Automatic Part Primitive Feature Identification Based on Faceted Models

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Abstract

Feature recognition technology has been developed along with the process of integrating CAD/CAPP/CAM. Automatic feature detection applications based on faceted models expected to speed up the manufacturing process design activities such as setting tool to be used or required machining process in a variety of different features. This research focuses on detection of primitive features available in a part. This is done by applying part slicing and grouping adjacent facets. Type of feature is identified by simply evaluating normal vector direction of all features group. In order to identify features on various planes of a part, planes, one at a time, are rotated to be parallel with the reference plane. The results showed that this method can identify the primitive features automatically accurately in all planes of tested part, this covered : pocket, cylindrical and profile feature.

Keywords: *Feature Recognition, Grouping, Normal Vector, Faceted Models.*

1. Introduction

The feature recognition of a part is the most important section of the design optimization process in CAPP and CAM. The basic principle of the feature recognition is to speed up decision-making system on the activity of the manufacturing process planning. This will help determine what processes are required, what tool to use, and any other things to become more efficient. Primitive features of a part, such as : pocket, cylindrical, and profile is a common form used. Identification of primitive feature will automatically save time and effort in the process planing.

Various methods have been established to develop feature identification automatically. V.B. Sunil and S.S. Pande designed and implemented automatic feature recognition system freeform surface CAD models of sheet metal in the STL format. [1]. R. Abu and Masine detected feature recognition automatically through the model of B-rep based TNOF, TNOE, TOF, and P/D [2].

G. Kiswanto and A. Yahya develop identification Closed Bounded Volume (CBV) in a complex faceted models through Paired Normal Vectors Bucketing method (PNVB) for automatic tool-path planning [3]. Raymond et al. presented algorithm to identify features by implementing the octree representation of B-rep models for locating features on the assembly process [4].

C. Weber and S. Hahmann presents a new technique to detect a sharp feature in the point cloud geometry using the Gauss map clustering and selection process of iteration [6]. G. Kiswanto, R. Widyanto and P.E. Kreshna developed surface feature identification in the form of flat, saddle, convex, and concave with a combined method of Gauss Bonnet and Spherical Image [10].

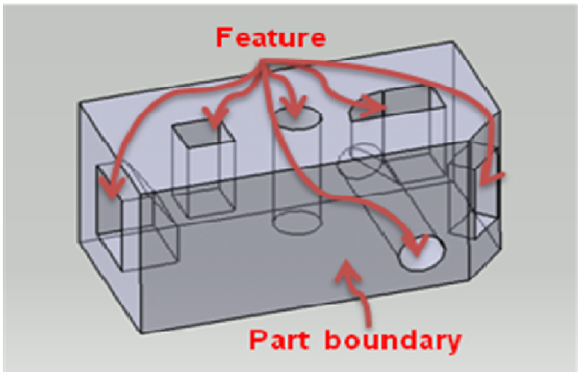

Fig. 1 Primitive feature in a part.

G. Kiswanto et. al [3][10] discussed *automatic feature identification* by employing information from normal vectors of faceted model. This information is further manipulated together with curvature information to determine feature that is available on a sculptured surface, such as: flat, sadle, concave, convex and *closed bounded volume* (CBV) feature. Detection of primitive feature, such as : pocket, cylindrical, and profile, on prismatic part based on faceted models by utilizing normal vector information still needs to be investigated further (Fig. 1). Therefore, this paper presented research focused on this one.

2. Faceted Models

Processing faceted models data structure is needed since the information from the data STL-files cannot be directly used. Data of STL-files need to be processed first so as to structure the data in a coordinate system. STL format is the most commonly used because it is easier to read and understand and can be opened in any text editor for further evaluation when necessary. The STL Files (ASCII format) contains the following data :

```
solid
    facet normal ------- ------- -------
        outer loop
            vertex ------- ------- -------
            vertex ------- ------- -------
            vertex ------- ------- -------
        ensloop
    endfacet
    -------
    -------
end
```

STL file format stores objects in a 3D surface triangles composed three (3) vertices that are at a particular location in a 3D coordinate system. Here is an explanation of the contents of the STL file above:

