A NEW METHOD TO AUTOMATICALLY DETERMINE PARTING LINE IN INJECTION MOLD DESIGN

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Abstract

A new method was proposed to automatically determine parting line for molded part which includes undercut features and free form surfaces in the product model. The brief procedure included: 1) simplifying the product model by recognizing the undercut features and transforming the product solid model into the discrete surface model using the finite element method; 2) determining visibility of mesh based on an angle between normal vector of mesh and parting direction, and decomposing complex surface into single surfaces; 3) merging transitional surfaces into visible/invisible surface group based on merge rules and determining parting line by searching the largest edge loop of these two surface groups. Results from demonstration cases show that parting line can be easily determined using this method and efficiency of injection mold design is greatly improved.

1 Introduction

Mold cavity and core are important working parts of mold which directly affect product molding. For a majority of molded parts, design of mold base, gate, runner, and cooling channel are not sensitive to details in shape and structure of product. Therefore, design scheme can be copied from one to another without any changes when the shape and structure of product are similar. However, even a small change in the shape and structure of product will affect the design scheme of mold cavity and core.

Design process of mold cavity and core for a molded part includes three related tasks namely, i.e. determining parting direction, parting line and parting surface. The determination of parting line plays an important role which affects not only parting surface generation but also mold structure and cost. Parting line is easy to be determined for some regular product and hard for some irregular products. In the general mold cavity design process, to determine parting line greatly lies on experience of the mold designer. Although this design method depending on designer's experience also has its advantages, the automatic determination of parting line is still the main content of this research field.

2 Literature review

There are some studies which have been done in this research field. Ravi proposed nine criteria[1] for computer-aided parting line and parting surface design, and an approach[2] for determining parting line by extruding the projected silhouette curves along parting direction and finding the intersected curves of extruded body and part body. Ganter[3] proposed an algorithm on computer-aided parting line design for cast pattern production, which a planar parting line is obtained by sectioning the molded part. Tan[4] proposed a method of generating parting line by triangulating the surfaces of product and classifying the surfaces into visible, invisible and degenerate faces. Weinstein[5] divided the surfaces of product into convex and concave regions to determine parting line and Wong[6] determined parting line by slicing the 3D CAD model of product. Nee[7] divided the surfaces of product into three groups according to their orientation to the parting direction and determined parting line by the largest edge-loop of these surface groups. Zhou[8] improved the Nee's approach and considered the effect of undercut features on the determination of parting line. Meanwhile, the optimization factors were introduced to evaluate the candidate parting lines.

Although these researches presented different kinds of methods for automatic determination of parting line, they are only suitable for the simple product model and will get the unreasonable parting line when the product model is complex which include free form surfaces and undercut features. In this paper, we presented an improved approach for this problem by combining the advantages of all these above methods. In our approach, the first step is to simplify the product model by suppressing the undercut features. After simplified, the product model will be transformed into the discrete surface model using the finite element method. Then the visibility of meshes will be determined based on an angle between normal vector of mesh and parting direction, and the complex surface will be separated into single surfaces. Finally, the parting line will be determined by adjusting all transitional surfaces into visible or invisible surface group and searching the largest edge-loop of these two surface groups.

3 Basic concepts

3. 1 The visibility of surface

The surfaces of product model include plane, conic surface and free form surface. Figure 1 shows these three types of surface, i.e. (a) plane; (b) conic surface; (c) free form surface, where $\vec{P}_D$ is parting direction and $\vec{L}_i$ is the normal vector of surface F_i. Determining the visibility is easy for the plane because the normal vector is exclusive. But it is hard for the conic or free form surface because the normal vector is not exclusive. For the conic or free form surfaces, the entire surface is visible, invisible or hybrid type of visible, invisible and transitional. The visibility of conic or free form surface can be determined as follow expressions[9], i.e. (1) if $\vec{P}_D \cdot \vec{L}_i > 0$, then the surface is visible, (2) if $\vec{P}_D \cdot \vec{L}_i < 0$, then the surface is invisible, (3) if $\vec{P}_D \cdot \vec{L}_i$ can not be determined, then the surface is hybrid type of visible, invisible and transitional.

