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DEVELOPMENT OF STEP HOLE RECOGNITION SYSTEM FOR COMPUTER AIDED PROCESS PLANNING

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Abstract. Current CAD system represents part by set of vertices, lines face and/or volume. This type of presentation is not suitable for most manufacturing application such as Computer Aided Process Planning (CAPP). At manufacturing level, decisions are mainly based on higher entities, which are commonly called manufacturing features. This paper describes the development of STEP Hole Recognition System called S_HoRS for CAPP. S_HoRS will convert geometrical data specifically holes from the STandard for the Exchange of Product model data (STEP) file into feature based model suitable for process planning activities, especially for tool and die components. Rule-based algorithm is used for the recognising process. The output from S_HoRS is the hole's feature data such as radius, height and the coordinates system. Current implementation of the S_HoRS is limited to simple hole features.

Keywords: Hole features, computer aided process planning, feature recognition, STEP file, rule-based algorithm

Abstrak. Sistem CAD masa kini mewakili komponen dengan vertex, garis, permukaan dan/ atau isipadu. Perwakilan ini tidak sesuai untuk kebanyakan applikasi pembuatan seperti Perancangan Proses Terbantu Komputer (CAPP). Pada tahap pembuatan, kebanyakan keputusan adalah berdasarkan pada entiti tertinggi di mana ia biasa dipanggil sebagai sifat pembuatan. Kertas kerja ini membincangkan pembangunan Sistem Pengecaman Lubang STEP yang dinamakan S_HoRS untuk Perancangan Proses Terbantu Komputer. S_HoRS akan menukarkan data geometri terutamanya lubang dari fail STEP kepada model berdasarkan sifat, sesuai untuk aktiviti perancangan proses terutamanya bagi komponen alatan dan acuan. Algoritma yang berdasarkan aturan digunakan dalam proses pengecaman. Perlaksanaan terkini bagi sistem tersebut terhad untuk sifat lubang sahaja.

Kata kunci: Sifat lubang, perancangan proses berbantu komputer, pengecaman sifat, sifat lubang, fail STEP, algoritma berasaskan aturan

1.0 INTRODUCTION

Feature Recognition has been regarded as an important task that bridges CAD and Computer Aided Process Planning. Computer-Aided Process Planning system

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involves the interpretation of part design and subsequently, produces a set of detail manufacturing sequence to produce the part. However, most of the existing CAD system does not provide part feature information, the higher level entities suitable for CAPP input. In other word, CAPP systems do not understand the three dimensional geometry of the designed parts from CAD systems in term of their engineering meaning related to manufacturing or/and assembly [1]. To solve the CAD and CAPP interface problem, feature recognition is one of the most efficient approaches to this problem.

Many techniques have been proposed for feature recognition problem [2-6]. The type and format of data provided by the geometric modeller greatly influence the feature recognition techniques that were developed. Some research works have been undertaken for feature recognition from STEP file [7,8]. The purpose of STEP is to build a common standard that ensures the product data can be communicated electronically across different platforms, e.g. CAD, CAM and CAE.

Cicirello and Regli [9] presented an approach that uses machining features as an index-retrieval mechanism for solid models. One of the technical approaches for this research is to perform machining features extraction to map the solid model to a set of STEP machining features. The machining features that were recognised in this approach were hole and pocket. The technique that was used to extract the machining features is a graph-based approach named Model Dependency Graph (MDG). MDG is a mechanism for archival and retrieval of models in CAD databases and can be employed using a query by example paradigm. In addition, based on MDG, it can create query artefacts that partition the database of solid models into different morphism classes. The proposed approach considers only plain, unattributed solid models; where there is no tolerance, manufacturing attributes, surface finish specifications, etc.

