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Penulis	: Achmad Yahya Teguh P, S.T. M.T.
NIP	: 19800205 200501 1 002
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Mengetahui,
Dekan Fakultas Teknik
Universitas Lampung

Dr. Ir. Lusmeilia Afriani, DEA
NIP 19650510 199303 2 008

Penulis,

Achmad Yahya Teguh P, ST MT
NIP 19800205 200501 1 002

Menyetujui,

Ketua Lembaga Penelitian
Universitas Lampung

Dr. Eng. Admi Syarif
NIP. 196701031992031003

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Development of Closed Bounded Volume (CBV) Grouping Method of Complex Faceted Model through CBV Boundaries Identification

Gandjar Kiswanto
Dept. of Mechanical Engineering
University of Indonesia
Depok, Indonesia
e-mail: gandjar_kiswanto@eng.ui.ac.id

Achmad Yahya Teguh Panuju
Dept. of Mechanical Engineering
University of Lampung
Bandar Lampung, Indonesia
e-mail: yahyateguh@gmail.com

Abstract— **For developing automatic tool-path planning in multi-axis roughing processes of complex faceted models, the so called Opened Bounded Volume (OBV) and Closed Bounded Volume (CBV) must be identified. The CBV feature in a complex faceted model can be detected through *Paired Normal Vectors Bucketing* method (PNVB). This paper describes further method to partition the CBV in a model that contains more than one CBV. Possibilities of CBV configuration are identified to define the boundaries between detected CBV. The faceted model is mapped on matrix, in order to analyze the existence of boundaries through matrices scanning procedure. An algorithm is developed and implemented to get the final CBV groups. At the end, each CBV group has its own data structure, to enable further analysis in planning the manufacturing processes. The developed method and algorithms can successfully identify and group all the CBV that exist in complex faceted models.**

Faceted model; closed bounded volume; grouping; algorithm (key words)

I. Introduction

Feature identification at the beginning of manufacturing process is an important aspect in CAPP and CAM optimization. In a manufacturing decision support system, recognizing what features in a model will define the next steps. It will include deciding what process will be needed, what tool will be used, and other components. Thus, if the features in a model are not well identified, we can not do the next steps efficiently.

Closed bounded volume (CBV) is a unique feature in a model (Fig. 1). In such a way, CBV existence will make the model become complex, because it is impossible to machine the CBV with three-axis machining without changing the jig's orientation. Even in a five-axis machining, we can't do it automatically if the CBV was not well detected at the beginning of the process.

Many methods have been developed to enrol the feature identification process. Henderson and Anderson have built an expert system by converting B-rep solid models to some facts and rules [2]. Nnaji and Liu introduced a system to extract relevant features for manufacture and assembly from CSG-based CAD system, by converting CSG to B-rep structure [3]. Raymond presented algorithm to identify feature by implementing octree concept of B-rep [8]. Risal Abu and Masine developed an algorithm to identify features based on TNOE, TNOF, P/D and TOF data [9].

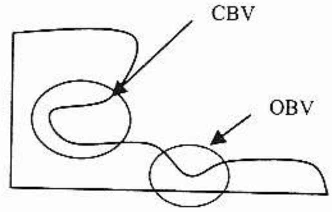

Figure 1. Closed and opened bounded volume in a model

The methods mentioned above have not discussed about CBV in detail. Kiswanto introduced a method to recognize CBV by using faceted model data [10]. The method detects CBV, but if the model contains more than one CBV, it was not be able to differ and to divide one CBV to another. To perform an automatic system which is able to generate tool path in each CBV, it is necessary to develop another algorithm to divide and to partition the CBV into groups, based on the location.

II. Closed Bounded Volume Detection in Faceted Model

A faceted model is a representation of a solid model in triangular mesh form. The surface is tessellated logically into a set of oriented triangles (facets). Entities such as points, lines, curves, and attributes such as layer, color, in the CAD systems will be ignored. Since the solid model is represented by mesh of triangles, the shape of the triangulation result is an approximation. The accuracy depends much on triangulation resolution. Higher the resolution, better the shape we get.

