VOL. 12, NO. 14, JULY 2017 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

AUTOMATIC CORE AND CAVITY GENERATION FOR 3D CAD MODEL USING NORMAL VECTOR AND SCANNING RAY APPROACHES

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ABSTRACT

Injection moulding process is widely used in plastic product industry. Mould design is one of the crucial stages in the injection moulding manufacturing design. Mould design currently utilizes commercial CAD software and is knowingly time consuming. This paper proposes an algorithm that automatically generates core and cavity for a 3D CAD model with regular and free-form faces by selecting the best parting direction using normal vector approach and detecting through holes and undercuts using scanning ray approach. The implementation of this algorithm were able to generate a 3D model of core and cavity in a fully automatic manner without user interaction in a short span of time and faster than using commercial CAD software.

Keywords: computer aided design, parting direction, undercut, scanning ray.

1. INTRODUCTION

Design works in current manufacturing and industrial field utilize commercial CAD software. To operate such software, a design engineer is required to be equipped with knowledge, skills and experience. These requirements however vary from one designer to another which could lead to inconsistency in design works. Moreover, the design work starting from product design to manufacturing design is knowingly time consuming. Manufacturing design is a very crucial and important phase as it determines the quality of the end product [1]. It acts as a link by taking information from product design, analysing and processing the information and providing manufacturing data to manufacturing processes. Therefore, many research have been made to improve and automate the manufacturing design phase which would assist design engineers to increase productivity, provide consistent quality and reduce designing time.

Injection moulding is one of the manufacturing processes that is widely used in the plastic product industry. The manufacturing design for injection moulding includes mould design. One of the early stages in mould design is determination of parting direction and feature recognition. Feature recognition such as through holes and undercuts were studied by many researchers and among the approaches that were used to detect them are polyhedron face adjacency graph [2], graph-based recognition [3], feature-based [4,5] and surface visibility [6,7]. There are also many approaches to determine parting direction, such as Euler-based approach [8], visibility map [8, 9], Gaussian sphere [10, 11] and region-based approach [12].

The focus of this paper is to describe two approaches which are normal vector and scanning ray. The objective is to propose an algorithm that generates core and cavity by (1) selecting the best parting direction using normal vector approach and (2) detecting through holes and undercuts using scanning ray approach.

2. METHODOLOGY

The proposed algorithm shown in Figure-1 is implemented and simulated using a computer programming and solid modeller software. A 3D CAD model is input into the program, topological and geometrical information is then extracted from the body. Each face in the body is analysed and the normal vector of the face is stored in an array of data. Face normal vectors with different directions are selected as candidate parting directions for the body. Next, the body is scanned using scanning rays with direction of the candidate parting direction to detect any through holes and undercuts. The best parting direction is then selected based on the least undercut criteria. All through holes are covered before the core and cavity is generated. The core and cavity generation however will only proceed if no undercut is present.

Step 1

A readily available 3D CAD model from any solid modeller software is used as input into the program. The user then defines the blank tolerance, *T* and point distance, *D*.

Step 2

When a 3D CAD model is input into the program, the program extracts the topological and geometrical information from the body and stores all entity such as vertices, edges and faces into an array of storage data.

Step 3

The normal vector for each face in the body is generated. A planar face has a constant direction of normal vector at any point on the surface as shown in Figure-2(a) Therefore, only one normal vector is stored. A non-planar face however, has changing directions of normal vector at different point on the surface as shown in Figure-2(b), hence more than one normal vector are stored.

VOL. 12, NO. 14, JULY 2017 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

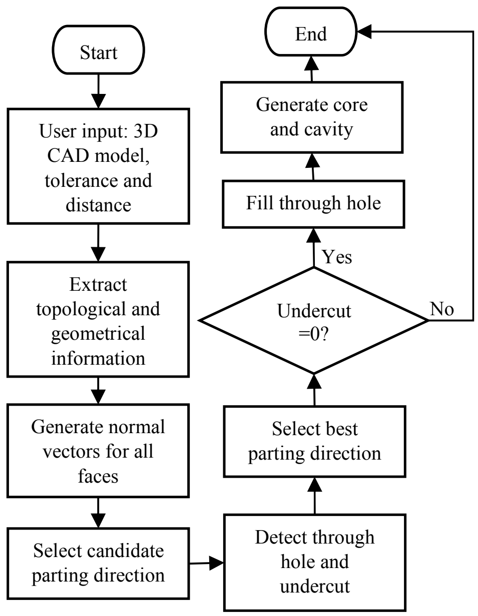
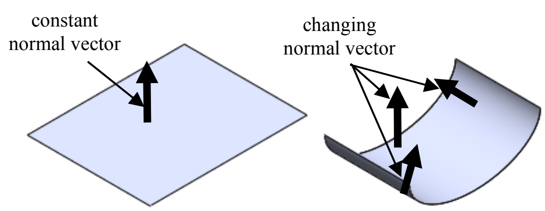


Figure-1. Flowchart of proposed algorithm.