Han *et al.* [10] proposed integrating feature recognition and process planning in the machining domain to achieve the goal of CAD/CAM integration. The system that was proposed uses STEP as input and output formats. STEP is the interface for portability between CAD and planning systems, feature recognition for manufacturability and setup minimisation, feature dependency construction, and generation of an optimal feature-based machining sequence. The geometric reasoning kernel of Integrated Feature Finder (IF^2) that was used in this work was able to recognise holes, slots and pockets. IF^2 is a hint-based reasoning system.

Bhandarkar and Nagi [7] developed feature extraction system that uses STEP file as input and to define the geometry and topology of a part. In addition, the system generates STEP file, as output with form feature information in AP224 format for form feature process planning. The STEP file can be exchanged between various companies and can serve as input to further downstream activities such as process planning, scheduling and material requirement planning (MRP). The feature recognition algorithm is boundary-representation (B-Rep) based and follows a sequential approach through an existing classification of features. The algorithm is developed for prismatic solids produced by milling operations that contains elementary shape such as plane and cylindrical surfaces (possibly using non-uniform rational B-splines (NURBS)). The feature extraction system can store the feature data in a computer interpretable format which can be transmitted between various locations. In addition, the system also aimed at overcoming the shortcomings of the design by feature approach, which is limited by the number of features in the pre-defined library of features.

Ismail *et al.* [8] developed an experiment feature recognition system to recognise simple and complex holes features using geometry and topology information from Boundary representation (B-rep) model. In their work, spatial addressability information of geometric modellers is used as a basis for the feature recognition algorithm. Complex hole consists of multiple curve edge segments. This happens when a hole intersects with an edge or vertex of a part. The faces of the hole are either cylindrical faces or conical faces. Another advantage of the algorithm is that the hole and/or boss features that exist on sloping faces and at slanting angles to the part could also be recognised.

Staley *et al.* [11] described a system for recognising holes from 3D solid geometric database and eight primitives were used to classify multi-diameter holes consisting of planar, cylindrical, spherical, toridal and conical faces. The user interactively selects a hole and specifies the start and end section vertex on the cross section face. If the input string matches any of the grammars, the system returns a value 'true' and specifies the type of hole that is recognised.

However, none of the above researchers have focused on STEP file from CAD software and knowledge-based system to recognise hole features for CAPP in particular. The aim of this paper is to describe the development of a hole recognition system suitable for mechanical parts that consist of hole features such as tool and die components.

2.0 HOLE FEATURE DEFINITION

Feature has many definitions and there is no consensus on a common definition. The term feature is derived from Latin word "facture" which means the act of making or formation [12].

Hole feature is the feature that removes material in the shape of several standard holes. The standard holes are simple hole, counter-sunk hole and counter-bored hole. The holes can be created to a specific depth or completely through body [13].

Noort *et al.* [14] defined form features as regions of the part that have some functional meaning. Form features contain class-specific design information that is captured by means of feature elements and feature constraints. Feature elements are shapes and user-defined variables. Features constraints can be, for example, a geometric distance face-face constraint, a dimension constraint, which specifies a dimension to be within a given range, and on-boundary constraint, which specifies a feature face to be on the boundary of the part.

2.1 STEP file

A STEP file is a text file that contains geometrical data of a component including boundary representation data such as shells, faces, vertices; surface geometric data such as planes, cylinders, cones, toroidal; curve geometric such as lines, circles, ellipses, b-spline curves [15]. A brief description of some STEP elements is shown in Table 1.

Table 1 Brief description of some STEP elements

STEP element	Description
CARTESIAN_POINT	Address of a point in Cartesian space.
ADVANCE_FACE	A face that is associated with a type of surface
CYLINDRICAL_SURFACE	A face of cylinder in which the geometry is defined by the associated surface, boundary and vertices.
CIRCLE	A circle in which the geometry is defined by the associated surface, boundary and vertices.
PLANE	A plane in which the geometry is defined by the associated surface, boundary and vertices.
LINE	A line in which the geometry is defined by the associated surface, boundary and vertices.

