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AUTOMATIC SELECTION OF FORMS AND DIMENSIONS OF CUTTING TOOLS FOR FINISHING SCULPTURED SURFACES FROM STL MODELS

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ABSTRACT

Ball end cutters, flat end cutters and fillet end cutters are used for finishing sculptured surfaces. Ball end cutter permits the access to concave zones but gives a bad surface finish. The other cutters produce a good surface finish and their material removal rate and feed rate are important compared to ball end cutters. To optimize the finishing of sculptured surfaces, it is more efficient to choose firstly flat end cutters and fillet end cutters for machining a maximum area and secondly choose ball end cutters for inaccessible zones by taking into account the existence of regions of different local forms. In this paper, a methodology is proposed to optimize the finishing of sculptured surfaces from their STL models on 3-axis CNC milling machines by the selection of the adequate cutters from a given combination of cutters forms. This methodology : 1) determines the parameters of points and triangles, 2) estimates the unit normal vectors, 3) identify the local forms of points and triangles, 4) creates the regions 5) selects the forms and the dimensions of the adequate cutters.

Keywords: STL Model, Sculptured Surface, Finishing, Interference, Cutting Tools.

1. INTRODUCTION

Sculptured surfaces are machined on 03, 04 or 05-axis CNC milling machines in three stages: roughing, semi-finishing and finishing. To obtain a good surface finish in a minimum machining time, the forms and the dimensions of the cutting cutters, the cutting conditions and the machining strategies must be chosen judiciously. Three forms of cutters are used for finishing sculptured surfaces: ball end cutters, flat end cutters and fillet end cutters. Ball end cutter is the most used because it permits the access to concave zones but it gives a bad surface finish. The other cutters produce a good surface finish and their material removal rate and feed rate are important compared to ball end cutters. To optimize the finishing of sculptured surfaces, it is more economic and more efficient to choose firstly flat end cutters and fillet end cutters for machining a maximum area and secondly choose ball end cutters for inaccessible zones by taking into account the existence of regions of different local forms. The researchers have considered different aspects related to the machining of sculptured surfaces [1-8].

In this paper, a methodology is proposed to optimize the finishing operation of sculptured surfaces from their STL models on 3-axis CNC milling machines by the selection of the adequate cutters from a given combination of cutters forms. This methodology permits: 1) determination of the parameters of points and triangles, 2) estimation of the unit normal vector at each vertex, 3) identification of the local forms of vertices and triangles, 4) creation of regions 5) selection of the forms and the dimensions of the adequate cutters.

2. PROPOSED METHODOLOGY

2.1. Parameters of points and triangles

To accelerate the methodology, the principal parameters of vertices and triangles are determined. For each triangle, its neighbors are identified and its area and its angles are calculated. For each vertex, based on the neighbors of the triangles, its neighbors and the triangles sharing it are identified.

2.2. Unit normal vector estimation

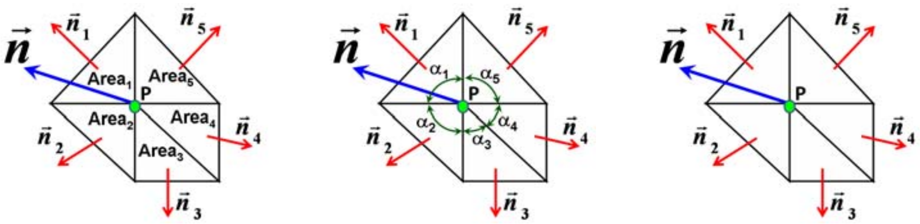
By reason of the absence of a continuous model, the unit normal vector must be well estimated to position correctly the cutter. The normal vector $\vec{N}(N_x, N_y, N_z)$ at a vertex is calculated from the triangles sharing this vertex by [6]:

$$\vec{N} = \frac{\sum_{i=1}^{k} \omega_i \cdot \vec{n}_i}{\sum_{i=1}^{k} \omega_i} \tag{1}$$

Where ω_i, $\vec{n}_i$ and k are respectively the weighting factor, the unit normal vector of the ith sharing triangle and the number of shared triangles. In this work, the weighting factor can be the triangle area (Figure 1.a), the triangle angle (Figure 1.b) or a constant (Figure 1.c).

