Construction of Hybrid Geometric Modelling for Injection Mould using CAD/CAM System

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Declaration

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LIST OF ABBREVIATIONS

n	Normal direction
d	Parting direction
FAH	Face Adjacency Hypergraph
CAD	Computer Aided Design
ACIS	3D ACIS Modeler
CAM	Computer Aided Manufacturing
B-rep	Boundary Representation
AAG	Attributed Adjacency Graph
EAAG	Extend Attributed Adjacency Graph
EAFEG	Extend Attributed Face-Edge Graph
FFC	Face-to-Face Composition

ABSTRAK

Projek ini menerangkan prosedur tentang pengecaman ciri automatik untuk membantu dalam merangka acuan. Pendekatan perwakilan hibrid digunakan dalam penyemakan bentuk secara automatik untuk mengekstrak maklumat geometri ciri untuk mengenalpasti bentuk pemotongan. Perwakilan sempadan (B-rep) diterapkan dalam perwakilan bentuk dengan menggunakan topologi dan geometri. Cara-cara yang dicadangkan yang menggunakan Hypergraph Adjacency Face menggambarkan bentuk-bentuk pemotongan dengan mewakili hubungan antara wajah bentuk. Komposisi Face-to-Face digunakan untuk mengkaji hubungan antara bentuk utama dan bentuk pemotongan. Part A, Part B dan Part C dicipta dan digunakan bentuk runcit automatik untuk mengklasifikasikan bentuk depresi dan protrusi. Algoritma berdasarkan kaedah heuristik digunakan untuk menentukan garis perpisahan yang terbaik dan arah pemisahan bahagian dengan membandingkan maklumat geometri mereka terhadap ciri tersebut. Penyemakan bentuk secara automatik ini mengenalpasti bentuk cembung dan cembung mereka mengikut kemurungan atau muka protrusi wajah mereka dan hubungan adjancensi muka mereka. Cara-cara ini membantu dalam mewujudkan acuan automatik. Ini akan memudahkan proses pembuatan acuan dan mengurangkan masa dalam membentuk reka bentuk. Oleh itu, cara-cara ini akan mendatangkan kesan yang besar dalam meningkatkan produktiviti dalam industri perkilangan

ABSTRACT

This project describes a procedure for automatic feature recognition to help in mould designing. Hybrid representation approach is used in automatic feature recognition to extract the geometric information of the feature in order to identify the undercut features. Boundary representation(B-rep) is applied in the shape representation by using the topology and geometry. The proposed approach that used the Face Adjacency Hypergraph describes the shape of the undercut features by representing the relationships among the faces of the features. The Face-to-Face Composition is applied to study the relationship between the main feature and undercut features. Part A, Part B and Part C were created and used the automatic feature recognition to classify the depression and protrusion feature. The algorithms based on the heuristic rule is used to determine the best parting line and parting direction of the parts by comparing their geometric information of the feature. These automatic feature recognition identified their shape of concave and convex feature according their depression or protrusion faces and their face adjacency relationship. These approaches are helpful in creating the core and cavity automatically. It will help to simplify the process of mould designing and reduce the time of moulding designing. Therefore, these approaches will have significant effect on increasing the productivity in manufacturing industry.

CHAPTER 1

INTRODUCTION

1.1 Background

Plastic product is widely used in our daily life. A wide variety of plastic products can be produced by the injection moulding process. Injection moulding is a simple and common method for mass production in manufacturing industry. However, a good design of mould of injection moulding must be according to the specification, manufactured under the controlled condition, and commissioned.

The injection moulding is a complex system consisting multiple components that are subjected to many cycles of temperature and stress. The poor mould design will cause the product quality become low amd inefficient moulding processes. Engineers should do more research on designing injection moulds that are perfectly fit with the high quality standard, which means that the mould can produce many parts with acceptable quality in the same time ensuring the minimal life cycle cost while taking a minimum amount of time, money, and risk to develop. Injection molding is referred to as a "net shape" manufacturing process because the moulded parts are ejected from the moulding process in their final form. The type of mould can be classified into two type which two-piece mold and multiple piece mold.

The 3D ACIS Modeler (ACIS) is a geometric modeling kernel that is used by many software developers which can help the industries in their engineering works such as computer-aided design (CAD), computer-aided manufacturing (CAM), computer-aided engineering (CAE), architecture, engineering and construction (AEC), and coordinate-measuring machine (CMM). ACIS has been implemented in C++

languages programming. ACIS is kind of tool to represent the shapes of feature by extracting geometry and topology of the feature.

In Computer-aided design (CAD), automatic regular form and freeform feature recognition can help to improve the mould designing process. The feature recognition can be applied on the 3-dimensional (3D) and 2-dimensional (2D) feature. Basically, the CAD only can extract the geometric entities of point, lines, angles and surfaces which is used for describing an object dimension and shape. The mould designers use the geometric information to construct the mould model in CAD software. But the problem is 3D feature of the model are difficult to be identified. One of the approaches to solve this problem is transforming the 2D geometric entities to 3D model. Thus, the designer can generate 3D part from 2D geometric data.

An undercut feature is a depression or protrusion that prohibits part ejection from a mould. The presence of undercut features would affect mould cost, structure and quality of the part. Study on the relationship between the undercut features and their mouldability are important to help to improve the quality of mould.With help of feature recognition of 3D features, the undercut features of the part can be easily determined in a short time. The undercut features can be classified into two classes which is protrusion and depression. The depression features are in concave regions such as local recesses, slot, pockets and holes while protrusion in convex region such as cylinders, bosses, cones and spheres. When designing the mould, the designer will try to choose best parting direction and parting line to reduce the undercuts features.

