

## ATTRIBUTE BASED FEATURE RECOGNITION FOR MACHINING FEATURES

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**Abstract.** Automated feature recognition is considered a critical component for integration of CAD/CAPP/CAM. The automation of process planning requires the implementation of a feature recognition procedure, so that decisions relating to steps of process planning activities can be made. Various methodologies have been developed to automate feature recognition. This paper presents an approach to feature recognition using rule based on different characteristics specific to each feature such as the total number of faces, the total number of edges, the type of faces, and the attribute of feature i.e. protrusion/depression. The proposed method is implemented using Graphics Interactive Programming (GRIP) and Unigraphics solid modeler. The results show that the proposed technique is capable of recognizing features with a unique set of attributes. The rule is also simple, easy to understand and implement.

*Keywords:* CAD, CAPP, CAM, solid models, features, feature recognition

**Abstrak.** Automasi pengecaman ciri adalah satu komponen yang kritikal dalam mengintegrasikan CAD/CAPP/CAM. Aturcara pengecaman ciri perlu dilaksanakan dalam perancangan proses supaya keputusan berkaitan dengan aktiviti perancangan proses boleh dibuat. Berbagai kaedah telah dibangunkan untuk mengautomasikan pengecaman ciri. Kertas kerja ini membentangkan satu pendekatan kepada pengecaman ciri menggunakan *rule based* yang berdasarkan sifat-sifat tertentu sesuatu ciri seperti jumlah permukaan, jumlah bucu, jenis muka, dan sifat-sifat lain ciri seperti lekuk/cembung. Kaedah yang dicadangkan dilaksanakan menggunakan *Graphics Interactive Programming (GRIP)*, dan permodelan padu *Unigraphics*. Hasil ujian menunjukkan bahawa pendekatan yang dikemukakan dapat mengecam ciri yang mempunyai satu set sifat-sifat yang unik. Pendekatan ini juga ringkas, mudah difahami dan digunakan.

*Kata kunci:* CAD, CAPP, CAM, model padu, ciri, pengecaman ciri

### 1.0 INTRODUCTION

Creating link between Computer-Aided Design (CAD) and Computer-Aided Process Planning (CAPP) is one of the most difficult tasks in concurrent design and manufacturing. Without proper interface between CAD and CAPP, it is impossible to generate process plan efficiently. Feature recognition is the key element in linking CAD and CAPP [1], and one of the principle elements in accomplishing the goal of integrating CAD/CAM. The first step towards achieving integration of CAD and

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Automatic Process Planning (APP) is automatic interpretation of design data [2]. Process planning requires interpretation of a part drawing or a model into information in a form suitable for process planning. Recent developments have focused on automatic interpretation of design data stored in CAD models into high-level features useful for process planning.

Features give a higher conceptual meaning to component characteristic by dissecting component geometry into recognizable and meaningful forms, and this is very important in the manufacturing context as they can capture the higher-level engineering content of a part [3, 4]. Therefore, features are considered the communication medium between design and manufacture.

Various techniques have been developed to automate extraction of information on features and geometry from solid models. However, some of these methods suffer several drawbacks and many papers have discussed these problems [2, 5 - 9]. For example, the recognition algorithm may be very complex, the number of recognition rules large, and the limited number of features that they can recognize. Most of these problems are due to the complexity of working with a 3D solid model input.

This paper presents a simple approach to feature recognition method for a selected machining feature. It is expected that the proposed method will be simple to understand, thus making it easier to implement. The method used an approach based on the different characteristics specific to each feature. Features that can be recognized are the selected machining features that are commonly found in milling processes.

## 2.0 LITERATURE REVIEW

### 2.1 Feature Definition

Features are very important in the manufacturing context as they capture the higher level engineering content of a part. In addition, features provide a powerful means of capturing design intent, alleviate tedious construction procedures and allow the user to reason at a higher level of abstraction than that provided by geometric and topological entities [10, 11].

Feature contains geometric and topological information in a part model and it represents high-level entities useful in part analysis [12]. There is a wide spectrum of engineering activities resulting in a variety of definitions suitable for each activity. For designers, a feature might represent functionality; for assembly planners, a feature represents a region of part, which will match or connect with a corresponding feature on another part, etc.

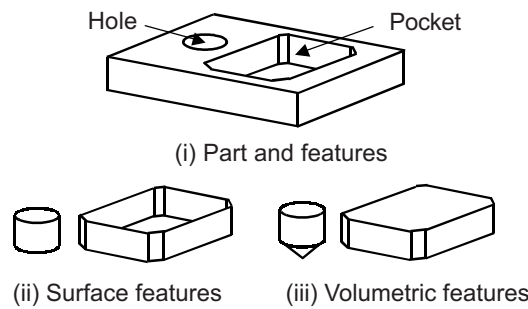
Many types of feature classification have been presented by various researchers. Each research group has defined its own set of features. There has been a rough consensus on distinguishing between “*form features*” and “*machining features*” [13].

