Undercut feature recognition for core and cavity generation

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Abstract. Core and cavity is one of the important components in injection mould where the quality of the final product is mostly dependent on it. In the industry, with years of experience and skill, mould designers commonly use commercial CAD software to design the core and cavity which is time consuming. This paper proposes an algorithm that detect possible undercut features and generate the core and cavity. Two approaches are presented; edge convexity and face connectivity approach. The edge convexity approach is used to recognize undercut features while face connectivity is used to divide the faces into top and bottom region.

Keywords: Computer-aided design, undercut, two-plate mould

1. Introduction
In the current plastic injection mould industry, the mould design works commonly utilize commercial CAD software. In order to operate the software, design engineers are required to have experience, knowledge and skills. This however could lead to inconsistency in the design works due to the variation of work from one designer to another. Moreover, time consumption is a known factor that increases operational cost and the design work beginning from product design towards manufacturing design is significantly time consuming. Mould design is a very critical and essential phase as it defines the quality of the final product and also acts as a link which takes information from the product design team, evaluating and processing the information and transferring the manufacturing data to the manufacturing process team.

Many research have been made to develop and automate the mould design process which would support the mould design team and help provide consistent quality, increase productivity and reduce designing time. In the plastic industry, injection moulding is one of the manufacturing process that is widely used and mould design is one of the stages is injection moulding process. In mould design, undercut feature recognition is the initial step to start the designing process. Undercut feature recognition such as through holes and pockets were previously studied by researchers and among the approaches that were used to recognize them are graph-based recognition [1], polyhedron face adjacency graph [2], surface visibility [3], feature-based [4,5], volume-based [6] and plane projection [7].

This paper aims to propose an algorithm that generates core and cavity by (1) recognizing the undercut features using edge convexity approach and (2) dividing the faces into top and bottom regions using face connectivity approach.

2. Methodology
Figure 1 shows the proposed algorithm which is implemented and simulated using a computer programming software which uses C++ and ACIS language, and solid modeller software. The 3D CAD design of any part is input into the system and the topological and geometrical information of the part is
extracted and stored in the system. All edges in the body is then analysed for its convexity. Two types of convexity is categorized, concave and convex. Next the undercut features are recognized based on the edge convexity. The number of undercuts are then determined based on the parting direction inserted by the user. All faces are then analysed using face connectivity to be divided into top and bottom regions. If there are undercut present the system will exit, while if there are no undercut existing the system will proceed. Shut off surfaces are created for through holes and the core and cavity is finally generated.

\[\text{Figure 1. Flowchart of proposed algorithm}\]

**Step 1**
The user input an existing 3D CAD design of a part into the system and the vector of parting direction, \(P_d\).

**Step 2**
The system extracts the topological and geometrical information from the 3D CAD part and stores all entity such as vertices, edges and faces into an array of storage data.

**Step 3**
All edges stored are analysed for its convexity. The convexity of an edge is analysed by intersecting two extruded bodies created from the faces sharing the edge. The two faces that share the edge is extruded along the face normal, creating an extruded body for each face. The extruded bodies are then intersected, if the intersection results a solid intersection, the edge is a concave edge as shown in figure 2 (a), however if the intersection results a NULL, the edge is a convex edge. This test is proven consistent with the theory of a concave edge where the angle between the faces sharing the edge must be less than 180° as shown in figure 2 (b).
Figure 2. Concave edge (a) intersection of two extruded bodies (b) faces sharing the edge is less than 180°

Step 4
Faces that share a concave edge is grouped together creating a face region. This face region is a possible undercut region. The face region is then extruded along both negative and positive parting direction to infinity, if the extruded body intersects other faces at both direction, the face region is recognized as an undercut feature. However if the extruded body only intersect one of the directions, for example it intersects only along positive parting direction, the face region is considered to belong to the bottom region and vice versa.