An example of STEP file for a blind/through hole is shown in Table 2. In general, the geometrical data of a blind/through hole is as follows:

(1) The entity #27, refers to CIRCLE with the radius of 2.0 mm. The CARTESIAN_POINT or centre of the circle is entity #23 and described as follows:

$$X = 4.0,\ Y = 5.0,\ Z = 7.0$$

(2) After the entity of circle, there is always an entity of plane (#72) with CARTESIAN_POINT as follows:

$$X = 4.0,\ Y = 5.0,\ Z = 7.0$$

The CARTESIAN_POINT of the PLANE is the same with the CARTESIAN_POINT of the first circle. The entity of a plane can show either

Table 2 Partial STEP file of through and blind holes

```
ISO-10303-21;
Header;
•
Data;
•
#23=CARTESIAN_POINT(‘’,(4.,5.,7.));
#27=CIRCLE(‘’,#26,2.);
...............................................................................
#68=CARTESIAN_POINT(‘’,(4.,5.,7.));
#72=PLANE(‘’,#71);
#73=ADVANCED_FACE(‘’,(#33,#67),#72,.T.);
...............................................................................
#153=CARTESIAN_POINT(‘’,(4.,5.,0.));
#157=CIRCLE(‘’,#156,2.);
...............................................................................
#175=CARTESIAN_POINT(‘’,(4.,5.,0.));
#179=PLANE(‘’,#178);
#180=ADVANCED_FACE(‘’,(#163,#174), #179,.T.);
...............................................................................
#199=CARTESIAN_POINT(‘’,(4.,5.,7.));
#203=CYLINDRICAL_SURFACE(‘’,#202,2.);
•      .
ENDSEC;
END-ISO-10303-21;
```

the circle is a circle with plane or otherwise. The entity #73 ADVANCE_FACE indicates that the entity #27 CIRCLE is a circle without plane because the entities in the second close quote as in line #73 have more than 2 entities (#33, #67) and this means that the circle is subtracted from the plane (#72).

(3) The second CIRCLE is shown in entity #157 with a radius of 2.0 mm. The CARTESIAN_POINT or centre of the second circle is described as follows:

$$X = 4.0,\ Y = 5.0,\ Z = 0.0$$

The entity #179 PLANE that has the same CARTESIAN_POINT with the second circle is used to determine whether the second a circle is circle with plane or otherwise. The entity #180 ADVANCE_FACE indicates that the entity #157 CIRCLE is a circle without plane because the entities in second close quote as in line #180 have more than 2 entities (#163, #174) and this means that the circle is subtracted from the plane (#179).

(4) The entity #203 shows a CYLINDRICAL_SURFACE with the radius of 2 mm. The CARTESIAN_POINT or centre of the CYLINDRICAL_SURFACE is described as follows:

$$X =4.0,\ Y = 5.0,\ Z = 7.0$$

The geometrical data of CYLINDRICAL_SURFACE shows that the x-axis and the y-axis of the CYLINDRICAL_SURFACE are the same with the first circle and the second circle. The radius of CYLINDRICAL_SURFACE, either first CIRCLE or second CIRCLE, will have the same values. It indicates that first circle and second circle are adjacent to CYLINDRICAL_SURFACE.

3.0 OVERALL SYSTEM DESCRIPTION

The proposed system comprises of user database, inference engine and interface. It is developed using KAPPA PC because it has a good programming environment composed of graphical tools for object management, rule management and code management.

3.1 Database

The database of the system consists of STEP file from UniGraphics CAD/CAM Software. This STEP file is postprocessed first before input to KAPPA PC [16] using C language. The holes' geometric information after postprocessing is represented in a hierarchy tree as shown in Figure 1. The overall system hierarchy tree is shown in Figure 2. Results of feature database are also highlighted in this tree.

