

Development of Initial Tool Orientation Method At Close Bounded Area for 5-Axis Roughing Based on Faceted Models

Himawan Hadi Sutrisno, Gandjar Kiswanto, and Jos Istiyanto
 Dept. of Mechanical Engineering, Universitas Indonesia, Depok, Indonesia
 Email: gandjar_kiswanto@eng.ui.ac.id

Abstract- In the rough machining, especially for complex models, it is often found limitation area that cannot be machined by ordinary 3-axis machining operation. for example models consist of close bounded volume (CBV area). Generally, rough machining strategy adopts 3-axis machining method. With the use of 5-axis milling machine, it is expected that the lack of ability of roughing process for particular shape is overcome. To perform roughing process on that area, determination of initial tool orientation is the starting step needed to obtain an accurate direction and sculpture position. First, to determine CC-point on the surface of a workpiece, identify CC-point position on CBV area, determine the neighboring CC point closest to CC-point in CBV area, then to make position vector from the point in CBV against the nearest neighbour CC-point on the highest Z value. This method is successfully applied for the shapes which contain CBV area on the surface where machining process is performed.

Index Terms—tool orientation, roughing, 5-axis, CBV area

I. INTRODUCTION

Roughing process aims to create workpiece closest to the final form. This process has a larger proportion compared to the finish machining process in terms of waste material disposal, even though the shape that is generated still has a high degree of roughness. In an attempt to increase efficiency, in particular for roughing process, some researchers try to find the compatible methods to cope with the problem [1], [2].

Faceted model is widely used in the research on the development of machining method until now [3]-[5], however; there are some using point cloud as the basis for data [6], [7].

To get sculptured orientation, it is approached by analysing machining accessibility against the surface where machining proses takes place. This method is successfully developed by Sutunyanakit. K *et al.* [8]. Meanwhile, limited area detection, another concept which is successfully developed by Kiswanto. G *et al.* [9], is conducted by analysing the difference of normal vector directions in one vertical line toward a triangle model. The method can detect when a model has more than one limited areas in one vertical line.

Making sculptured orientation for machining process is an early step to determine a sculptured trajectory. Some studies about sculptured orientation emphasize on the ability of milling machine used. M. N Osman Zahid *et al.* [10] uses some configuration in an attempt to find sculptured orientation on each workpiece shape. Another thing was experienced by Kung-hung chen *et al.* [11], who use a mathematical model in determining the geometric correlation with direction of sculptured orientation. Besides sculptured trajectory, other factors which can be used in order to increase effectiveness of initial machining are selection of sculpture used [12], selection of machining parameter [13], [14], and optimization of waste material disposal [15], [16].

II. METHOD OF INITIAL TOOL ORIENTATION SET UP

Single step process in machining process does not only provide possibility to improve effectiveness of machining time but also provides possibility to decrease error owing to setting the workpiece repeatedly on the next machining process. Based on the above, 5-axis initial machining with additional two degrees of freedom compared to generally used method, is expected to be the solution to improving the machine capability. The developed method has a flow chart as Fig. 1.

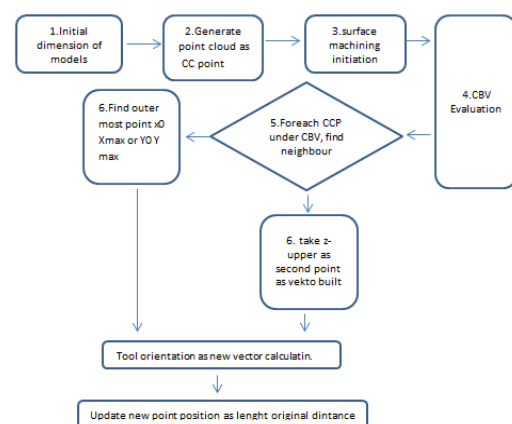


Figure 1. Flow chart

To ensure that the method developed can be applied to make initial sculptured orientation, particularly for the workpiece containing CBV area, the method developed is applied to the sample models below (Fig. 2):