3. 2 Single and complex surfaces

All surfaces of product can be transformed into 2D meshes by the finite element method. Three types of mesh are defined as (a) visible mesh, (b) invisible mesh, and (c) transitional mesh, where $\vec{P}_D$ is the parting direction and $\vec{L}_{ij}$ is the normal vector of mesh f_{ij}. The visibility of mesh is determined by these follow expressions, i.e. (1) if $\vec{P}_D \cdot \vec{L}_{ij} > 0$, f_{ij} is visible mesh, (2) if $\vec{P}_D \cdot \vec{L}_{ij} < 0$, f_{ij} is invisible mesh, and (3) if $\vec{P}_D \cdot \vec{L}_{ij} = 0$, f_{ij} is transitional mesh. Two types of surface are defined including single surface and complex surface. In the single surface, all meshes are the only one type of visible, invisible or transitional. But in the complex surface, all meshes are hybrid types of visible, invisible and/or transitional. The diagram of these two types of surface are showed in Figure 2, where, (a) represents the single surface whose all meshes are visible mesh, (b) represents the single surface whose all meshes are invisible mesh, and (c) represents the complex surface whose meshes are the hybrid types of visible, invisible and transitional. Symbols of "+" indicates that the mesh is visible, symbols of "—" indicates that the mesh is invisible, and symbols of "0" indicates that the mesh is transitional.

4 The process of determining parting line

4.1 Simplifying the product model

Because the existence of undercut feature will affect on the automatic determination of parting line, the first step to determine parting line is to recognize the undercut feature. The graph-based method is applied in the undercut feature recognition process[10]. The Figure 3 shows the sub-graph of these three typical undercut features, i.e. (a) concave, (b) convex, (c) through. The concave type has one undercut feature attachment face n_1 and all edges in the cut-set A_c are convex edge. The convex type has also one undercut feature attachment face n_1, but all edges in the cut-set A_c are concave edges. The through type has two undercut feature attachment face n_1, n_8 and all edges in the cut-set A_c are convex edges. In the recognition process, the first step is to express the product model with extended face attribute adjacency graph (EFAAG). Then the undercut features can be recognized by matching sub-graph of undercut features with the EFAAG of product model. When all sub-graphs of undercut features are recognized, the EFAAG of product model will be reconstructed to simplify the product model.

4.2 Transforming the product model

After simplified, the product model will be transformed into the discrete surface model using the finite element method. Whatever the plane, conic or free form surface in the product model can be represented by 2D surface meshes. The transforming process is showed as Figure 4. The product model can be described as $\Omega = \{F_i\}(i = 1,2,\cdots,M)$, where Ω represents the product model; F_i is each surface of model; and M is surface number. After the transformation, each surface F_i can be expressed by a series of meshes namely $F_i = \{f_{ij}\}(i = 1,2,\cdots,m; j = 1,2,\cdots,n)$, where m is mesh number in the row and n is mesh number in the column. The triangular or quadrangular mesh is often applied in the transformation process. Although the number of mesh is determined by experience, there are some principles to be complied with. For example, the number of mesh in the surface should be in accordance with the curvature of surface. The bigger curvature the surface has, the larger number of the mesh it has.

4.3 Separating the complex surface

In general, parting line is the largest edge loop in response to a certain parting direction and is composed of silhouette curves in the surface. For a single surface, the silhouette curve is always at the edge of surface. But the silhouette curve of complex surface is not at the edge of surface and generally hard to be determined. In order to separate the complex surface into single surfaces, a certain plane perpendicular to parting direction will be chosen as the projecting plane. The complex surface will be projected into this plane and formed a 2D shape. Then the silhouette curve can be determined by extruding the curve of this 2D shape along parting direction and finding the intersected curve of extruded surface and complex surface. The process of separating complex surface is expressed in Figure 5, where, $\vec{P}_D$ represents parting direction, A represents the projecting plane, S_+ and S_- represent the single surfaces after separated.

4.4 Determining the parting line

The parting line is the largest edge-loop of visible or invisible surface group in the product. Because the existence of transitional surfaces will affect on the automatic determination of parting line, it should be adjusted into visible or invisible surface group. The adjustment rules are listed as follow.

