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A new hybrid method for demoldability analysis of discrete geometries☆

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ABSTRACT

In this paper, a new method for demoldability automatic analysis of parts to be manufactured in plastic injection is presented. The algorithm analysis is based on the geometry of the plastic part, which is discretized by a triangular mesh, posing a hybrid discrete demoldability analysis of both the mesh nodes and facets. A first preprocessing phase classifies mesh nodes according to their vertical dimension, assigning each node a plane perpendicular to the given parting direction. By selective projection of facets, closed contours which serve as the basis for calculating the demoldability of the nodes are created. The facets are then cataloged according to demoldability nodes that comprise demoldable, non-demoldable and semi-demoldable facets. Those facets listed as semi-demoldable are fragmented into demoldable and non-demoldable polygonal regions, causing a redefinition of the original mesh as a new virtual geometry. Finally, non-demoldable areas are studied by redirecting the mesh in the direction of the sliding side, and again applying the processing algorithm and cataloging nodes and facets. Resoluble areas of the piece through mobile devices in the mold are obtained. The hybrid analysis model (nodes and facets) takes advantage of working with a discrete model of the plastic part (nodes), supplemented by creating a new virtual geometry (new nodes and facets) that complements the original mesh, providing the designer not only with information about the geometry of the plastic piece but also information on their manufacture, exactly like a CAE tool. The geometry of the part is stored in arrays with information about their manufacture for use in downstream applications.

1. Introduction

Injection molding is a manufacturing process of plastic parts which can make parts with complex geometries and freeform surfaces. It is suitable for high production volumes because of its reduced cycle time. Essentially, an injection mold consists of two parts called the upper and lower cavity, within which the plastic is injected, leading to the desired body. The main parameters that largely determine the structure of a mold are: the presence of undercuts, the chosen parting direction, and the parting line generated between the various mold components. Demoldability geometric analysis aims to determine these parameters automatically based on the definition of the geometry of the part to be molded. Selecting the parting direction and the parting surface is of great significance so that the number of side cores is reduced to a strict minimum. The number and volume of the side cores increases the mold complexity and the costs of manufacture and the time spent in the manufacturing cycle of the pieces to be processed and, ultimately, its production cost.

During the conceptual phase of the design process, customers often impose a large number of changes in the geometry of the part. It is necessary to validate demoldability quickly, detecting and differentiating automated small undercuts and areas that cannot be manufactured. Moreover, in the preparation of price studies for the manufacturing of plastic parts, a quick and accurate review of part geometry in their manufacture can be a determining factor in achieving a deal. The commercial CAD systems used today by companies for the resolution of analysis demoldability still involve a great deal of manual interaction on the part of the designer. The

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knowledge of the CAD tool is not sufficient and great experience is required in the manufacture of plastic parts.

Reducing design and manufacturing time, establishing good precision and quality in the finished piece and being able to make design changes quickly are the main concerns of the designers of new products in the industry of injection molding. Solving these problems requires a complete automation of the analysis process of the plastic part for its manufacture. Numerous methods at the research level have addressed the analysis of geometric demoldability, but they have many disadvantages in that they are either linked to the modeler to analyzing the piece internally, or need additional computing devices such as GPU's, or are not valid for analyzing all kinds of plastic parts.

In order to solve the problems described above, a new method for analyzing the geometric demoldability and calculation of the parting line is presented. This method is based on the discrete model of the plastic part consisting of a triangular mesh. This methodology develops a hybrid analysis of the part mesh, analyzing the demoldability of both mesh nodes and their facets. A first preprocessing phase classifies discrete mesh nodes according to their manufacturability. Based on this information, a second algorithm processes the mesh facets and color them based on their demoldability. The geometry of the plastic part is stored in separate arrays of nodes and facets with information on their manufacture for use in downstream applications. The new analysis algorithm developed results in a new virtual mesh of the plastic part that complements the initial nodes and adds new semi-facets to provide information not only on the part geometry but also on part manufacture. The resulting mesh represents the demoldability map of the plastic part. Nodes and facets are colored just as with a CAE tool. This algorithm improves the methods developed so far, since is valid for all kinds of plastic parts, for any modeler, and requires no additional hardware, allowing changes to be implemented quickly during the early stages of design and studies of price.