(a) (b)

Figure-2. Normal vector of (a) planar face and (b) non-planar face.

Step 4

There are two criteria for a normal vector to be selected as candidate parting direction (Pd_n). The first criteria is when the normal vector is extended to infinity, there are no interception between the normal vector and its face or any other faces in the body. The second criteria is that the normal vector direction is not similar with other normal vector direction, if similar, the normal vector must belong to the face with the largest surface area. If both criteria are fulfilled, the normal vector is selected as Pd_n.

Step 5

Through holes and undercuts are then detected using scanning rays along direction of Pd_n. The scanning ray is emitted from $+Pd_n$ infinity to $-Pd_n$ infinity as shown in Figure-3.

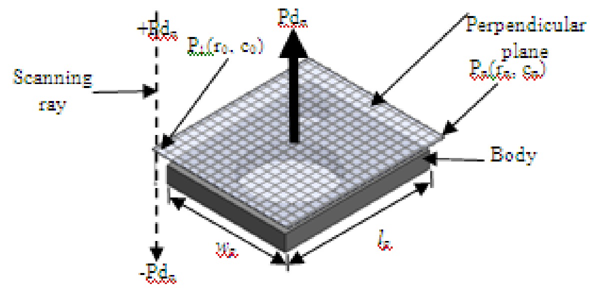


Figure-3. Scanning ray.

The scanning ray moves from the first point, $P_1(r_0, c_0)$ to the next, until the last point, $P_n(r_n, c_n)$ along the row, *r* and column, *c* of a plane perpendicular to Pd_n. The total number of points, *Np* depends on the area of perpendicular plane and the distance between points, *D* as in Equation 1 where *D* is decided by the user while width, w_p and length, l_p are similar to the body's width, w_b and length, l_b. An array of data storage for each point is created to store the total number of faces intercepted with the ray.

$$Np = (w_p \times l_p)/D. \tag{1}$$

Step 6

The result from step 5 is tabulated for analysis as shown in Table-1 where face is intercepted at point $P(r_n, c_n)$ with scanning ray at normal vector x,y,z of candidate parting direction Pd_n. A through hole feature is detected when a group of points with '0' intercepted face is between a group of points with '>0' intercepted face, while an undercut is detected when a group of points with '>2' intercepted face is present. The through hole or undercut faces are then stored for further use. The Pd_n with zero or least undercut is selected as the best Pd. If there are ties, the Pd_n that belonged to the face with the largest surface area is selected as the best Pd.

Table-1. Scanning ray result table.

Candidate parting direction	Normal vector	Point		Intercepted face	Detected feature
Pd_n	x,y,z	r_0	c_0		
		...	...	...	...
		r_n	c_n		

Step 7

The program will only proceed if the selected best Pd has no undercut. If undercut exist at the selected best Pd, the program will exit.

Step 8

The stored through hole faces are removed from the body and filled up to create solid through holes. The void from the through hole is covered with B-spline surface to create a filled body.

VOL. 12, NO. 14, JULY 2017 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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Step 9

The core and cavity are then generated by subtracting the filled body with a blank as shown in

Figure-4 with length, l, width, w and height, h based on Equation 2 where tolerance, T is decided by the user and the body is dimensioned as length, l_b , width, w_b and height, h_b . The blank is split into two at the parting plane positioned at the bottom of the body creating a lower half blank, upper half blank and floating lumps [13]. The floating lumps and solid through holes are then united with either lower or upper half blank depending on which half it touches.

$$h = h_b + (T\times 2);\ l = l_b + (T\times 2);\ w = w_b + (T\times 2). \qquad (2)$$

Where $T > 0$.

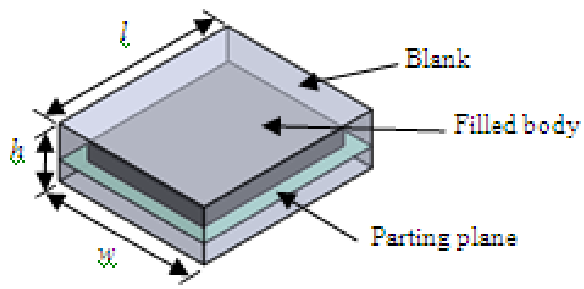
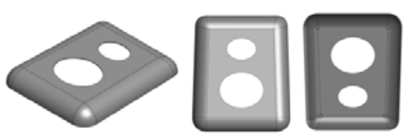


Figure-4. Core and cavity generation.

3. RESULTS AND DISCUSSIONS

The program is tested using an input of "car remote key cover" as shown in Figure-5 with length 58mm, width 45mm and height 5mm.



(a) (b) (c)

Figure-5. Car remote key cover (a) isometric view (b) top view and (c) bottom view.