(1) If the largest edge-loop of transitional surface is

surrounding by the largest edge loop of visible surface group, then the transitional surface will be adjusted into visible group. It can be expressed as,

$$\forall f_3^i \in G_3,\ \text{if}\ S(f_3^i) \subset L(G_1),\ \text{then}\ f_3^i \to G_1$$

(2) If the largest edge-loop of transitional surface is surrounding by the largest edge loop of invisible surface group, then the transitional surface will be adjusted into invisible group. It can be expressed as,

$$\forall f_3^i \subset G_3,\ \text{if}\ S(f_3^i) \subset L(G_2),\ \text{then}\ f_3^i \to G_2$$

Where, G_1 represents the visible surface group, G_2 represents the invisible surface group, G_3 represents the transitional surface group, $f_3^i(i=1,\cdots,n)$ represents the i surface in G_3, $S(f_3^i)$ represents the largest edge loop of f_3^i, $L(G_1)$ represents the largest edge loop of visible surface group, $L(G_2)$ represents the largest edge loop of invisible surface group. Suppose that P_L represents the parting line, G_3' represents the transitional surface group adjusted into G_1, G_3' represents the transitional surface group adjusted into G_2, then the parting line can be determined by the expression as,

$$P_L = (G_1 - G_3') \cap (G_2 + \overline{G_3'})$$

5 Case study

The approach presented in this paper is applied in a mold cavity design system. The mold cavity design system is built on the Unigraphic CAD/CAE/CAM software. The development tools are VC++ and UG/OPEN. UG/OPEN is a strong development tool kit of Unigraphic which includes UG/OPEN API, UG/OPEN GRIP and etc. The interface of this software is displayed in the Figure 6.

The approach presented in this paper was demonstrated by a molded part as Fig 7. Fig 7(a) shows the product model. In Fig 7(b), the product model is simplified by excluding the undercut features. Fig 7(c) shows the discrete surface model. In this example, the quadrangular mesh is applied and the size of element is 8. Because there is no complex surface in this product, the visibility of each surface can be determined by the visibility of mesh in the surface. When all transitional surfaces are adjusted into visible or invisible surface group, the parting line can be easily determined by searching the largest edge-loop of visible or invisible surface group. Fig 7(d) shows the parting line of this molded part.

6 Conclusion

An improved approach to automatically determine parting line in injection mold design was presented. There are some advantages of this approach, including 1) the graph-based method is applied to recognize the undercut features in the product, and the product model will be simplified before determination of parting line; 2) the product model is transformed into discrete surface model and the visibility of surface will be determined by analyzing the visibility of 2D surface meshes; 3) the silhouette curve of complex surface is located by extruding the projected silhouette curves along parting direction and used to separate the complex surface into single surfaces; 4) the new adjustment rules is presented to adjust all transitional surfaces into visible or invisible surface group and the parting line is determined by searching the largest edge-loop of these two surface groups. The result of a demonstration case shows that the parting line of complex product which include undercut features and free form surfaces can be determined correctly.

Acknowledgements

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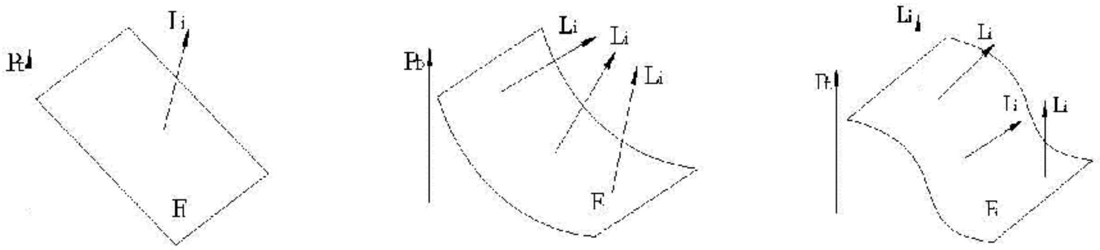
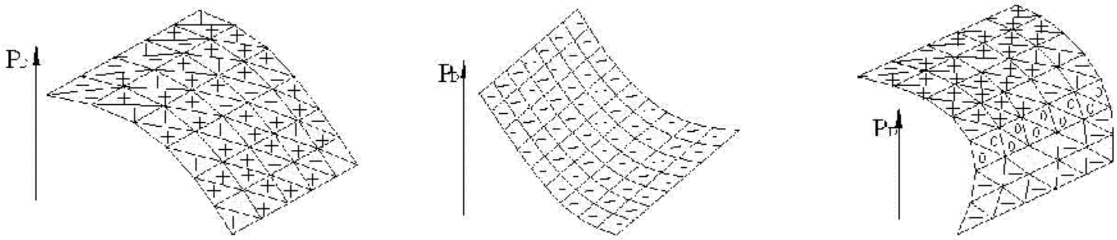