2. Background and related work

Demoldability analysis and calculation of the parting line are considered extremely important tasks in the design of the plastic part due to their influence on the quality and the costs of the manufacturing process. Both academic and industrial researchers have been seeking new methodologies to address the recognition of the surface of the plastic part in its application to the analysis of demoldability in order to achieve high levels of quality while reducing design time and production.

Many methodologies for determining the demoldability of the part along the parting direction are based on visibility analysis. The visibility map of a surface is the set of all directions from which the surface is completely visible. In terms of geometrical analysis of the surface of the plastic part, a parallelism between the concepts of visibility and demoldability can be established. The complexity of calculating the visibility of a surface obviously depends on the complexity of the surface itself which, in the extreme case of freeform surfaces, would be determined by calculating the visibility of each of its points. One of the first methods used for analyzing parts demoldability applying visibility maps was proposed by Chen et al. [1], who introduced the concept of the pocket for the calculation of non-demoldable areas. Chen et al. [2] created an algorithm for obtaining the optimal parting direction, by dividing objects into pockets. In these pockets visibility and moldability play the same role. Chen et al. [3] set both global and local visibility levels in order to extend their work to internal undercuts features and to decompose them into separable portions (based on complete visibility) and undercuts (on partial visibility). Weinstein and Manoochehri [4] obtained optimal parting directions by means of the location of common visibility areas of concave surfaces, the partition line being obtained by analyzing the surfaces belonging to the convex area.

Much research is based on features recognition in casting and plastic parts. A feature is a geometric region of the piece which has additional information about its manufacture. Currently, the solid modeling of the piece does not store this information explicitly. The methods of extracting features allow the development of methodologies that enable us to extract the required information and enter it as an input in a structured algorithm. On the plastic parts, undercut features encompass geometric regions of the piece, which are not accessible along the parting direction. Identifying undercut features directly affects the determination of the partition line and the design of upper and lower cavity, as well as the design of the mobile devices of the mold. Researchers have used different techniques for determining undercut features. Fu et al. developed a complete solution for the computer-aided design of plastic injection molds including the definition, classification and recognition of undercut features [5], determining the parting direction [6], parting line and surfaces [7], upper and lower cavities [8], and design of side cores [9]. Ran and Fu [10] proposed a methodology for obtaining the automatic design of internal pins in injection mold CAD via the automatic recognition of undercut features. Wuerger and Gadh [11,12] used the concavity features to locate the parting direction, using the convex hull of the part and then the Boolean difference with the piece. Kurt and Gadh [13] extended this research to the concavity features created by extrusion or rotation of a flat section. Lu and Lee [14] performed an analysis of the undercut features method by means of the elements of interference. Yin et al. [15] provided an algorithm to recognize undercut features for near net shapes. Ye et al. [16] proposed an undercut features recognition hybrid method that takes advantage of graph recognition methods. With this method the plastic part is configured by 'extended attributed face edge graphs', while undercut features recognition is based on searching for the 'cut sets' of undercut sub-graphs. In [17] Ye extended their work to side core design. Based on the curvature properties of entities in the B-Rep model Zhang et al. [18] describe an approach to recognizing DP features. Bassi et al. [19] proposed an automatic mold feature recognition system to recognize protrusion and depression as well as intersecting depression features. Other methods combine features recognition algorithms with visibility and accessibility analysis. Surti et al. [20] proposed a projection based methodology to analyze the visibility of a part from a given parting direction without discretizing the part. Singh et al. [21] describe an automated identification, classification, division and determination of the parting direction of complex undercut features of die-cast parts. Then the undercut features are classified using a rule-based algorithm. The 3D solid object in the format B-Rep, boundary representation, means the geometric and topological representation of the object may not be unique, since it depends on the procedures used for the CAD model generation, or the internal kernels used by the CAD program. Furthermore, the recognition of features for a piece created in a CAD system is linked to the modeler with which it was created. Another important issue in the automated recognition of features is the treatment of the interacting features. An interacting feature is the result of the intersection of multiple features. The difficulty in recognizing the interacting features is given mainly because, in the interaction between features, a destruction of the adjacency relationships between features that were in contact occurs. Furthermore, the decomposition from a complex feature to several individual features creates problems of multiple interpretations, generated mainly by the sequences in which the features are recognized.

Nee et al. [22,23] addressed the problem of demoldability by classifying plastic part surfaces according to their orientation with