BUILT AUTOMATIC FEATURE RECOGNITION SYSTEM BASED ON SWEEPING PRIMITIVE RULE

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1- ABSTRACT

This research introduces an Automatic Feature Recognition (AFR) system. The architecture of AFR system include three modules; (1) Computer graphics (CAD package) module for part drawing by using (Mechanical Desktop 0.9); (2) Extraction module, in this module a new extraction algorithm used to extract the low-level entity (point coordinate specification, vector direction and magnitude) based on the export part profile STEP (ISO 10303, part 21) file from the previous module; (3) Automatic feature recognition module, it is knowledge-base subsystem, in this module a new feature recognition algorithm called Sweeping Primitive Rule (SPR) constructed based on three feature recognition techniques, they are; (a) Syntactic pattern (primitive); (b) Sweeping operation; and (c) logic rule. This (SPR) algorithm considered as the main contribution to increase the flexibility for recognize different types of simple features (Cylindrical, Slot and Step) in addition to recognize new types of composed form feature (SW, WS, SD, DS, DW and WD-Slot) for symmetrical rotational parts.

Keyword

Feature extraction and recognition, Syntactic primitive rule, Sweeping operation and logic rule and Expert system.

2- INTRODUCTION

During the last two decades much effort has been devoted to the area of feature technology to ease the problem of Computer-Aided Design (*CAD*) integration with downstream activities [1].

Feature-Based Design (FBD) has been used in the integration of engineering activities. Integration is a technology used to realize automatic transmission and conversion of component information for CAD and CAM. Thus, the concept of feature is the medium of information transmission in the integration [2, 3].

FBD is a process in which parts are specified in terms of their constituent parameterized form features, instead of geometry command such as line, arc, or primitive commands such as cylinder and cone. It ensures that the feature information necessary for the downstream application such as inspection as a part of process planning is incorporated as early as in the design cycle to contribute the progress in concurrent design (also called simultaneous and parallel design) [4, 5, 6].

Feature technology is the kernel technology and a defacto standard of CAD/CAM integration. *Feature* is the medium for transmitting information among CAD/CAM systems [7, 8].

Features are defined as generic shapes with which design and manufacturing engineers associate certain attributes knowledge useful in reasoning about the products [1]. Feature technology is categorized by two popular approaches is: Automatic Feature Recognition (AFR) and Design by Feature [7].

Automatic Feature Recognition (AFR) techniques are important tools for achieving a true integration of design and manufacturing stage during the product development. It is applied to identify geometrical entities, features in the CAD model, which are semantically significant in the context of specific downstream manufacturing activities [9].

Two key tasks performed to complete the AFR: Firstly; extract the low-level information from a CAD model and Secondly; translate it into high-level to recognize a feature [1]. Figure (1) shows a component in automatic feature recognition approach.

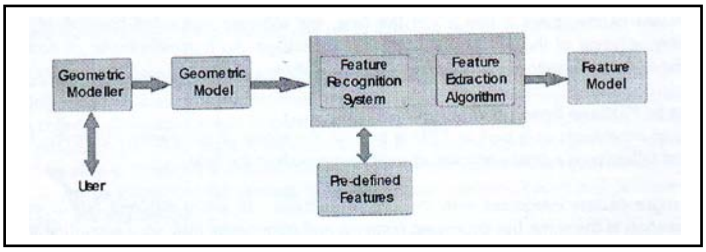


Figure 1. Component of automatic feature recognition [10]

3- AUTOMATIC FEATURES RECOGNITION SYSTEM ARCHITECTURE

AFR system for recognizing form features consist of three models they are as follows:

1- Computer graphics by CAD package.

2- Extraction part information (point coordinates) from STEP file.

3- Recognized Cylindrical, Step and slot feature by (SPR). Figure (2) shows the models that algorithm consist it.

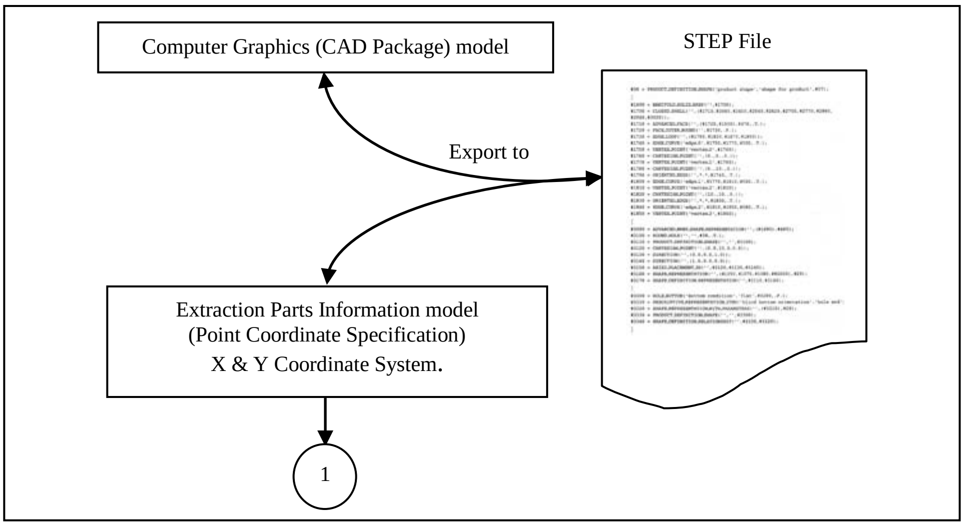


Figure 2. Automatic features extraction and recognition system architecture………continue

