obtain reconstructed images and used the hierarchical method to obtain non-traditional voxel surface with a polygon surface of the three-dimensional model.

Literature [14] combined the different sizes of the voxel and pixel mapping to remove the object outside the region and get the pixel corresponding to the voxel quickly and efficiently. Literature [15] applied the calibrated camera to obtain the image at any viewpoint, and applied the discrete visible boundary method to solve the problem of recognizing the visible surface to realize the three-dimensional reconstruction of the object. The octree representation uses a step-by-step approach to the octree structure and obtains real three-dimensional entities based on information obtained from different perspectives by literature [16].



The three-dimensional model reconstructed by the space engraving method has the problems of large surface roughness and severe serration on the edge. In this paper, we propose a method based on the octree principle to study the spatial sculpture method. The effect of the method on improving the smoothness of the 3D model is obvious.

2. Space Engraving Process

The essence of 3D reconstruction is to carve the initial envelope based on the two-dimensional image of the target obtained in different angles. Therefore, it is necessary to set the size of the initial envelope before engraving. In addition, since the envelope is engraved according to the image, it is necessary to ensure that the engraved three-dimensional entity is consistent with the real entity, which requires to scale the target contour in the image according to the position of the target relative to the camera. Therefore, three-dimensional reconstruction based on vision can be achieved in three steps: image sequence acquisition and camera calibration, envelope division and projection changes, space engraving and surface refinement. The flow chart is shown in Figure 1:

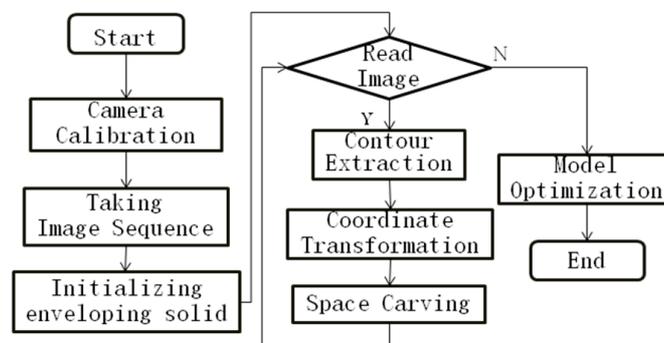


Figure 1. The Schematic diagram of three-dimensional reconstruction algorithm based on space engraving method

The algorithms applied to 3D model reconstruction are as follows:

a. Image Acquisition

Collecte the images first and then store them in the structure array Camera.image. The image is processed to get the outline of the target and stored in the structure array Camera.silhouette with the contour vector $[u_i, v_i, 1]$ (where $i = 1, 2, \dots, 36$).

b. Camera Calibration

We use Matlab Calibration Toolbox to complete the calibration of the camera's internal and external parameters and establish the rotary axis coordinate system $\Sigma XAYAZA$ (hereinafter referred to ΣA). Then, the rotation axis coordinate system $\Sigma A R$ and T are calculated and the external parameters we got will be stored in the camera array Camera.R and Camera.T. At last, we store the calibrated internal parameters in Camera.K.

c. The Establishment Of Rotating Axis Coordinate System

In the image acquisition system, the rotation axis's actual position of the turntable is unknown to the camera. For this reason, the rotation coordinate system ΣA is introduced and the spatial equation of the rotating shaft is obtained according to the initial internal parameters of the camera and as the YA axis of the rotary axis coordinate system ΣA . To facilitate the restoration of target information, we define the rotation axis coordinate system YA as the new world coordinate system $\Sigma XwYwZw$ (hereinafter referred to as ΣW).

Beside establishing the world coordinate system ΣW , we need an initial estimation of the envelope. First, we should estimate an envelope volume. In this paper, $1/4$ of dist is used as the initial length and width (L and W) of the initial envelope and $1/2$ dist as the height (H) of the initial envelope. The establishment of the camera and the location of the spatial model shown in Figure 2.

