13th International Research/Expert Conference
"Trends in the Development of Machinery and Associated Technology"
TMT 2009, Hammamet, Tunisia, 16-21 October, 2009

# TOWARD THE ROUGHING OF SCULPTURED SURFACES FROM A REGULAR CLOUD OF POINTS

**Z. Tchantchane[1], M. Bey[2]**
**Centre de Développement des Technologies Avancées (CDTA),**
**Cité 20 Août 1956, BP N°17 Baba Hassen, Algiers,**
**Algeria**
**1: ta.zahida09@hotmail.fr; 2: bey_mohamed@yahoo.com**

## ABSTRACT
*Sculptured surfaces used in the design and manufacture of molds, dies …etc. are obtained generally in three stages: roughing, semi-finishing and finishing. In recent years, the Reverse Engineering is used in the duplication of objects from physical model or prototype that are defined by a cloud of points which can be regular or irregular. To duplicate an object, two techniques are used: 1) tool path is generated based on the reconstruction of the CAD model, 2) tool path is generated directly without passing by the reconstruction of the CAD model. The first technique is a difficult task and expensive in time. In this paper, for roughing sculptured surfaces defined by 3D regular cloud of points on 3-axis CNC milling machines using flat end mill cutter, a methodology is proposed permitting the automation of this process by firstly generating the Z-map model and the triangles, secondly generation of contours, selection of tool radius and generation of offset contours and finally the tool path is generated in "One-Way" and "Zig-Zag" using parallel plane machining strategy.*
**Keywords**: Sculptured Surface, Regular Cloud of Points, Reverse Engineering, Roughing, Z-map, Parallel Planes Strategy.

## 1. INTRODUCTION
Sculptured surfaces used in the design and manufacture of molds, dies …etc. are machined on 03 or 05-axis CNC milling machines in three stages : roughing, semi-finishing and finishing by considering surface definition, machining parameters, tools …etc. In recent years, the Reverse Engineering is used for duplicating objects from physical models or prototypes. For this process, the first step is the acquisition of the coordinates of a cloud of points using a contact or non-contact devices where the cloud of points can be regular or irregular. Both methods generate a dense cloud of points in three-dimensional space which is used in the reconstruction of the CAD models. In consequence, there is no relationship between these points which complicates the generation of the tool path. Different problems related to the machining of sculptured surfaces given by their CAD models are considered [1-4]. For the object defined by a cloud of points, a reduced number of researchers are published. Different methods are proposed for 3-axis machining [5-8] and for 5-axis machining [9-10]. In [11], OuYang considered the selection of the optimal ball end mill for finishing sculptured surfaces. In this paper, for roughing sculptured surfaces defined by 3D regular cloud of points on 3-axis CNC milling machines using flat end mill cutter, a methodology is proposed that automatically generates the Z-map model and a set of triangles approximating the cloud of points. Next, the tool radius is selected allowing roughing of the maximum cutting planes and finally, contours, offset contours and tool path using parallel plane machining strategy in "One-Way" and "Zig-Zag" sweeping modes are generated sequentially. This methodology reduces the product development cycle and hence the costs which increases the productivity.

## 2. PROPOSED METHODOLOGY

The proposed methodology is divided into three stages (Figure 1). In the first stage, from 3D regular cloud of points, the coordinates of a grid of points are calculated using Z-map model and then a set of triangles are generated. In the second stage, the contours are generated and then the offset contours are determined based on the selected tools. The tool path is generated in the last stage.

