Journal of Multidisciplinary Engineering Science and Technology (JMEST)
ISSN: 2458-9403
Vol. 12 Issue 3, March - 2025

Create Personalized Products Through Triangular Mesh Segmentation And Reconstruction Technology

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***Abstract*—As the consumer market continues to refine, niche influence gradually escalates. In order to meet the diverse needs of different groups of people, personalized products gradually play an important role in the consumer market. The rise of 3D printing technology has provided new possibilities for the production of personalized products. The Voronoi diagram is a mathematical concept that divides space into different regions based on the distance to a set of specified points. Each region corresponds to an area close to one of the points, representing a region that is closer in space than any other point, and is therefore commonly used in computational geometry for the generation of meshes. In this article, mesh processing techniques are used to cut the triangular mesh model of general products into several segments through the cutting plane, and the intersection of the cutting plane and the mesh edge of the original model is used as the new mesh of the Voronoi figure node, and the intersection between the cutting plane and the outer mesh edge of the original model is the boundary of the new mesh. Then, the Delaunay triangle construction technique is used to reconstruct the mesh of the cutting plane, and different printing colors are assigned to each section to complete a personalized product with another visual effect. Finally, the finished product is output with a 3D printer to verify the feasibility of this system.**

Keywords—Voronoi diagram, 3D printer

I. Introduction

3D printing technology has had a significant impact in the fields of manufacturing and product design, making product design more personalized. Designers and consumers can create their own products based on specific needs and preferences. This allows products to better meet the unique requirements of individual customers, both in appearance and function. For product designers, 3D printing provides a way to quickly prototype. This allows them to quickly test and modify the product's design to meet their customers' specific needs. This speeds up the product development cycle while also reducing the risk of design errors. It also makes it easier to produce personalized accessories and parts. This is great for producing relatively small batches of products or products that require special customization, such as personalized phone cases, eyeglass frames or customized car parts. Therefore, 3D printing technology is more suitable for mass customization production, that is, the production of similar products with individual differences. This production method allows manufacturers to create products based on customer demand without having to produce the same product in large quantities. 3D printing technology is also used in education and art. Students and artists can use this technology to create unique artwork and learning tools. Overall, 3D printing technology provides greater freedom and flexibility for personalized products, while also promoting innovation in the fields of manufacturing and design. As this technology continues to develop, we can foresee more application scenarios and possibilities.

The working process of a 3D printer is: (1) Design the 3D CAD model of the part. (2) Convert CAD files into STL format files, determine the placement position, and construct the cutting layers and related supporting materials. Finally, the print command is sent to the 3D printer. (3) The 3D printer reads the cross-sectional information and moves, selectively extruding the required materials, and stacking the final product. Therefore, for ordinary users, how to construct the required models is a technical threshold that is difficult to overcome. Therefore, even though the current price of 3D printers is within the range acceptable to the general public, they cannot be widely used by ordinary users. Therefore, another purpose of this article is to help ordinary users how to use 3D printers to print the auspicious totems left by various ethnic cultures as decorations to promote the beauty of the inherent culture [1].

The Voronoi diagrams is a method proposed by the Dutch climatologist A. H. Thiessen to calculate the average rainfall based on the rainfall of discretely distributed weather stations. That is, all adjacent weather stations are connected to form a triangle, and the vertical bisectors of each side of these triangles are made, so that several vertical bisectors around each weather station form a polygon. Use the rainfall intensity of a unique weather station contained in this polygon to represent the rainfall intensity in this polygonal area, and call this polygon a Voronoi diagrams.