3.2 Recognition Algorithm

The recognition algorithm of S_HoRS uses rule-based technique where rules are specified with an IF Condition and THEN Conclusion syntax. Condition is composed by a set of tests on object attributes linked by logic operator (AND, OR, XOR).

As an example, the rule for through hole at XY plane (refer Figure 3) is written as follows:

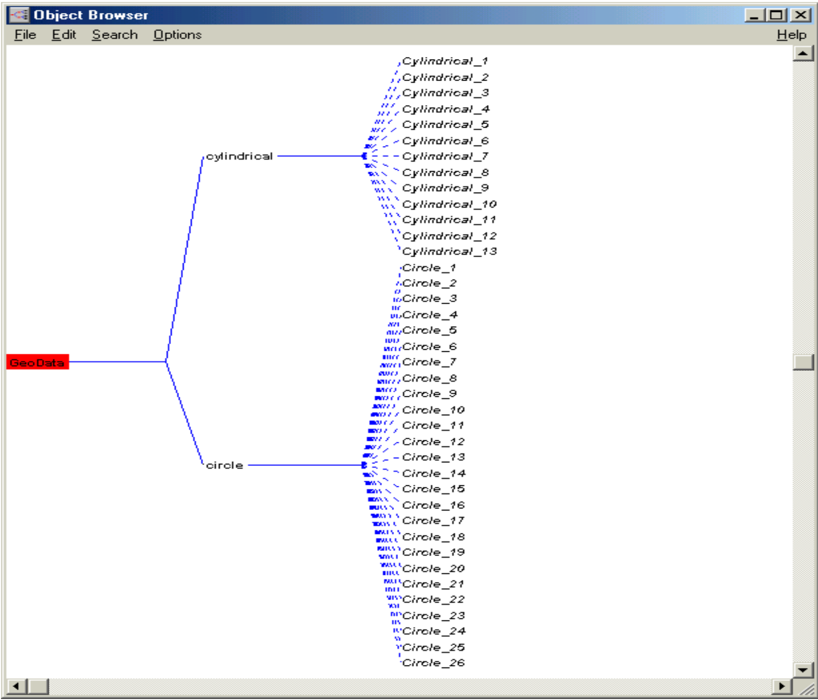


Figure 1 Holes' geometrical and topological data

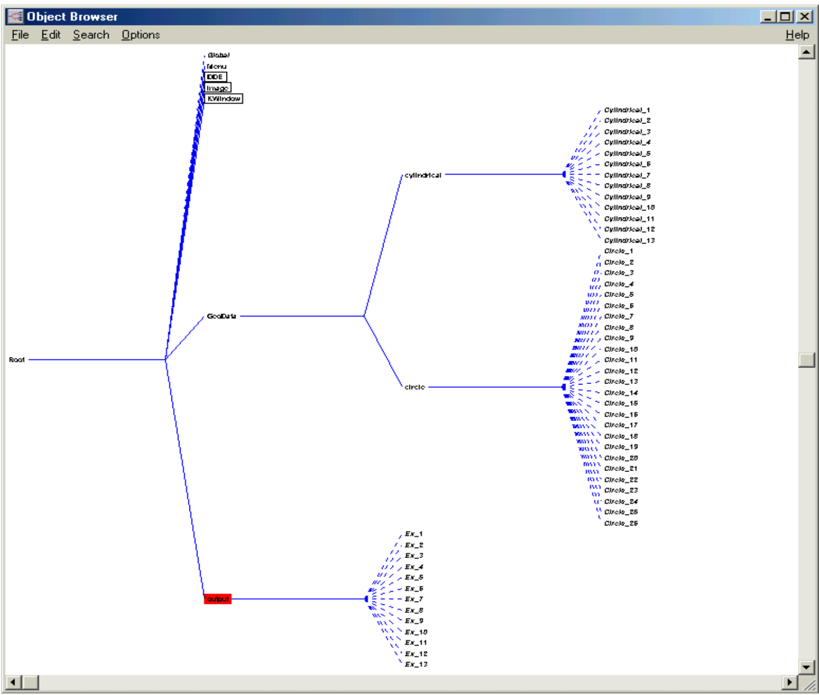


Figure 2 STEP hole recognition system hierarchy tree

If
CiX and *CiY* for a circle (*C1*) equal to *CiX* and *CiY* for other circle (*C2*), and also equal to *CyX* and *CyY* for one of the cylindrical (*Cy1*)
and