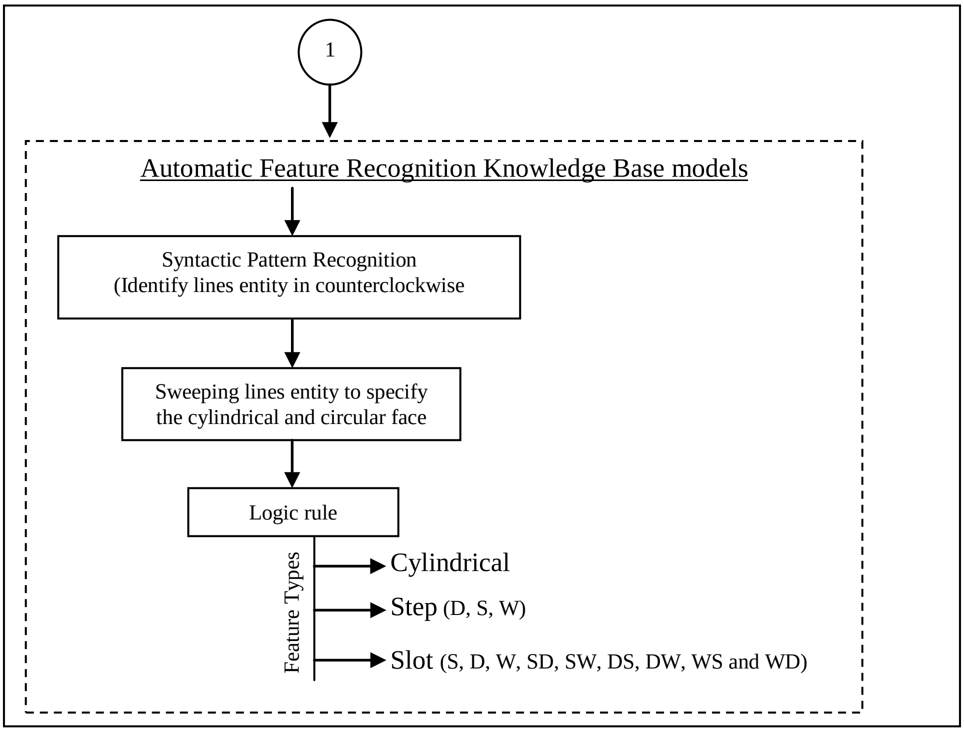


Figure 2. Automatic features extraction and recognition system architecture

3-1 Computer Graphics (CAD Package) module

CAD package is used with some design guideline to facilitate design, integration and transformation of design information into manufacturing information.

Drawing used in this work is classified as wireframe 2D drawing. 2D drawing is a system for specifying locations in a drawing based on vertical and horizontal axes (X and Y linear coordinate system, X and Z linear coordinate system and Y and Z linear coordinate system).

Mechanical desktop package has been used to implement these drawing. This package can be represent the 2D drawing by line entity as shown in Figure (3) in order to draw the upper profile of the symmetrical rotational parts.

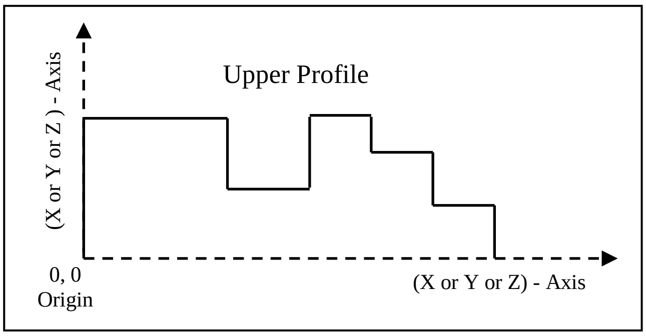


Figure 3. Upper profile of symmetrical rotational part

Rotational parts are symmetrical about their axis, and can be defined as (only one axis of rotation, geometrical axis is identical to the axis of rotation and cross-section perpendicular to the axis of rotation).

One of the methods for modeled rotational parts is rotational sweeping of a chain of primitive entity. Primitive entity defined by geometric elements such as line.

3-2 Feature Extraction Module

Different CAD package use different types of database structure to store the information of the part in a CAD file. The design file contain all the information the part designer wants the part should. This model contain save the drawing in SETP 10303 part (21) file to analyze and define the drawing as line depend on point coordinate that represented in STEP file. The vector direction and magnitude to these points are also provided. Figure (4) shows the structure of STEP file. The extraction method based on the data from STEP file as shows in Figure (5).

```
ISO-10303-21;
HEADER;
/********************************************************************
 * Generated by software with PDE/Lib inside                  *
 * PDE/Lib Version 3.2.2, created Thu Mar 23, 2000 at 18:38:49  *
 * International Technegroup Inc. (www.iti-oh.com)             *
 ********************************************************************/
FILE_DESCRIPTION(('),'2;1');
FILE_NAME('Drawing1.stp','2009-06-04T08:41:49',('),('),'AutoCAD STEP 2000i','AutoCAD 2000i',', , ');
FILE_SCHEMA(('CONFIG_CONTROL_DESIGN'));
ENDSEC;
DATA;
#125=CARTESIAN_POINT (", (X1, Y2, 0.0));
#126=DIRECTION (", (0.0, Direction, 0.0));
#127=VECTOR (", #126, Magnitude);
#128=LINE (", #125, #127);
#129=CARTESIAN_ POINT (", (X2, Y1, 0.0));
.
#161=CARTESIAN_ POINT (", (Xn-1, Yn, 0.0));
#162=DIRECTION (", (0.0, Direction, 0.0));
#163=VECTOR (", #162, Magnitude);
#164=LINE (", #161, #163);
#165=CARTESIAN_POINT (", (Xn, Yn-1, 0.0));
ENDSEC;
END-ISO-10303-21;
```

Figure 4. Structure of STEP file

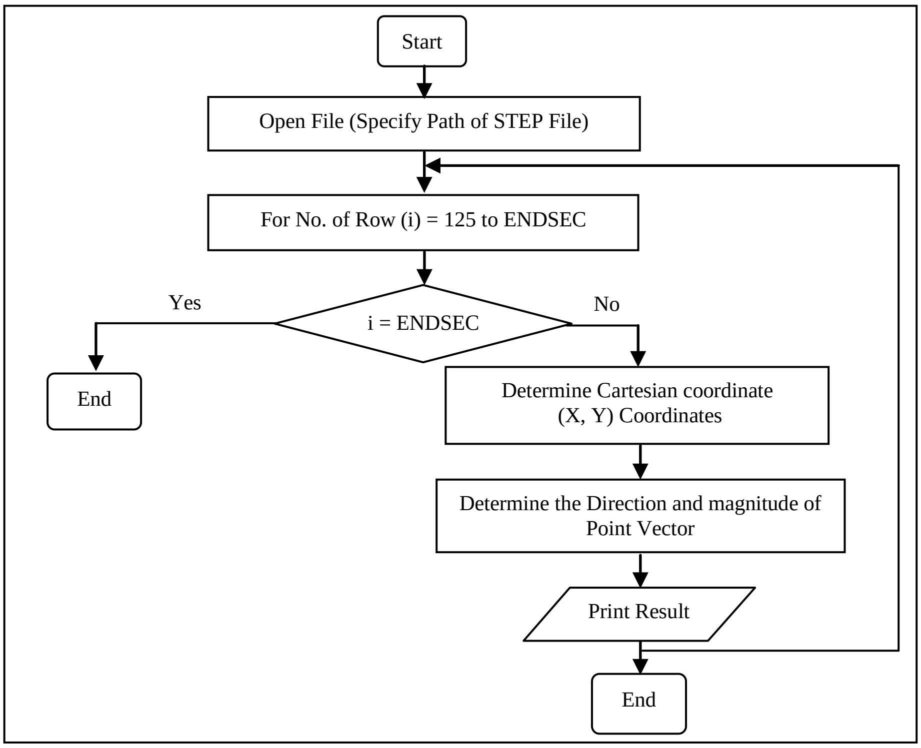


Figure 5. Algorithm for extraction entity from STEP file

3-3 Automatic Feature Recognition Knowledge-Base models

The objective of feature recognition represented process of converting CAD data of a part into model of the manufacturing activity required to create the part.