1 SOLID marks the beginning of a faceted models representation to be closed with the word ENDSOLID
2 FACET NORMAL indicates that there will be a triangular surface with normal vector value is the vector direction after the FACET NORMAL to meet with ENDFACET which means a surface triangle was formed, and their sequence information and the location of the vertex, and the normal vector of the triangle them
3 OUTER LOOP marks the beginning of the loop of the coordinates of the vertices are built of the triangle to meet with ENDLOOP
4 VERTEX is the point of making up a triangle that has previously been defined by the OUTER LOOP. Information that was once the word VERTEX is the position of a point on a 3D coordinate system

Reading of normal vector direction is used to assist in the rotating part or feature identification that has certain characteristics. Normal vector direction of the triangle will be in accordance with the order of vertex, normal vector in seeking to follow the right hand rule. If clockwise rotation, then the normal vector will lead the plane. Conversely, if the rotation is counter clockwise, then the normal vector out of the plane. This can be explained in the figure below.

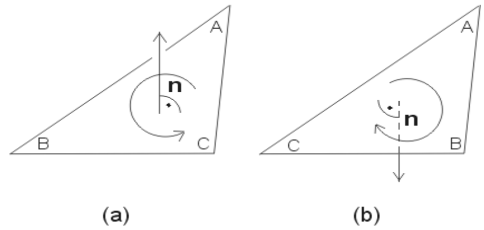

Fig. 2 Normal vector following the right hand rule.

As shown in Figure 2(a) and 2(b) above, the order of vertices data is in counter-clockwise. Then, by following the right hand rule, the normal vector, as a result of cross product between the vectors connecting the vertices, is pointing out the plane accordingly. While in Figure 2(b), the normal vector is pointing into the plane.

3. Algorithm Development

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 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 STL format. Framework of research automatic part primitive feature identification based on faceted models is done by steps algorithm in Fig. 3.

Step of feature identification algorithm begins with the processing of data structures and detecting outer normal vector to the STL file that contains information about the data facet and three vertices of each triangle forming.

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The next process is the rotation transformation, where the faceted model data structure is rotated towards the plane of reference. Then slicing process is conducted where the faceted model is sliced by the slicing planes with predefined slicing interval. Next step is feature grouping. In this step the facets intersected by the slicing planes are grouped. However, the group of facets come from the part boundary is eliminated, so that leaving the groups of feature only. The final step is identification of normal vector direction of facets of the group features. These steps are repeated as many as number of outer planes available on the part.

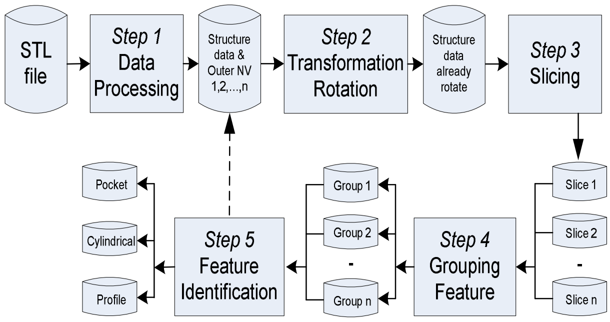


Fig. 3 Diagram of feature identification algorithm.

3.1 Slicing Process

Feature identification is started by finding normal vector direction of all facets belong to the features. Finding facets and normal vectors that are related to the feature can be done simultaneously and straight forward by slicing the faceted model with slicing planes. The slicing planes, as seen in Fig. 4 are planes parallel to the reference plane. In this case, the XY plane is simply chosen as reference plane.

Then the database is developed for facets which are intersected by each slicing plane. Facets index are stored in a vector data structure. The interval between slicing planes is determined based on the specified accuracy and also the distance between Z-minimum and Z-maximum value of the faceted model.