The total number of Pd_n selected from the generated normal vectors was 28. The body was scanned using scanning ray at all Pd_n and the results were tabulated as follow:

Table-2 shows the result of three candidate parting direction Pd_1, Pd_{14} and Pd_{28} with normal vector 0, 0, 1, 0.5, 0.5, 1 and 0, 0,-1 respectively. Random group of points were selected in the table to show the feature detected. Figure 6 shows the intercepted faces, f_1, f_2, f_3 and f_4 at Pd_{14} (r_{10}, c_{16}) which is detected as an undercut while Figure-7 shows that no faces were intercepted at Pd_1 (r_{81}, c_{61}) which is detected as through hole.

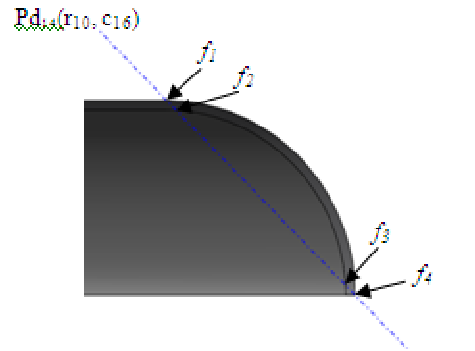


Figure-6. Undercut detection at $Pd_{14}(r_{10}, c_{16})$ (front sectional view).

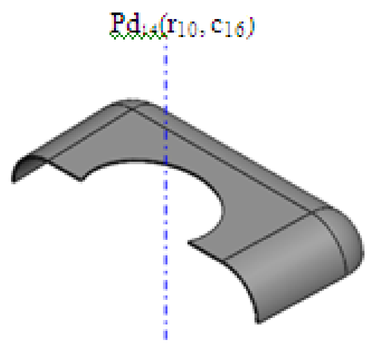
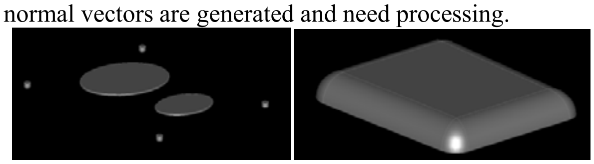


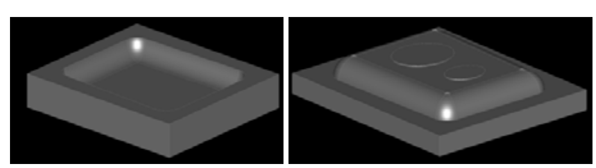
Figure-7. Through hole detection at $Pd_1(r_{81}, c_{61})$ (isometric sectional view).

Two candidates of parting direction Pd_1 and Pd_{28} were selected as the best parting direction as both have zero undercut. The normal vector of Pd_1 and Pd_{28} are opposite to each other indicating that Pd_1 is +Pd while Pd_{28} is -Pd. Through hole solids, filled body, core and cavity were generated as shown in Figure 8 and 9. The total time taken for the algorithm to complete and generate a core and cavity 3D model is less than a minute. The time taken however may have a small variation in seconds, depending on the 3D part model complexity where more time is taken if the 3D part model has more free-form faces as more normal vectors are generated and need processing.



(a) (b)

Figure-8. 3D model generated (a) hole solids and (b) filled body.



(a) (b)

Figure-9. 3D model generated (a) cavity and (b) core.

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Table-2. Car key cover scanning ray result.

Candidate parting direction	Normal vector	Point		Intercepted face	Detected feature
Pd_1	0,0,1	r_0	c_0	2	-
		...	...	...	..
		r_{80}	c_{60}	0	Through hole
		r_{81}	c_{61}	0	
		r_{82}	c_{62}	0	
		…	…	...	...
		r_{166}	c_{139}	2	-
...	...	...	...	...	...
Pd_{14}	0.5,0.5,1	r_0	c_0	2	-
		...	...	...	...
		r_{10}	c_{16}	4	Undercut
		r_{11}	c_{17}	4	
		r_{12}	c_{18}	4	
		…	…	...	...
		r_{166}	c_{139}	2	-
...	...	...	...	...	...
Pd_{28}	0,0,-1	r_0	c_0	2	-
		...	...	...	...
		r_{30}	c_{60}	0	Through hole
		r_{31}	c_{61}	0	
		r_{32}	c_{62}	0	
		…	…	...	...
		r_{166}	c_{139}	2	-

.

4. CONCLUSIONS

The result shows that the algorithm using normal vector is able to select the best parting direction and using scanning ray is able to detect through holes and undercut automatically and directly generate a 3D model of core and cavity for the 3D CAD model that was input into the program without any user interference. The time taken was less than a minute which is impossible to achieve using commercial CAD software. This algorithm assists design engineers to reduce the designing time which would also help to increase their work productivity and provide consistent design quality.

ACKNOWLEDGEMENT

This research is supported by Universiti Sains Malaysia under the Research University Grant (No: 814247).

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