The hybrid representation method is the key to generate the feature recognition algorithm based on the geometric data and entities. The hybrid representation in this porject consists of Extend Attributed Adjacency Graph (EAAG), Boundary

Representation (B-rep), Face Adjacency Hypergrpah and Face-to-Face Composition. By using those representations, all the parts and features can be represented by faces, edge and adjacency information relationship and detail can be extracted and transformed to useful data. The data can generate some rules to help in feature recognition like determining the protrusion and depression. In solid modeling and CAD, boundary representation is often abbreviated as B-rep is a method for representing shapes of the feature using the limits. The B-rep will focus on the 3D structures such as cylinder, cube, cuboid, sphere and pyramid by analyzing the different entity in the model. These representation can recognize various isolated feature effectively.

The aim of this project is using the hybrid representation method to generate some algorithms to help the feature recognition in 3D model. All the undercut features like protrusion and depression need to be determined by these algorithms. These algorithms will be inserted in the ACIS program so that the construction of mould for injection moulding will be done automatically.

1.2 Problem statement

Injection moulding is widely used in the manufacturing industry. Normally, the design of mould is done manually and it is time-consuming and complicated. The automatic feature recognition will help to promote automatic mould construction for industrial uses. There are several feature recognition and representation method have implemented for representing the shape of the feature and determining the undercut feature, but some of the methods have limitation for some specific feature. Besides that, some of the methods are too complicated and need a lot of geometric data to support the method. Thus the hybrid representation can combine some feature recognition and representation methods to produce the best method that can ideally represent the feature of the part such as undercut features and shape of the features. The parting line and parting direction also have to be identified and proved by the algorithm. Therefore, the determination of undercut features and choosing the best parting direction and parting line will be done automatically which can help in mould designing. The mould designing method will be simplified and saving time.

1.3 Objectives

The objectives of the project are as follows:

1. To automatically recognize the undercut features by using the hybrid representation approach and extracting the tolopogy and geometry of the feature.
2. To generate an algorithms based on hybrid representation to determine the parting direction of the part.
3. To generate an algorithms to identify the parting line and parting surface to automatically construct the core and cavity with the aid of CAM software.

1.4 Scope of work

The scope of this project is as follows:

1. Apply the ACIS API Function in Microsoft Visual Studio to extract the topology and geometric information of the part.
2. Study on topology and geometric information and find out the relationship between the entities of the feature.
3. Apply the feature representation to represent the shape of the feature to identify the undercut features.

4. Integrate the representation to form hybrid representation to identify the normal direction, volume size and center point of the feature by creating new algorithms. It will help to determine parting line and parting direction.
5. Convert all the algorithms and the hybrid representation method into the C++ programming in Microsoft Visual Studio. It helps to construct the mould in Microsoft visual studio automatically.

1.5 Chapter outline

This thesis consists of five chapters with the outline as follows:

- Chapter 1 begins with an overview of injection moulding process for manufacturing industry. Through background study, automatic feature recognition and hybrid representations can contribute a lot to this project. This chapter also included the problem statement, objectives and scope of work for this project.
- Chapter 2 provides the literature review for previous studies in related areas. The feature recognition to determine the undercut features, parting line and parting direction of mould have been reviewed. The hybrid representation for the regular form and irregular form feature have been studied
- Chapter 3 indicates the methodology of this project. In this chapter, apply hybrid representation about the automatic feature recognition and automatic core and cavity generation
- Chapter 4 presents all the results of this project and the results has been evaluated and discussed.
- Chapter 5 draws the conclusion for this project and recommendation for future work that can be continued in future.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This literature review consists of five sections, starts with the fundamental about the injection moulding. Next section is about how to identify the undercut features of a part. After that, the review continues with automatic feature recognition based on the geometry information. The next following section is reviewing about how to apply the feature representation in the feature recognition. In next review, parting direction and parting line of the part are determine with help of hybrid representation.

2.2 Fundamental of injection moulding

Injection moulding is a manufacturing process by injecting the molten material into designed mould to produce parts. The first injection molding machine was patented in 1872. A screw injection moulding machine was developed and widely used in mass production manufacturing industry (Chen *et al.*, 1993). Mould design is critical because involving a lot of important criteria with direct implications to quality and productivity (Lakkanna *et al.*, 2016). The plastic materials used in injection moulding are polymers, chemicals, thermosetting and thermoplastic. The injection moulding is a complicated system that must simultaneously meet many requirement imposed by the injection moulding process. The primary important function of the mould is to contain the melted polymer material within the mould cavity so that the melted polymer material can completely filled into mould cavity to form a plastic component. The second important function of the mould is used to transfer heat efficiently from the molten polymer to the coolant the mould, such that injection moulded products may be produced in high efficiency and productivity. The third important function of the mould is to eject the part from the mould in an effective manner without damaging the part (Kazmer & Kazmer, 2012).

The mould design is directly related to the quality of mould and the time required to generate a mould (Ratzlaff & Giovannetti, 2016). To minimize the moulding cycle time and costs, molders strive to operate fully automatic processes with minimum mold opening and ejector strokes. The operation of fully automatic molding processes requires careful mold design, making, and commissioning.