A form feature, also known as a shape feature, refers to a shape macro constructed for convenience of construction, with little connection with function or manufacturing. A form feature may be either positive or negative, depending on whether it is protrusion or depression. On the other hand, a machining feature is a negative form feature associated with a distinctive machining process [13].

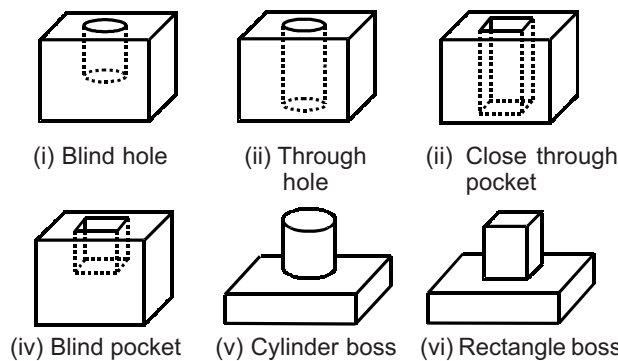
For the purposes of machining, features are often conceived as a solid volumes that have to be removed from the raw stock to generate the part and defined as a shape that represent volumes to be removed by machining [14]. In general, machining features model is material removal operation.

Machining features have been defined both as surface and as volumetric features (as shown in Figure 1). When defined as surfaces, machining features are collections of B-rep faces that are to be created by machining operations [14]. Historically, the dominant approach was to define machining features as collections of surfaces.

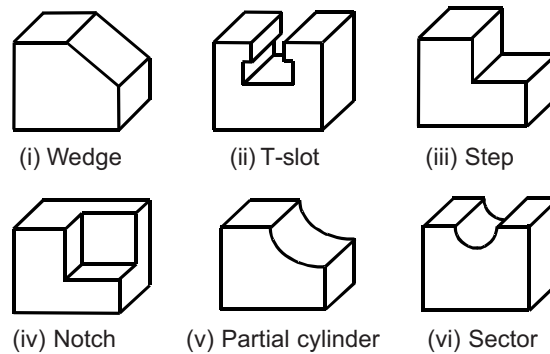
For the purposes of input to the feature identification, machining features are classified into two types [6]: non-isolated and isolated machining features. A non-isolated feature is created when a 2D loop touches the outer most loop of the view, whereas, an isolated features is created when a 2D loop does not touch the outermost loop. Isolated machining features include blind hole, through hole, closed through pocket, blind pocket, cylinder boss, and rectangle boss, as shown in Figure 2. Non-



**Figure 1** Surfaces and volumetric machining features



**Figure 2** Isolated machining



**Figure 3** Non-isolated machining features

isolated features include wedge, T-slot, step, notch, partial cylinder, and sector (as shown in Figure 3).

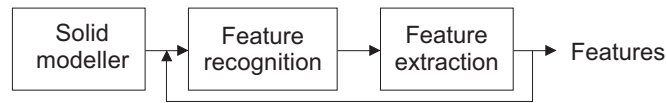
## 2.2 Feature Recognition Approach

Feature recognition is the recognition of expected patterns of geometry, corresponding to a particular engineering functionality of an object [15, 16]. Feature recognition involves the identification of geometric and topological instances, which belong to a feature instance from a geometric model and extracting required parameter information [11]. Feature recognition can be used to extract information relevant to a domain different to the one in which the design was made.

The process of feature recognition comprises of three major tasks [17]: (i) feature definition, in which the rules for recognition are specified. For the features to be recognized, they need to be precisely defined. Each instance of the feature must be identified. The definition of features involves determining the minimal set of necessary condition that classify a feature uniquely [11]; (ii) feature classification, in which potential feature are classified; and (iii) feature extraction, in which features are extracted from the solid model, and stored for further analysis.

In general, all previous work in feature recognition can be broadly classified into [18]: human-assisted feature recognition and automatic feature recognition (AFR). If feature recognition is carried out manually, there is considerable human intervention in all stages of the recognition process. In AFR, the recognition and extraction stage are completely automated. The automated feature recognition potentially allows the design and manufacturing stages to be integrated.

The role of AFR in CAD is to identify the machinable features on a 3D model of a mechanical component. In AFR (as shown in Figure 4), recognition is made using the geometric and topological information stored in the database of the solid modelers, and the computer program processes the information from the database to discover and extract feature automatically [8].



**Figure 4** Automatic assisted feature

Rule-based methods identify a feature based on certain pre-specified rules that are characteristic to the feature [18]. The entities expressed in the rule are typically the boundary elements: faces, edges, loops and vertices. Constraint operators typically included parallel, perpendicular, adjacent, equal, concave, convex and other relationships or conditions that these entities must satisfy to define a particular feature. Rule-based feature recognition can be used to identify features given that the rules can be written, the rules are correct; a solid model exists for the part and a search technique is available to match the solid model to the rule conditions.

