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CYLINDRICAL AXIS DETECTION AND PART MODEL ORIENTATION FOR GENERATING SUB DELTA VOLUME USING FEATURE BASED METHOD

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ABSTRACT

For lathe machining, pre-processing of the CAD data in Computer Aided Process Planning (CAPP) is essential since it is the link between CAD and CAM. Thus, cylindrical part model orientation is important to be determined in order to ensure the cutting parameter is correctly setup. Without proper orientation during the pre-processing of the cylindrical part model, further calculation and setup will be erroneous. Therefore, this paper will focus on initial part orientation and its processing in order to generate the delta volume of material to be removed for the lathe machining. By using feature based method, axis from normal vector of the recognised face from the cylindrical part model will be analysed and configured to the required orientation. The algorithm will later generate the Sub Delta Volume for Finishing (SDVF) and Sub Delta Volume for Roughing (SDVR) of the part model. Consequently, volumes of the SDVF and SDVR will be estimated and compared.

Keywords: CAPP, part orientation, sub delta volume.

INTRODUCTION

Computer Aided Process Planning (CAPP) is the main solution in bridging Computer Aided Design and Manufacturing (CAD/CAM) system. Process planning encompasses the activities and functions to plan detailed set of procedures and instructions to produce a part. CAPP based on recent study include three categories which are variant approach, semi variant and generative approach. Research trend on CAPP is moving towards generative approach and one of the most popular and convincing method is feature based method. Features of part model will be recognised and processed to examine the topology and geometry of part and determines the existence and definition of features. Contributing to efficient calculation, part orientation and early setup are necessary in order to avoid mislead result such as incorrect volume of the generated sub delta volume and incorrect stock model dimension. This research intends to concentrate on the early stage of pre-processing of the cylindrical 3D CAD part model by focusing on axis and part orientation. This paper will introduce automatic 3D rotational method and propose a technique on generating sub delta volume for finishing and roughing of cylindrical part commonly for lathe machining.

LITERATURE REVIEW

Researchers reviewed on CAPP over the years are very few. Xun Xu *et al* [1] had reviewed CAPP systems and methodologies. Twelve methods have been reviewed from the year 2002 to 2009. CAPP methods those days were trending towards expert system and feature based system was the popular method of experts' system. Meanwhile, Y. Yusof *et al* [2] had done a survey of the most established methods of CAPP and states that feature based method was the most popular method that had been used in the majority of CAPP works. Also an effort was done on recognizing machining features by using rule based on different characteristics specific to feature such as the total number of faces, edges by using Unigraphics software [3]. However, in this method, part recognition became more difficult as the number of features increased. Sankha Deb *et al* [4] developed feature recognition and extraction of CAD data from a commercial CAD software system, CATIA V5 to form a CAPP system by using artificial neural networks (ANN). Moreover, data exchange (not only to geometry, but also to additional information such as dimensions, dimensional and geometrical tolerances and surface roughness), between different computer systems were being focused [5]. Younis *et al* [6] proposed a CAPP system on metal turning machine by choosing over variant-group technology-process planning. While Yuliang Su *et al* [7] used hybrid genetic algorithm to plan for turning machining. Furthermore major work on surface recognition of regular and free form face to generate Delta Volume is been done [8]. Sub Delta Volumes were generated by the identification of the features of 3D CAD model and this study explored the machining features like finishing (SDVF) and roughing (SDVR). The generations of SDVF and SDVR need proper model setup, and many studies had emphasize on it [9–11] especially during the CAD data transition from one system to another. For the convenient of the 3D solid modeling .SAT file format will be used. The .SAT file is an open format and so the external applications can have access to the geometric model.

ALGORITHM PROCESS OVERVIEW

The study is dealt with using several software to prepare 3D CAD model and processing it. 3D CAD model is prepare by using CAD software and exported into .SAT format. The algorithm is developed by using an open source 3D solid modeling engine. Feature based method is implemented to recognise the part model topologies. Figure-1 shows the overall flow chart of the algorithm. The algorithm is divided into four main phases, which are 3D CAD model pre-processing, planar face identification, cylindrical face identification and delta

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volume generation. The details of each phase process will be explained on the next sub section.

