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Boundary Adjustment Algorithm Based On Element Triangulation

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***Abstract*— To address the issue of edge thickness affecting surface quality and color in 3D printing, particularly when dealing with variations in the thickness of upper and lower surfaces, a surface isometric offset transformation method is employed to obtain the optimal subsurface structure. Based on these offset surfaces, adaptive offset calculations are performed for the exterior surface structure using different offset distances for different surfaces. Subsequently, each surface is iteratively optimized, redesigning the surface structure of the printed part to meet the requirements for surface quality and color depth. The results show that the adaptive offset method for surfaces is superior to the traditional edge line offset method in 3D printing. It provides an effective surface treatment method for color printing, especially under requirements for translucency and light colors, allowing for customized surface thickness settings based on parameters such as surface hardness and brightness, thereby enabling adaptive surface thickness.**

***Index Terms*—adaptive surface thickness, face offset, Stacking of colored pigments.**

I. INTRODUCTION

3D printing additive manufacturing is an advanced technology that builds specific structural objects by adding materials layer by layer, and is widely used in multiple industries [1]. This technique originated with the manufacture of three-dimensional (3D) structures layer by layer from computer-aided design (CAD) drawings [2]. With the development of the 3D printing industry, the demand for highly reproduced color surfaces is also increasing. Through the analysis of the microstructure of the colored surface [3], the reduction of roughness, surface pore impregnation and the enhancement of coating transparency can improve the accuracy of surface color reproduction. High-quality color 3D printing requires attention to every detail, the size of the print particle, the precise control of the printing speed, as well as the distribution of the internal color and full consideration of the optical characteristics [4]. Yuan Jiangping et al. [5] verified the influence of color layer features such as color ladder and sequence on color reproduction quality of color 3D printing surface, and proposed in the report that color 3D printing should not only be limited to color layer printed on surface, but also consider the importance of overall or local features of 3D model in color layer sequence and width allocation.

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In 3D printing, slicing schemes and parameter Settings are crucial to print time and print quality [6]. Monochrome printing emphasizes the optimization of surface strength and roughness, while color printing requires more detailed consideration of factors such as surface color layer thickness, color layer stacking order and color material particle diameter, which directly affect the final print effect. With the increasing thickness of the printed layer, the transparency and surface roughness of the material tend to increase [7], and the characteristics of the color layer are also sensitive to the printing resolution of the color layer. This shows the importance of developing an effective 3D printing slicing strategy, especially in color printing, where the influence of internal tones on external surface tones must be accurately understood [8]. The setting of boundary coloring width is a problem that cannot be ignored, and an intelligent adjustment method based on adaptive feedback is urgently needed to solve it.

The stacking of colored pigments affects the saturation and hue of the color. At present, most of the color 3D printing systems on the market are mainly opaque color printing, using opaque pigments as ink layers applied to the surface of 3D objects. Although dark surfaces are less affected by the color width, in clear or light parts, pigment stacking significantly affects the reproduction quality of the surface color. Although a finer color layer thickness can provide higher surface quality and finer detail [9], increasing the wall thickness can improve the color stability and dyeing effect of the print [10]. Through accurate and efficient forward and backward prediction of the print layer, optimizing the stacking strategy of the ink [11] can significantly improve the effect of color 3D printing. In terms of transparency, increasing the thickness of the white ink layer can significantly reduce the transparency, while the transparency of the color ink with the same film thickness is still higher [12]. For 3D printing using transparent or translucent materials, the internal color is likely to show through these materials, thus affecting the color perception of the final product. Literature [13] has conducted in-depth research on the reproduction of translucent materials. Considering the long-range effect of translucent materials, the optical properties need to be evenly distributed throughout the volume of the object, and the method of assigning the color value of the nearest point on the surface to each internal voxel has been successfully adopted. Therefore, the color and transparency of each voxel are crucial. Under the premise that the surface quality meets the requirements, the surface thickness adaptively changes with the surface color.