The unit normal vector $\vec{n}$ at this vertex is given by:

$$\vec{n} = \frac{\vec{N}}{\sqrt{N_x^2 + N_y^2 + N_z^2}} \tag{2}$$



a. Area. *b. Angle.* *c. Constant.*

Figure 1. Weighting factors for unit normal vector estimation at a vertex.

2.3. Local forms of points and triangles

Sine the STL model is discrete, the identification of the local form of a vertex is based on geometrical considerations by determining the position of its neighbors relative to its tangent plane. The different local forms are determined using the following conditions:

1. Convex: if all its neighbors are below the tangent plane.
2. Convex developable: if some of its neighbors are below the tangent plane and the others belong to the tangent plane.
3. Concave: if all its neighbors are over the tangent plane.
4. Concave developable: if some of its neighbors are over the tangent plane and the others belong to the tangent plane.
5. Planar: if all its neighbors belong to the tangent plane.
6. Saddle: if some of its neighbors are over the tangent plane and the others are below the tangent plane.

The local form of a triangle depends on the local forms of its vertices. So, the local form of a triangle is «X» if at least the local form of two of its vertices is «X».

2.4. Regions

The selection of the adequate cutters (forms and dimensions) must take into account the different local forms that compose the surfaces. So, assume that a region is a local form that is defined by a set of triangles having the same local form. The determination of these regions is based on the local forms of triangles and the neighbors of each triangle. Six local forms can be found (concave, convex, concave developable, convex developable, saddle and planar). For each local form, several distinct regions can be created. From a database of cutters, for each triangle of each region, it is associated a maximum of three optimum forms of cutters (flat end cutter, fillet end cutter and ball end cutter) that avoid the interference problems.

2.5. Forms and dimensions of the adequate cutters

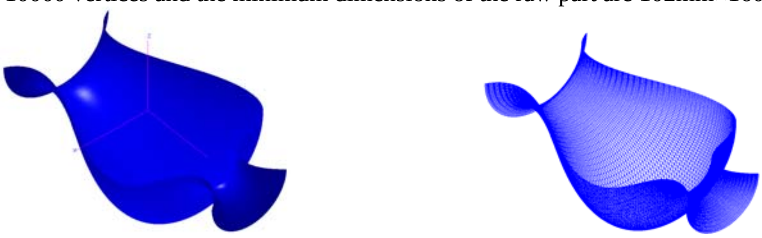
To optimize the finishing of sculptured surfaces, a set of cutters of different forms and dimensions are associated to each region. For each cutter form, a maximum of three different dimensions can be used (maximum, second maximum and minimum). In this work, four combinations are proposed:

1. Flat end cutters and ball end cutters (maximum of six cutters).
2. Fillet end cutters and ball end cutters (maximum of six cutters).
3. Flat end cutters, fillet end cutters and ball end cutters (maximum of nine cutters).
4. Ball end cutters (maximum of three cutters).

The objective of the combinations is the minimization of the machining time by selecting big cutters for machining the maximum area of surfaces and small cutters for inaccessible zones.

3. RESULTS

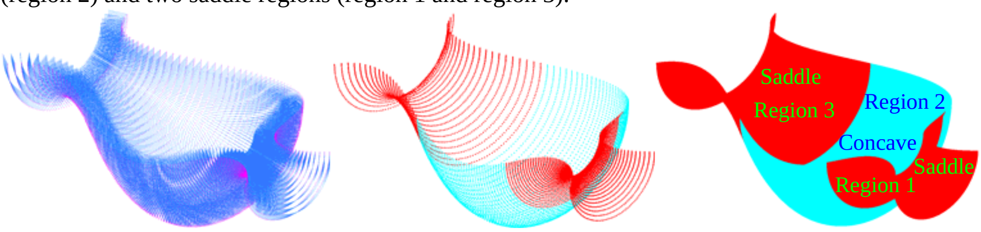
The proposed methodology has been implemented in an object-oriented software running under Windows using C++ Builder and the graphics library OpenGL [9]. It is validated on an STL model generated from a CAD model of a sculptured surface (Figure 2). This STL model contains 19602 triangles and 10000 vertices and the minimum dimensions of the raw part are 102mm×160×51mm.



a. CAD model. *b. STL Model.*

Figure 2. CAD and STL model of the surface.