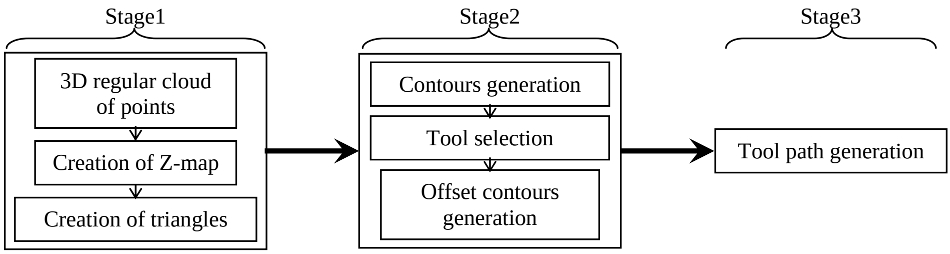



*Figure 1. Proposed methodology.*

### 2.1. Z-map model creation and unit normal vector estimation

In this work, the cloud of points is supposed regular and the measuring is done on planes parallel to the YZ plane along the Y-axis. To simplify the creation of triangles and manipulation of the mesh of points, the regular cloud of points is replaced with a uniform grid of points on the XY plane by specifying the steps "$d_x$" and "$d_y$" along X-axis and Y-axis respectively (Figure 2). Next, the Z-map model is obtained by calculating the Z coordinate of all points of the grid by interpolations along Y-axis and along X-axis based on the coordinates of the original cloud of points (Figure 3). Once the Z-map is determined, a set of triangles that approximate the shape of the object are created. Since the CAD model of the cloud of points is unknown, for each vertex of the grid, the normal vector is estimated by reconstructing a B-Spline surface using the interpolation [13] in the neighborhood of the considered point. Once the B-Spline surface is reconstructed, the tangent vectors $\vec{T}_u$, $\vec{T}_v$ and the unit normal vector $\vec{n}$ at a specific point (*u*, *v*) on the parametric plane can be calculated [13]. In this work, for each point of the Z-map model, a B-Spline surface is reconstructed from a grid of (3×3) points and the degrees of the surface *p* and *q* are equal to two. Nine situations can be distinguished depending on the position of the considered point (Figure 4). For calculating the unit normal vector, the parametric coordinates *u* and *v* for different situations are: 1) u=0, v=1; 2) u=0, v=0.5; 3) u=0, v=0; 4) u=0.5, v=1; 5) u=0.5, v=0.5; 6) u=0.5, v=0; 7) u=1, v=1; 8) u=1, v=0.5; 9) u=1, v=0.

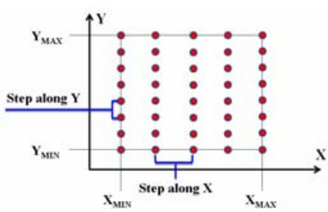



*Figure 2. Grid of points.*

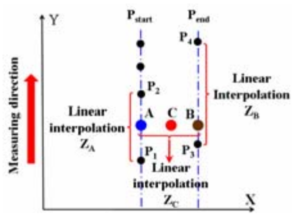



*Figure 3. Z coordinate determination.*

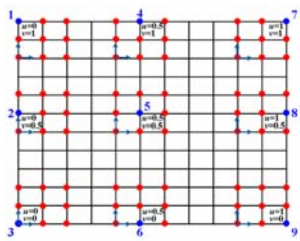



*Figure 4. Different situations.*

### 2.2. Contours generation

Before generation of the roughing tool path, the first step is to calculate the contours for each cutting plane that delimit the material to be removed. These contours are generated from the different intersections between the set of triangles and horizontal cutting planes defined from the depth of cut. To accelerate this process, the triangles are grouped into horizontal slices. Notice that for all vertices of triangles, the unit normal vectors are estimated. Once the segments are generated for each plane, the different contours belonging to this cutting plane are created. The next step is to orient correctly the contours which is necessary to determine the correct offset direction during the construction of the tool path. These contours can be oriented in clockwise (CW) or in counterclockwise (CCW) direction.

