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Automatic detection of the optimal ejecting direction based on a discrete Gauss map

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Abstract

In this paper, the authors propose a system for assisting mold designers of plastic parts. With a CAD model of a part, the system automatically determines the optimal ejecting direction of the part with minimum undercuts. Since plastic parts are generally very thin, many rib features are placed on the inner side of the part to give sufficient structural strength. Our system extracts the rib features from the CAD model of the part, and determines the possible ejecting directions based on the geometric properties of the features. The system then selects the optimal direction with minimum undercuts. Possible ejecting directions are represented as discrete points on a Gauss map. Our new point distribution method for the Gauss map is based on the concept of the architectural geodesic dome. A hierarchical structure is also introduced in the point distribution, with a higher level "rough" Gauss map with rather sparse point distribution and another lower level "fine" Gauss map with much denser point distribution. A system is implemented and computational experiments are performed. Our system requires less than 10 seconds to determine the optimal ejecting direction of a CAD model with more than 1 million polygons.

Keywords: Ejecting direction; Undercut detection; Injection molding; Feature recognition; Concurrent engineering; CAD

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1. Introduction

Most plastic parts for consumer products are produced by injection molding. With this method, the molded part must be removed from the mold core in a single ejecting direction. In order to realize the smooth removal, the part should be designed such that it does not have any "undercuts" in the ejecting direction; otherwise, expensive sliding core mechanisms are necessary. Figure 1 illustrates an example of undercuts. Since concave shapes on the part interfere with the mold, the formed part cannot be removed from the mold in any direction (see Figure 1(a)). By using the sliding core mechanisms, the interfering portions on the core and cavity are resolved (see Figure 1(b)) and the molded part can be smoothly ejected.

A reduction of the number of component parts is a basic strategy to design a product with low production cost [1]. When using this strategy, more functions are expected on a single part; therefore, the part shape tends to be complex and it often has many undercuts. After the part is designed, mold engineers spend much time designing injection molds with many sliding cores in order to resolve the undercuts.

In this paper, a system is proposed to assist the mold designer of plastic parts that have sliding core mechanisms. Supplied with a CAD model of a part, the system automatically determines the optimal ejecting direction of the part with the minimum number, minimum area, or minimum

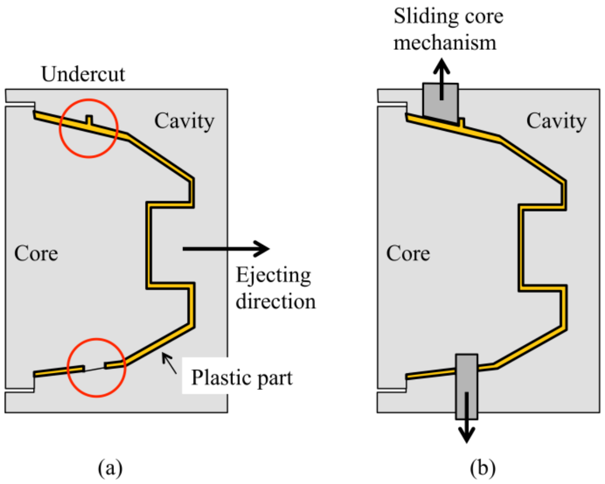

Figure 1. (a) Core and cavity with two undercuts, (b) examples of sliding core mechanism for resolving the undercuts.

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Figure 2. Rib features placed on a plastic part.

volume of the undercuts. Since plastic parts are generally very thin, many rib features are placed on the inner side of the part to give sufficient structural strength, as shown in Figure 2. Each rib feature strictly constrains the possible ejecting direction. Our system extracts rib features from the CAD model of the part, and derives the possible ejecting directions based on the geometric properties of the extracted features. It then selects the optimal direction with the minimum number of undercuts. Our system is not applicable for parts that have no rib features. This limitation does not reduce the practical value of the method because such parts without rib features are generally very small and of a simple shape, and the molding engineers can design a cavity and core for the part without any difficulty.

The system uses a discrete representation of the Gauss map [2] for recording the candidate ejecting directions, where each direction corresponds to a point on a unit sphere. Points (= candidate directions) are not uniformly distributed on the sphere based on the equal angular interval in the spherical coordinate system. More points are placed in the region near the north and south poles. On the other hand, fewer points are given in the zone near the equator line, which decreases computation accuracy. Our new point distribution method for the discrete Gauss map is based on the concept of the architectural geodesic dome. This method can locate points on the unit sphere in a constant density. A hierarchical structure is also introduced in the point distribution, with a higher level “rough” Gauss map with sparse point distribution and another lower level “fine” Gauss map with a much denser point distribution.

An algorithm based on this structure is developed to select the optimal ejecting direction. In the first step, a rough Gauss map with sparse point distribution is used to select the optimal ejecting direction. The fine Gauss map with dense point distribution is then used to accurately determine the optimal direction around the initial solution. Our system requires less than 10 seconds to determine the optimal ejecting direction of a CAD model with more than 1 million polygons.

The organization of this paper is as follows. In Section 2, the related studies are briefly reviewed. The basic processing flow of our rib-feature-based ejecting direction determination algorithm is explained in Section 3. Details of the algorithm are given in Section 4, as well as an explanation of the performance improvements obtained by introducing the discrete and hierarchical Gauss map representations. In Section 5, experimental results of the automatic determination of the optimal ejecting direction are illustrated.

2. Related studies

The undercut detection and the selection of the undercut free ejecting direction of plastic parts are interesting research topics and many research works have been carried out in the CAD field. Priyadrashi and Gupta proposed an algorithm for detecting undercuts of a part ejected in a specific parting direction [3]. They used the graphics hardware function for accelerating the detection algorithm [4]. However, their method is not applicable for selecting the optimal ejecting direction.

Wuerger and Gadh proposed an algorithm for automatically selecting the undercut free ejecting direction based on the CAD model of the part [5]. In their subsequent paper, this method is extended to handle rotational ejection [6]. Since their works are theoretical, several imaginary applications of the algorithm are only given for very simple examples. The applicability of the method to real plastic parts with complex shapes is not evaluated.

Khardekar et al. proposed two methods for automatically determining the undercut free ejecting directions from a polygonal CAD model [7]. Unlike [5] and [6], they implemented working systems and applied them to several CAD models to verify their practical applicability. Although they introduced the parallel processing capability of GPU to accelerate the systems, they still require 10 minutes to determine the possible ejecting direction for a simple part with several thousand polygons. These studies focused on the automatic detection of the undercut free ejecting direction. Most actual plastic parts currently used in practice have very complex shapes and are not free of undercuts. The methods proposed in [5], [6], and [7] are not applicable for such parts and therefore cannot assist the designers.

Chen et al. proposed an algorithm applicable to a part with undercuts [8]. In their method, “pocket” shapes are extracted using the difference between the convex hull of the part and the original part shape. The visibility maps of the pockets are mapped on a unit sphere. The optimal ejecting direction with the minimum number of undercuts is determined by finding a pair of antipodal points located on the maximum number of visibility maps. Chen et al. extended this idea by using two levels of visibility for determining the ejecting direction [9]. With the same visibility map concept, Nee et al. determined the optimal ejecting direction as the direction with the minimum undercut volume [10, 11].

In contrast to the theoretical works carried out by Chen et