Once the information regarding the index of facet, index of vertex, and coordinates of vertex are identified and stored in the data array, then facets that intersected by the slicing plane are to be found. The search is done through the facet index. The slicing algorithm can be explained as follows.

```
Algorithm: Slicing
Input: STL File
Output: Facet Slice File

Write_data_structure_facet
Define_interval_slicing
For(every_facet)
  If(Zmin<Zslice<Zmax)
    Save_the_data_facetslice
    Zslice=Zslice+interval
  End
  If(Zslice>Zmax_or_Zslice<Zmin)
    Break
  End
End
```

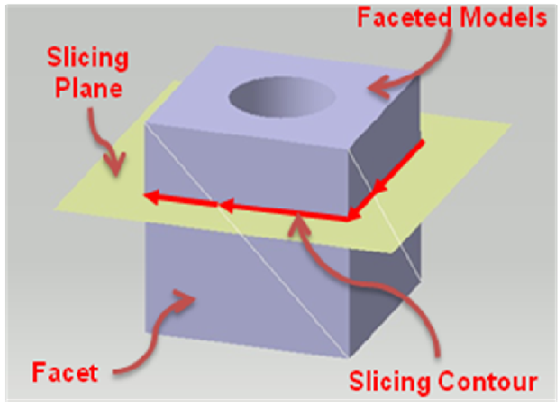


Fig. 4 Illustration of the slicing process on faceted models

This algorithm is performed by checking each facet whether intersected by the slicing plane or not. If it is intersected, index of facet is stored in an array data. Intersection checking with each facet was conducted for each slicing plane. In order to minimize searching time, only facets located near the slicing plane are checked. Intersection between a facet and the slicing plane is found when the Z-value of two vertices of any edge of the facet is met the following rules:

- $Z_1 < z < Z_2$, OR
- $Z_1 > z > Z_2$

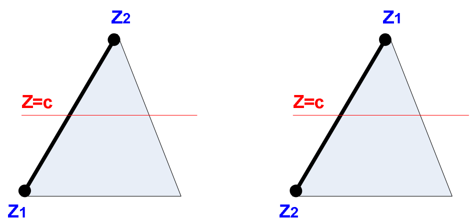


Fig. 5 Intersection point of the triangular facet.

Intersection point of the plane Zslice = c (Fig. 5), are in a position greater than the coordinates of the point Z minimum (>Zmin) and the coordinates of the point less than Z maximum (<Zmax) or Zmin <Zslice <Zmax.

3.2 Feature Grouping

Other information that is necessary for detecting features is the facets connectivity information. The adjacent facets method is used to determine the facet connectivity. Every edge of a facet, thus the two vertices that form the edge, is shared by another facet. Once an edge of a facet is found to be intersected by the slicing plane, other facet who shares the same edge can be found easily. This procedure is run for the rest of process until no more new facet is identified.

Furthermore, for each slicing, all facets which are intersected and are adjacent facets are grouped in the same of group of adjacent facets. Two or more different slicing might intersect the same facet. However, only different facets are finally grouped to form an adjacent group. All adjacent group data are stored in the so called Group Matrix.

To obtain group of features, all adjacent facet groups are evaluated. This evaluation produces the so called Adjacent Groups which are candidates of groups for Feature Grouping. In Feature Grouping, groups of adjacent facets that belong to part boundaries are eliminated. The part boundary is the group of adjacent facets that having outermost normal vector. Algorithm of Grouping Feature can be seen as follows:

```
Algorithm: Feature Grouping
Input: Intersected Facets
Output: Feature Group Data

Write_data_facetslice
For(every_facetslice)
  If(data_facetslice_unique)
    Save_the_data_GroupMatrix
  End
End

Write_data_GroupMatrix
For(every_facet_GroupMatrix)
  If(adjacent_triangles)
    Save_the_data_GroupAdjacent
  End
End

Write_data_GroupAdjacent
For(every_GroupAdjacent)
  Find(group_part_boundary)
    Eliminate_group_part_boundary
  End
End
```

3.3 Feature Identification

By knowing normal vector direction on the Group Feature, a rule to identify types of feature on the group can be developed. Before this feature identification process is executed, normal vectors of the same direction are eliminated, leaving only different normal vector directions of the Group Feature. Rules for feature identification can be described as in Fig. 6.