The facets are arranged by certain rules. Each facet is uniquely recognized by a unit normal and three vertices. A vertex will only meet other vertices, also an edge will only meet another edge.

The normal vector will define the facet orientation. Commonly, the direction of the normal is outward. It will be

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applied consistently through all the facets. By that, one can simply define which part is outside and which part is inside for the whole model.

All these data is kept in a list, usually in stereolithography format (STL). The amount of memory needed for this format depends on how many facets in the model. But usually it is still smaller than the amount of memory needed by other format. But in other side, STL format doesn't contain instant information about the model such as the model's features. Numbers in the list of coordinates and normal vectors must be processed to gather information needed.

As mentioned before, CBV can be detected by such a method called Paired Normal Vector Bucketing (PNVB) in a faceted model [10]. The principle of this method is to find head to head facet configuration as we seen in Fig. 2.

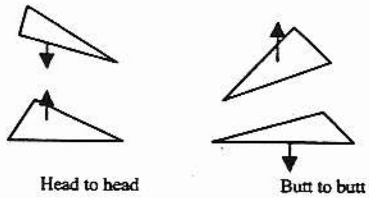

Figure 2. Oriented facets configuration

In order to get the configuration as seen above, rule as below is implemented to the list of normal units:

```
If(vj < 0)
   vj = -1
elseif(vj > 0)
   vj = 1
end
```

With v_j as j component (depends on what axis assumed to be the height component in the model) on unit normal.

First, points cloud above the model is created (Fig. 3). Spots in points cloud will become template for our future cutting contact points. From each spots from points cloud, a slicing line (SL) is drawn to the bottom of the model. At this phase, there are some intersection points between SL and the model's facets as our future cc points. Along the slicing line, a configuration of facets that are being sliced by the line is gained. Every head to head facet configuration means CBV, while butt to butt configuration indicates solid part of the model.

Until this phase, all SL's parts which contain CBV are detected (Fig. 4). If there are more than one CBV in a model, the method will detect them as one.

III. Closed Bounded Volume Grouping Method

Many parts contain more than one CBV. To optimize the process planning in CAPP and CAM system, tool path for CBV should be generated by the system automatically. For this purpose, each CBV must be analyzed separately. It means that the first thing the system has to do is separating CBV to groups, based on the location. Some possibilities of basic CBV configuration in a model is shown in Fig. 5.