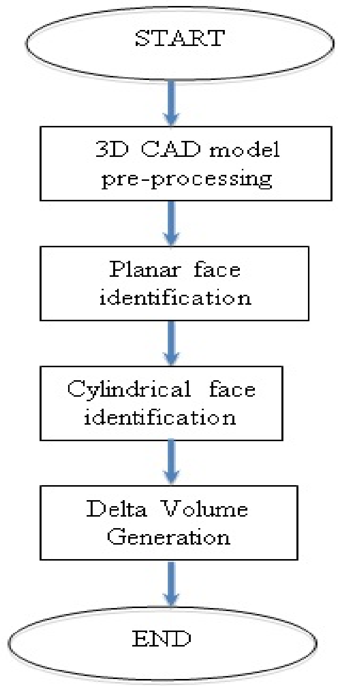

Figure-1. Process flow chart.

a) 3D CAD model pre-processing

The phase contains two steps 1) processing of the topological and processing part's volume and 2) from the data extracted; the next step will be the generation of stock model.

Step 1: 3D CAD model imported in .SAT file format will be processed and the topological data of the part will be configured using feature based method. From the topological structure, more information will be extracted and from the body of part, volume of the part model will be calculated. Other than that, most important data and classification will be from the faces**.** Figure-2 shows the classification of part model faces.

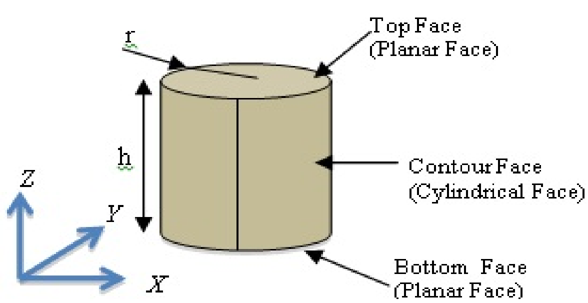

Figure-2. Classification of 3D CAD model's faces.

Step 2: Apart from topological data, generation of cylindrical stock model work piece's dimension and volume will be made. The algorithm will calculate an appropriate stock model based on bounding box tolerance based on customer input. Using the bounding box without tolerances, the stock model dimensions are generated. The generated stock model will consider the formulated model as Equation. (1).

Cylinder stock model volume = $\pi \times r^2 \times h$ (1)

where:
r = radius of cylinder
h = height

Box stock model volume = $x \times y \times z$ (2)

where:
x = length
y = width
z = height

The algorithm will also consider square box stock model considering four jaw chuck machining. The formula is stated in Equation. (2).

b) Planar face identification

The algorithm will identify the faces of the 3D CAD model and it will start with planar faces. Axis of cylinder will be detected and then the algorithm will decide on the rotation of 3D CAD model.

Step 1: Two types of faces i.e. planar and cylindrical faces will be evaluated. Planar faces are identified as the most possible bottom face of 3D CAD model. Cylindrical faces are the contour faces. For planar faces, direction of normal vector of *x*, *y* and *z*-axis of the faces will be considered to return the automatic rotational translation of the CAD model. The translation will detect the normal vector of planar faces which considers the bottom and the top face of the cylinder. If the bottom or the top face is not in the direction of *z*, the algorithm will recognise that the part is not in vertical position. If this condition is detected, it is then been rotated to the required orientation. Figure-3 shows the 3D CAD model orientation in three positions. If it is in the condition of (b) and (c), then the system will translate the 3D CAD model by rotating to the required position (a). This is the key step of face recognition as most of the calculation of SDVF and SDVR will be based on the require position (a).

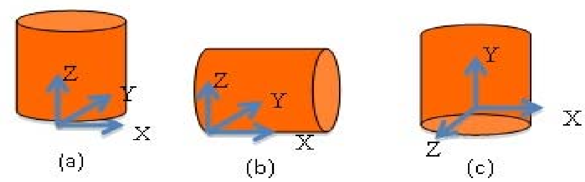

Figure-3. (a) 3D CAD model's vertical orientation, required position (b) part oriented in horizontal *x* axis and (c) part oriented in horizontal *y* axis.

Step 2: After the planar faces being recognised, the algorithm will then automatically rotate the 3D CAD model into the required position. The equations of 3D CAD model rotational on *y*-axis and *x*-axis will be based on Equation. (3):

Rotation on x-axis:

$y' = y \cos q - z \sin q$
$z' = y \sin q + z \cos q$
$x' = x$

$$Rx(q) = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos q & \sin q & 0 \\ 0 & -\sin q & \cos q & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

Rotation on y-axis:

$z' = z \cos q - x \sin q$
$x' = z \sin q + x \cos q$
$y' = y$

$$Ry(q) = \begin{pmatrix} \cos q & 0 & -\sin q & 0 \\ 0 & 1 & 0 & 0 \\ \sin q & 0 & \cos q & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \quad (3)$$

Where:
x' = new x coordinate
y' = new y coordinate
z' = new z coordinate
q = rotational angle = 90°

c) Cylinder face identification

After the planar faces, the algorithm will then move to identify circular faces. While the planar faces are detected for part orientation, the circular faces are identified to generate more face which is used for the generation of the SDVF and SDVR.