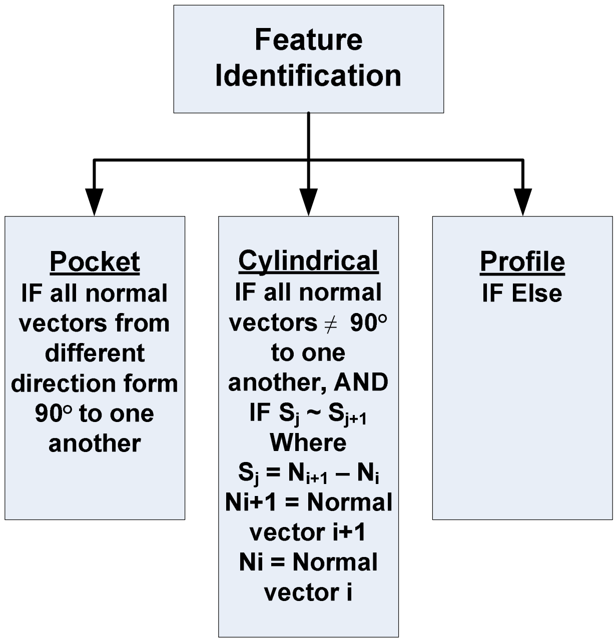


Fig. 6 Rules of feature identification.

Fig. 6 shows that IF normal vector (N) direction perpendicular to each other or form 90° thus "Pocket" feature is identified. However, IF normal vectors of the group is ≠ 90° to one another AND if angle formed by Ni and Ni+1 is equal or nearly equal with angle formed by Ni+1 and Ni+2, and so on, where N is normal vector, then the feature is a "Cylindrical". Furthermore, IF none of the characteristics mentioned above are met, then the feature is "Profile". Algorithm of feature identification can be shown as follows:

```
Algorithm: Rule of Feature Identification
Input: Feature Group
Output: Type of Feature

Reading_the_data_groupfeature
Define_normal_vector
For(NV_every_group)
  If(Θ=90°)
    as "POCKET"
  Elseif(Θ≠90° and ΔΘ≈0)
    as "CYLINDRICAL"
  Else
    as "PROFILE"
  End
End
```

4. Implementation and Result

The method described above, is implemented in 3D CAD model as shown in Fig. 7. The model consists of pocket, cylindrical, and profile in direction [0 0 1], cylindrical feature in direction [0 1 0], profile feature in direction [1 0 0], and pocket feature in the direction [-0.707 0.707 0].

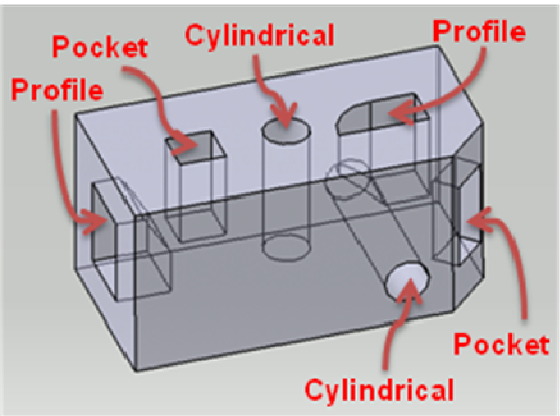
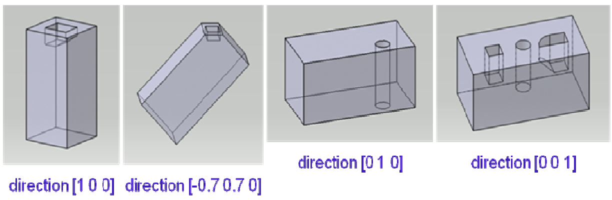


Fig. 7 3D CAD Model.

The 3D CAD model is then processed (triangulated) to form faceted model. The data structure is developed based on this faceted model. Then, the planes of outer normal vector are to be found to start feature identification. The detected outer plane (by finding outer normal vector) is rotated to be aligned (parallel) to the reference plane (Fig. 8). Slicing process is then performed, and continued by feature grouping and feature identification. This step is repeated according to the number of planes of the outer normal vector which are detected.



(a) (b) (c) (d)

Fig. 8 The illustration of rotation transformation.

Slicing process, feature grouping and feature identification are explained as follows. For example, outer normal vector of detected outer plane is in direction [0 0 1] (Fig. 8(d)). To simplify feature identification process, all features that are located on planes which are sliced by the slicing plane are ignored. In other words, only features which are located on the planes parallel to the reference plane (slicing plane) are considered. This process is repeated as many as number of detected outer planes. An example of slicing process can be seen in Fig. 9 shown below where four slicings are conducted. The distance of first slicing plane with respect to the reference plane is determined to be half of the predefined slicing interval.