The first step is the determination of the correct direction of the unit normal vector for each segment which is obtained from the normal vector of its vertices (Figure 5). The next step is the determination of the right orientation of the contours. For each contour, from the vertices $S_1$, $S_2$ and the unit normal vector $\vec{N}_1$ of its first segment, two situations are considered:

a. If the Z component of $\vec{N}_1 \times \overrightarrow{S_1S_2}$ is positive, then the contour is in the right orientation (Figure 6).

b. If the Z component of $\vec{N}_1 \times \overrightarrow{S_1S_2}$ is negative, then the contour is in the wrong orientation and must be reversed (Figure 7).

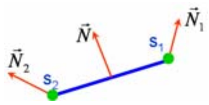


*Figure 5. Segment unit normal vector.*

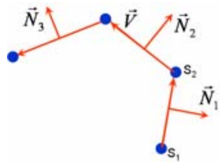


*Figure 6. Correct orientation.*

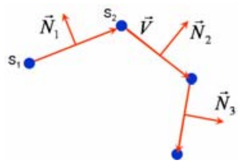


*Figure 7.Wrong orientation.*

### 2.3. Offset contours generation

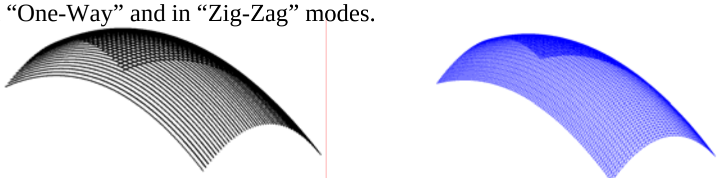
In order to eliminate the risk of interferences, the first step is to determine the tool radius allowing the machining of a maximum of cutting planes. This step is necessary since using a big tool radius can create loops and the elimination of these loops leads to uncut areas. These loops are detected using sweep line algorithm. So, in this work, the tool radius “R” allowing the machining of a maximum number of cutting planes is selected and then the offset contour are obtained by offsetting each segment with an offset distance equal to the sum of the tool radius “R” and the stock allowance “ε” defined by the user according to its unit normal vector.

### 2.4. Tool path generation

To rough an object defined by a cloud of points, parallel plane machining strategy in “One-Way” and “Zig-Zag” modes are used. With this strategy, the user introduces the direction of the tool movements and the distance between two consecutive paths. Giving these parameters, the intersection points between the set of parallel segments in the given direction and the offset contours are determined and the machining segments are identified. After, the tool path is generated either in “Zig-Zag” or in “One-Way” mode. For machining, the tool starts machining the linear segments and then it passes along the offset contours in order to obtain a good surface.

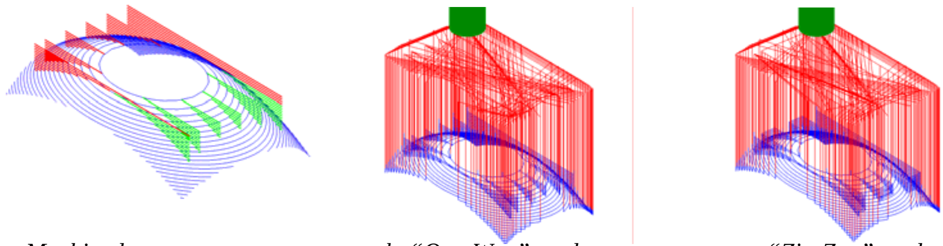
## 3. RESULTS

The proposed methodology has been implemented in an object-oriented software running under Windows using C++ Builder and the graphics library OpenGL. This software is designed for roughing any 3D regular cloud of points to be machined on 3-axis CNC milling machine where the measuring is done along Y-axis. To demonstrate the effectiveness of the proposed methodology, simulated clouds of points are obtained from the intersection of a convex NURBS surface with parallel planes (Figure 8.a) where the distance between two consecutive planes, the maximum number of points along the Y-axis and the number of planes are equal to 1 mm, 291 and 46 respectively. For this example, Z-map and triangles are generated from a grid of points defined by 100 points along Y-axis and 30 points along X-axis (Figure 8. b). To generate tool path; tool radius, stock allowance and depth of cut are fixed to 10mm, 1mm and 1mm respectively. Figure 9 shows offset contours, machined segments and tool path in “One-Way” and in “Zig-Zag” modes.