Generally, integration between manufacturing activities depends on the representation or description of the details of geometric parts. A production rule is being used to represent and process these details to get the efficient result for this stage.

The basic idea of production rule is based on the form of condition – action pairs: if this condition occurs, then this action is done, otherwise that action will be done.

The term production rule is used to describe different systems based on one very general, underlying idea – the notion of condition – action pairs; a production rule consists of three parts:

1- A rule base composed of a set of rule.

2- A special, buffer – links working memory, which is sometimes referred to as context. And,

3- An interpreter, checks to see if the conditions specified in the IF part of a rule match similar pattern in a knowledge system database.

The condition of part of a rule is checked every time a rule is selected for firing. Rules (Procedural knowledge) are best represented as rule base. These rules are the real corner stone of building the knowledge base of system (form feature recognition).

The inference strategy used in this system is forward – data driven (undirected - goal) that starts with unknown goal and tries to use the expert programs rule to get to the goal.

The rules used in this research may be categorized as follows:

1- Rules for finding the types and positioning of lines after applying on (Syntactic Pattern Recognition).

2- Rules for specifying or determine the form feature by applying on (Logic Rule & Expert System method).

1- Syntactic Pattern Recognition Knowledge Base: Syntactic pattern recognition is a formalized technique for representing complex patterns. It consists of simple sub-patterns and relation among sub-patterns. A given pattern is decomposed recursively into simpler sub-patterns called primitives. The primitives or entities coding consist of an alphabet (a, b, c, d, e, f, g and h). This alphabet refers to the position or direction of the line entity in clockwise and counter-clockwise. Figure (6) shows the pattern primitive Types.

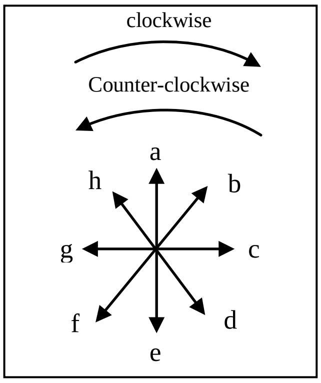


Figure 6. Pattern primitive types

After extracting the cartesian point from STEP File, rules are used to define the line entity as shown in Figure (7).

Facts:

F1- X1 is value
F2- Y1 is value
………
Fn- Xn is value
Fn- Yn is value

[(**Rule 1:**
(IF (Line-Definition = X1, Y1, X2 and Y2))
(Then (Type-Of-Entity = Line1)))
(**Rule n:**
(IF (Line-Definition = Xn-1, Yn-1, Xn and Yn))
(Then (Type-Of-Entity = Line n)))]

Figure 7.Rule entity definition

Some of rules used to convert the entities form to new entities coding for line in clockwise shows in Figure (8).

Facts:

F1- entity is Line1
F2- entity is Line2
F3- X1 is value
F4- Y1 is value
F5- X2 is value
F6- Y2 is value

[(**Rule 1:**
(IF (Type-Of-Entities = Line)
AND (X 1 < X2 and Y1 = Y2))
(Then (Line-Coding = Line c)))

(**Rule 2:**
(IF (Type-Of-Entities = Line)
AND (X 1 < X2 and Y 1 < Y2))
(Then (Line-Coding = Line b)))]

Figure 8. Some rules for new entities in clockwise

The description of 2D upper profile for symmetrical rotational part using string of pattern primitive such as "a, c, f, c, b, c, e, c and e" in clockwise and "a, g, a, g, d, g, h, g and e" in counter-clockwise as shows in Figure (9).

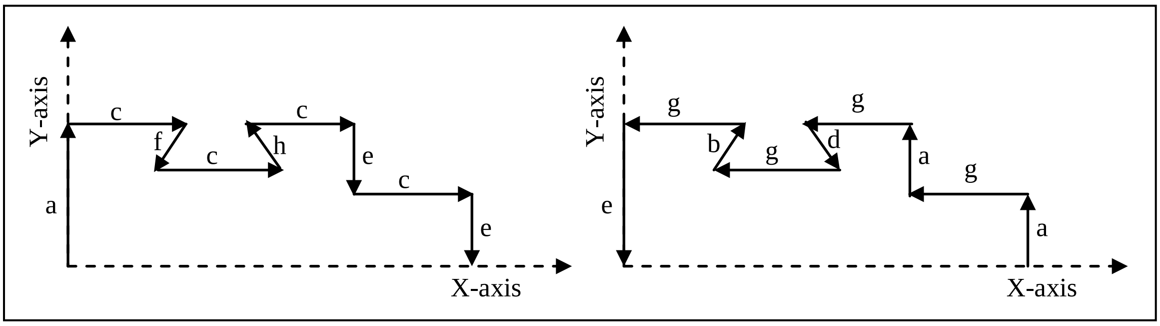


Figure 9. String of pattern Primitive

2- State Transition Diagram and Automata (Sweeping Operation): After analyzing half of the profile of the part in 2D which should contain only line segments. Part model is formed by using the "space sweeping" or "sweeping operation".

Sweeping represents the contour rotation around its axis. This operation is accomplished by sweeping the point of lines in 90°, 180°, 270° and 360° around the X or Y or Z axis to crating a solid in the form (cylindrical and circular faces).