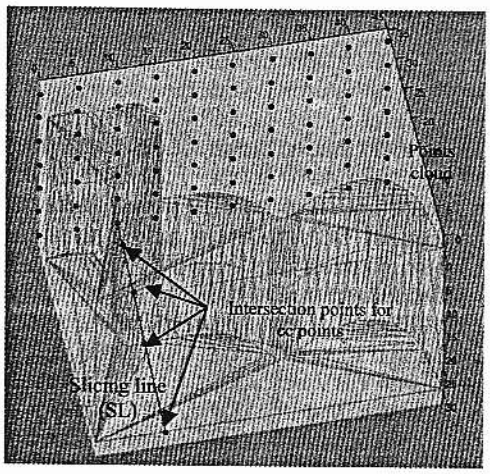

Figure 3. Slicing line through a model

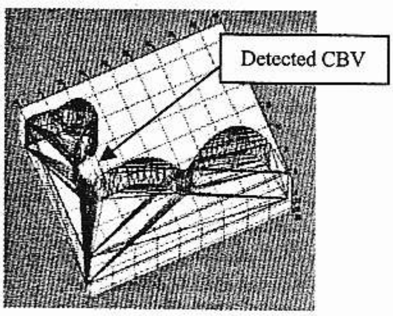

Figure 4. CBV detection in a model

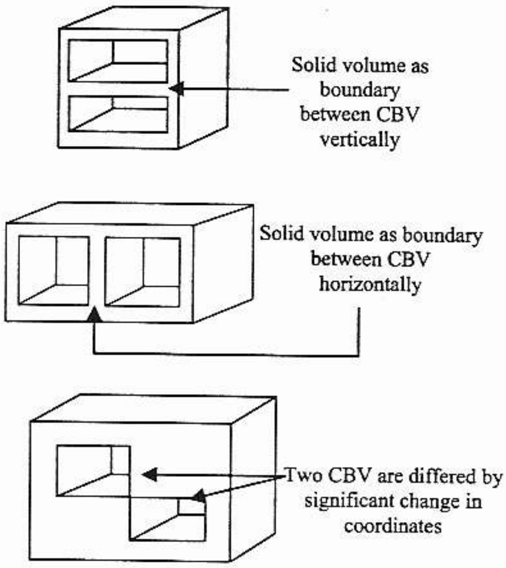

Figure 5. CBV configuration possibilities in a model

Three basic boundaries between CBV are defined: solid volume detected by vertical scanning, solid volume detected by horizontal scanning, and sudden or significant change in CBV coordinates.

Again, since STL format only provides data of facets' coordinates and their normal units, then the numbers must be scanned and be analyzed to define where the boundaries exist. In order to do this, a data structure in a 3D matrix form is made, consisting two layers. Elements in each layer represent slicing lines that have been discussed above. The first layer consist SL's indexes, linked to another data structure which contains data from facets sliced by the SL. And the second layer consist amount of CBV detected in each SL. If a CBV is detected, the slot in the matrix will be written as 1, and if there are two CBV, it will be 2, and so on. And if there is no CBV detected, the number written will be 0, which indicates that the SL is a full solid. For next discussions, this matrix will be called map matrix (Fig. 6).

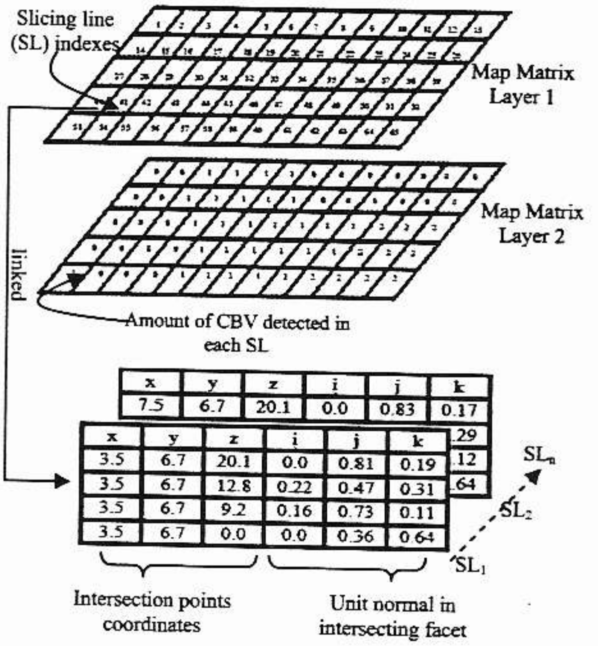

Figure 6. Map matrix as data structure

The idea of the method is how to find boundaries between CBV, based on facets data in STL format. Three kinds of boundaries are described as follow:

1. Solid volume, which is detected by vertical scanning through the model. It is simply recognized with the existence of butt to butt configuration between two head to head configurations. Illustration for this condition is shown in Fig. 7.
2. Solid volume, which is detected by horizontal scanning on map matrix. Its existence can be identified by finding solid volume pattern in map matrix (Fig. 8).