Voronoi diagrams have physical meaning in different fields, including physics, materials science, biology, and geography. A Voronoi diagram is a mathematical concept that divides space into regions based on distance to a specified set of points. Each region corresponds to an area close to one of the points, indicating that the region is closer in space than any other point. In physics and materials science, Voronoi diagrams are used to represent the spatial distribution of points, such as particles, atoms, or other entities. The areas in the Voronoi diagram correspond to the area around each point, indicating that this area is closer to that point than any other area. Voronoi diagrams play a role in optimizing resource allocation. For example, in physical simulation or computational modeling, using Voronoi diagrams can help efficiently allocate computing work or resources between different computing nodes or regions. In materials science and engineering, Voronoi diagrams are used to analyze the microstructure of materials. The map helps identify grain boundaries and unit structures in the material, providing insights into mechanical properties and behavior. Voronoi patterns often appear in natural systems, such as the arrangement of cells in biological tissues, the distribution of seeds in sunflower heads, or the crystalline structure of certain minerals. Studying Voronoi diagrams in these situations helps scientists understand the underlying processes that form these patterns. While Voronoi diagrams are used for mesh generation in computer graphics and computational geometry, the elements of Voronoi diagrams can be used to create meshes that approximate surfaces, which is particularly useful in simulation and computational-aided design. In summary, Voronoi diagrams provide a way to divide space based on the proximity or influence of specific points, making them a valuable tool for understanding and representing a variety of physical phenomena and structures [2][3][4].

II. 3D MODEL AND TRIANGULAR MESH CONVERSION

Currently, all formats accepted by 3D printers are STL format. Therefore, to integrate with the 3D printer system, the 3D model must be converted into STL format. The STL format uses an approximate outer surface to represent the surface or solid entities of an object. The STL file includes a sequence of surface data. Each surface is represented by a unit normal vector and three vertices coordinates, so 12 numbers are used to represent a surface. The output format of STL can be divided into two types: ASCII and Binary. The ASCII STL file is only for users to see its format and further edit it, but it takes up a lot of space. The Binary format is a more reasonable choice.

A. *ASCII STL file format*

The content of the ASCII STL file lists the geometric data of each triangle mesh line by line. Each line begins with 1 or 2 keywords. For example, in an STL file, a facet represents a triangular mesh surface with a normal vector. The STL 3D model is composed of a series of triangular mesh surfaces. The first line of the entire STL file records the file path and text file name. Each facet in the file consists of 7 lines of data. The facet normal is the normal vector coordinate of the triangular mesh surface pointing to the outside of the entity. The outer loop indicates that the subsequent three rows of data are the coordinates of the three vertices of the triangular mesh surface, and the order of the three vertices is counterclockwise along the normal direction of the mesh surface. So the ASCII STL file format is as follows [5]:

```
solid name
facet normal ni nj nk
outer loop
vertex v1x v1y v1z
vertex v2x v2y v2z
vertex v3x v3y v3z
endloop
endfacet

endsolid name
```

B. *Binary STL file format*

Binary's STL file content uses a fixed number of bits to record the geometric information of each mesh surface. The first 80 bits of the file are used to record the file name, followed by a 4-byte integer to represent the number of triangular mesh faces of the model, and then the geometric information of each triangular mesh face is recorded sequentially. Each triangular mesh surface has 50 bits, which are three 4-bit-floating point numbers (normal vector of the mesh surface), three 4-bit-floating point numbers (the coordinates of the first vertex), Three 4-bit-floating point numbers (the coordinates of the second vertex), three 4-bit-floating point numbers (the coordinates of the third vertex), and the last two bits record the attributes of the triangular mesh surface. So the Binary STL file format is as follows [5]:

```
UINT8[80] ; Header
UINT32 ; Number of triangles
foreach triangle
REAL32[3] ; Normal vector
REAL32[3] ; Vertex 1
REAL32[3] ; Vertex 2
REAL32[3] ; Vertex 3
UINT16 ; Attribute byte count
```

For example; Figure 1 shows the ASCII file format of triangle mesh.

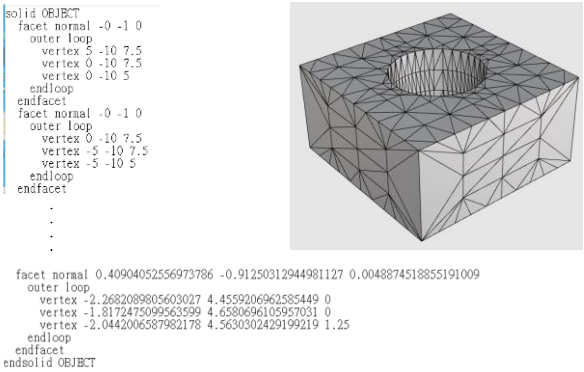

Figure 1 The ASCII file format of triangle mesh

III. DELAUNAY TRIANGLE MESH CONSTRUCTION PROCESS

The key to establishing Voronoi graphics is to reasonably connect discrete data points into a triangulation. This triangulation is called Delaunay triangulation. Therefore, before creating the Voronoi graphic feature, the Delaunay triangular mesh must be constructed. The following is the construction process of Delaunay triangle mesh.