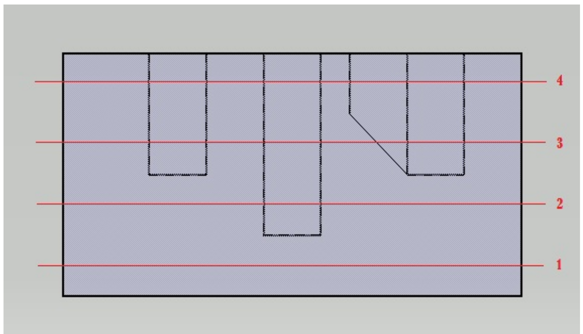


Fig. 9 View slicing the XY plane.

The results of each slicing can be seen in Fig. 10. In Slice 1, the intersection occurs with the part boundary only, while in Slice 2, the intersection is with part boundary and cylindrical feature. Slice 3 shows intersection with part boundary, pocket, cylindrical, and bottom part of profile feature. Slice 4 intersects with part boundary, pocket, cylindrical, and the upper profile feature (Fig. 10).

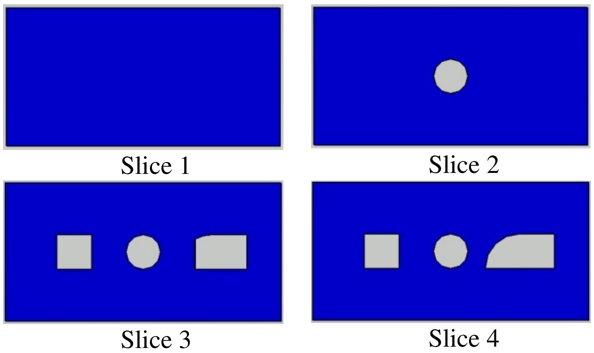


Fig. 10 View the result of XY plane slicing.

As explained above, Feature Grouping is carried out through several steps: Sorting, development of Group Matrix, and Adjacent Facets grouping. The following figure shows data transformation to form feature grouping (Fig. 11).

The final process is Feature Identification. This is done through the rule explained in section 3.3 and as shown in Fig. 6. The following figure (Fig. 12) shows the result of feature identification evaluated on only one outer plane which is aligned with the reference plane.