*a. Cloud of points.* *b. Generated Triangles*

*Figure 8. Creation of triangles.*



*a. Machined segments.* *b. “One-Way” mode.* *c. “Zig-Zag” mode.*

*Figure 9. Generated tool path.*

To obtain these results the developed software takes a time that depends on the density of points, the number of points of the grid and the different machining parameters. For this example, the results are obtained in nearly 15 seconds.

## 4. CONCLUSION

In this paper, a methodology is presented permitting the automation of the roughing of sculptured surfaces defined by 3D regular cloud of points to be machined on 03-axis CNC milling machines using flat end mill cutter. This methodology uses Z-map model to generate a set of triangles that approximate the initial cloud of points, generates the contours, selects the tool radius allowing roughing of the maximum cutting planes, generates offset contours and tool path using parallel plane machining strategy in “One-Way” and “Zig-Zag” modes. This methodology reduces the product development cycle by eliminating the reconstruction of the CAD model and hence the costs which increases the productivity. In perspective of this work, selection of the optimum tool radius for each cutting plane, tool path optimisation and contour parallel offset machining will be studied.

## 5. REFERENCES


[1] B. K. Choi, C. S. Jun : Ball-end cutter interference avoidance in NC machining of sculptured surfaces, Computer Aided Design, Volume 21, pages 371-378, 1989.

[2] E. Duc : Usinage de formes gauches contribution à l’amélioration de la qualité des trajectoires d’usinage, Thèse de doctorat, Ecole Normale Supérieure de Cachan, France, 1998.

[3] D. C. H. Yang, Z. Han : Interference detection and optimal tool selection in 3-axis NC machining of free-form surfaces, Computer Aided Design, volume 31, pages 303-315, 1999.

[4] S. C. Park : Tool path generation for Z-constant contour machining, Computer Aided Design, Volume 35, pages 27-36, 2003.

[5] A. C. Lin, H. T. Liu : Automatic generation of NC cutter path from massive data points, Computer-Aided Design, Volume 30, pages 77–98, 1998.

[6] J. W. Choi, S. M. Hurl and S. H. Lee : Free-form Surface Generation from Measuring Points using Laser Scanner, International Journal of the Korean Society of Precision Engineering, Volume 3, No. 4, pages 15-23, 2002.

[7] S. C. Park, Y. C. Chung : Tool Path Generation From measured Data, Computer-Aided Design, Volume 35, pages 467–475, 2003.

[8] H. Y. Feng, Z., Teng : Iso-planar piecewise linear NC tool path generation from discrete measured data points, Computer-Aided Design, Volume 37, pages 55–64, 2005.

[9] P. Breteau, F. Thiébaut, P., Bourdet and C. Lartigue : Towards an approach for rapid copying of free form surfaces in 5 axis machining, IDMME 2006, May 17-19, Grenoble, France, 2006.

[10] K. L. Chui, W.K. Chiu and K. M. Yu : Direct 5-axis tool-path generation from point cloud input using 3D biarc fitting, Robotics and Computer-Integrated Manufacturing, Volume 40, pages 270-286, 2008.

[11] D. OuYang, B. A. Van Nest, H. Y. Feng : Automatic Ball-End Milling Tool Selection from 3D Point Cloud Data, Flexible Automation and Intelligent Manufacturing, FAIM2004, Toronto, Canada, pages 253-260, 2004.

[12] D. OuYang, B. A. Van Nest, H. Y. Feng : Determining gouge free ball-end mills for 3D surface machining from point cloud data, Robotics and Computer Integrated Manufacturing, volume 21, pages 338-345, 2005.

[13] Y. Zhou Y.: Surface interpolation and approximation, Master Thesis, Michigan Technological University, USA, 1999.