The construction of Delaunay triangulation is also known as the construction of irregular triangulation, which is to construct a triangulation from discrete data points, and to determine which three data points form a triangle, also known as automatically connected triangulation. That is, for *n* discrete points on the plane, the plane coordinates are (*xi*, *yi*), *i*=1, 2, ... , *n*, and three similar points form the best triangle, so that each discrete point becomes the vertex of the triangle, As shown in Figure 2.

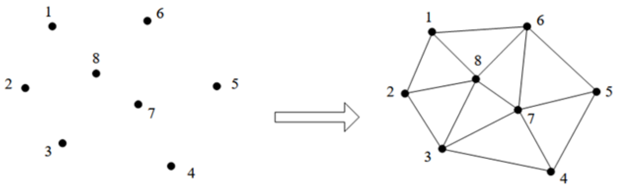

Figure 2 Automatically connect to the triangulation

The result of automatically connecting the triangulation network is the labels of the three vertices of all triangles, such as: 1, 2, 8; 2, 8, 3; 3, 8, 7, ... At the same time, in order to obtain the best triangle, when constructing the triangulation network, the three internal angles of the triangle should be made as acute as possible, which conforms to the criteria for the Delaunay triangle.

1. The circumcircle of any Delaunay triangle cannot contain any other discrete points.
2. Two adjacent Delaunay triangles form a convex quadrilateral. After swapping the diagonals of the convex quadrilateral, the smallest of the six internal angles no longer increases. This property is the minimum angle, maximum criterion.

To achieve this goal, Tsai (1993) proposed a general algorithm for constructing Delaunay triangles in n-dimensional Euler space - Convex Hull interpolation algorithm. The calculation steps are as follows [6];

Step 1: Calculate the four points in the point set satisfying min (x-y), min (x+y), max (x-y), max (x+y), and form a linked list of points in a counterclockwise direction. These 4 points are the closest points among the discrete points to the 4 corner points of the circumscribed rectangle containing the discrete points. The polygon formed by these 4 points is used as the initial Convex Hull.

Step 2: For each point I on Convex Hull, set its subsequent point to J, calculate the distance from all points on the right side of the vector line segment IJ to IJ, and find the point K with the largest distance.

Step 3: Insert K between I and J, and assign K to J.

Step 4: Repeat steps 2 and 3 until there is no point on the right side of the line segment IJ of the point set.

Step 5: Assign J to I, take the subsequent points of J, and repeat steps 2, 3, and 4.

Step 6: When there are no discrete points on the right side of the connection between any two adjacent points in Convex Hull, a polygon (Convex Hull) containing all discrete points is formed, as shown in Figure 3.

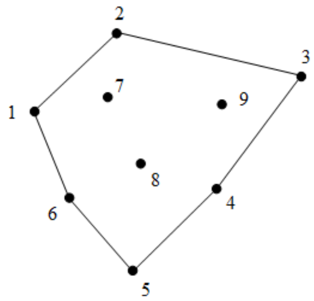

Figure 3 Convex Hull including all discrete points

Step 7: Look for a triangle composed of two adjacent Convex Hull sides in the Convex Hull linked list each time, and the interior and boundary of the triangle do not contain any other points on Convex Hull. After removing this point, a new Convex Hull linked list is obtained. Repeat this process until there are only three discrete points on the Convex Hull list. The last three discrete points in the Convex Hull linked list form a triangle, so the points in Convex Hull form a number of preliminary Delaunay triangles, as shown in Figure4.

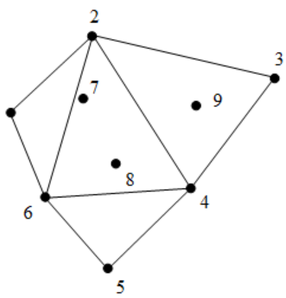

Figure 4 Preliminary Delaunay triangles

Step 8: After completing the preliminary Delaunay triangle, the remaining discrete points that are not on Convex Hull are divided by point-by-point interpolation until all non-Convex Hull discrete points are inserted, as shown in Figure 5.