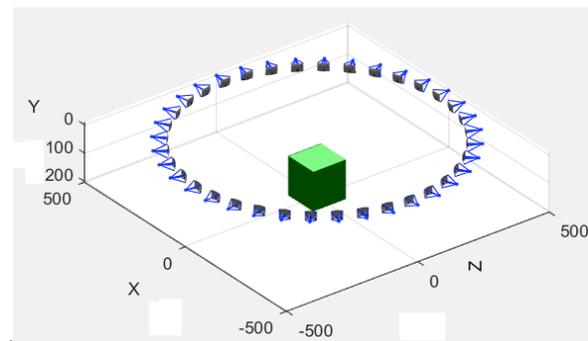


Figure 2. Space model of camera and target

d. Initial Division Of Enveloping Body

First, the coordinates of the envelope are divided into n points. Making the initial value of n is equal to 6000 and the values of x , y , and z in each voxel of the envelope upper left vertex coordinates- $V_i(v_{xi}, v_{yi}, v_{zi})$ ($i = 1, 2, \dots, n$) are stored in the structure array `voxel.X`, `voxel.Y` and `voxel.Z` respectively. Then the spatial coordinates of each corner point of the envelope are $(\text{voxel.X}, \text{voxel.Y}, \text{Voxel.Z})$. A single point can be described in the form of matrix table $[v_{xi}, v_{yi}, v_{zi}]^T$. The division process and the coordinates of the selection is as shown in Figure 3:

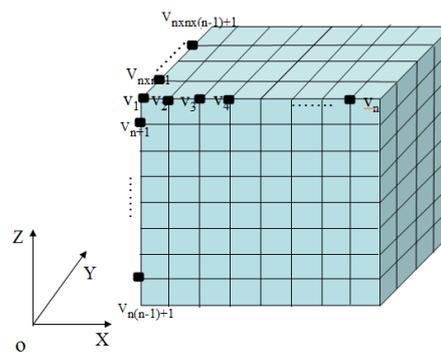


Figure 3. The specific division of the envelope and the selection of voxel coordinate points

e. Initial Engraving

These voxels can be engraved using the rotation matrix obtained when the camera is calibrated and the spatial point coordinates of the obtained envelope. The sculpture is divided into two processes to complete:

(1) Project the point V_i in the world coordinate system ΣW into the pixel coordinate system ΣUV to find the pixel point $[u_i \ v_i]$ in the pixel coordinate system ΣUV . First, determine whether voxel is max (u) or max (v) (max (u) and max (v) are respectively the maximum and minimum boundaries of the image) to estimate whether the initial estimate voxel is in the initial envelope. If not included, return to step c to have a further amplify of the envelope and then projection until it is included in the initial envelope.

(2) Determine whether the projection of the voxel is beyond the area outside the image (as shown in Figure 4). We should carve out the coordinates of the voxel beyond the image and keep the voxel coordinates projected in the image.

(3) Determine whether the remaining voxel projection is within the contour of the object. As in the second layer in Figure 4, We should engrave the coordinates of the voxel that is not within the object contour. As shown in Figure 5, we get a single perspective voxel_{new} of the carved results.

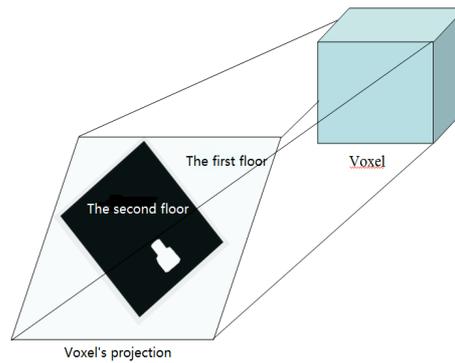


Figure 4. voxel projection

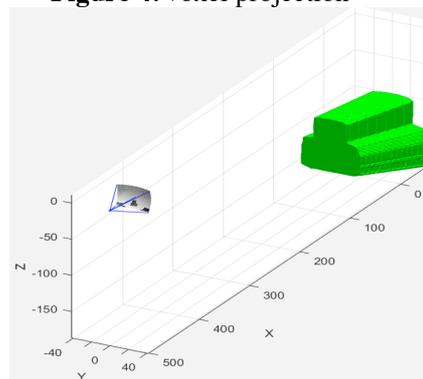


Figure 5. single-angle carving results

f. Engraved Again

Although carving out a single perspective of voxel_{1new} on step-by-step basis, the single voxel volume is too large here because the segmentation precision is limited. The object eventually carved is too rough. In this situation, we need to go back to step d to re-set the dividing accuracy of the envelope. Let n equals to 20000 and cycle step e to carve the subject of the envelope again and ultimately get a single angle voxel₁ in higher view accuracy.