The presence of undercuts feature such as protrusion and depression will become a critical issue in mold designing. Now, the shorter mould designing and manufacturing lead time become major concern in mould making industry to maintain their competitive edge in market. By using the advanced knowledges in CAD/CAM software, mold design process can be automatic process to replace the manual method which is time consuming (Fu *et al.*, 1999).

2.3 Identification of undercut features

To design a mould of injection moulding, the feature of the part has to be analysed carefully to ensure good quality of the mould and will not be affected by the presence of undercut features. The method of determining and classifying the undercut features is very important. Undercut features can be classified into two type which are concave feature (protrusion) and convex feature (depression). Concave regions such as slot, pocket and holes has the probability to become an undercut features of the part. Convex regions such cylinders, bosses , cones and spheres are low potential as undercut feature (Fu *et al.*, 1999). Figure 2.1 shows the core, cavity, side core and side-cavity in the mould of the injection moulding.

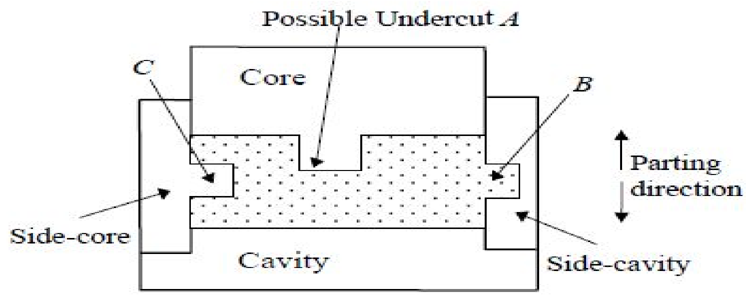

Figure 2.1 Mould of the injection moulding (Fu *et al*., 1999)

Identification of non-convex region on the part determined the obstruction of part and the region probably contains undercut features. According to Chakraborty and Venkata Reddy (2009), external undercut features and internal undercut features are the major concern to be identified out. Internal undercut features are moulded by the form pins or split cores inside the core and cavity but the external undercut features are moulded in by the side cores or side cavities.

The presence of external undercut feature on the mould and the parting direction of the external depression is difference with the main parting direction of the part. It means that the mould is required a side core which is removable metal blocks to form a certain shape of the external undercuts. The internal undercut features usually presented on the internal walls of the parts (Cam, 1997). The process of making the mould become difficult and time-consuming. The mould of injection mould will be designed into multiple pieces mould.

Candidate retraction space was used for retracting the corresponding undercut facet, first come with horizontal direction and then vertical direction, without intersecting with the part. However, the solid body is a very huge body with finite dimension to be attached to every undercut facet during retraction. This solid body volume and size were same with the core or cavity. Then, each of the undercut facet was computed it retraction space (Banerjee & Gupta, 2007).

2.4 Automatic feature recognition approach

In the design of plastic injection moulds, automatic feature recognition can be the method of generation of the core and cavity. The integration of CAD/CAM can be used for automatic extraction of geometric information from 3D geometric models (Huang & Yip-Hoi, 2002). The part informations was extracted into data that can be used in CAD software like 3D ACIS Modeler. After the data collection, a program interpreted and transformed the data into geometric information like shell, faces, edges, vertices and points by using various representation and algorithm.

Many researches had done on developed various algorithms for regular shaped feature recognition. The information of regular shaped feature can be easily extracted. The 3D part in IGES file can be extracted directly from all the attributes such as entity, type, appearance, and the position coordinates. The 7 forms of the regular features are shown in Figure 2.2. The 3D part only can focus on square, rectangular, triangular and loop that contain circular or partial circular arc (Liu *et al.*, 1994). Recognition rules that focus to recognise regular shape are simple compared to recognise freeform shape. It is difficult to generate a recognition rules. Freeform surface recognition method are very restricted and limited because freeform features do not have common pattern similarity (Bok & Mansor, 2013).