The following equations are used to sweep the points of lines in counter-clockwise:

1- If rotate about Y-axis as shows in Figure (10):

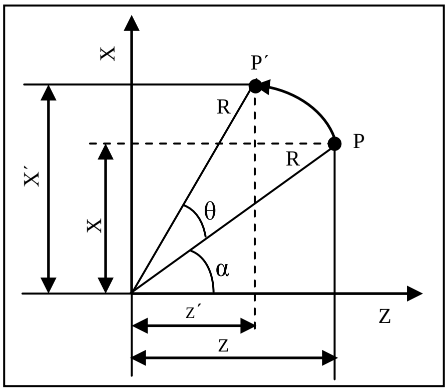


Figure 10. Rotate about *Y*-axis

$Z = R * Cos\,(\alpha)$

$X = R * Sin\,(\alpha)$

$Z' = R\,Cos\,(\theta + \alpha)$

$\quad = R\,Cos\,(\theta)\,Cos\,(\alpha) - R\,Sin\,(\theta)\,Sin\,(\alpha)$

$Z' = Z\,Cos\,(\theta) - X\,Sin\,(\theta)$ -- (1)

$X' = R\,Sin\,(\theta + \alpha)$

$\quad = R\,Sin\,(\theta)\,Cos\,(\alpha) + R\,Cos\,(\theta)\,Sin\,(\alpha)$

$X' = Z\,Sin\,(\theta) + X\,Cos\,(\theta)$ -- (2)

2- If rotate about X-axis as shows in Figure (11):

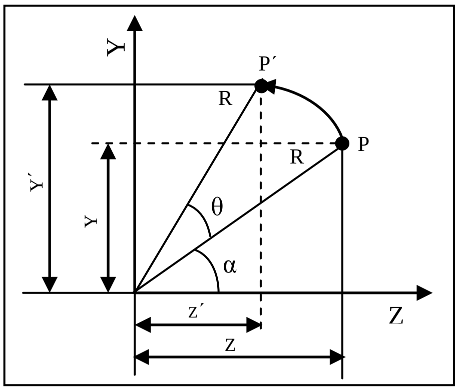


Figure 11. Rotate about *X*-axis

$Z = R * Cos\,(\alpha)$

$Y = R * Sin\,(\alpha)$

$Z' = R\,Cos\,(\theta + \alpha)$

$\quad = R\,Cos\,(\theta)\,Cos\,(\alpha) - R\,Sin\,(\theta)\,Sin\,(\alpha)$

$Z' = Z\,Cos\,(\theta) - Y\,Sin\,(\theta)$ -- (3)

$Y' = R\ Sin\ (\theta + \alpha)$

$= R\ Sin\ (\theta)\ Cos\ (\alpha) + R\ Cos\ (\theta)\ Sin\ (\alpha)$

$Y' = Z\ Sin\ (\theta) + Y\ Cos\ (\theta)$ -- (4)

Cylindrical and circular planner face shows in Figure (12).

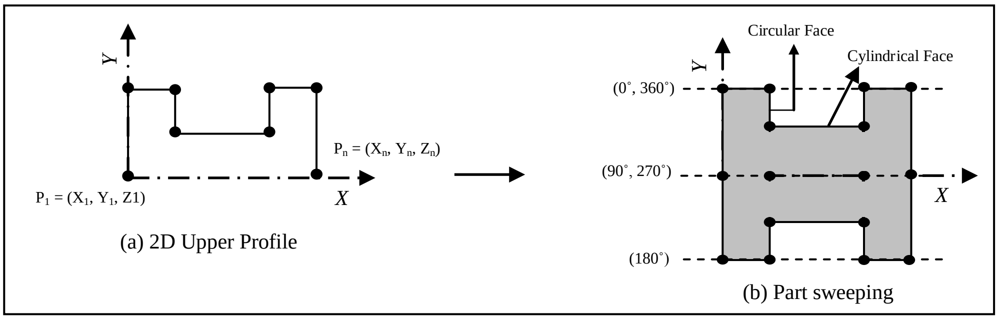


Figure 12. Example to sweeping operation

X = 0, Rotate about X-axis, Z = 0, 2-D Drawing.

1- Rotate P1 by 90˚ and 180˚ about X-axis:

$Z'_1 = Z_1\ Cos\ (\theta) - Y_1\ Sin\ (\theta)$

$Z'_1 = 0\ Cos\ (90) - Y_1\ Sin\ (90)$

$Z'_1 = 0\ Cos\ (180) - Y_1\ Sin\ (180)$

$Y'_1 = Z_1\ Sin\ (\theta) + Y_1\ Cos\ (\theta)$

$Y'_1 = 0\ Sin\ (90) + Y_1\ Cos\ (90)$

$Y'_1 = 0\ Sin\ (180) + Y_1\ Cos\ (180)$

2- Rotate Pn by 90˚ and 180˚ about X-axis:

$Z'_n = Z_n\ Cos\ (\theta) - Y_n\ Sin\ (\theta)$

$Z'_n = 0\ Cos\ (90) - Y_n\ Sin\ (90)$

$Z'_n = 0\ Cos\ (180) - Y_n\ Sin\ (180)$

$Y'_n = Z_n\ Sin\ (\theta) + Y_n\ Cos\ (\theta)$

$Y'_n = 0\ Sin\ (90) + Y_n\ Cos\ (90)$

$Y'_n = 0\ Sin\ (180) + Y_n\ Cos\ (180)$

After applying these equations to rotate entities, cylindrical and circular faces can be represented in three axes (X, Y and Z) as shows in Figure (13).

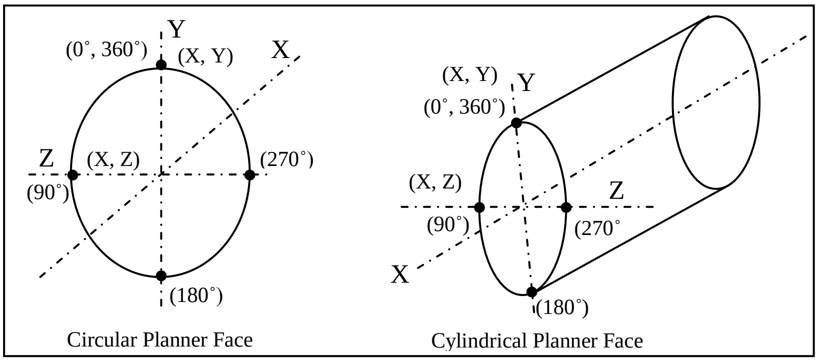


Figure 13. Faces generated by sweeping operation

3- Logic Rule and Expert System: This method present the machining/inspection feature by applying a set of production rules. If codition1and condition2 is true then define form feature. These rules are used to specify the base face (base face is a face which has a concave adjacency with at least one boundary face), and Then the boundary faces are being determined.