There are numerous researchers who have developed rule-based algorithm for feature recognition. Preiss and Kaplansky [19] developed a rule-based algorithm that identified individual cutting operations by goal-driven search. Choi *et al.* [20] used pattern-matching technique to define a 3D boundary file data structure for representing the solid model. Henderson and Anderson [21] converted B-rep solid models and feature definitions into facts and rules of expert system. The reasoning mechanism of Prolog searches through the facts to recognize features according to the rules. Nnaji and Liu [22] developed a system that extracts features relevant to assembly and machining from a CSG-based CAD system with the ability to transform a CSG structure into a B-rep. Raymond *et al.* [23] presented an algorithm that uses an octree representation of a B-rep for identifying assembly features. Their algorithm is used to support the geometric reasoning required to locate assembly features on disjoint bodies.

Despite these advances in automatic feature recognition, a number of problems still exist. Especially in using rule-based algorithm, the main disadvantage is that a rule must be defined for each specified features. This could result in a large and unmanageable number of rules, is time consuming, and rules may be written too specific and ignore feature that are similar but not identical. In response to this problem, this paper presents an improved and more rigorous feature recognition that will reduce the number of rules in the rule-based method for feature recognition. It is expected that these rules are simple to understand, thus making it easier to implement.

### 3.0 ATTRIBUTE-BASED FEATURE RECOGNITION TECHNIQUE

The feature recognition method presented in this paper uses a B-rep scheme together with the attributes of feature as the basis to define a feature [24]. The B-rep in its

basic form provides the low level information that is not directly usable for feature recognition. Additional information regarding the elements of B-rep needs to be explicitly available to assist in feature recognition. Therefore, the attribute of feature i.e. protrusion and depression are combined with the elements of B-rep to facilitate feature recognition process. The protrusion/depression is used to differentiate between hole and boss for feature identification. The following section describes the concept of the proposed method.

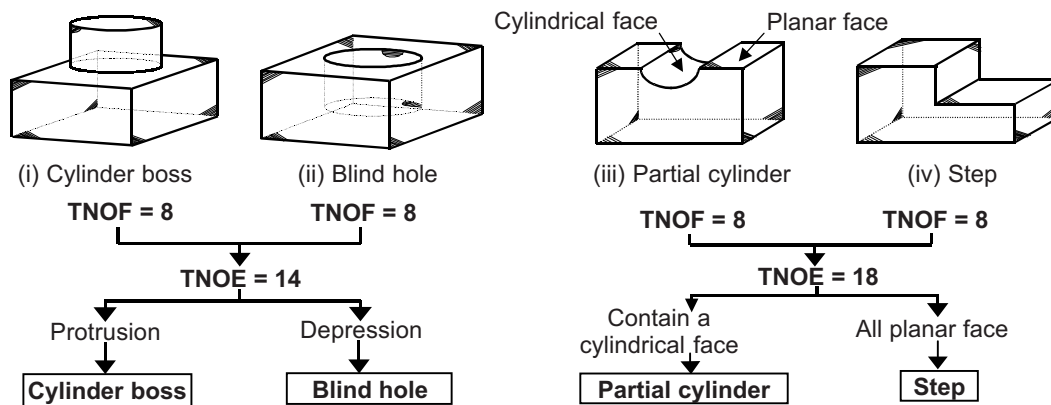
### 3.1 Concept of the Attribute-based Technique

The elements of B-rep such as the total number of faces (TNOF) as well as the type of faces (TOF), and the total number of edges (TNOE) together with the attribute of feature i.e. protrusion/depression (P/D) are used as the properties to differentiate each type of feature.

The procedure of the proposed method for feature recognition is as follows:

- (i) Count the TNOF and TNOE; if this information is adequate in recognizing a feature, go to step 3, otherwise go to step 2.
- (ii) Check P/D or verify TOF of feature.
- (iii) Feature type identified, and extract parameters.

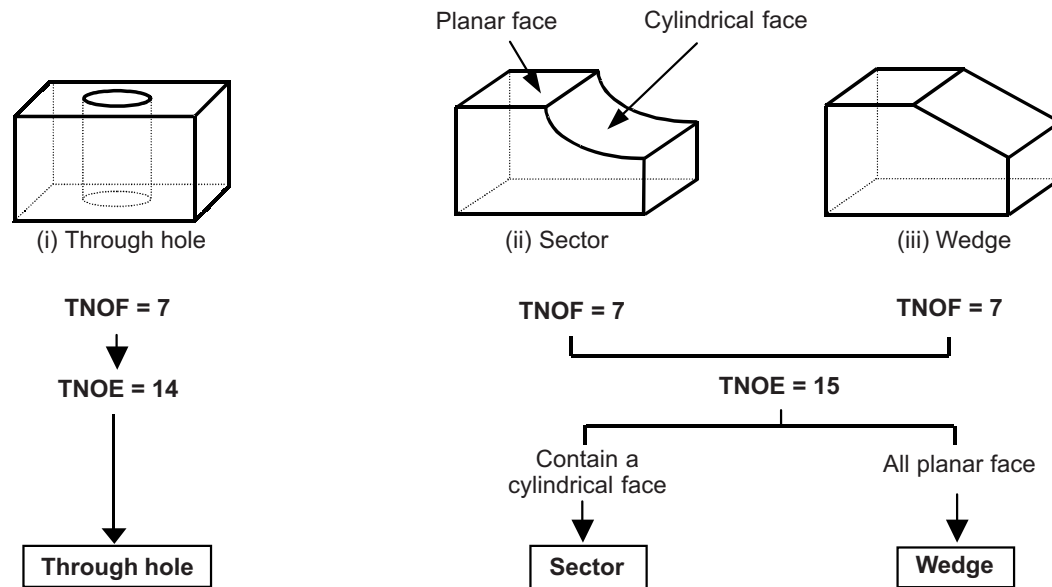
For example, refer to Figure 5, the properties for a cylinder boss, blind hole, partial cylinder, and step in a cube/box are that, each feature has TNOF of eight (8). The TNOE for both blind hole and cylinder boss is also the same i.e. 14, and TOF both features have is the same i.e. contains 7 planar faces and 1 cylindrical face. Thus, the feature is checked for protrusion/depression. If it is protrusion, then it is a cylinder boss. If it is a depression, then it is a blind hole. For partial cylinder as well