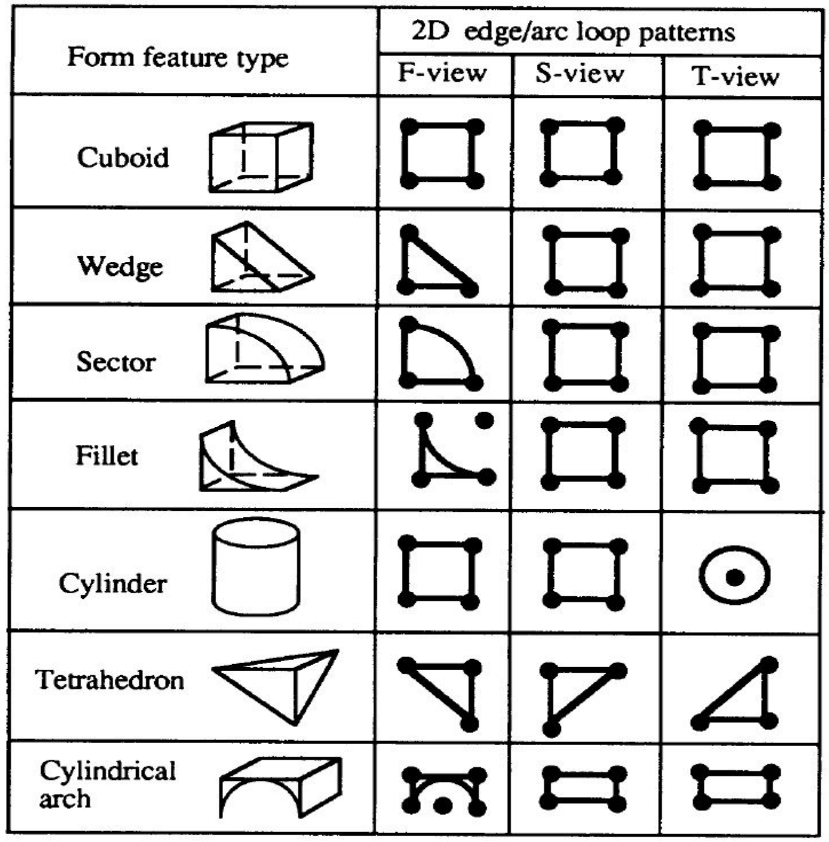

Figure 2.2 3D form features and their corresponding 2D form (Liu *et al*., 1994*)*

The freeform feature recognition method can be done by using principle curvatures. The entities like vertices, edges and faces are clustered into a curvature region, and then grouped into features if these entities are same curvature type. This method can be applied for both regular-shaped and freeform feature (Cai *et al., 2018)*. R.Langerak (2010) proposed the freeform feature recognition method. The global match on freeform was determined between the feature shape and the target shape by using an evolutionary computation procedure. If there are still some dissimilarities then the shape's similarity was further expanded in another evolutionary procedure.

2.5 Graph based and rule based representation

Many researchers proposed hybrid representation approach to recognize the feature based on graph and rule based representation. In solid modeling and CAD , (B-rep) is also an approach to represent the shape of solid model of the objects by using feature recognition method. Boundary representation of model consists of two information which is topology and geometry. The main topological things in B-rep is faces, vertices and edges. B-rep combined with boolean operation function to contruct or represent a feature. The feature-based design system has improved with B-rep. By separating the complex interacting features into simple feature so the objects geometry can be easily identified. The different entities in the object will be extracted (Wu & Liu, 1996). B-rep provided the basic information about faces, edges and vertices. The advanced information like face adjacencies and relationship among faces, edges and vertices can be extracted by relating the basic information.

In the graph-based representation, a class of features was determined by the required topological and geometric constraints. Gao and Shah (1998) proposed (EAAG) for feature recognition method by extending (AAG) and add several edge and face attributes. The EAAG consists five attributes which is convexity, loop, geometry, existence and blend type. The attributes of the node were checking the coincidence between faces and faces. Other node attributes checked the number of loops in the faces, concave hull and whether the face is planar or nonplanar. These attributes are shown in Table 2.1.

Table 2.1 EAAG Attributes

Arc (edge) attributes	Node (face) attribtues
Convexity: convex or concave	Source: stock or part face
Existence: real edge or a virtual edge	Convex hull: CH-face or non CH-face
Loop type: edge is on an inner or an outer loop	Number of loops: single or multiple
Geometry: curved or straight edge	Split status: unifiable or not
Blend type: smooth or sharp	Geometry: planar or non-planar

Nasr *et al.* (2014) proposed an approach for automatic feature recognition system involving extraction of the part data from STEP file. Analyze the geometric information and a simple algorithm was developed to extract the feature faces information. The maximum and minimum X, Y, Z values of part were determined to estimate the volume size of the part (Sundararajan & Wright, 2004). Determine the common edge between the faces and then group the faces to extract the information from edge loop of grouped faces by using dimensional algorithms. The algorithms and determine common edge method helped to identify holes and pocket of the part (Han *et al.*, 2001).

Ye *et al*. (2001) proposed that Extend Attributed Face-Edge Graph (EAFEG) as a boundary representation which extends the AAG to represent a solid model by adding edges and face attributes. EAFEG has two attributes which are face property and geometric type. The unique faces and edges correspond to generate the geometric information. Node and arc attributes are shown in Table 2.2. The example model geometric information can be represented as shown in Figure 2.3. By analyzing the arc attributes, the edge convexity played as an important for recognition of undercut features.

Table 2.2 EAFEG Attributes (Ye *et al*., 2001)

Attributes	Values
$C(n)$: face property	$C(n) = \{-1,0,1,2\}$
$C_g(n)$: geometric type	$C_g(n) = 1$: the face is planar
	$C_g(n) = 2$: the face is quadric
	$C_g(n) = 3$: the face is free-form surface
$Q_c(a)$: edge convexity	$Q_c(a) = -1$: edge is concave
	$Q_c(a) = 1$: edge is convex
	$Q_c(a) = 0$: edge is shared by two coplanar faces
$Q_p(a)$: parting line info.	$Q_p(a) = 1$: edge is a parting line
	$Q_p(a) = 0$: edge is not a parting line
$Q_L(a)$: loop type	$Q_L(a) = n$: edge e is on an inner loop of node n
	$Q_L(a) = 0$: edge e is on an outer loop
$V_1(a)$: vertex 1	$V_1(a) = (X_1, Y_1, Z_1)$
$V_2(a)$: vertex 2	$V_2(a) = (X_2, Y_2, Z_2)$

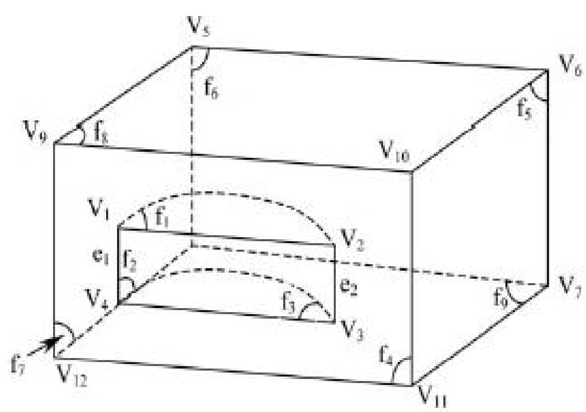

Figure 2.3 EAFEG (Ye *et al.*, 2001)

Concave edge was defined as the angle between the sharing faces is less than 180°; then the sharing faces which greater than 180° is convex edge.