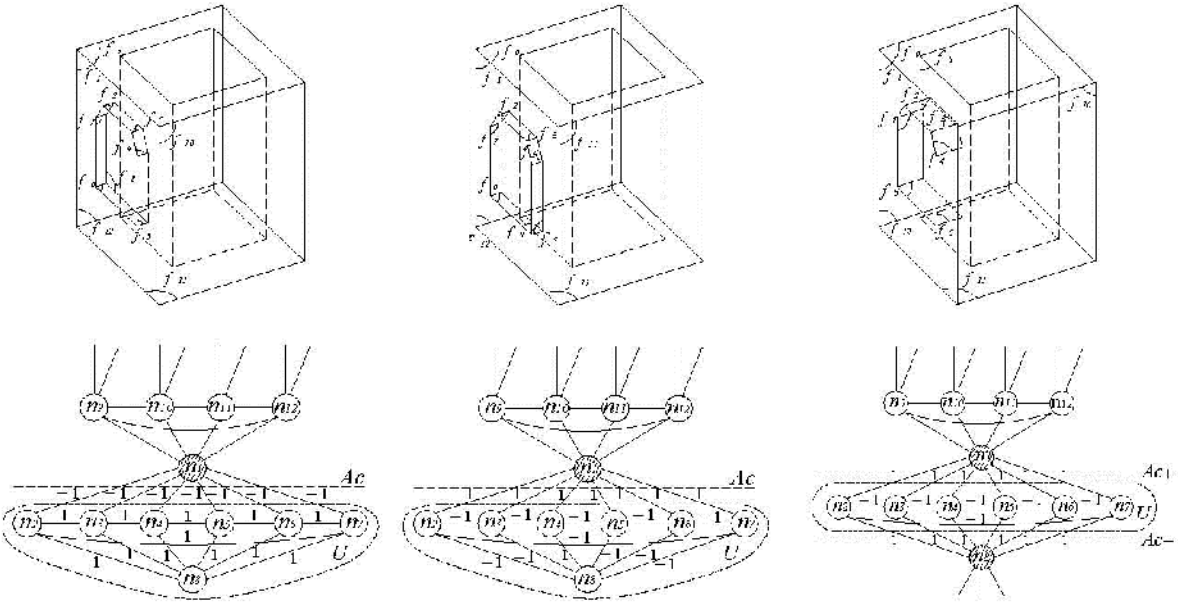
(a) (b) (c)

Fig.1: diagram of three types of surface.



(a) (b) (c)

Fig.2: diagram of single and complex surfaces.



(a) Concave (b) Convex (c) Through

Fig.3: diagram of three types of undercut feature and sub-graph.

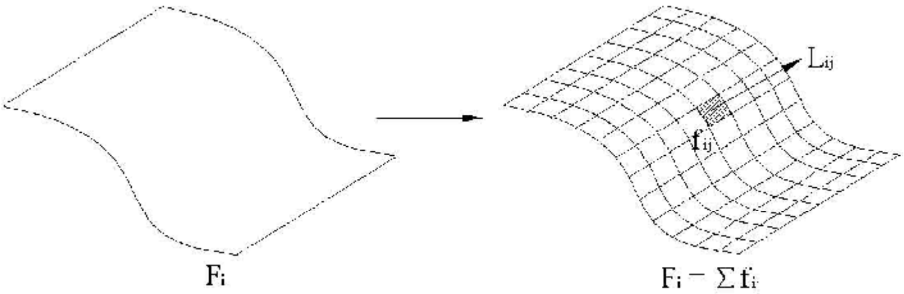


Fig.4: diagram of transforming process.

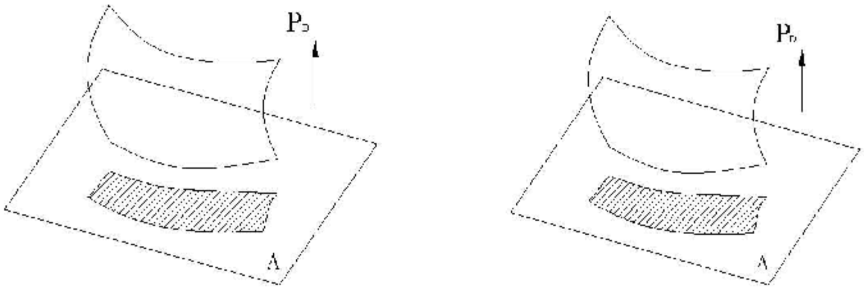


Fig.5: diagram of separating the complex surface.