According to the other 35 images under the view of the envelope carved by repeating the steps above, we get the voxel_i (i = 2, ... 36) at every perspective eventually. Finally, the required voxel_{3d} can be got by seeking the intersection of these voxels:

$$\text{voxel}_{3d} = \text{voxel}_1 \cap \text{voxel}_2 \cap \dots \cap \text{voxel}_{36} \quad (1)$$

Among them, the carving results of the voxel in three angles is shown in Figure 6 and the final carving results are shown in Figure 7.

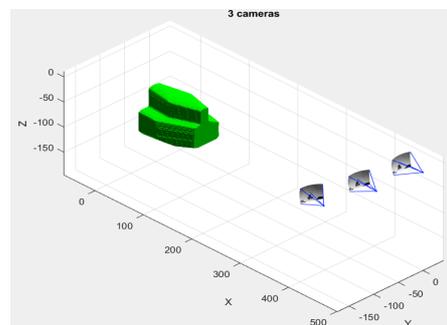


Figure 6. Space sculpture under three perspectives

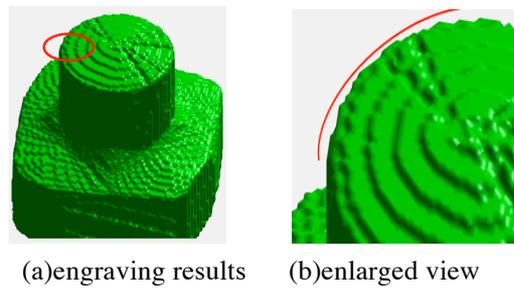


Figure 7. Carving results in 36 perspectives

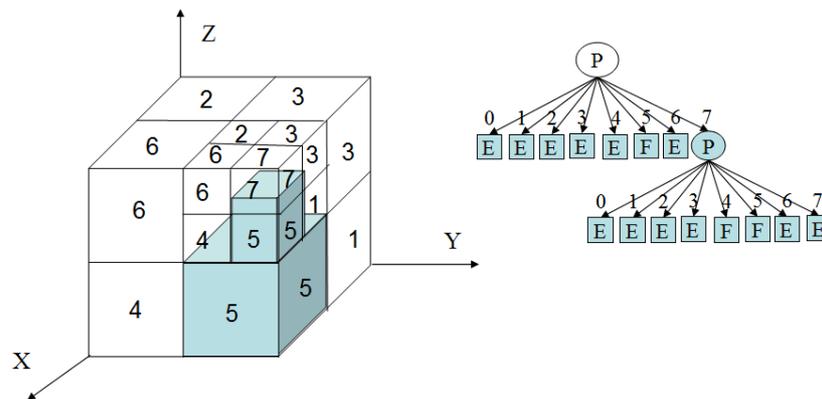
Figure 7(a) is a reconstructed three-dimensional model and the time t required for reconstructing the part is 13.7s. (b) is a partial enlarged view of a part of (a). From the figure (b), we know that the roughness of reconstructed three-dimensional model voxel 3d is very large and the edge has serious jagged situation. The main reason is the limit of dividing for n . In theory, the larger the value of n , we get the finer the division of the mesh and the higher accuracy of the model obtained by the projection transformation. But the bigger of n , we need the larger the memory space occupied by the computer and the longer the calculation time. It affects the three-dimensional reconstruction's efficiency seriously.

3. Making Model Surface Smooth

This paper introduces the concept of octree in view of the problem in Fig. 7. We complete the three-dimensional reconstruction of the entity but does not increase the time required for reconstruction and the calculated storage capacity by octree.