CIRADIUS for circle (*C1*) is equal to *CIRADIUS* for circle (*C2*), and equal with *CYRADIUS* for the cylindrical (*Cyl*)
and
CIPLANE for one of the circle (*C1*) is *FALSE*
and
CLANE for circle (*C2*) is *FALSE*
Then
the result is Through Hole

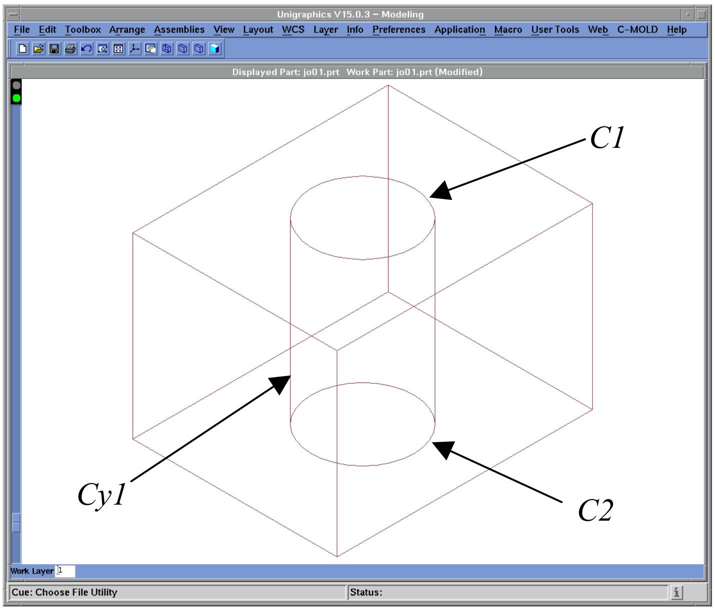


Figure 3 Definition of through hole

3.3 Inference Engine

This S_HoRS uses forward chaining, where four different strategies may be used in selecting the rule to be applied from a set of rules with the same priority: bestfirst, depthfirst, breadthfirst or selective. The rule structure of through hole that is used in recognition process using KAPPA-PC is shown in Figure 4. The rules for recognising through and blind holes in XZ plane and YZ plane have been developed as well.