Logic rule depends on the number and type of boundary face to determine the form feature. If base face connecting with two concave boundaries faces, the Slot and Step feature are determined.

To connect the base face with the convex boundary face is to find the cylindrical feature present one of the originality points in this research.

The relation used to define features depends on reading odd faces that present base face then connecting with two even faces that present the boundary faces as shown in Table (1).

Table 1. General relation of feature definition

Number of Features	Relation	Types of Feature
Feature 1	F_{i+2} F_{i+1}, F_{i+2}, F_{i+3}	Cylindrical or Slot or Step Feature
Feature n	F_{i+m-1} F_{i+m-2}, F_{i+m-1}, F_{i+m}	Cylindrical or Slot or Step Feature

i = initial face (start form zero)

m = number of faces

n = number of feature

Figure (14) shows the part, and the above relation is shown in Table (2):

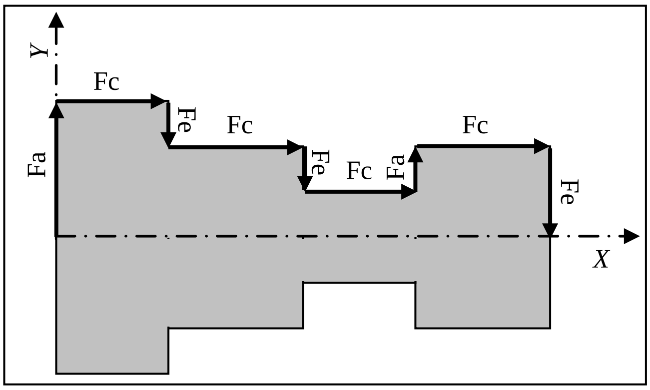


Figure 14. Part model

Table 2. Relation for Previous Part to recognized feature

Number of Features	Relation	Types of Feature
Feature 1	F_2 = Cylindrical Face c F_1 = Circular Face a, F_3 = Circular Face e	Cylindrical Feature
Feature 2	F_4 = Cylindrical Face c F_3 = Circular Face e, F_5 = Circular Face e	Step Feature
Feature 3	F_6 = Cylindrical Face c F_5 = Circular Face e, F_7 = Circular Face a	Slot Feature
Feature 4	F_8 = Cylindrical Face c F_7 = Circular Face a, F_9 = Circular Face e	Cylindrical Feature

Some of rules that implemented to achieve automated feature recognition for above part show in Figure (15).

<u>Facts:</u>

F1- Face (1) is Circular Face (a)
F2- face (2) is Cylindrical Face (c)
………
………
………
F9- face (9) is Circular Face (e)
[(Rule1:
(IF (Face (2) = Cylindrical-Face-c)
AND (Face (1) = Circular-Face-a)
AND (Face (3) = Circular-Face-e))
(THEN (Type-of-Feature = Cylindrical-Feature)))
(Rule 2:
(IF (Face (4) = Cylindrical-Face-c)
AND (Face (3) = Circular-Face-e)
AND (Face (5) = Circular-Face-e))
(THEN (Type-of-Feature = Step-Feature)))
….
….
(Rule 4:
(IF (Face (8) = Cylindrical-Face-c)
AND (Face (7) = Circular-Face-a)
AND (Face (9) = Circular-Face-e))
(THEN (Type-of-Feature = Cylindrical-Feature)))

Figure 15. Rules used for feature recognition

The types of Step and Slot feature that can be defined by (SPR) methods as follows:
1- Step features as (S-Step, small-Step and Big Step).
2- Slot features as (S-Slot, W-Slot and D-Slot). A second point of originality in this research is defining other types of Slot features after composed the S, W and D slot. These new features are: (DW, WD, SD, DS, SW and WS). Figure (16) shows the types of features that are recognized in this research.

Also, dimension of these features are determined as shows in Figure (16). These dimensions are:

$$T = Width\ of\ Top = \sqrt{(X_4 - X_1)^2 + (Y_4 - Y_1)^2 + (Z_4 - Z_1)^2} \quad (5)$$

$$B = Width\ of\ Bottom\ (Distance\ of\ base\ face) = \sqrt{(X_3 - X_2)^2 + (Y_3 - Y_2)^2 + (Z_3 - Z_2)^2} \quad (6)$$

$$Db1 = Distance\ of\ left\ boundary\ face = \sqrt{(X_2 - X_1)^2 + (Y_2 - Y_1)^2 + (Z_2 - Z_1)^2} \quad (7)$$

$$Db2 = Distance\ of\ right\ boundary\ face = \sqrt{(X_4 - X_3)^2 + (Y_4 - Y_3)^2 + (Z_4 - Z_3)^2} \quad (8)$$