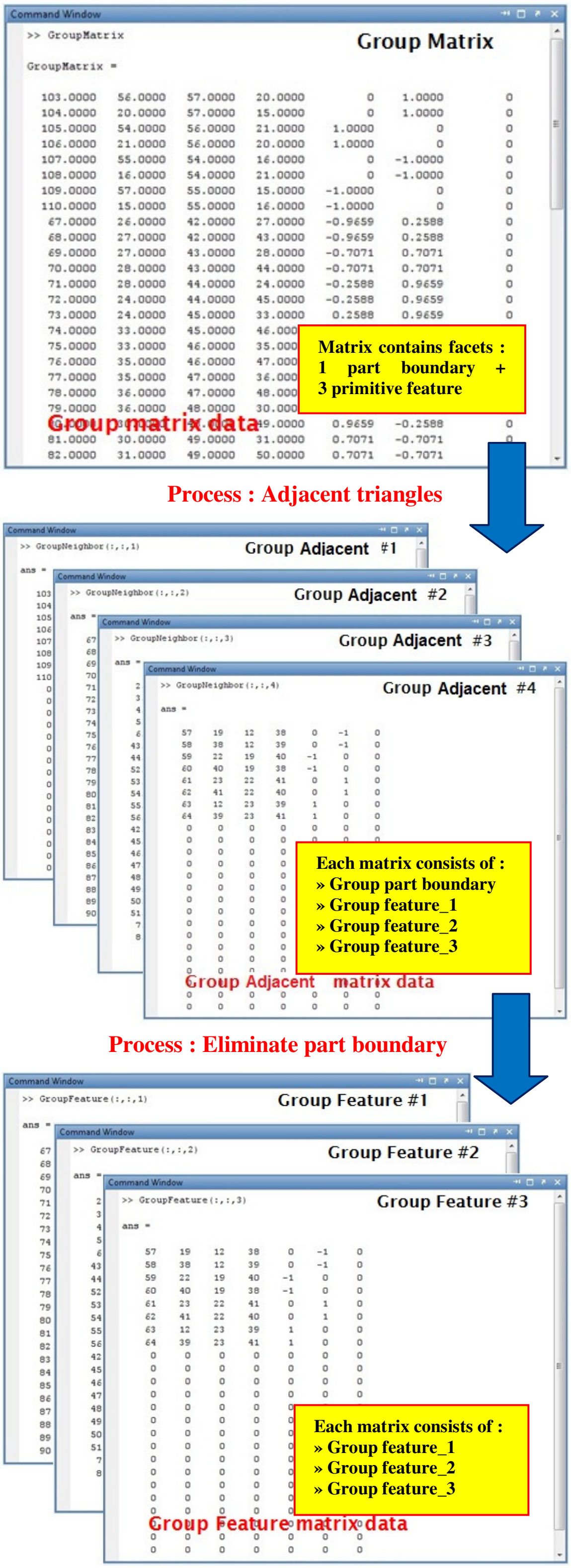


Fig. 11 Result of feature grouping.

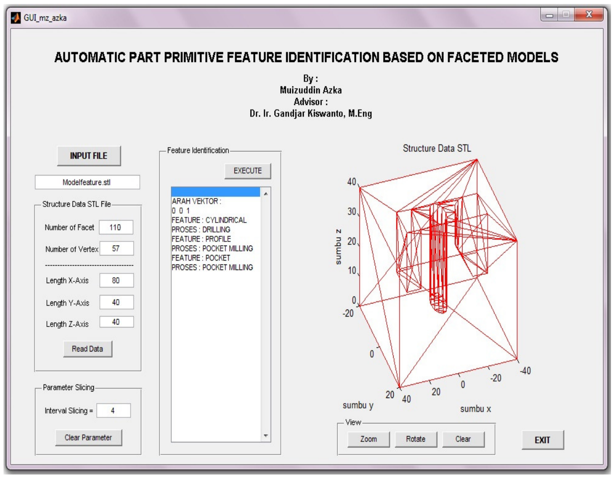


Fig. 12 Result of feature identification.

With the same process, the identification of primitive features in all outer planes are in direction [0 1 0], [1 0 0], [-0.707 0.707 0] and [0 0 1] as shown in Fig. 13 below.

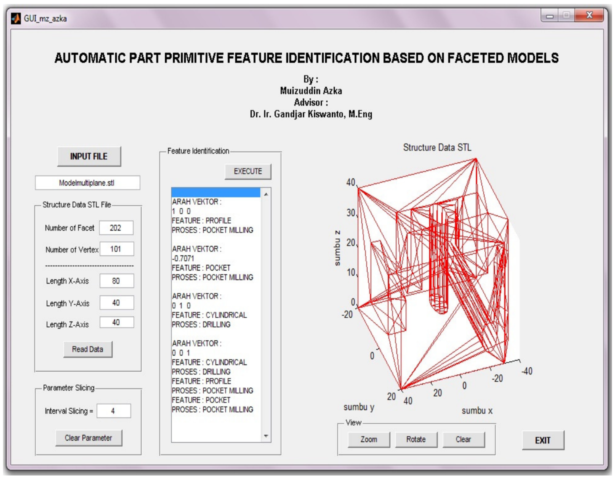


Fig. 13 Results of feature identification at various plane based on faceted models.

The figure above shows that all features that exist in the part are identified successfully. These features are two Profiles, two Pockets, and two cylindrical. The information of which features lie on which part plane is known correctly.

5. Conclusions and Further Research

To help improve the performance of CAPP and CAM in the manufacturing process, automatic feature recognition is required. This feature recognition is used to plan a more efficient process planning.

This paper discusses a method of feature grouping and identification by simply employing normal vector information and facets relationships (adjacency) of a faceted model. The developed method is able to detect and identify Pocket, Cylindrical, and Profile feature on a part.

Further research is to identify a more complex feature by also considering the facets adjacency. The identification should be able to mention number of different common planes within the feature.

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