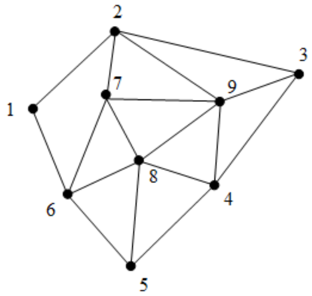

Figure 5 The final Delaunay triangles

IV. VORONOI GRAPHIC FEATURE CONSTRUCTION PROCESS

After understanding the construction method of Delaunay triangle mesh, you can construct Voronoi graphic features. The steps are as follows [7]:

Step 1: Scan the point data of the Voronoi graph from left to right and from top to bottom. If the distance between a certain point and the previous scanning point is less than the given proximity tolerance, the point will be ignored in the analysis, as shown in Figure 6.

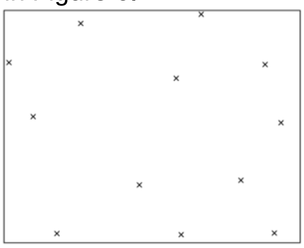

Figure 6 Arrange randomly distributed point data

Step 2: Construct a Delaunay triangulation from the discrete point data, number the discrete points and the constructed triangles, a record which discrete point each triangle is composed of, and record the numbers of all triangles adjacent to each discrete point. As shown in Figure 7.

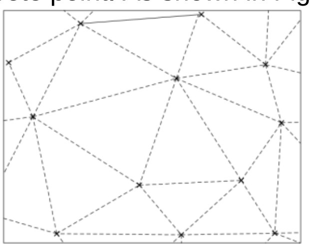

Figure 7 Delaunay Triangulation

Step 3: Draw the mid-perpendicular line of each triangle side. These mid-perpendicular lines form the edges of the Voronoi graph, and the intersection of the mid-perpendicular lines is the vertex of the corresponding Voronoi graph, as shown in Figure 8.

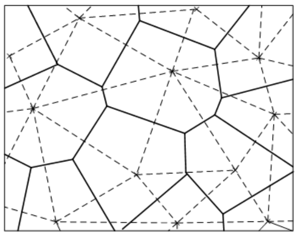

Figure 8 Construct Voronoi graphics

Step 4: The points used for the Voronoi graphics will become the anchor points of the corresponding Voronoi graphics, as shown in Figure 9.

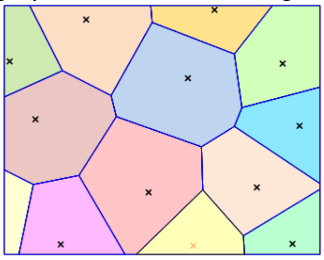

Figure 9 Voronoi graphics

V. SYSTEM OPERATION STEPS

In this article, mesh processing techniques are used to cut the triangular mesh model of general products into several segments through the cutting plane, and the intersection of the cutting plane and the mesh edge of the original model is used as the new mesh of the Voronoi figure node, and the intersection between the cutting plane and the outer mesh edge of the original model is the boundary of the new mesh. Then, the Delaunay triangle construction technique is used to reconstruct the mesh of the cutting plane, and different printing colors are assigned to each section to complete a personalized product with another visual effect. Finally, the finished product is output with a 3D printer to verify the feasibility of this system. The executing steps are as follows:

Step 1: Load the triangular mesh file of the original model, as shown in Figure 10.

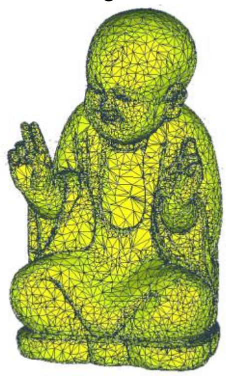

Figure 10 Original triangular mesh file.

Step 2: Set cutting plane, as shown in Figure 11.

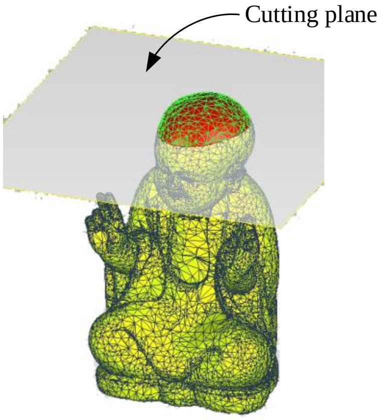

Figure 11 Set cutting plane

Step 3: Segment the model and reconstruct the cutting surface mesh, as shown in Figure 12 and Figure 13.