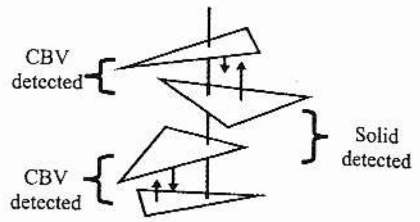

Figure 7. Solid between CBV Detected

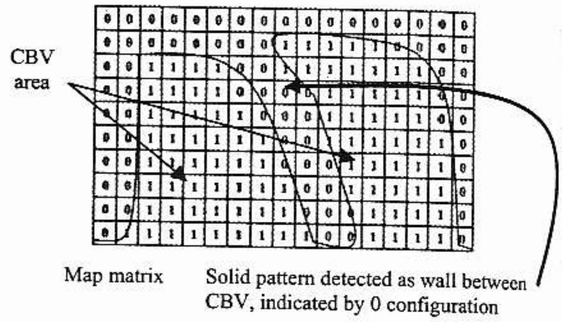

Figure 8. Solid wall detected horizontally

3. Significant CBV coordinates change, which can be detected through scanning Map Matrix. There are some cases where CBV can't be divided by solid wall. One example is presented in Fig. 5. It is necessary to read the pattern first. While scanning through SL, all the intersection point position have to be recorded to define the pattern. From Fig. 9 we can see that P_{n-2}, P_{n-1} and P_n are in a linear line. P_{n+1} position break this pattern, so we can decide that P_{n+1} is in a different CBV group. Smaller the distance between SL, this method's accuracy will be higher.

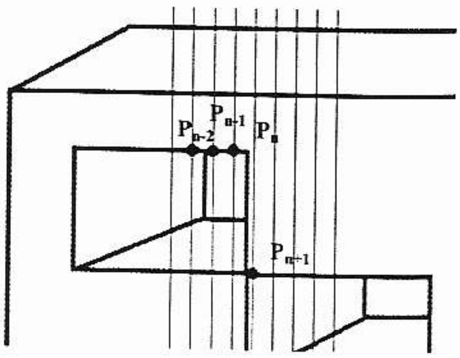

Figure 9. Sudden CBV Coordinates Change

Map matrix is used for scanning process on each slicing line. The following algorithm is implemented for CBV grouping:

```
Algorithm: CBV grouping
Input:
 Facets Data
 Map Matrix
Output: CBV Matrix Data

Find_ pattern_on_map_matrix
Define_horizontal_solid_boundaries_coordinates
Define_active_CBV (begin→1)
For(every_Slicing_Line)
  For(every _configuration)
    If(vertically_solid_detected)
        Active_CBV + 1
    Elseif(significant_coordinates_change)
    _detected
      Active_CBV + 1
    End
    If(CBV_detected)
      Input_data_into_active_CBV
    End
  End
  Confirm_to_horizontal_solid_boundaries
  _position
  If(entering_other_CBV_area)
    Active_CBV + 1
  End
End
```

IV. Implementation and Result

The method described above is implemented to a quarter impeller model as the complex model. We get the following result for CBV detection (Fig. 10):

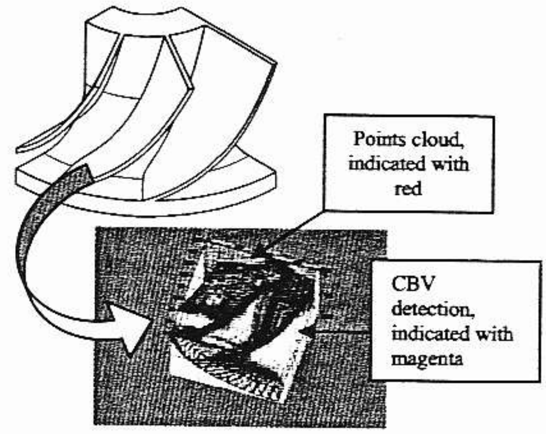

Figure 10. CBV detection in impeller model

The model contains three CBV, but it is considered as one. The system proceed to the next step, CBV grouping.

The model is mapped to the map matrix. Due to its complex shape, impeller would have all boundaries defined before. The mapping process is visualized in Fig. 11. Map matrix is seen as a portrait of the model on top view. The distance between every slicing line is free, but to get finer analysis result, it has to be as narrow as possible. One of the areas which has more than one CBV is marked by green line. The map matrix indicates it with 'number 2 spreading area'. Thus, the next algorithm can easily conclude that the area contains two CBV that are divided by a vertically detected wall. 'Number 0 spreading areas' tell the system that those areas don't have CBV in them. They could be empty areas or full solid areas. So the next algorithm shouldn't have to apply further processes to those areas.