**Figure 5** The properties of cylinder boss, blind hole, partial cylinder, and step in a cube/box

as step, both have TNOE of eighteen (18). Therefore, additional information regarding the type of feature is needed to uniquely identify each feature. To differentiate between partial cylinders and step the TOF may be used. Partial cylinder contains a cylindrical face and the remainders are planar faces, and all faces in step are planar faces.

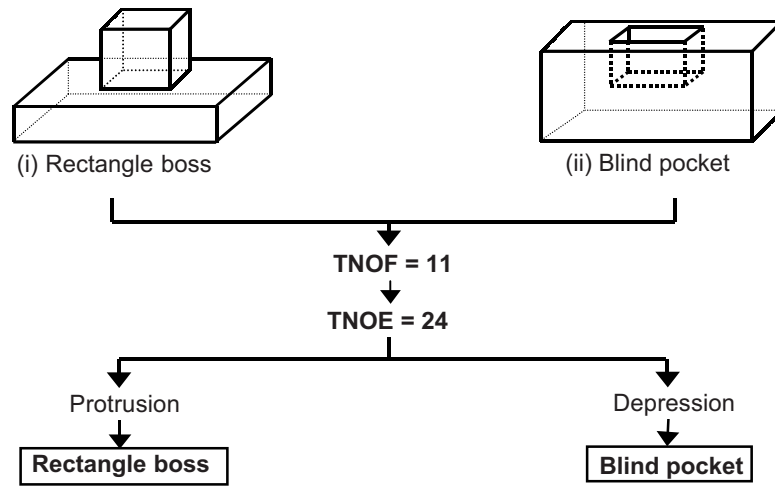
Similarly, other features may be identified this way. If a feature has a unique set of TNOF, TNOE, and P/D or TOF, the feature may be identified. For example, through hole, sector, and wedge have the same TNOF i.e. 7. However, TNOE is different i.e. 14 for through hole, and 15 for both sector and wedge. Therefore, through hole can be identified immediately because the TNOE is unique. For both sector and wedge, the TOF need to be identified in each feature to differentiate each type (as shown in Figure 6).



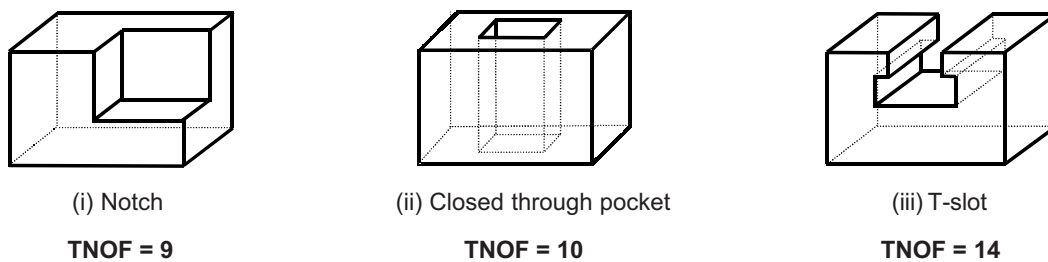
**Figure 6** The properties of through hole, sector and wedge in a cube/box

For rectangle boss and blind pocket, both TNOF and TNOE are the same i.e. 11 and 24 respectively. The TOF are all the planar faces. Therefore, the difference of character specific to each feature is the attributes i.e. P/D (as shown in Figure 7).

The properties of notch, closed through pocket, and T-slot in a cube/box are different as compared with other machining features. This is because TNOF for each feature is unique, i.e. 9 for notch, 10 for closed through pocket, and 14 for T-slot (as shown in Figure 8). Therefore, the properties of notch, closed through pocket, and T-slot only require the TNOF value to identify each feature.



**Figure 7** The properties of rectangle boss and blind pocket in a cube/box



**Figure 8** The properties of notch, closed through pocket, and T-slot in a cube/box

The flowchart of the proposed method is shown in Figure 9.