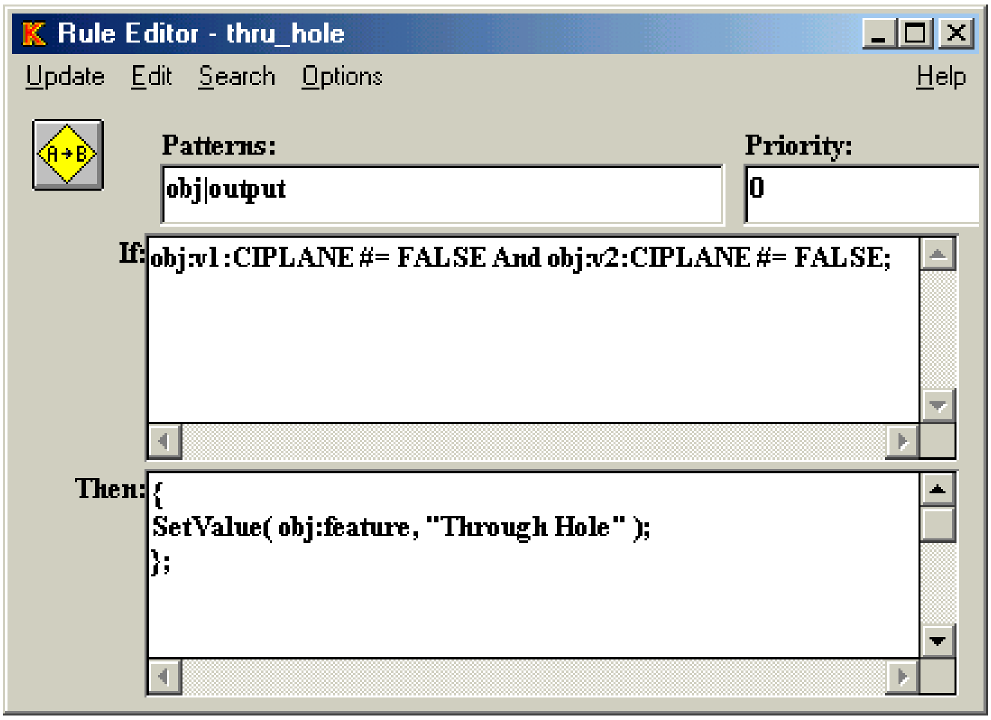


Figure 4 Rule editor for through hole

3.4 User Interface

The proposed user interface for S_HoRS is shown in Figure 5. The HRS offers five options in the main menu:

(1) Open STEP file
(2) Start Hole Feature Recognition Process
(3) View of STEP file
(4) Reset
(5) Exit

The STEP file is generated using UniGraphics CAD/CAM software. To start the recognition process, a STEP file must be post-processed prior to the recognition process. This can be done by clicking the function 'open STEP file'. Once processed, click the start Feature Recognition Process function to start the processing. The first step in S_HoRS is to pre-process the STEP files into a format suitable for KAPPA PC system. Then, rule-based technique is used to recognise the holes, features. The output from the system is feature information in text file format. The 'reset' button is used to reset the S_HoRS and hide the sub-window such as a result window.