$$H1 = Left\ hight = Db1 = Sin(45) \quad (9)$$

$$H2 = Right\ high = Db2 = Sin(45) \quad (10)$$

$$F1 = Offset\ from\ bottom\ to\ left\ side = Db1 = Cos(45) \quad (11)$$

$$F2 = Offset\ from\ bottom\ to\ right\ side = Db2 = Cos(45) \quad (12)$$

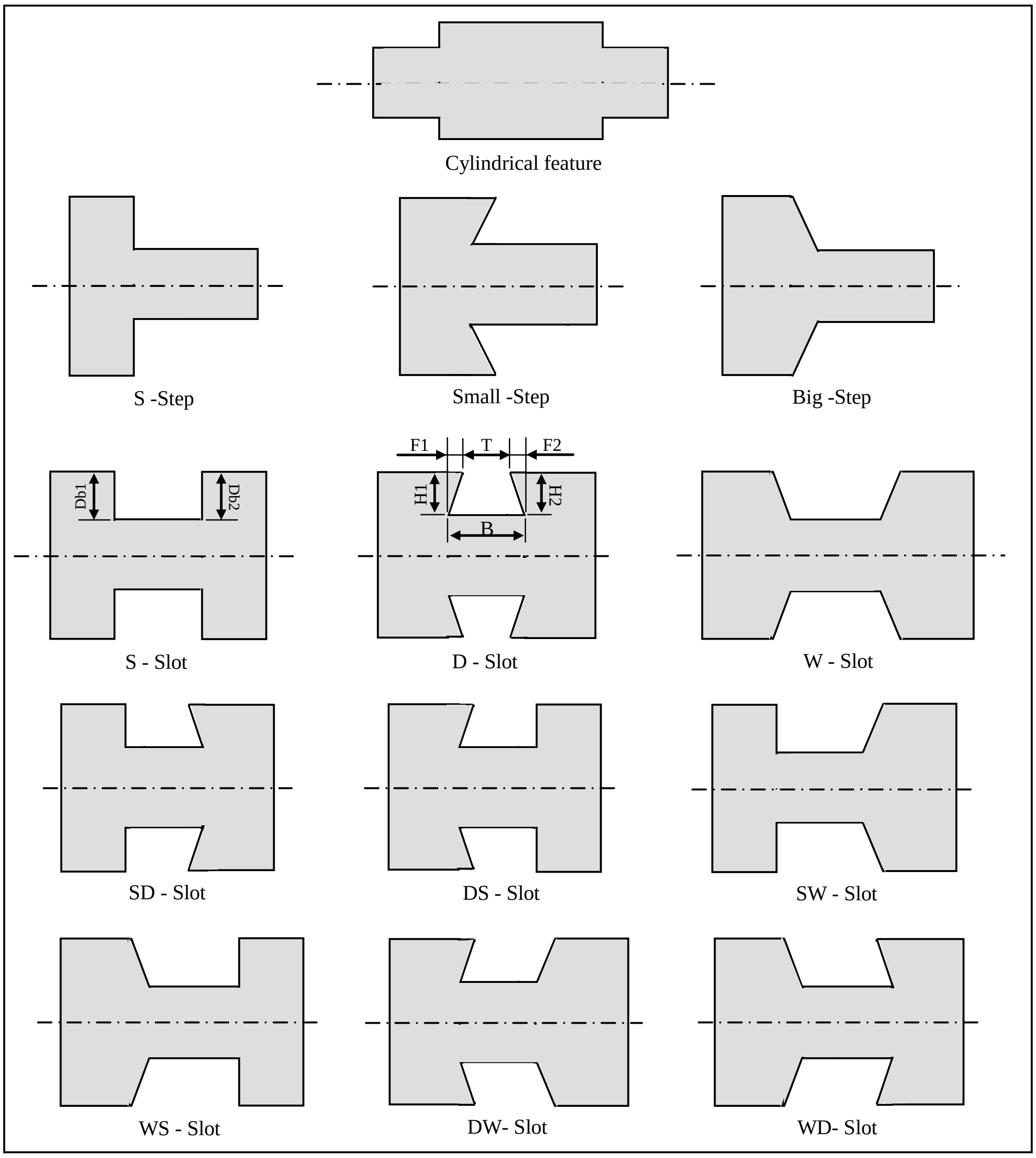


Figure 16. Types of features

4- TESTING AUTOMATIC FEATURES RECOGNITION SYSTEM

The design of Automatic Features Recognition (AFR) system comes from the need of recognize form features. To test this system, rotational parts profile applications are used.
AFR system is developed using visual basic 8 on Pentium (5) PC. This system is supported by mechanical desktop 9 to drawing part profile then export this profile to STEP file that represent the input source to AFR system.

4-1 Part Profile

The part profile module is described as an input of the system. Mechanical desktop package has been used as application software to create and preview part drawing. This interface between the AFR system and CAD package give the user ability to create any rotational part profile or editing previous one when the system already running. Figure (17) shows the window of part profile achieved by mechanical desktop software.

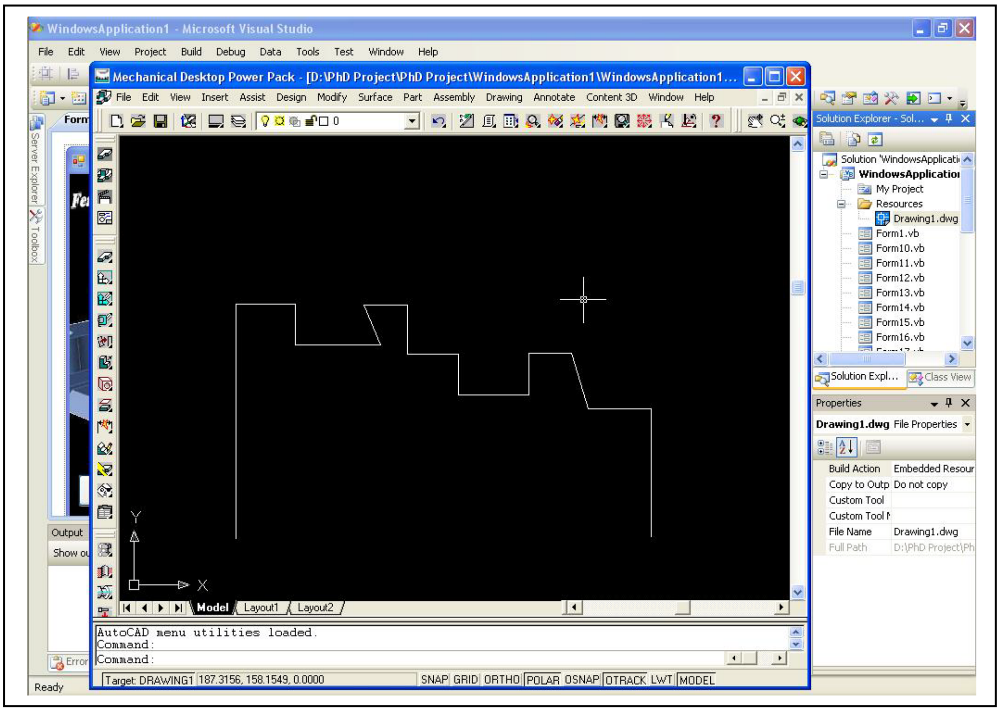
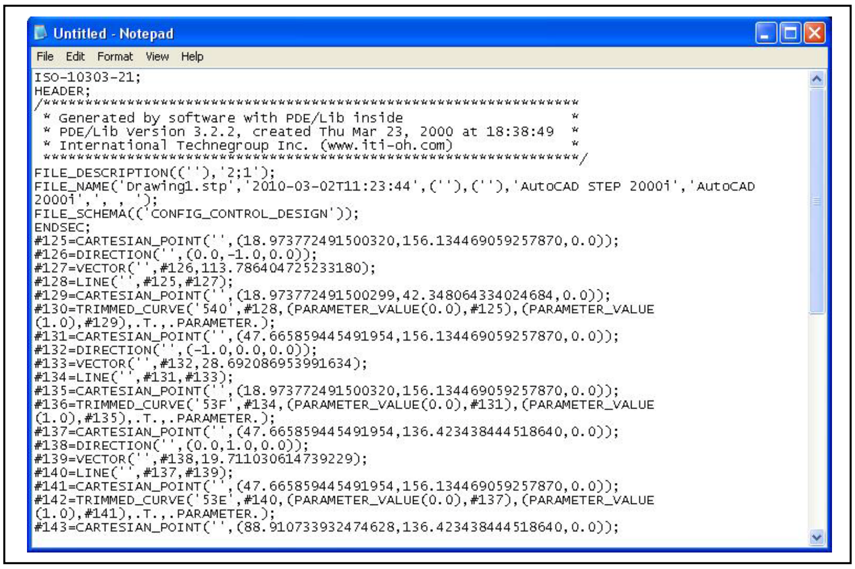