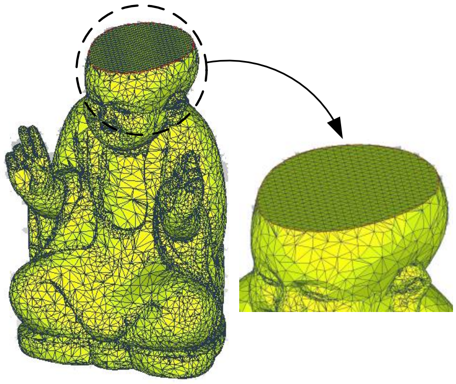

Figure 12 One of the segmented model

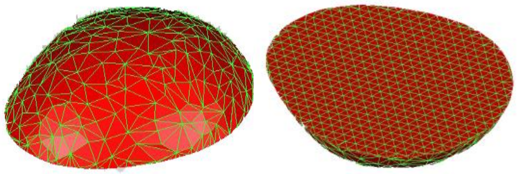

Figure 13 The other segmented model

Step 4: Set different cutting plane heights and repeat steps 2 and 3 to complete the segmentation of the entire model. The results are shown in Figure 14 and Figure 15.

Figure 14 All cutting planes

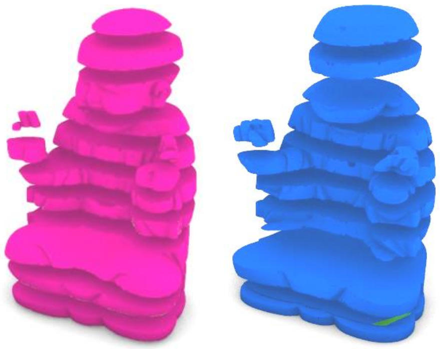

Figure 15 The segmented models

Step 5: Set up different groups and recombine the positioning to start the 3D printing process. The results are shown in Figure 16.

Figure 16 Reassembled model I

This method of dividing and reconstructing the mesh can also be applied to different cutting surfaces. For example, if a circular curved surface is used as the cutting surface, as shown in Figure 17, the segmented model will be as shown in Figure 18. Figure 19 shows the model of reorganization after summarizing different groups.

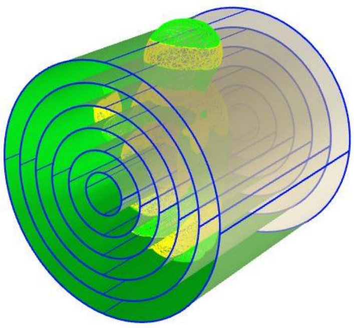

Figure 17 The cutting planes of circular curved surface

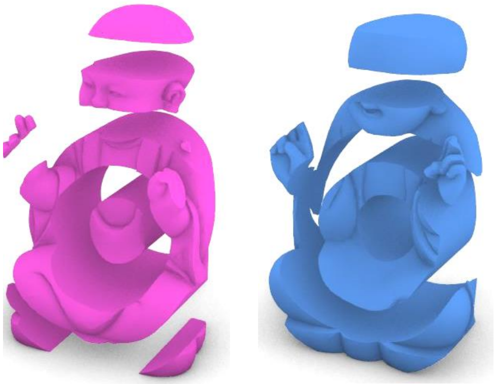

Figure 18 The segmented models

Figure 19 Reassembled model I

VI. Conclusion

In this article, mesh processing techniques are used to cut the triangular mesh model of general products into several segments through the cutting plane, and the intersection of the cutting plane and the mesh edge of the original model is used as the new mesh of the Voronoi figure node, and the intersection between the cutting plane and the outer mesh edge of the original model is the boundary of the new mesh. Then, the Delaunay triangle construction technique is used to reconstruct the mesh of the cutting plane, and different printing colors are assigned to each section to complete a personalized product with another visual effect. Finally, the finished product is output with a 3D printer to verify the feasibility of this system. Figures 20 and 21 show the finished products produced by processing different cutting plane and printing them with a 3D printer.

Figure 20 Personalized products -1

Figure 21 Personalized products -2

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