Traditional slicing software usually generates 2D sections and then performs boundary migration based on these 2D sections. This approach often has limitations when dealing with complex geometries and color levels. In order to solve this problem, an innovative variable surface thickness method is proposed by considering the long range effect of materials, color of voxels and color ladder effect. In this method, the 3D geometry structure is pretreated before slicing, and multiple surface isosurfaces can be generated by flexibly setting different offset distances according to multiple parameters such as surface color attribute, geometric position of adjacent surface and overall curvature direction of surface. It can not only achieve better in-plane structure and color reproduction effect, but also lay the foundation for intelligent adjustment of boundary color width and optimization of color layer stacking in the future. This innovative approach provides an effective solution for surface control in color 3D printing.

II. Boundary adjustment strategy

At present, the main migration strategy is to carry out edge migration on the basis of the contour lines obtained after slicing layer by layer. This approach, while simple, has some limitations when dealing with complex geometry and colorful 3D printing.

the layer-by-layer slicing process, the 3D model is first intersected with an array of planes parallel to the Z plane and segmented into a series of cross sections. Each cross section is described by a set of contours that precisely define the shape and boundaries of that layer. Traditional migration methods usually make edge migration based on these contours, that is, translate the outer or inner side of each contours according to the set distance, so as to generate new contours and build the layer structure after migration.

Although this contour-based offset strategy is simple in algorithm, low in calculation cost and easy to implement, and whether it is plastic or metal printing, the surface thickness can be adjusted by contour-based offset. However, this approach has the following limitations when dealing with complex geometry and colorful 3D printing.

Geometric distortion: During edge migration, especially for complex surfaces and edges, contours only describe the shape and boundary of the layer, and direct translation of these contours can result in geometric distortion. Especially in the area of large curvature, the offset contour may conflict with the original geometry and affect the print quality.

Uneven color: In color 3D printing, the stacking thickness of different color layers cannot be fully considered using only the contour line offset method. This method ignores the effect of the offset contour on other color layers, which may result in uneven colors or unnatural transitions between color layers.

Missing internal details: The contour migration method focuses on the adjustment of the external surface, often ignoring the internal detail structure of the model. This problem is particularly pronounced when printing transparent or translucent materials, resulting in the color and shape of the internal structure not being accurately represented on the external surface.

In order to overcome these limitations, this paper presents an isometric migration algorithm based on triangular surfaces. By shifting the normal vector direction of the triangular surface, the proposed method can control the surface thickness and internal color more precisely and avoid geometric distortion. At the same time, considering the overall geometry of the model, the algorithm can better maintain the internal and external consistency to ensure the printing effect.

III. Boundary adjustment algorithm

Triangular surfaces are widely used in various geometric modeling and data storage applications because of their simple geometric characteristics and the advantages of easy processing and rendering by computers. In the field of computer graphics and geometry processing, triangular surfaces are considered basic building blocks for representing complex surfaces and objects.

The method proposed in this paper takes the triangular plane as the minimum element plane, and carries out equidistance internal shrinkage according to different surface characteristics, aiming at solving the problem of surface thickness control. According to the color properties of each triangular surface, the geometric position of the adjacent surface and the overall curvature direction, the indentation distance can be flexibly adjusted to produce multiple isosurfaces.

A. Isometric migration policy

The basic idea is to adjust the vertex position of each triangular surface to ensure that the distance between each vertex and the surface on which it is located is consistent. However, due to the irregularity of the geometry, there is no central axis across the vertex, making all copoint surfaces symmetrical about this central axis, ensuring that the presence points are equally distant from each surface. The fundamental reason is that the same vertex may be shared by multiple triangular surfaces, which leads to the absence of a point that satisfies the offset distance to each surface.

For each edge of any triangular surface, its position is determined by two adjacent triangular surfaces, and there is an angular bisector of the edge, and the distance between the point on the surface and the two adjacent surfaces is equal. After the offset distance is determined, the offset edge can be uniquely determined, and then a new triangular surface can be constructed. The size of the offset triangular face can be determined by other triangular faces on the adjacent side.

In the process of isometric transformation, the triangular surface can be regarded as the intersection line of the plane where the other three adjacent sides are located and the plane where the triangular surface is located. By moving these planes equidistant in the direction of the normal, the new intersection line becomes the offset edge, thus obtaining the desired offset triangular surface.

Consider the case of a triangular pyramid, where there is a central axis across the vertex and the points on that axis are equally distant from each side. Moving the triangular pyramid along the central axis results in a new triangular pyramid whose sides are the same distance from the corresponding sides of the original triangular pyramid. Through this process, a triangular surface parallel to the bottom surface is taken in the new pyramid, and the distance between the surface and the bottom surface is the required offset distance, so as to obtain the result that satisfies the isometric offset condition.