### 3.2 Elements of the Attribute-based Technique

The fundamental in the technique consists of three steps (refer to Figure 10):

- (i) Input drawing – namely B-rep solid modelers.
- (ii) Feature recognition algorithm – namely recognition of feature type based on the characteristic specific of feature such as TNOF, TNOE, P/D and/or TOF. Then, the feature parameters are extracted. Programs will be developed for this process.
- (iii) Output result – Feature is recognized. These results can then be used for process planning.



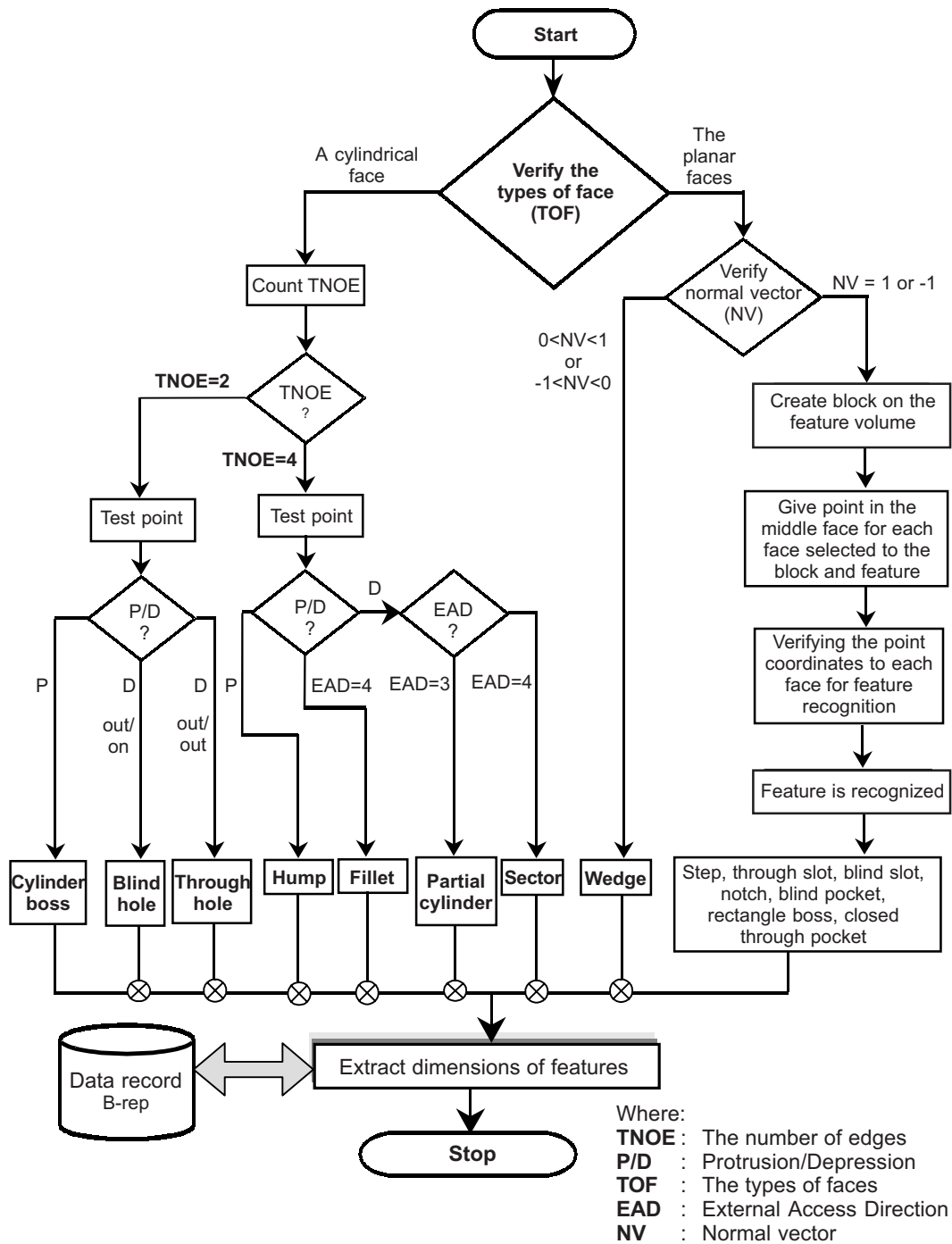
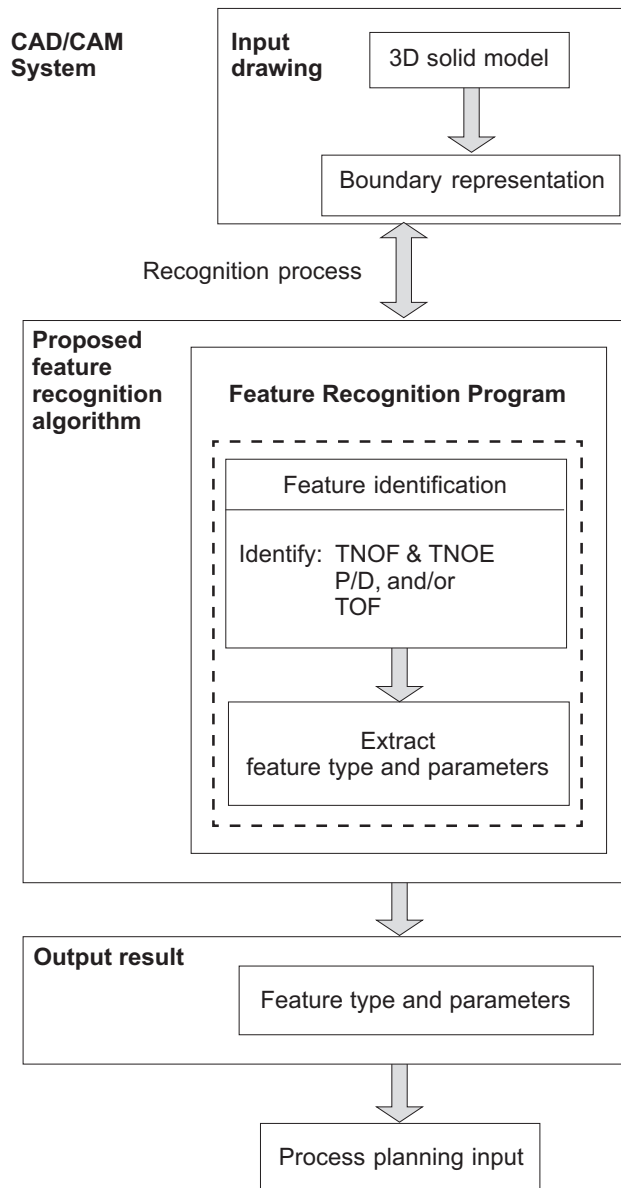