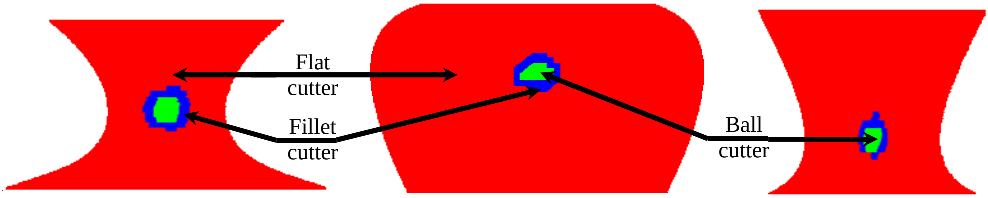
Once the unit normal vectors are estimated, the local forms of vertices and triangles are determined (Figure 3). The results show that this surface is composed of three distinct regions, one concave region (region 2) and two saddle regions (region 1 and region 3).



a. Unit normal vectors. *b. Vertices Local forms.* *c. Regions.*

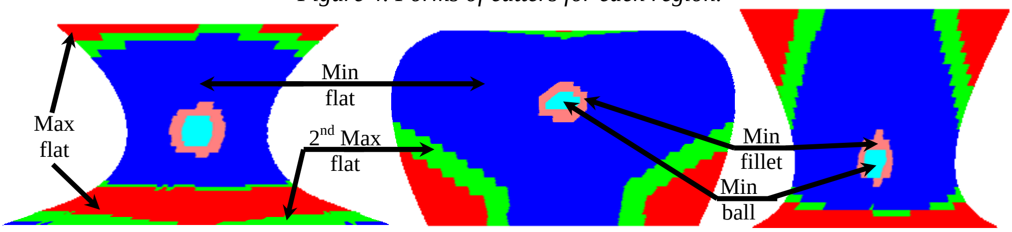
Figure 3. Local forms of vertices, triangles and regions.

Before going to the different combinations, the optimums cutters (three dimensions for each cutter form) for each region are determined. The results concerning the third possible combination (flat end cutter, fillet end cutter and ball end mill cutter) show that each region is machined with three forms of cutters and approximately the whole area is machined with flat end cutters (red color), the remaining area is machined with fillet end cutters (bleu) and ball end cutters (green) (Figure 4). The use of flat end cutters and fillet end cutter permits the machining with high feed rate and the obtaining of a good surface finish. The dimensions of the different forms of cutters for each region are given by Figure 5. It must be noticed that the dimensions of the cutters are for each region. Each region is machined with three flat end cutters, one fillet end cutter and one ball end cutter. So, fifteen different cutters are used for finishing this surface. For efficiency, a machining center must be used.



a. Region 1. *b. Region 2.* *c. Region 3.*

Figure 4. Forms of cutters for each region.



a. Region 1. *b. Region 2.* *c. Region 3.*

Figure 5. Dimensions of cutters for each region.

4. CONCLUSION

In this paper, an automated methodology is presented for selecting the adequate cutters for finishing sculptured surfaces from their STL models on 3-axis CNC milling machines. This methodology permits from the STL model of surfaces, the determination of the parameters of vertices and triangles, the estimation of the unit normal vector at each vertex, the identification of the local forms of vertices and triangles, the creation of the different distinct regions and finally, from a chosen combination of cutters forms, the determination of the forms and the dimensions of the adequate cutters for each region. This methodology permits the selection primarily the big flat and fillet cutters and then selects the ball end cutters for the inaccessible zones which reduces the total machining time and improves surface quality. This methodology is more efficient if machining centers with an important number of tools in their tool magazine are used.

5. REFERENCES

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