Wu and Liu, (1996) proposed the rule-based representation scheme to generate a set of heuristic rules are used to describe characteristic and definition for a class of features. The graph-based representation scheme also be converted into a rule-based representation. According to Falcidieno, (1989), the Face Adjacency Hypergraph Model (FAH) was used for shape feature recognition. The representation described the object faces, whereas the arcs and the hyperarcs represented the faces relationships. The Figure 2.4 describes the faces relationship of the cube.

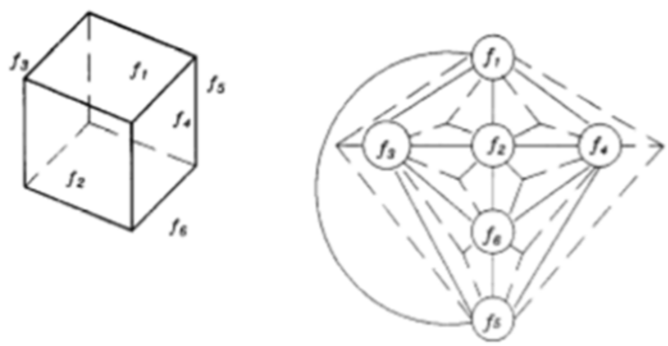

Figure 2.4 The Face Adjacency Hypergraph Model to describe the faces of the cubes (Falcidieno, 1989)

Bruzzone and Floriani, (1991) proposed that face-to-face composition (FFC) model of an feature is based on the decomposition into face-adjacent parts, components. There are two kinds of the components in FFC model: Positive components which consists protrusion feature. A negative components which consists depression feature. If there are face-adjacent between the two components,so that it means they are intsersecting at same face as shown in Figure 2.5.

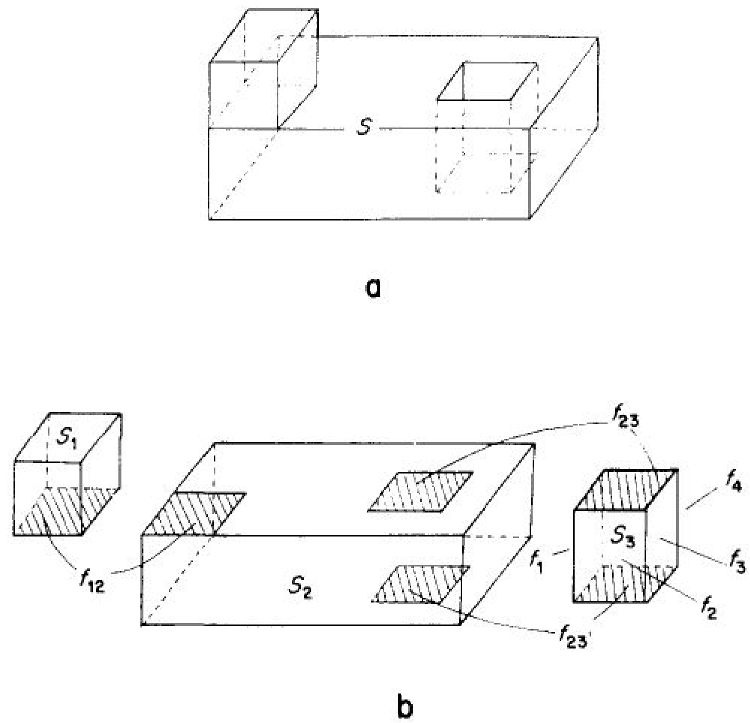

Figure 2.5 An object and its decomposition into 3 face-adjacent components (a) Object (b) Decomposition (Bruzzone & Floriani, 1991)

2.6 Generation of core and cavity

In injection moulding, a basic mould consists of two plates which is core and cavity. The separate line between core and cavity is called parting line which help to prevent any damage from opening and closing the mould. The parting directions, or mould-draw directions were identified to be a pair of opposite directions along which the core is moving away from cavity. The parting direction selection is important, because it affects all the following steps in a mould design, and involves many factors, such as the number of cores, and the shape of the parting surface (Fuh *et al.*, 2004). The parting direction of the mould is the direction of core moving away from the cavity. The anti-parting direction is the cavity moving away from the core.The Figure 2.6 shows the parting direction and anti-parting direction of a mould.

To determine the best optimal parting direction, the undercut features must be identified out then defined the normal direction of undercut features. The maximum total volume of the undercut will be the feature to affect the parting direction. The rest of the undercuts feature will become side core. The normal direction of the maximum total volume of the undercut has the high probability to become the parting direction of the part. To identify the parting line, Weinstein and Manoochehri(1996) claimed that their research about choosing parting direction and parting line based on the multi-objective function criterion. These criteria are complexity of the part, draw depth, number of undercuts, number of side cores, and the type of mold.