Figure 9 Flowchart of the proposed method



**Figure 10** Feature recognition framework

### 3.3 Algorithm of Attribute-based Technique

Based on the different characteristic specific to each feature, an algorithm for feature recognition is created by using ruled-based algorithm. This algorithm may be programmed based on simple logic rules. The following shows how this may be done for the proposed method.

INPUT : B-rep of part.  
 OUTPUT : Feature type, comprising faces, and dimensions.

```

get_faces_information
store_original_faces_information
for(each_face)
  get_face_types
  if
  for(a_cylindrical_face)
    calculate_TNOE
    verify_P/D
    verify_EAD
    if(feature_is_recognized)
      retrieve_original_faces_information
      return(feature_type, comprising_faces, feature_dimensions)
  else
  for(planar_faces)
    get_face_direction
    create_block(on_the_feature_volume)
    give_point(to_the_faces_selected(for block and feature))
    verify_point_coordinates
    if(feature_is_recognized)
      retrieve_original_faces_information
      return(feature_type, comprising_faces, feature_dimensions)
  else
    printf("known feature")

```

First, the algorithm work based on the verification of TOF, TNOE, and then P/D. If the algorithm is unable to identify the feature based on TOF, TNOE, P/D, then, the External Access Direction (EAD) is checked. For features that composite all the planar faces, the first step is by checking faces direction. The next step is creating block on the feature volume and then given a point for the selected faces to the block and feature. By examining the point coordinate, feature is recognized. Finally, the algorithm continues to extract the dimensions of identified feature.

#### 4.0 EXPERIMENTATION AND VERIFICATION

The method is implemented using Graphics Interactive Programming (GRIP) and Unigraphics solid modeler for testing and verification purposes. The implementation is performed in four stages: (i) the design and modeling of the parts is performed in the Unigraphics solid modeler, and the B-rep data defining the part is used as input

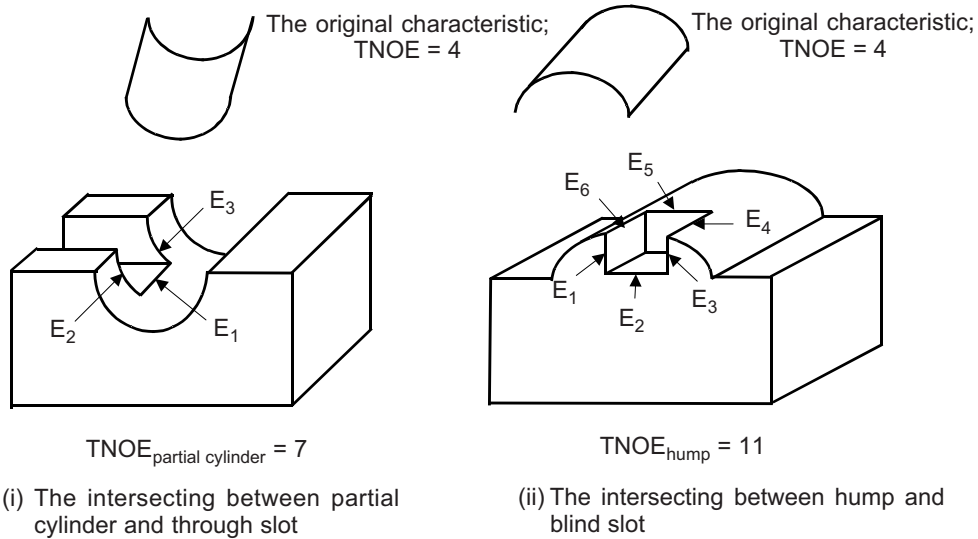
for the feature recognition algorithm. The solid models used are the selected machining features (refer to Figures 2 and 3), (ii) construction of the GRIP program of the proposed method that consists of four modules. These are program to access database, extraction of the specific characteristics to each feature, the execution of the recognition rules/algorithm, and extraction of dimensional parameters (refer to Appendix A); (iii) recognition process for the selected machining features; and (iv) output results of the recognition process that is useful as information for process planning.