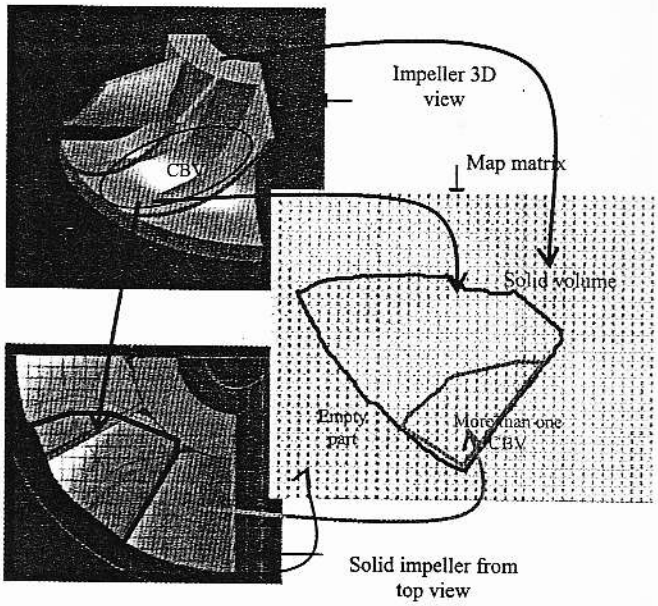

Figure 11. Model mapping process

And after implementing the algorithm, the final result is gained as seen in Fig. 12. Each CBV in this model has its own data structure, which contains cutting contact points data. The data structure is saved in another 3D matrix form called CBV Matrix Data (Fig. 13).

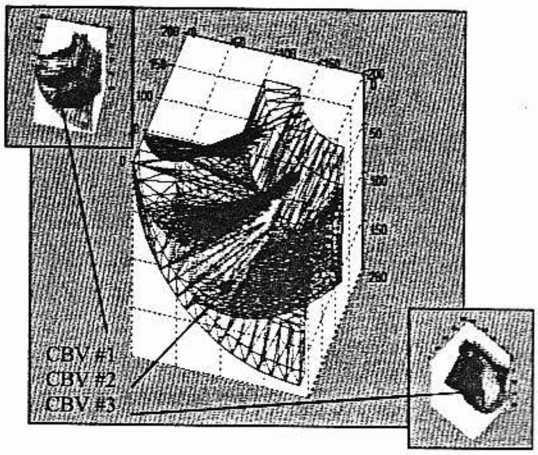

Figure 12. CBV grouping result

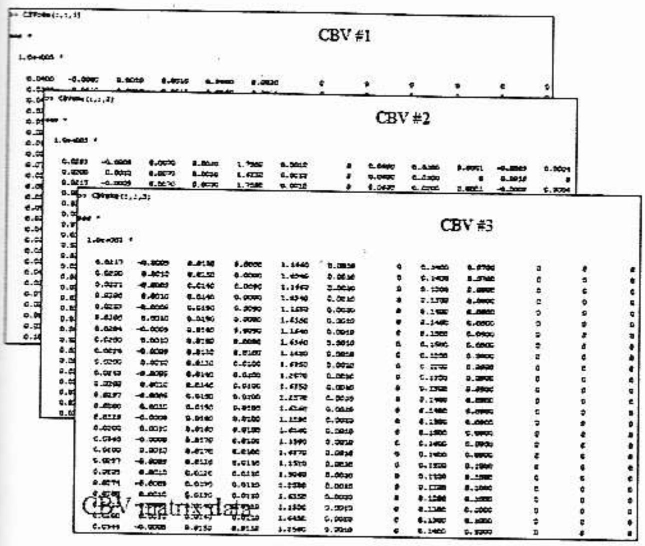

Figure 13. CBV Matrix Data

V. CONCLUSION

To enhance CAPP and CAM performance in assisting manufacturing process, complex features such as closed bounded volume should be identified automatically. This automatic detection is needed to plan the next phases efficiently. It also will reduce resources consuming in a manufacturing line.

This paper's aim is to propose method to recognize multi CBV in a model and to divide them into groups through finding the boundaries between the CBV. A method is applied by mapping a model to matrix, and implementing simple algorithm to group all CBV detected. An impeller model is a fine representation of a complex model containing complicated boundaries between its CBV. And the method has worked successfully in grouping the impeller's CBV. The result from this paper is useful to analyze each CBV and furthermore to generate tool path in it.

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