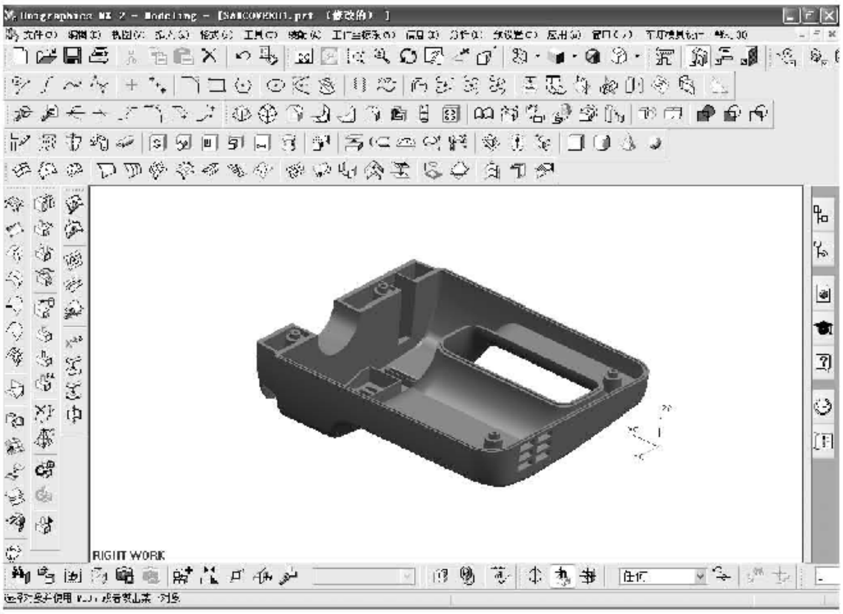
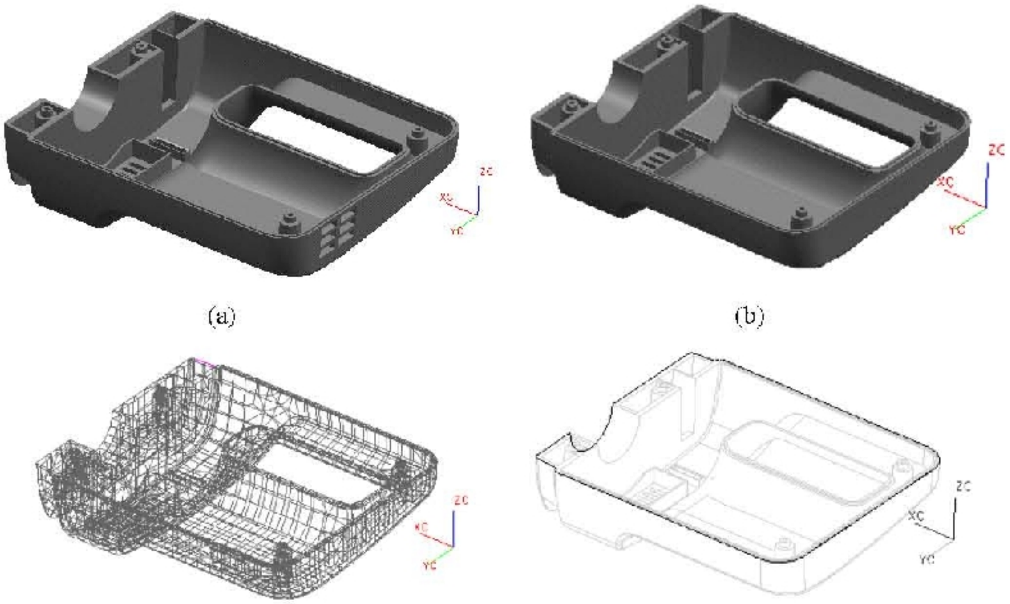


Fig.6: interface of Unigraphic software.



(a) (b)

(c) (d)

Fig.7: determining the parting line for a molded part.