Figure 17. Part profile in mechanical desktop package

The user export part profile to STEP file (Drawing.stp) that is useful to recognize machining/inspection features. Figure (18) shows parts of STEP file to above application.



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ISO-10303-21;
HEADER;
/*************************************************************************
 * Generated by software with PDE/Lib inside                            *
 * PDE/Lib version 3.2.2, created Thu Mar 23, 2000 at 18:38:49          *
 * International Technegroup Inc. (www.iti-oh.com)                       *
 *************************************************************************/
FILE_DESCRIPTION((''),'2;1');
FILE_NAME('Drawing1.stp','2010-03-02T11:23:44',(''),(''),'AutoCAD STEP 2000i','AutoCAD
2000i',',',' ');
FILE_SCHEMA(('CONFIG_CONTROL_DESIGN'));
ENDSEC;
#125=CARTESIAN_POINT('',(18.973772491500320,156.134469059257870,0.0));
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#127=VECTOR('',#126,113.786404725233180);
#128=LINE('',#125,#127);
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(1.0),#129),.T.,.PARAMETER.);
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#133=VECTOR('',#132,28.692086953991634);
#134=LINE('',#131,#133);
#135=CARTESIAN_POINT('',(18.973772491500320,156.134469059257870,0.0));
#136=TRIMMED_CURVE('53F',#134,(PARAMETER_VALUE(0.0),#131),(PARAMETER_VALUE
(1.0),#135),.T.,.PARAMETER.);
#137=CARTESIAN_POINT('',(47.665859445491954,136.423438444518640,0.0));
#138=DIRECTION('',(0.0,1.0,0.0));
#139=VECTOR('',#138,19.711030614739229);
#140=LINE('',#137,#139);
#141=CARTESIAN_POINT('',(47.665859445491954,156.134469059257870,0.0));
#142=TRIMMED_CURVE('53E',#140,(PARAMETER_VALUE(0.0),#137),(PARAMETER_VALUE
(1.0),#141),.T.,.PARAMETER.);
#143=CARTESIAN_POINT('',(88.910733932474628,136.423438444518640,0.0));
```

Figure 18. Part of STEP file to first example

4-2 Feature-based Design stage

This stage consists of the following steps:

1- Part profile coordinate (point definition) and blank size window: - the results in this window represent the coordinate points of part profile. The system also calculate the blank size after specify the maximum X and Y is shows in Figure (19).

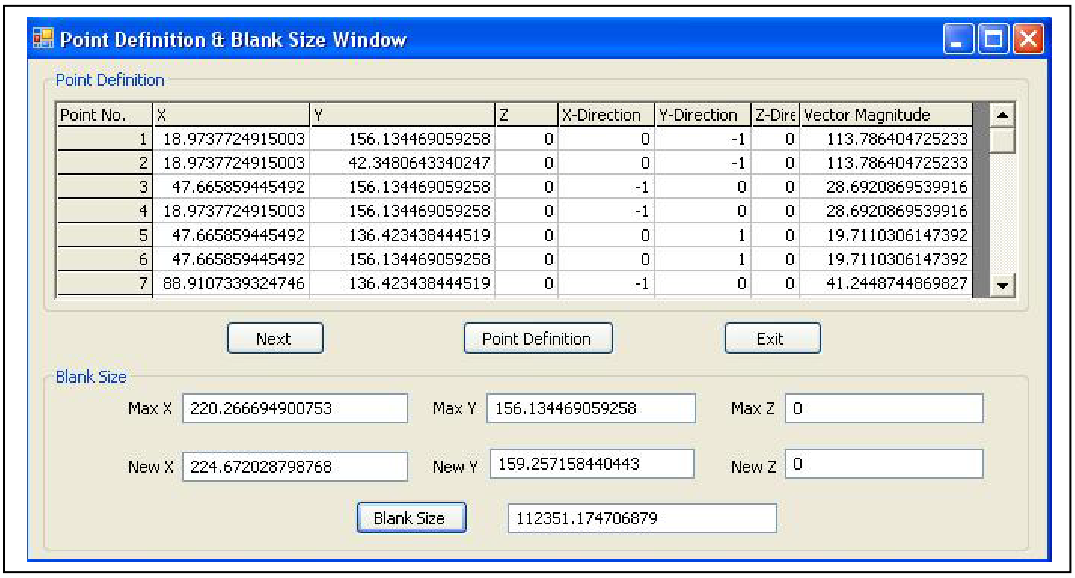

Figure 19. Point definition and blank size window

2- Line entity definition and sweeping it window: - AFR system determines the line entities that the part profile composed by syntactic pattern method. The line entities are [line a, line c, line e, line c, line h, line c, line e, line c, line e, line c, line a, line c, line d, line c, line e] the coordinate system to these line is also determine as shows in Figure (20).