3.1 Octree Principle

The Octrees' representation is a kind of enumeration representation in spatial position. It divides the spatial region of the entity into a grid (There is a cube). The sequence of the cube is used to represent the envelope here. According to the need to separate the outer cube again and cycle like this. When the split cube is smaller, the surface of the reconstructed entity is smoother. In theory, when the small cube is infinitely small, we need to reconstruct the required entity model. The process of decomposing the small cubes using the octree method is shown in Fig 8.



(a) the cube space where the object is located (b) the meaning of the shaded area in (a)

Figure 8. Octree's process of representation

3.2 Smooth Model

The octet tree principle is used to smooth the reconstructed three-dimensional model. In this paper, the initial shape of the envelope is not a cube and the smooth is carried out on the reconstructed three-dimensional model. The smoothing process is as follows:

(1) Finding out the resolution of the model has been resolved and its size has been defined in the program which is V/n^3 . V is the volume of the initial envelope that V equals $L * W * H$ and n is the number of meshes in each direction.

(2) A description which is referented to Fig 9. The square of the cube is $a = 1/3 * \text{Resolution}$, the cube is divided into eight subcategories that the angular coordinates of each subcube are denoted as

$Oct_{ij}(x, y, z)$ and each of the outermost voxel coordinate record points is as the center point called v_i when drawing a cube. ($J = 0, 1, 2, \dots, 7$; $i = 1, 2, \dots, n$) and j is the 8 nodes of the octree and i is the number of points at outermost.

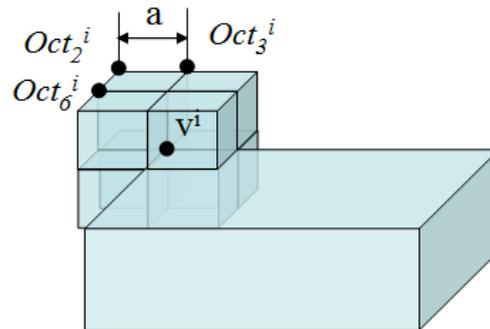
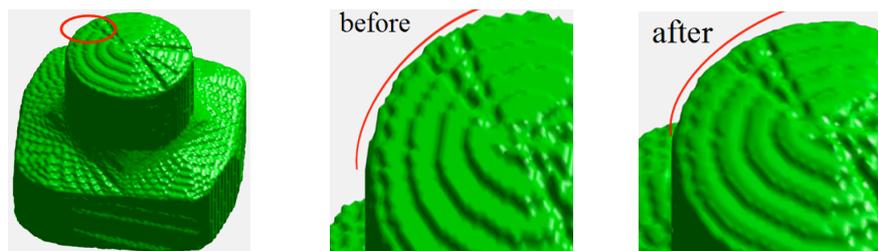


Figure 9. Draws the subgrid centered on the voxel's recording point

(3) Project the transformation of the surface of octagonal tree's Oct_{ji} and perform the space carving according to step e of section 2 to remove the points that do not belong to the contours of the object. A smoothing result is shown in Figure 10. Figure 10 (a) is a three-dimensional model after smoothing, Figure (b) and (c) are the local amplification of three-dimensional model. It can be seen from the figure that the smoothness of physical surface is significantly better after smoothing.



(a) the results of smoothing (b) Local magnification before smoothing (c) Local magnification after smoothing

Figure 10. The results before and after smoothing

3.3 Texture Mapping

After completing the three-dimensional reconstruction of the parts by the application of space sculpture, the surface loses the original texture and lacks realism. In order to increase the realism of the reconstructed three-dimensional entity, it is necessary to map the surface according to the image information. In this paper, the process of texture mapping is not discussed in detail, but simply gives the results of texture mapping. It is shown as Figure 11.

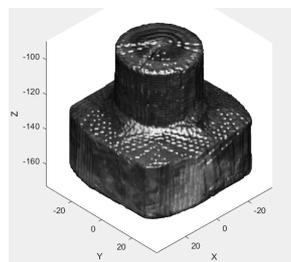


Figure 11. The result of texture mapping

4. Conclusion

This paper describes the realization of 3D reconstruction model based on traditional space engraving method. Then the principle of octree is introduced. When the first-order octree is applied to the reconstructed three-dimensional model surface, a smoother surface is obtained. At the same time, the texture is simply mapped to the model in order to increase the reality of the model.

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6. References

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