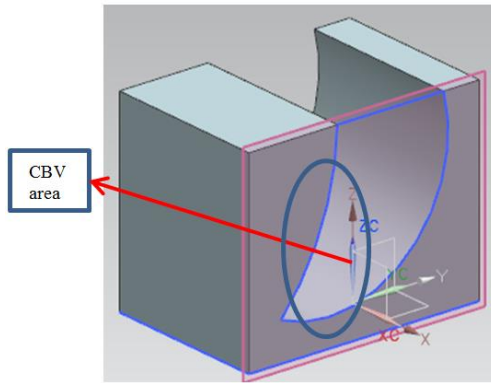


Figure 2. Workpiece model

A. Steps of Initial Tool Orientation Set-Up

In initial tool orientation set-up, CC point is the basis of information about the surface on which machining process is performed. The second factor, which is more important when 5-axis milling machine is used, is the tool direction at the Local Coordinate System (LCS) position on the workpiece surface. Direction of tool orientation and CC point on the LCS can be explained in Fig. 3 below.

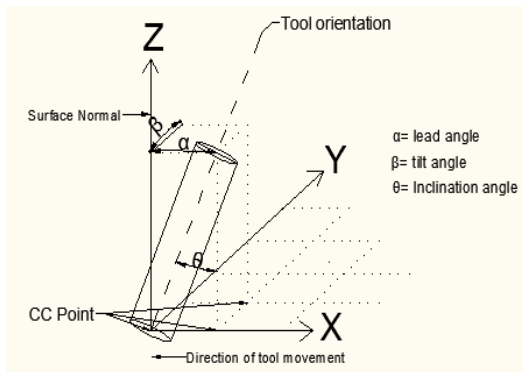


Figure 3. Initial tool orientation

To get direction of initial tool orientation on CBV area, the steps are as follows:

- Determination of the size of the workpiece. Each model, in the form of STL file, the length, the width and height are calculated from triangle position against a three-dimensional plane. Location of the furthest triangle on X axis identifies the maximum value of x: the same thing shall apply to Y axis and Z axis. Workpiece dimension will be counted from X max to X min, for Y axis from Y max to Y min, for Z axis Z max to Z min
- Making point cloud. The point cloud here, is a virtual point constructed to simplify calculation and is used as initial reference at the workpiece surface (cutter contact point or CC point).
- The next step is seeking point cloud which is on a solid model and on outer side model (under raw material). By adopting the Slicing Line method [17] and Fast Minimum Storage Ray Triangle Intersection method [18], which is applied for every point cloud along XY plane on Z = 0

(described in Fig. 4a), intersection of lines on the workpiece surface triangle is used as the basis for determining the CC point for machining process. The point cloud defined as CC point is the one outside two intersections from the slicing line in the vertical slicing line that covers workpiece, see Fig. 4 below.

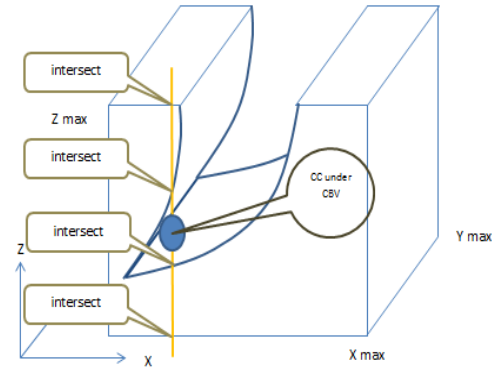


Figure 4. Intersection evaluation with slicing line

- CBV evaluation. From CC point determination in the previous step, it enables CC point to be in CBV area. From CBV evaluation concept that has been introduced by G. Kiswanto [9], CBV is between two solid models in one slicing line. Data of the slicing line on the previous step is used to classify CC point on each surface machining layer.
- CC point in CBV area. As it is described in Fig. 6 below, every CC point in CBV area is an essential point in making method of determination of initial tool orientation. This point is the starting point of vector position while the second point of the requirements for making a vector will be determined on the later phase. This point is identified as point (X1, Y1, Z1).
- The search of CC point nearest to CC point in the CBV area. In determining vector direction from two known points, the second point used is the highest Z value from the nearest CC point along the XY plane and outer from CBV area (beside of CC point on CBV area). After knowing the nearest point, with the value (X2, Y2, Z2), the next is to determine the highest CC point with the position (X2, Y2, Z max). And this point is identified as point (X3, Y3, Y3).

$$\begin{pmatrix} x3 \\ y3 \\ z3 \end{pmatrix} = \begin{pmatrix} x2 \\ y2 \\ z \text{ max} \end{pmatrix} \quad (1)$$

The i, j, k direction on a 3-dimensional plane is determined by using vector operation from point (x1, y1, z1) to point (x3, y3, z3) with the vector operation as follows:

$$\vec{AB} = \begin{pmatrix} x3 \\ y3 \\ z3 \end{pmatrix} - \begin{pmatrix} x1 \\ y1 \\ z1 \end{pmatrix} \begin{pmatrix} i \\ j \\ k \end{pmatrix} \quad (2)$$

From the operation vector above, the position of vector direction could be found.