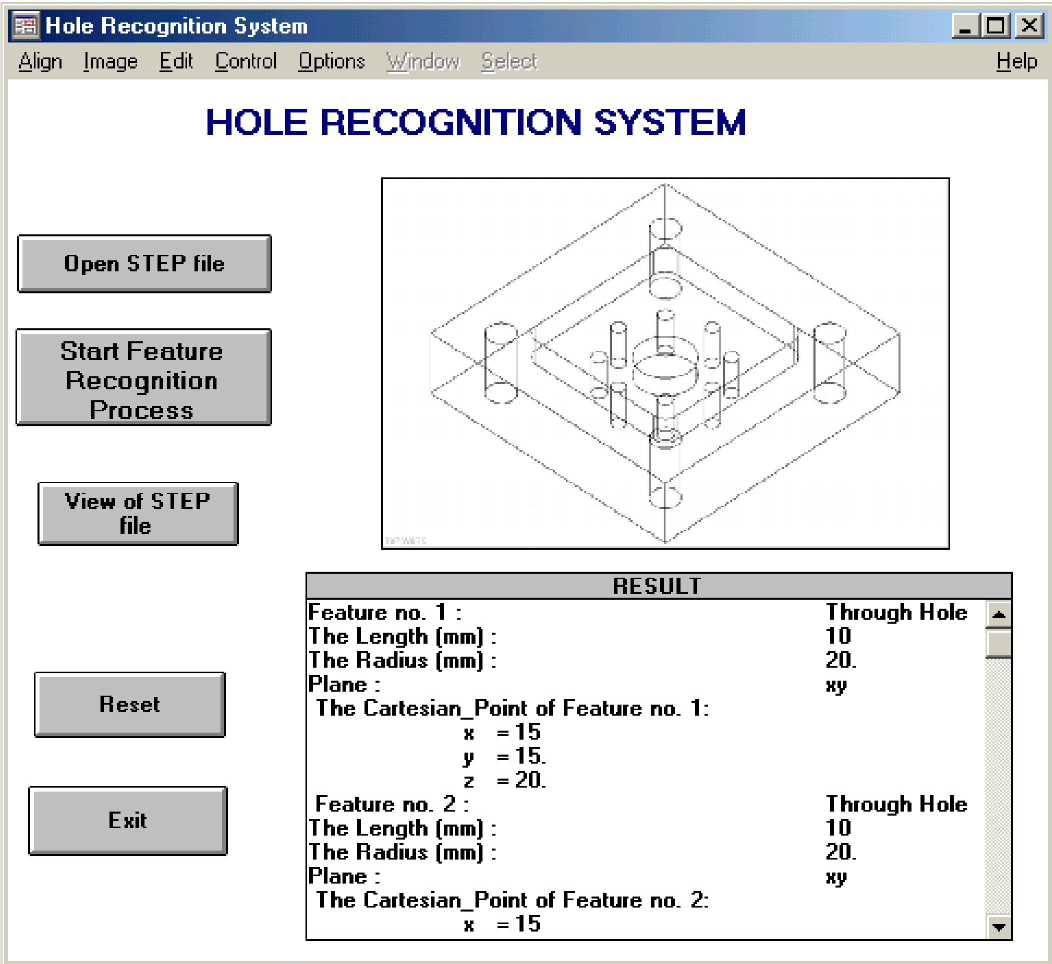
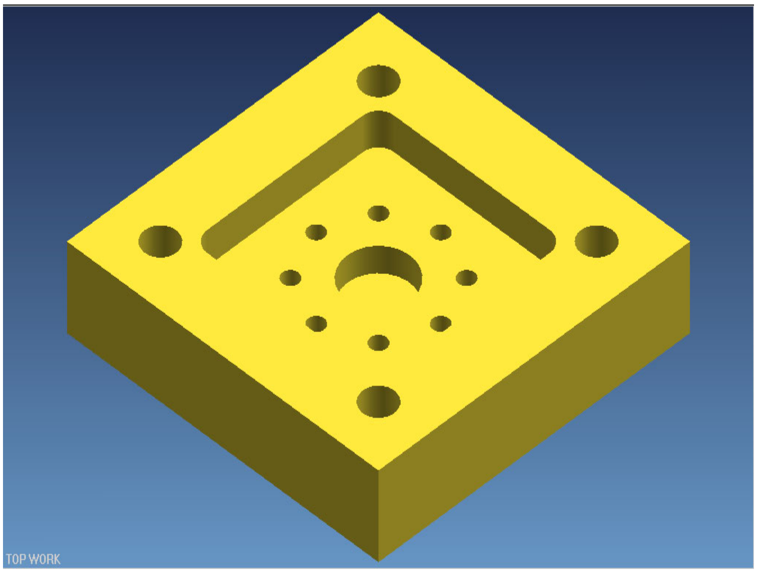