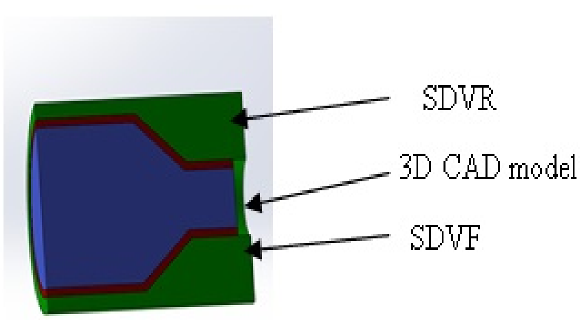

Figure-4. The part body recognition of 3D CAD model body, SDVF and SDVR in half section view.

d) Generation of sub delta volume of finishing (SDVF) and sub delta volume of roughing (SDVR)

After all the required data from the planar and cylindrical faces is identified, the SDVF and SDVR are generated. This will implement several steps and techniques to suit the cylindrical shape.

Step 1: Face-offsetting technique will be use on generating the new faces and continue to generate new part volume for finishing. This new generated parts are based on the cylindrical faces only. The solid modeller will divide the cylindrical face into two and the offset function of solid modeller will not work if the faces are merging together. The direction of the offset face will follow the normal direction of the face selected. This solution will generate uniform distance between the generated faces and the original faces.
Step 2: With the new offset faces generated, it is then being lofted in anticipation of the original faces to generate the new part volume of SDVF. With the new generated SDVF, the volume is then being calculated.

Step 3: Roughing process is the first material removal process. The process will remove the materials from stock model roughly before the finishing process which will remove work material in narrower tolerances. To get the generated body of SDVR, the body of SDVF and the original part model will be subtracted from the generated stock model cylinder. This is directly using Boolean subtracts operation. This is express in Equation. (4).

$$SDVR = S - SDVF - 3D\ CAD\ model \quad (4)$$

Where S = stock model cylinder

IMPLEMENTATION AND DISCUSSION

An example of 3D CAD model which has 8 faces, 14 edges, 8 vertices and 8 loops had been used.
The parts details are shown in Figure-5 (a) and the face classification and face's number is expressed in Figure-5(b).

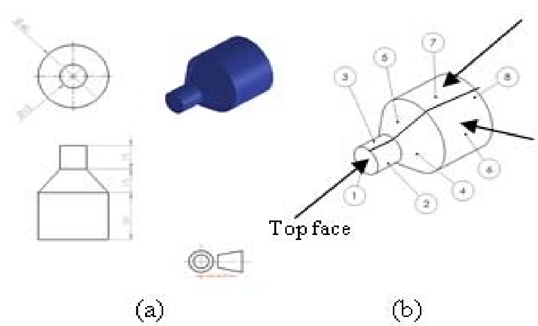

Figure-5. (a) The detailed drawing of example 3D CAD model, (b) The top, bottom and contour faces definition and its 8 faces.

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Part rotation

Figure-6 shows the example 3D CAD model been rotated in *x*-axis direction of 90°. The original position of the 3D CAD model is in *y*-axis horizontal as it is rotated to 90° *x*-axis using Equation. (3).

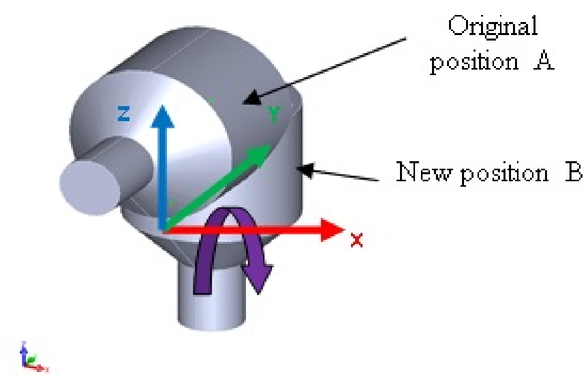

Figure-6. Part with *y*-axis horizontal in original position A and part after the rotation of 90° *x*-axis in new position B.