The algorithm of the proposed method was tested on several-selected machining features. The results showed that the algorithm has the capability to recognize the selected machining features. Each time a feature is identified; the resulting information is stored in a *feature\_data* list.

In this paper, only the results on features with a cylindrical face will be discussed in detail as an example. These features are partial cylinder, hump, fillet, sector, cylinder boss, blind hole, and through hole. The main rules for recognizing these features are based on TOF, TNOE, P/D, and EAD. The process of recognition for these features is by checking the TOF in the first step. In the next step is the verification of TNOE and P/D respectively. If a feature has unique attribute P/D such as cylinder boss, blind hole, and through hole, then the feature may be identified immediately, the other characteristics such as EAD is not needed. This is because the P/D is checked by the algorithm after TOF and TNOE, and then EAD to recognize a feature. However, if P/D is not adequate, the EAD is checked.

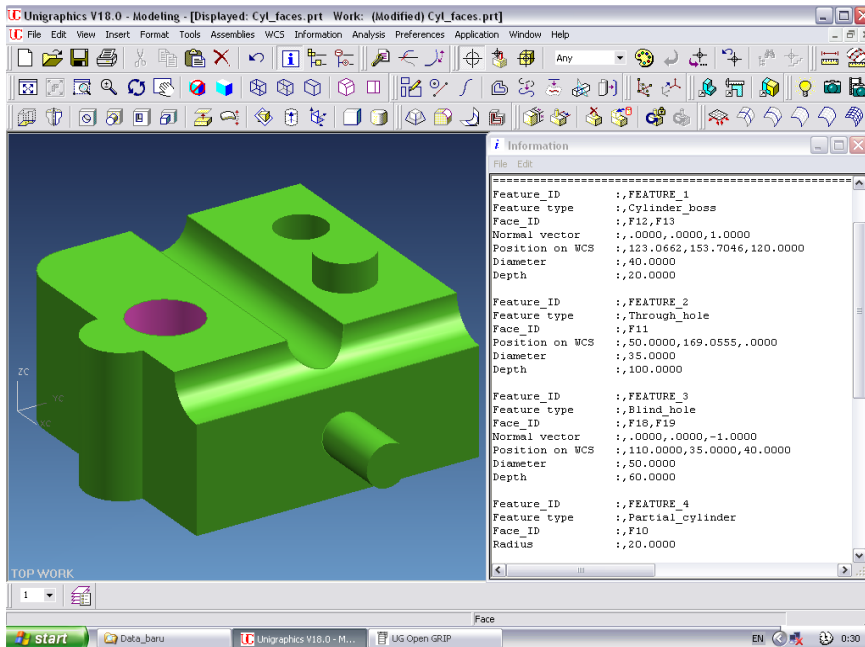
In actual practice, it is difficult to differentiate between cylinder boss, blind hole, and through hole. This is because the cylindrical protrusion may be recognised as a hole. However, by using test point to differentiate the attribute P/D for feature identification both cylindrical protrusion and hole can be recognised accurately. For features such as hump, partial cylinder, fillet, and sector, the test point is also significant to differentiate between each feature. However, it still requires another characteristics i.e. EAD by verifying the geometric properties to circular edges. This is only limited to the implementation for features with cylindrical faces.

Another characteristic for identification to the features with the cylindrical face i.e. TNOE is also significant for feature identification. However, if the interactions between features occurred it poses a significant problem. This is because if the number of edges on the cylindrical faces increases, then the characteristics of original feature are destroyed. In this example, the through slot and partial cylinder share  $E_1$ ,  $E_2$  and  $E_3$  as common edges (refer to Figure 11 (i)), so that the original characteristic of partial cylinder i.e. TNOE is 4 now becomes 7. The case is the same for the interactions between hump and blind slot (as shown in Figure 11(ii)), they share  $E_1$ ,  $E_2$ ,  $E_3$ ,  $E_4$ ,  $E_5$  and  $E_6$  as common edges, so the hump has TNOE of 11. Therefore, in such cases, the pre-defined rules for TNOE to each feature cannot be used for feature identification.