- Determining initial tool orientation. As a result of the CC point grouping on the above, the making of initial tool orientation generates in 2 groups of orientation direction. The group of CC points in CBV area is constructed in the same way as the previous step. Meanwhile, the group of CC points outside CBV area (OBV area), direction of sculptured orientation, follow the direction of normal vectors or in line with the vertical axis

III. IMPLEMENTATION AND VISUALISATION

In this study, faceted models (STL file) used for the database calculation. Faceted model also known the triangular mesh, polyhedral models, as well as tessellated models. its aadvantages in data processing and time computing. The STL file can be seen with ASCII format below, the information needed in this file is the triangle positions in an indexed list as calculation objects

```
Solid
Facet normal -1.000E-00 +1.5786 +1.7864
Vertex -5.000 -1.2500 +0.0000
Vertex -5.000 -1.4000 +0.0000
Vertex -5.000 -3.2500 +0.0000
Ensloop
Endfacet
-----
End
```

To get information and position of all triangles, the matlab software is used to compute the above file.

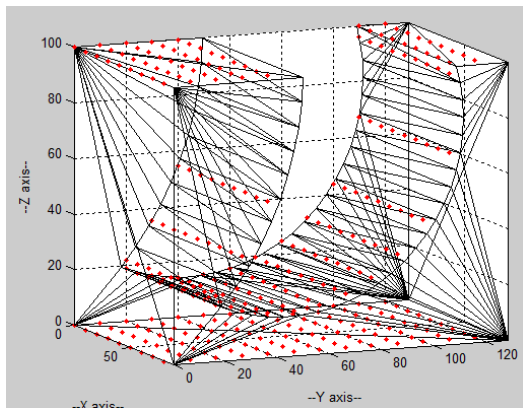


Figure 5. The making of point cloud

In the point cloud creation process, the function of triangulation data reader and determination of point cloud can be seen in psedocode below:

```
[T,V] = stlreader(FILENAME) returns the
triangles T and vertices V separately,
T(:,1:3) have vertex indices
T(:,4:6) have face normal vector
V vertices
file = fopen(filename,'r');
xMnMx = [1000 -1000];
yMnMx = [1000 -1000];
zMnMx = [1000 -1000];
```

```
i = 1;
j = 1;
count = 0;
array = zeros(3);
%% point cloud
density = 10; %wide points cloud
horizontal_stepover = density;
vertical_stepover = 10;
max_min = maxmin(V);
```

Explained in Fig. 5 above, the distance between point clouds towards the flat plane as well as vertical plane is determined by density value. The Implication of density value is the distance between the sculpture or step over when machining is carried out. Initial formation of point cloud is carried out along a flat plane for example XY plane from the minimum value to the maximum value. Beginning from the creation of point cloud on XY plane at elevation $z = 0$, then it is also made on each altitude level (Z level) with the value between levels of density equal to density of point cloud. The making of point cloud on every Z level is a layering step on the feeding process, this considering the depth of cut on the machining process.

According with the previous description, by the slicing line method, each slicing line will look like a triangle intersection by iterations and will be stored in the data index and will be evaluated for CBV area grouping. The point cloud at CBV area can be seen in Fig 6. Below.