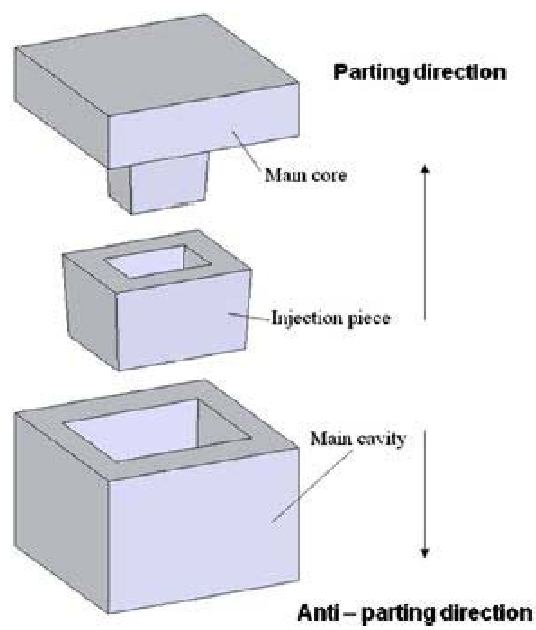

Figure 2.6 The mould show its parting direction (Weinstein & Manoochehri, 1996)

Chen *et al.* (1993) claimed an advanced method was developed for finding an optimal pair of parting direction. The geometry of an object was extracted out to help in selecting the non-convex region. The non-convex region direction will be determined if the direction is same with the possible parting direction. The parting direction can generate the core and cavity without any undercuts features present. If the condition is achieved, the parting direction will be the best direction to separate the core and cavity.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The chapter explains the approach and methods used to complete this research. It includes the automatic feature recognition, hybrid representation approaches, determination of parting line and parting direction and construction of mould.

Figure 3.1 demonstrates the flow chart of this experiment. The constructed part is used for automatic feature recognition in the program. Type of the undercut feature is identified based on their faces. For depression feature, the parting direction in depression feature was determined and then the depression body was constructed according to the maximum volume which is determined by the program. For protrusion feature, the mid point of the protrusion feature are identified and compare to get the parting line. All the information is stored which is used for the construction of core and cavity.