Step 5
All remaining faces that are not included in any regions are then grouped into top or bottom region using the face connectivity approach. A face may be grouped into the top region if it abide these rules: (1) the face when extracted along positive parting direction must not intersect with any other faces and (2) the face is sharing an edge with any faces in the top region. These rules are similar for bottom region with negative parting direction. The second rule however is exempted for the initial face in each top and bottom region.

Step 6
The number of undercut must not be more than zero for the system to proceed. If not, the system will exit.

Step 7
Shut off surface is created for any existing through hole.

Step 8
Finally the core and cavity are generated [8].

3. Results and Discussion
The system is executed using two 3D CAD inputs, Part A and Part B as shown in figure 3 (a) and (b) with both parting direction along z-axis. The dimension of Part A is length 56mm, width 23mm and height 32mm, and Part B is length 160mm, width 140mm and height 10mm. Part A has a total of 17 faces while Part B has 29 faces.

Figure 3. 3D CAD inputs (a) Part A (b) Part B
Table 1 shows the face region and the edge convexity for Part A and Part B. Random edges and faces were selected in the table to show the analysed faces and edges. Each convexity and region is assigned a value where, top: 1, bottom: 0, none: 2, concave: 3, convex: 4. The remarks for Part A shows that no undercut feature were recognized while Part B had two region of undercut features. Figure 4 and figure 5 shows the top, bottom and undercut regions that were grouped based on the remarks in table 1.

This is proven by the output generated which shows that for Part A, the top and bottom regions were grouped and the core and cavity were able to be generated as shown in figure 6. However due to detection of undercuts in Part B, the core and cavity were not able to be generated and only the top and bottom regions were grouped as shown in figure 7. Part A had 6 faces in the top region and 5 faces in the bottom region while Part B had 9 faces in the top region and 12 faces in the bottom region. Part B also had undercut features with 4 faces at each undercut region as shown in figure 8.

The computational time taken from start to finish for Part A is 4.21 seconds while Part B is 5.13 seconds. The time difference is due to the number of faces that the system had to process where Part B had more faces than Part A thus more computational time taken.

| Table 1. Face connectivity and edge convexity of Part A and Part B |
|---------------------------------------------------------------|
| **Part A** | **Remark** | **Part B** | **Remark** |
| Face | Shared Edge | Convexity/Region | Face | Shared Edge | Convexity/Region | |
| 3 | 9 | 1 | Top region | 0 | 73 | 2 |
| 4 | 1 | 4 | | 26 | 75 | 3 |
| 5 | 11 | 4 | | 25 | 77 | 3 |
| 6 | 1 | 1 | | 28 | 2 | |
| 8 | … | 0 | Bottom region | 1 | … | 2 |
| 13 | 4 | 3 | | 22 | 70 | 2 |
| 9 | 0 | 4 | | 21 | 7 | 3 |
| 10 | 17 | 4 | | 24 | 2 | |
| 11 | 0 | 0 | | … | … | … |
| … | … | … | Undercut region | … | … | … |
| 14 | 39 | 3 | Bottom region | 5 | 6 | 4 |
| 15 | 0 | 0 | | 8 | 11 | 4 |
| 16 | 37 | 3 | | 6 | 14 | 4 |
| 17 | 0 | 0 | | 11 | 0 | |
Figure 4. Part A face regions (a) top region (b) bottom region (c) bottom region

Figure 5. Part B face regions (a) undercut region (b) bottom region

Figure 6. Part A output (a) top region (b) bottom region (c) cavity (d) core
Figure 7. Part B output (a) bottom region (a) top region

Figure 8. Undercut features of Part B

4. Conclusion
The results and outputs have proven that the algorithm using edge convexity approach was able to recognize the undercut features and the connectivity approach was able to divide the faces into top and bottom regions automatically. The system was also able to generate core and cavity for parts without undercut and detect undercut features for parts with undercuts which makes it easier for the user to adjust the part design and remove the undercut. The computational time taken for both parts were satisfactory and obviously faster than using commercial CAD software. Even though this system is still not robust and has limitations for now, but extension work of this system will eventually help mould designers to increase productivity by reducing the designing time.

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