SDVF generation

Sub Delta Volume for Finishing (SDVF) generation will be based on the tolerances of finishing thickness given by the user. It is normally between 25µm RA until 1µm RA [12]. The technique used to build the SDVF is by offsetting the surface of part model via the normal direction which will generate a new surface in uniform distance. These surfaces then being loft by using the 3D solid modeling engine API function. SDVF model generated is shown in Figure-7, and the SDVF's volume in Figure-8.

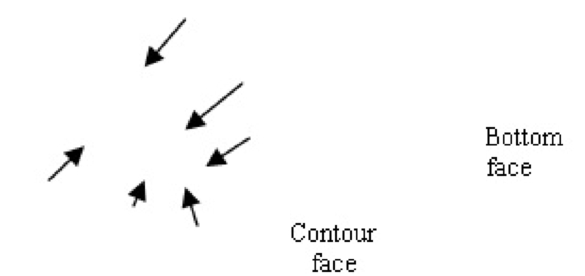

Figure-7. Sub delta volume for finishing of the part and the 6 bodies generated.

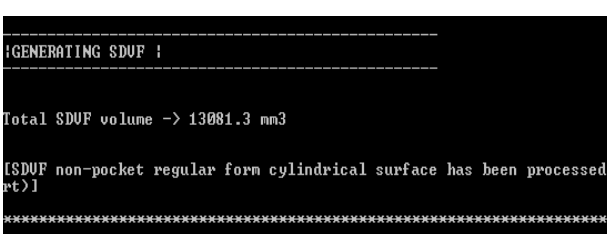

Figure-8. Display of the volume of SDVF.

SDVR generation

Sub delta Volume generation will be based on the basic principle of subtraction of SDVF and part model from the stock model cylinder. The input of cylinder diameter and height will be from user input. SDVR model generated is shown in Figure-9, and the SDVR's volume in Figure-10.

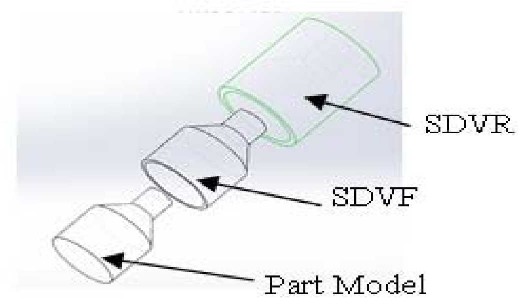

Figure-9. Exploded view of assembly of SDVR, SDVF and part model.

Figure-10. Display of the volume of SDVR.

Delta volume generation

Results comparison of volume of all the parts is being measured and the results are stated in **Table-1** below:

Table-1. Volume of the generated SDVF and SDVR.

No	Sub Volume Part	Volume Generated (mm³)	Volume From commercial CAD system (mm³)	Differences %
1	3D CAD model Volume	49872.6	49872.78	0.00
2	SDVF	13081.3	13195.05	0.86
3	SDVR	60175.5	71715.92	16.09
4	Overall Volume	124433.3	134783.75	7.68

Volume of the 3D CAD model generated and compared with same design develop with comercial CAD software are showing some different. The greatest difference is shown in SDVR's volume which is 16%.

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While SDVF different is 0.86%. This happen as the surface being offset new face will be generated according to the normal directions as shown in Figure-11. As the result, it will produce some gap between the surfaces which were not in the same normal direction. Although they were different in comparison with generated in CAD software the volume is still sufficient as it is only require the overall volume of the material need to be removed.

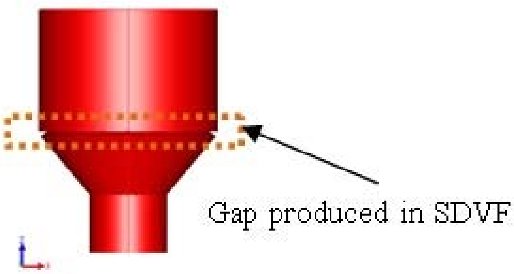

Figure-11. Gap that effecting the volume in sub delta volume for finishing.

CONCLUSIONS

The algorithm is capable of detecting the axis of cylindrical part model and able to automatically rotate the part model into required position for further calculation of generating more specific volume which is SDVF and SDVR. This study has introduced a new technique on generating SDVF and SDVR. Thus, the result shown overall volume different of 7.68% from the volume generated from commercial CAD software.

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