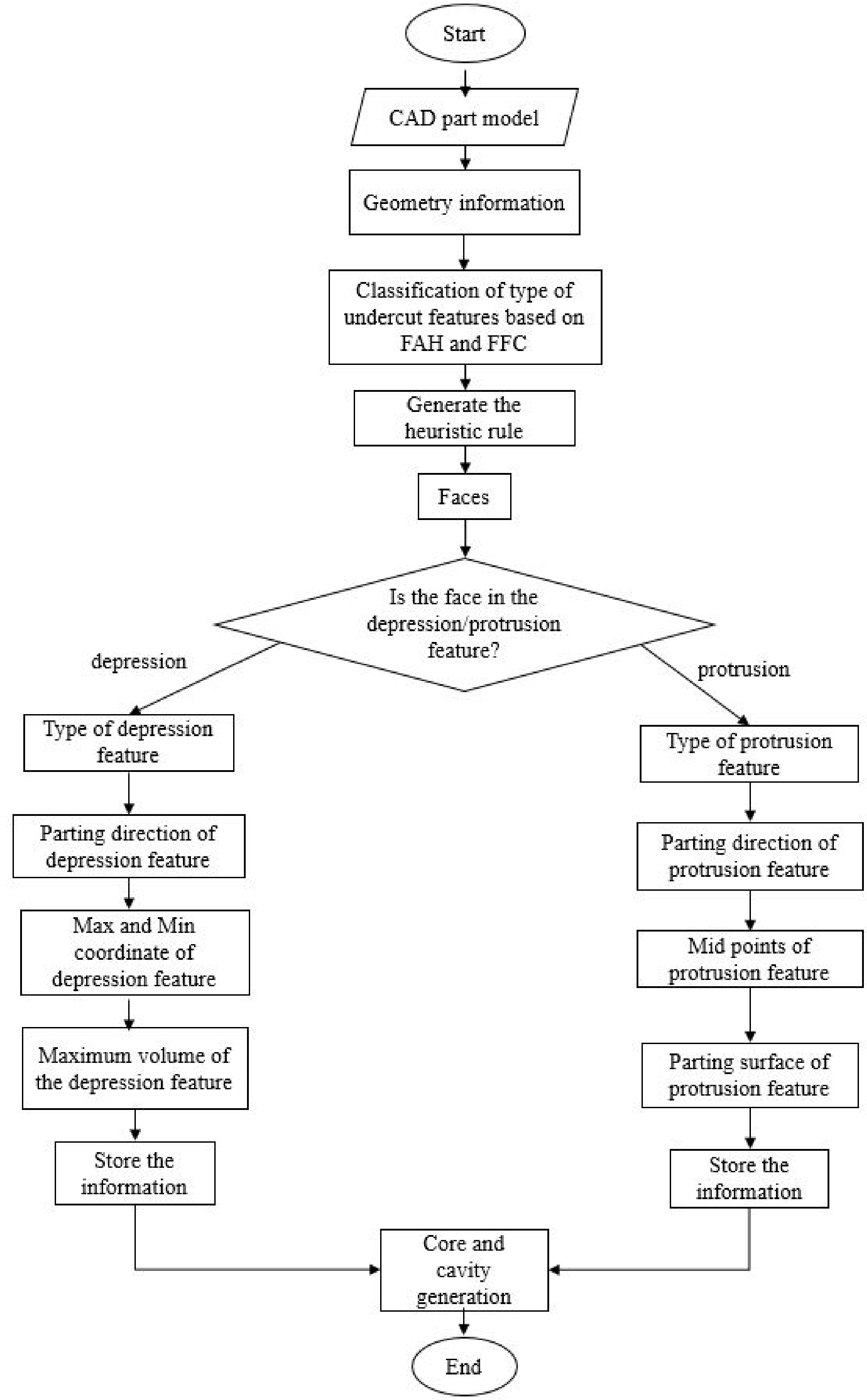

Figure 3.1 Flow Chart of experiment

3.2 Construction part of injection moulding in ACIS

These parts which were used for the automatic feature recognition have been created by using ACIS software. There were 3 parts have been created and analyzed their feature. Part A consists of depression feature like through hole and blind hole are as shown in Figure 3.2. Part B consists of protrusion feature like external cuboid and cylinder feature are as shown in Figure 3.3. Part C consists of protrusion and depression features are as shown in Figure 3.4. There parts were created to be used in analyzing their feature and identify their undercut features.