B. External surface migration algorithm

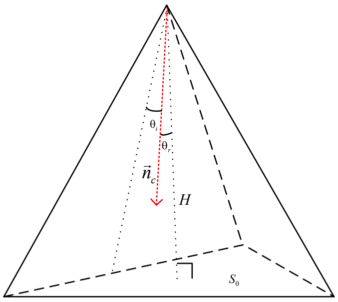


Fig.1 Parameters of the triangular pyramid

Suppose we want to take a triangular face S_0, its normal vector is $\vec{n}$, the equation of the face is $Ax+By+Cz+d=0$, the three adjacent faces intersect at a point P, we take the central axis normal vector $\vec{n}_c$ of this triangular pyramid, we can find the height H of the triangular pyramid with the vertex P as the vertex and the triangular face as the base is S_0.

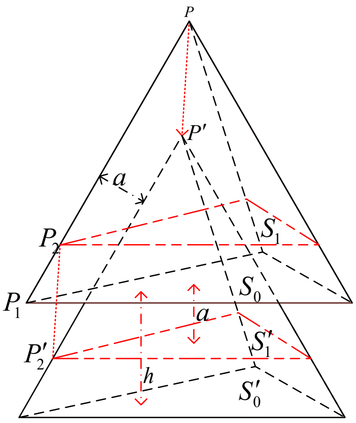


Fig.2 Effect of the triangular pyramid after the offset

According to the properties of the triangular pyramid, the properties of the triangular pyramid after migration can be calculated. Since the distance to satisfy the isometric deviation is the vertical distance between the offset plane and the original plane, it is still necessary to obtain the distance that the new triangular pyramid moves along the normal vector $\vec{n}_c$. Suppose that the offset distance obtained is a, the distance between the triangular plane and the offset triangle plane is, and the distance between the triangular plane and the offset triangle plane is h:

$$h=\frac{a*|\cos\theta_r|}{|\cos\theta_i|} \tag{1}$$

Where the Angle θ_i between the central axis and the side normal vector, the Angle θ_r between the central axis and the ground.

The triangular surface after migration is in equal proportion to the original triangular surface, and is smaller than the size of the original triangular surface. Due to the relationship after migration, it is known that there is a maximum value a_{max}, which satisfies:

$$a_{Max}=\text{h-}H=\frac{H*|\cos\theta_i|}{||\cos\theta_i|-|\cos\theta_r||} \tag{2}$$

At this time, the relationship between the new pyramid and the original pyramid has been obtained. A triangle S_1' is taken inside the new triangular pyramid, which is similar to the original triangular plane and satisfies the isometric migration condition, and can be obtained by shifting a triangular plane along the central axis at a certain distance. The triangle is completely equivalent to the triangular surface, satisfying the following relation:

$$P_2'=P_2+\frac{a}{|\cos\theta_i|}*\vec{n}_c \tag{3}$$

In the protopyramidal species. The following relationship is satisfied:

$$\frac{P_2-P_1}{P-P_1}=\frac{h-a}{H} \tag{4}$$

Thus, the equation relationship between the offset result and the vertex of the original plane can be obtained. The point to be offset and the offset point meet the following relation:

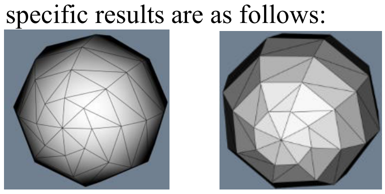
$$P_2'=P_1+a*\vec{k} \tag{5}$$

The following relation is satisfied:

$$\vec{k}=\frac{||\cos\theta_r|-|\cos\theta_i||}{H*|\cos\theta_i|}*(P-P_1)+\frac{1}{|\cos\theta_i|}*\vec{n}_c. \tag{6}$$

IV. EXPERIMENTAL RESULTS AND ANALYSIS

This paper presents a new method for setting wall thickness for 3D printing. Experiments were carried out for normal migration and the presence of multiple coplanar surfaces. The specific results are as follows:



(1) (2)

Fig.3 Sphere and Combination results

of triangular surfaces. the offset results are in line with expectations.