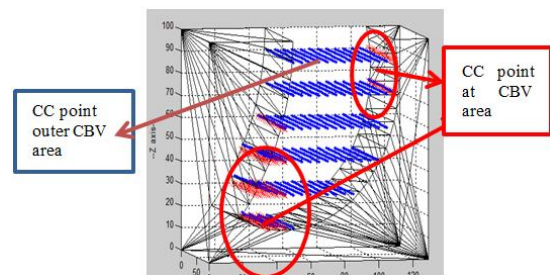


Figure 5. CC point inside CBV and outside CBV area

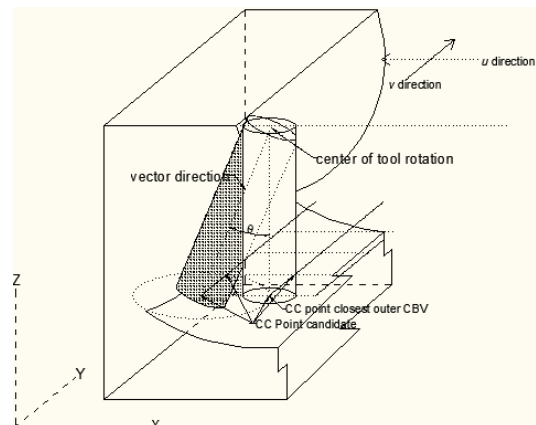


Figure 6a. Determining CC point position

After the point clouds are separated into position in the CBV area and OBV area, the grouping of them will help the grouping of the tool orientation. Fig. 6a as the illustration of vector direction of CC point at CBV area. In this area, the determination of the tool orientation is

based on the vector position reference formed between the CC points under the CBV area and the highest CC points outside the CBV area (see Fig. 6b). whereas In the OBV area, the tool orientation has the same direction with the normal vector of workpiece

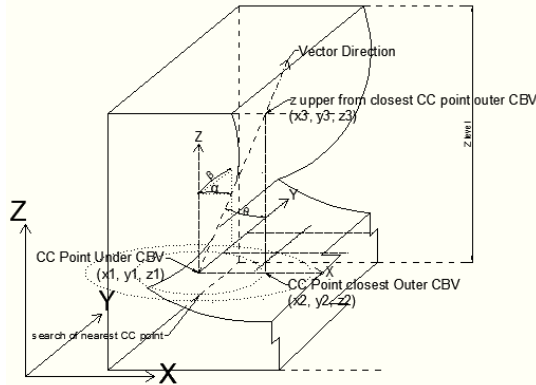


Figure 6b. Determining nearest neighbor and the highest z value

When this action is performed, the tool orientation of each CC points on the OBV area is parallel to the normal vector of the workpiece while CC points under CBV area form the tool orientation to the closest highest point outside the CBV area as illustrated in Fig. 8 below.

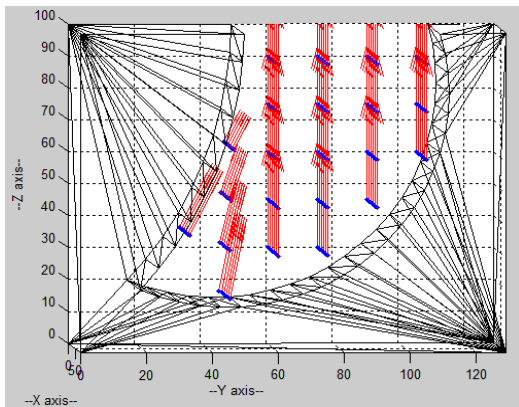


Figure 7. Initial tool orientation set-up

IV. CONCLUSION

From the results of the applications to several models that have been described, the method of making initial tool orientation on CBV area by adopting CBV evaluation result and the calculation of vector position from two points can be applied. This method is a simple one so the computation system does not need to take a long time.

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Himawan Hadi Sutrisno is Doctoral student in mechanical engineering Universitas Indonesia, place and date of birth: blitar and 05 may 1981. He received a BS in mechanical engineering in Brawijaya University 2004. MS in mechanical engineering Universitas Indonesia in 2008. His research interest include 5-axis machining, simulation and application machining method.



Gandjar Kiswanto is associate professor of mechanical engineering in Universitas Indonesia, Depok, Indonesia. Place and date of birth: Pontianak and 20 April 1972. He receive a BS in mechanical engineering at same university in 1993, and an MS and a Doctoral both in Production Engineering and Machine Design from KU-Leuven (katholieke Universiteit) Leuven, Belgium in 1998 and 2003, respectively. His research interest include machining, CAD/CAM system, micro machining and micro processing



Jos Istiyanto is associate professor of mechanical engineering in Universitas Indonesia, Depok Indonesia. Place and date of birth: Pemalang and 27 Januari 1975, He receive a BS and Master Degree in mechanical engineering at same university in 1998 and 2003. PhD in Mechanical Engineering Yeungnam University South Korea in 2012. His research interest include micro fabrication, CAD/CAM system,

machining and fabrication.