Above line entities sweeping by Denavit-Hartenberg (DH) method to determine the cylindrical and circular faces. The part consists of the following faces [Circular face a, Cylindrical face c, Circular face e, Cylindrical face c, Circular face h, Cylindrical face c, Circular face e, Cylindrical face c, Circular face e, Cylindrical face c, Circular face a, Cylindrical face c, Circular face d, Cylindrical face c, Circular face e]. The coordinate of these faces are determined in four angles ((0˚, 360˚), 90˚, 180˚ and 270˚) as shows in Figure (20).

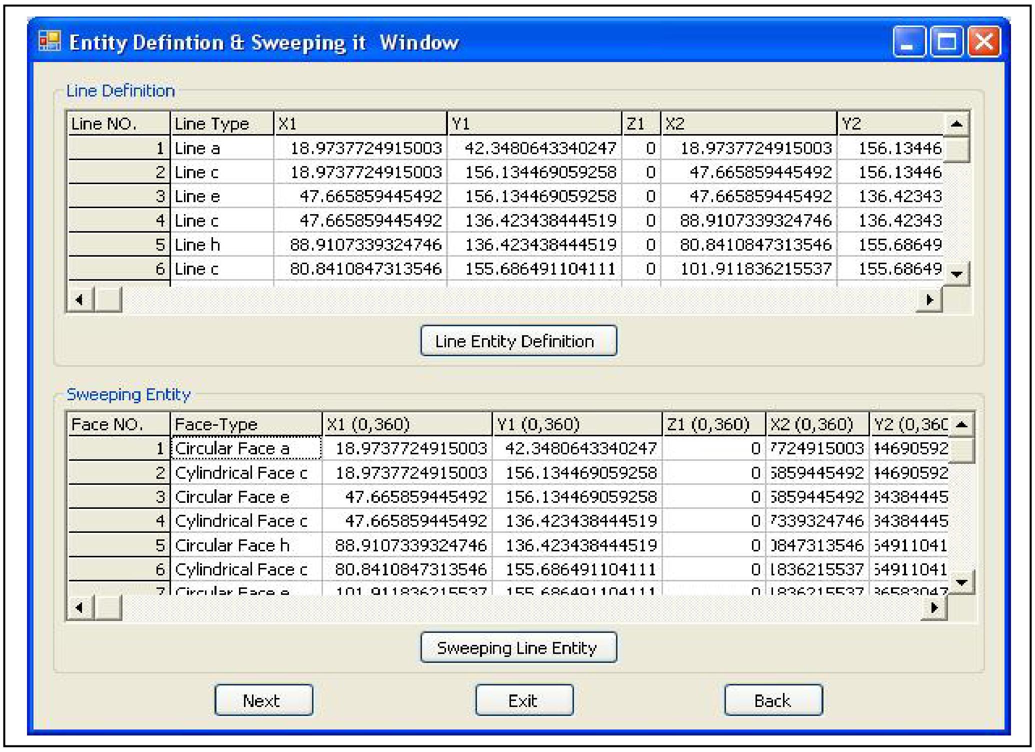

Figure 20. Line entity definition and sweeping it window

3- Form feature recognition window: - by using logic rule method the AFR system determine form features that rotational part consist it. The types of feature determined by system are [Cylindrical feature, SD slot, Cylindrical, S-step, S-slot, Cylindrical and Big-step]. The dimension of these feature also determined. The face edge coordinate (X1, Y1), (X2, Y2), (X3, Y3) and (X4, Y4). Width of top, width of bottom, Distance of left boundary face, Distance of right boundary face, offset from bottom to the left side and offset from bottom to the right side are also determined as shows in Figure (21).

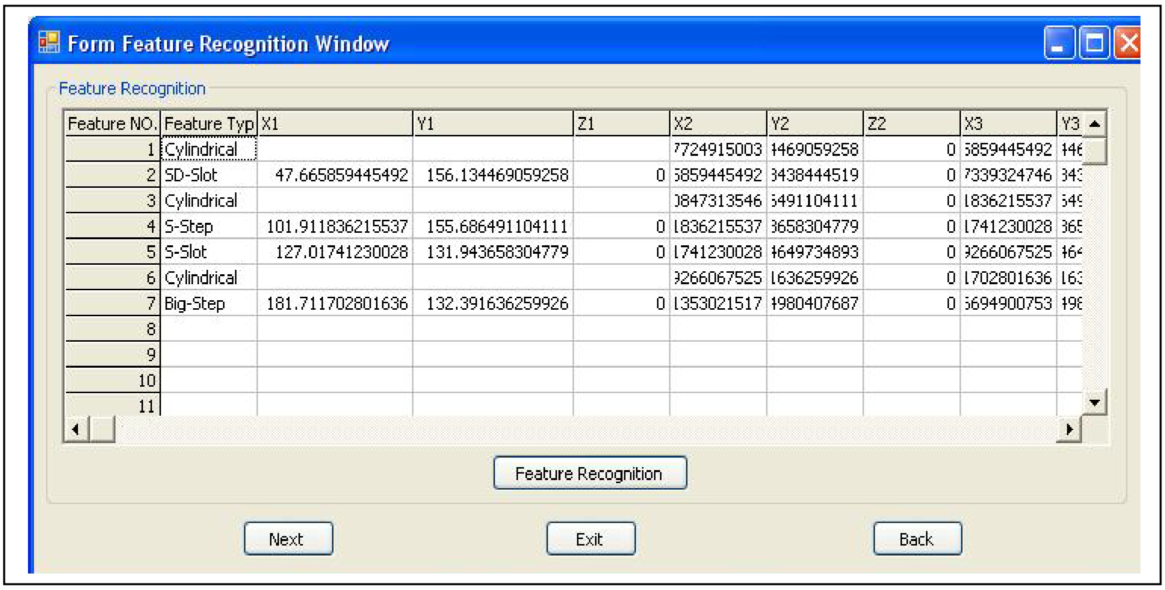

Figure 21. Form feature recognition window

5- SUMMARY AND CONCLUDING REMARK

One of the most important aspects in concurrent engineering processes is the sharing of information in a consistent and simultaneous way along the production cycle. Manufacturing system requires the information of the part to be machined and measured, from CAD system.

STEP is an International Standard for the computer-interpretable representation and exchange of product data. The objective is to provide a neutral mechanism capable of describing product data throughout the life cycle of a product and can be playing a very important role in the integration of manufacturing systems activities which is intended to be used in a CIM environment.

The main conclusions of this research are:

1- The output of computer graphic module by using (Mechanical Desktop 0.9) is a part profile exported as a STEP (ISO 10303, part 21) file.

2- The AFR system proposed new algorithm for extraction part profile information (point coordinate specification, vector direction and magnitude) from STEP (ISO 10303, part 21) file.

3- Three methods of feature recognition (syntactic pattern (primitive), sweeping operation method and logic rule) are used to define line entity, sweep line to find cylindrical and circular planner face, and connect base face (cylindrical planner face) with at least one concave boundary face (circular planner face) to determine different simple types of form features (S-Slot, D-Slot, W-Slot, Small Step and Big Step) beside new types of composed features (SW, WS, SD, DS, DW and WD-Slot) that represent one of the originality points in this research.

4- Logic rule used to connect base face with convex boundary face to determine (Cylindrical feature) which represent the second point of originality in this research.

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