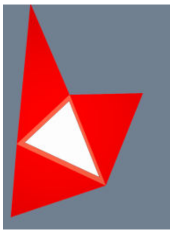


Fig.4 Offset result diagram

The results of computer simulation show that the algorithm proposed in Chapter 3 can accurately meet the requirements of triangular surface migration, showing strong robustness. The application in color 3D printing is particularly prominent, which can achieve fine color stacking Settings, give each isosurface the required color, and adjust the structure under the surface according to demand, ensuring the accurate control of adaptive surface thickness. And adjust the underplane structure according to the demand to ensure the accurate control of adaptive surface thickness. Compared with traditional methods, the algorithm not only improves the offset accuracy, but also comprehensively considers the local characteristics of the surface to ensure the visual and structural consistency of the 3D model after the offset, and significantly improves the overall quality of 3D printing and the quality of color reproduction. This method makes the printing of complex shapes more stable and reliable, and provides strong algorithmic support for 3D printing with high precision, high quality and high color requirements.

In Figures 5, an offset transformation is performed on two adjacent faces. Through verification, the correctness of the edge connection is confirmed. As shown in FIG. 15 and FIG. 16, the edges of the adjacent triangular surfaces after migration transformation are still collinear, and the structural relationship of the original surface is retained, and the internal contraction of the surface is realized.

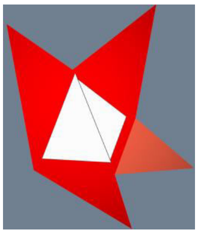


Fig.5 Edge connection diagram

Although the local structure is fully considered in this algorithm, there are still some problems in dealing with the connection of triangular surfaces. The migration result of each triangular surface is only related to the structure of the coplanar surface, ignoring the relative relation of all the coplanar surface. the resulting vertex position is not unique. As shown in Figure 6, when the triangular surface is joined, there will be an excess extension surface at one vertex. Although the algorithm uses the VTK toolkit to remove degenerate elements and convert triangles to polygons, this method still has limitations in specific applications.

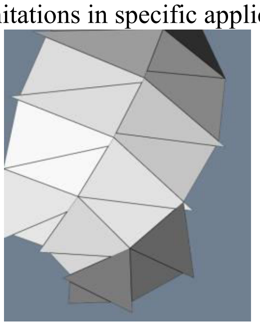


Fig.6 Mapping point connections

Although the removal of degenerate elements can optimize the geometry, it may result in mixed and uneven colors at some vertices. Especially in color 3D printing, the accurate stacking and uniform distribution of colors is the key to ensure the quality of print results. Although the current algorithm has certain advantages in the processing of local structures, it still needs to be further optimized in dealing with complex problems such as triangular surface connection and color processing.

V. Conclusion

In this paper, an isometric migration algorithm is proposed to expand the thickness of the outer surface of the data stored in the triangular surface format. The algorithm is particularly suitable for situations where a specific color stack thickness is required, making up for the overall geometry factor that is ignored by traditional 3D printing when setting the surface thickness of the slice.

Firstly, the different conditions of color layer thickness shrinking inside the surface are analyzed in detail to ensure the robustness of the system. In the traditional 3D printing process, only the coating thickness of the surface color is usually considered, and the impact of the overall geometry on the color reproduction is ignored. The research of this paper focuses on how to obtain the inner shrink surface in the triangular surface with different structural characteristics, so as to ensure the equidistant deviation of each triangular surface.

Specifically, the method in this paper solves the problem that the offset vertex position is not unique due to the irregular geometry by finding the inner shrink surface equidistant from the target triangle inside the pyramid. By equidistant each surface along the normal direction, and dynamically adjust the offset according to the relationship between the triangular surface and the adjacent surface, the high precision equidistant offset is realized.

At present, color 3D printing is mostly limited to applying color to a surface. However, with the improvement of the requirements for printed parts, the thickness of the color layer will become non-negligible in the future under the conditions of transparent, translucent and lighter color 3D printing. By analyzing and dealing with the thickness problem of color layer stacking, this paper provides the basis for adaptive modification of surface layer thickness.

The indent migration algorithm proposed in this paper can not only achieve more accurate color reproduction effect in color printing, but also maintain internal color stability in transparent and translucent materials printing. This provides new solutions for future applications of 3D printing technology, especially in areas that require high-quality surface finishes and complex geometric structures.

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