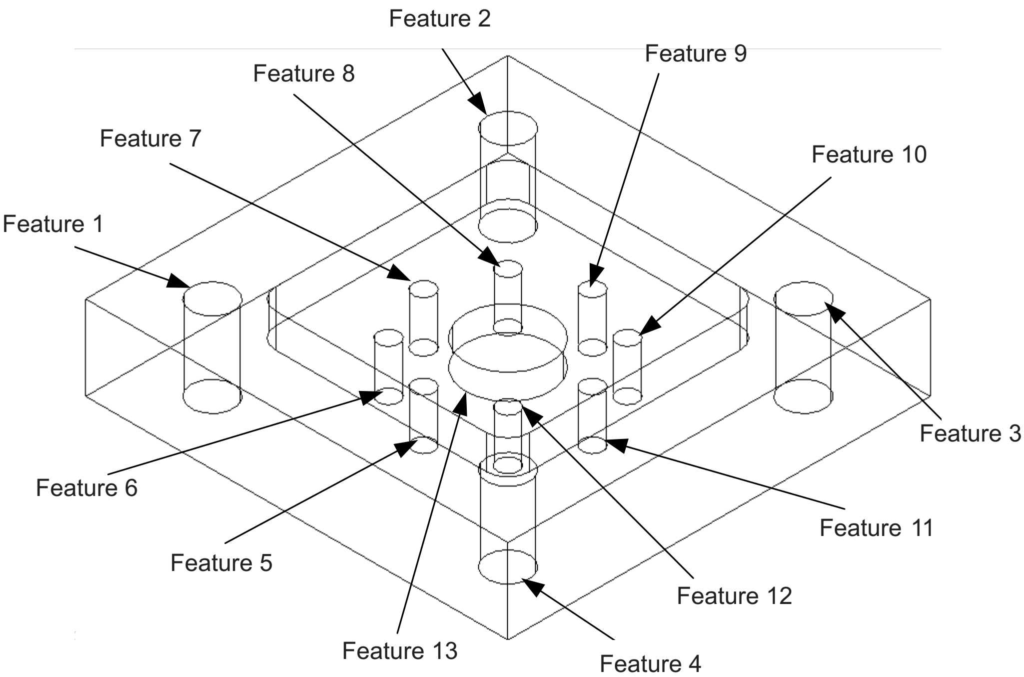
Figure 5 Main window of S_HoRS

4.0 RESULT AND DISCUSSION

The case study's test parts are shown in Figure 6. The part consists of four through holes (diameter 40 mm), eight through holes (diameter 24 mm), and one blind hole (diameter 20 mm). The partial results of features recognised are shown in Table 3. All features labelled in Figure 6 are recognised. S_HoRS can also recognise holes features in xy, xz and yz plane with the correct length and radius of each hole.



(a) Solid model



(b) Wireframe model and feature identification

Figure 6 Test part 1

Table 3 Partial processed data results for case study 1

Feature no. 1 :	Through hole
The length (mm) :	10
The radius (mm) :	20.
Plane :	xy
The Cartesian_Point of Feature no. 1:	
x = 15	
y = 15.	
z = 20.	
Feature no. 2 :	Through hole
The length (mm) :	10
The radius (mm) :	20.
Plane :	xy
The Cartesian_Point of Feature no. 2:	
x = 15	
y = 85	
z = 20.	
Feature no. 3 :	Through hole
The length (mm) :	10
The radius (mm) :	20.
Plane :	xy
The Cartesian_Point of Feature no. 3:	
x = 85	
y = 85	
z = 20.	
Feature no. 4 :	Through hole
The length (mm) :	10
The radius (mm) :	20
Plane :	xy
The Cartesian_Point of Feature no. 4:	
x = 85	
y = 15.	
z = 20.	
Feature no. 5 :	Through hole
The length (mm) :	5
The radius (mm) :	12
Plane :	xy
The Cartesian_Point of Feature no. 5:	
x = 5.	
y = 30	
z = 12	
Feature no. 6 :	Through hole
The length (mm) :	5
The radius (mm) :	12
Plane :	xy
The Cartesian_Point of Feature no. 6:	
x = 35.8578	
y = 35.8578	
z = 12	

5.0 CONCLUSION AND FUTURE WORK

The case study using S_HORS has demonstrated that the STEP file and rule-based technique is applicable for recognising simple hole form features. The output from the system is a set of manufacturing data for holes such as radius, length and their coordinates useful for process planning activities especially to produce process plans for tool and die components. However, one of the shortcomings of using this system is that a hole that is drilled at an angle to the entrance face (elliptical edges) would not be recognised. Complex holes are not recognised as well. The work is being extended to include:

(1) The integration of a rule management system into S_HoRS
(2) Development of intelligent process planning system using feature-based as an input.
(3) Recognise more manufacturing features such as slot, pocket and step.

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