**Figure 11** Intersecting features which share common edges

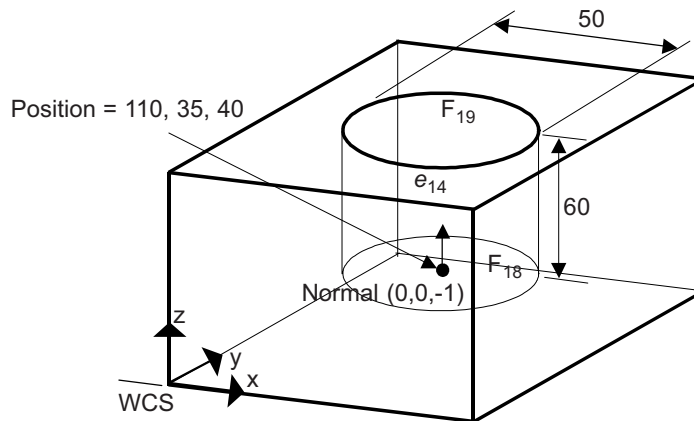
Several parts with a varying number of features, with and without interactions, were tested. Each time a feature is identified the resulting information is stored in a *feature\_data* list (as shown in Figure 12; right side). Figure 12 shows that the resulting information (on the right side) in the *feature\_data* lists are in the form of description



**Figure 12** The recognition results of the proposed method for features covered in a part

language, where parameters of feature are described based on their dimension. The part has features that are blind hole, through hole, cylinder boss, hump, partial cylinder, sector and fillet. The program also extracts faces and dimensions of feature. The dimensions of features include radius, diameter, depth, and normal vector. For example, the result of the parameters extracted for a blind hole feature in the part (refer to Figure 12; right side). For example it shows that for faces  $F_{18}$  and  $F_{19}$ , the diameter of blind hole is 50 mm, depth 60 mm, position of feature in the coordinate (110, 35, 40) mm from World Coordinate System (WCS), and the normal vector is (0, 0, -1).

The results of experimentation showed that the proposed method for feature recognition is capable of automatically identifying the feature type, comprising faces and feature dimensions. The data extracted from the geometric model as shown in Figure 12 is a multiple interpretation of feature, for example blind hole (as shown in Figure 13) that is useful for process planning.



**Figure 13** Parameters of a blind hole

## 5.0 DISCUSSIONS

The work presented in this paper is part of a larger effort to make machining features easily recognized. The key idea here is the use of a B-rep scheme together with the attributes of each feature as a basis to define the feature. The different characteristics specific to each feature such as the type of faces (TOF), the number of edges (TNOE), the attribute of features i.e. protrusion/depression (P/D), and the external access direction (EAD) are used as the properties to differentiate between each type of features especially for the features with the cylindrical faces. For the feature that consists of all the planar faces, the recognition rules are based on TOF, verification of axis direction to the normal vector of feature, and verification the point coordinate

both faces of the block attached to the feature volume and faces of feature based on the feature types and the axis direction of normal vector.

The rules for the feature recognition process of the proposed method for features with the cylindrical faces only involve checking TOF, TNOE, and P/D respectively, and if these are not enough to recognize the feature, EAD is checked. For the features with all the planar faces TOF is checked first, and then the axis direction of normal vector and point coordinates of faces respectively. This is fundamentally different from the other feature recognition methods.

In the technique used by Choi *et al.* [20], Henderson and Anderson [21], and Napsiah and Nooh [24], the feature recognition requires searching one by one for each element and associates of surface such as hole starting surface, hole element surfaces, hole bottom surface, circular edge, adjacent face, and entrance face to recognize feature in a part. In Napsiah and Nooh [25], the attribute of feature i.e. protrusion/depression is used together with the techniques used by Choi's for hole/boss recognition. Lee and Devarajan [6] need five attributes of features i.e. protrusion/depression, external access direction, boundary geometry, boundary perimeter, and exit status to identify both isolated and non-isolated machining features.

The proposed method has similarity to the method used by Napsiah and Nooh [25], and Lee and Devarajan [6], especially in depression/protrusion and external access direction identification. However, the recognition rules to each feature are different. The main difference of the proposed method with other methods is that, the verification of TOF, TNOE, the axis direction of normal vector, and the verification of point coordinate to the faces.

The proposed method has both advantages and disadvantages. The advantage is that, the recognition rules are simple, easy to be implemented, and the recognition process to the features is faster because the data structure of the solid model is input directly to the recognition system without any modification. The disadvantage is that, if the intersecting between features occurred, where the TNOE on a part increases it will be more difficult to recognize feature. However, feature can still be recognized by identifying the increase in number of edges (refer to Figure 12). The problem will be more complex if two or more features intersect.

The program for the proposed method to perform recognition for machining features can be implemented using suitable program software. The commands of each module can be found in most program software that are usually used in the feature recognition method. Therefore, the proposed method can be implemented using suitable program softwares.

## 6.0 CONCLUSIONS

This paper has presented a simple method for feature recognition. In this approach, rules for recognition processes are based on the different characteristics specific to each feature such as the total number of faces (TNOF), the total number of edges

(TNOE), the attribute of features i.e. protrusion/depression (P/D), the types of faces (TOF) and external access direction (EAD). This is fundamentally different from the other feature recognition methods, where the rules for recognition process are large and complicated. Thus, the rule is simple, easy to understand, and easy to be implemented.

The data extracted contain information such as feature type and dimensions of feature that is required for process planning functions for manufacturing a part. This information can be used as input to automate process planning such as automation of selection of cutting tools, selection of machining operations, machining parameters, determination of tool paths, operation type, and cutting type selection.

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