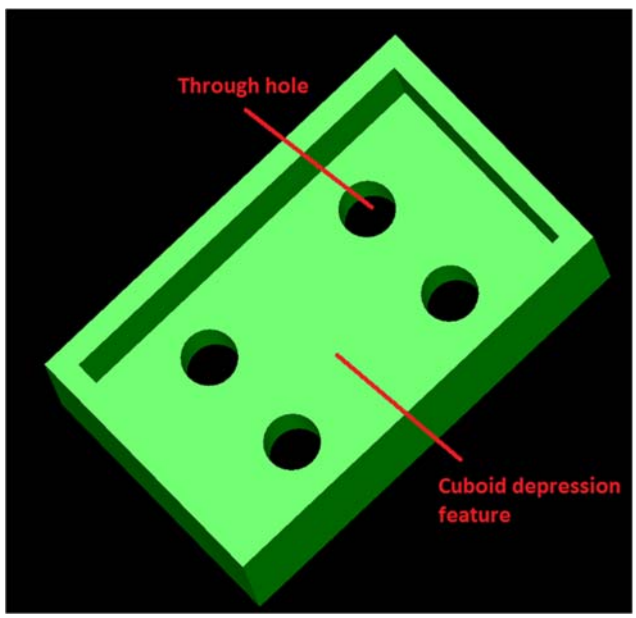

Figure 3.2 Part A

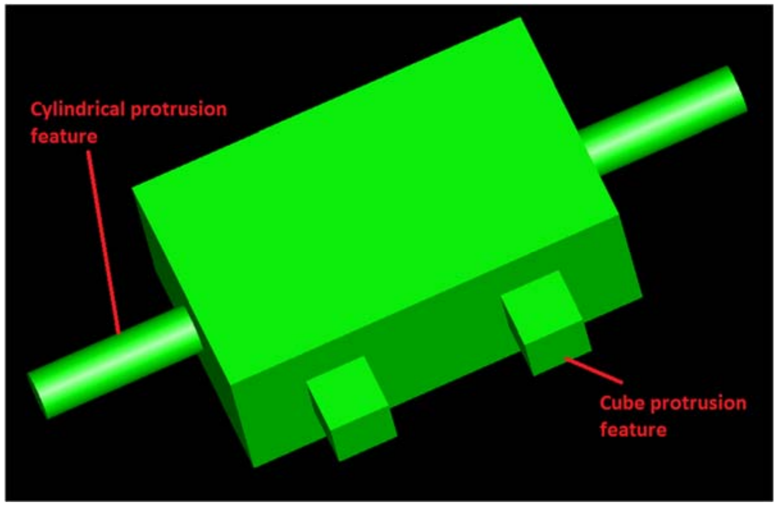

Figure 3.3 Part B

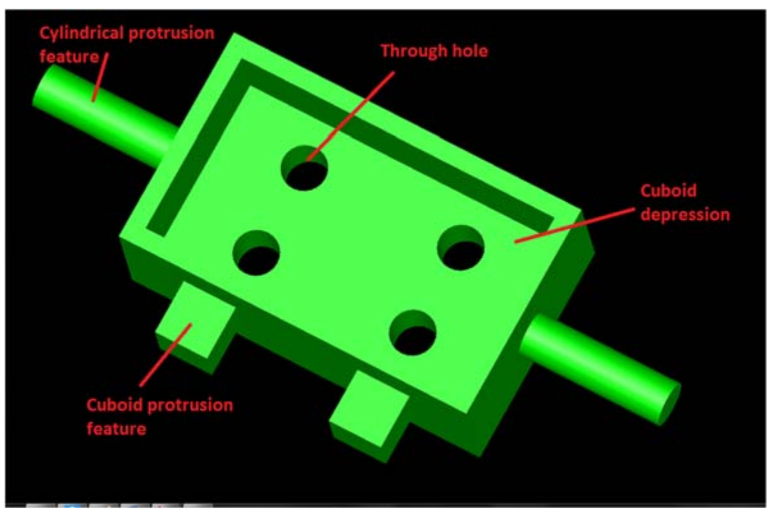

Figure 3.4 Part C

3.3 Geometry and topology of the feature

After the construction of the parts from the ACIS, apply the global topological traversal functions to obtain the geometry information lists of lumps, shells, wires, faces, edges, and vertices of the parts. The number of the each lists of the part will be calculated and recorded by the global topological traversal functions. The traversal of the list of classes used the ‘ENTITIY_LIST’ to show all lists. ‘class_list_count()’ showed the number of the class. The program is as shown in Figure 3.5

```
ENTITY_LIST lump_list;
        ENTITY_LIST shell_list;
        ENTITY_LIST wire_list;
        ENTITY_LIST face_list;
        ENTITY_LIST edge_list;
        ENTITY_LIST vertex_list;
              ENTITY_LIST loop_list;
              // Obtain the geometry information from the entity list
        get_lumps (my_part4, lump_list);
        get_shells (my_part4, shell_list);
        get_wires (my_part4, wire_list);
        get_faces (my_part4, face_list);
        get_edges (my_part4, edge_list);
        get_vertices (my_part4, vertex_list);
              get_loops(my_part4, loop_list);

              // Variable declaration of the total number of each entity
        int num_lumps = lump_list.count();
        int num_shells = shell_list.count();
        int num_wires = wire_list.count();
        int num_faces = face_list.count();
        int num_edges = edge_list.count();
        int num_vertices = vertex_list.count();
       int num_loop = loop_list.count();
//-------------------------------------------------------------------------------------
------------------------------------------------------------------------------
        printf ("The original model has :\n");
        printf ("\t %d lumps\n", num_lumps);
        printf ("\t %d shells\n", num_shells);
        printf ("\t %d wires\n", num_wires);
        printf ("\t %d faces\n", num_faces);
        printf ("\t %d edges\n", num_edges);
        printf ("\t %d vertices\n", num_vertices);
              printf ("\t %d loop\n", num_loop);
```

Figure 3.5 Global topological traversal functions (Spatial Product Documentation, 2014)

Some assumptions have to be made in this traversal algorithm. This algorithms assume there are no non-manifold edges and no non-manifold vertices. Second assumptions is there are no closed edges.

3.4 Identify the position parameters and normal direction of faces

This function 'sg_get_face_par_box' determined a parameter space 'SPApar_box' encompassing the given face of the part. The data that has been extracted from 'sg_get_face_par_box' and stored in 'f'. Then, 'f' is transformed into geometric information. A 'SPApar_pos' is a position in the parameter-space of a surface. (u, v) parameter space coordinate was defined when evaluated on a surface, a 3D object space coordinate was generated. 'SPAposition' is transforming the (u,v) vectors into x, y, and z vector direction. Next, evaluated the faces of the part by using 'surf.eval (`mid_param, mid_pos, deriv`)' ,so the mid point of each face of the part can be identified. The program used the 'normalise' equation to convert a vector to unit vector and find the direction which is normal to the faces. The normal direction of the faces on the feature were identified and demonstrated in the Figure 3.6 whereas the coding of the program is shown in the Figure 3.7.

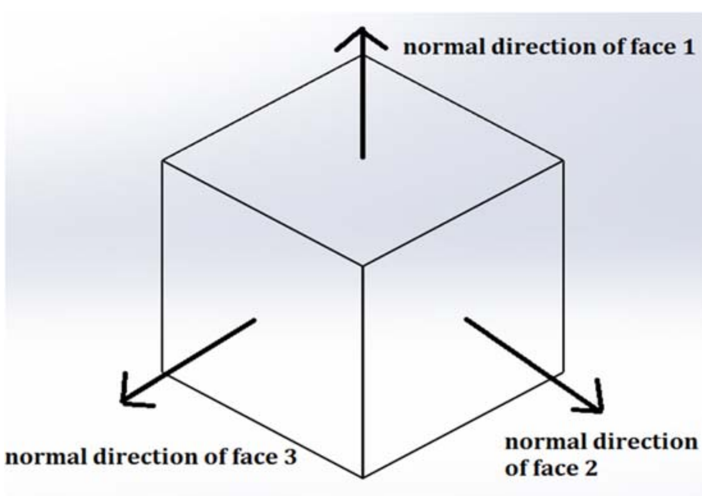

Figure 3.6 Normal direction of the faces on the feature

```
SPApar_box f_range;
logical success = sg_get_face_par_box (f, f_range);


// Examine the u and v directions at the midpoint of the face
surface const & surf = f->geometry()->equation();
SPApar_pos mid_param = f_range.mid();
SPAposition mid_pos;
SPAvector deriv[2];

// Evaluation of the  faces of the part
surf.eval(mid_param, mid_pos, deriv);

// Determination of the face's normal direction
SPAvector surface_normal = deriv[0] * deriv[1];
SPAunit_vector  face_dir  =  normalise((f->sense()  ==  FORWARD)  ?  surface_normal  :  -
surface_normal);
```

Figure 3.7 Identify position parameters and normal direction

3.5 Classification of protrusion and depression features

The solid objects considerd here are those bounded by 2 manifold feature. The Face Adjacency Hypergraph model (FAH) was used to analyse the face relationship of the undercut features by constructing the FAH representation which use the nodes to describe the object faces. The Face-to-Face composition (FFC) was used to identify the face adjacent information between the features based on the decomposition of the components in the feature. The classification of face classified the faces according to the shape and interaction. Type of the undercut features were classified according to the number of undercut faces, type of faces and composition of the feature. Table 3.1 to Table 3.5 show the classification of the undercut features