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Direct integration of reverse engineering and rapid prototyping based on the properties of NURBS or B-spline

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Abstract

As product varieties increase and life cycles shorten, the need to reduce product development time becomes more critical to maintain competitiveness in the market. The reduction of the product development time, therefore, requires revolutionary improvements rather than gradual changes in technology. Based on a novel strategy the procedure for integration of reverse engineering and rapid prototyping was developed in this paper. Direct integration of reverse engineering and rapid prototyping is not a new issue and its importance has been demonstrated by many authors. However, all traditional algorithms for integration of RE and RP operate on scattered points directly such that some useful information for example curvature, normal and geometric shape, which are necessary for adaptive slicing in RP, cannot be obtained. To resolve the difficult dilemma a new algorithm is developed to build a bridge between scattered points and adaptive slicing.

Keywords: Reverse engineering; Rapid prototyping; NURBS; Adaptive slicing

1. Introduction

As product varieties increase and life cycles shorten, the need to reduce product development time becomes more critical to maintain competitiveness in the market. The reduction of the product development time, therefore, requires revolutionary improvements rather than gradual changes in technology. Both reverse engineering (RE) and rapid prototyping (RP) are emerging technologies that can play a promising role in reducing the product development time.

Revere engineering is a technology that enables us to generate a computerized representation of an existing part based on point data capturing from the part surface. It can be useful in many situations: (1) when the design model of a product is created by an artist and CAD data of the model need to be captured; (2) when a product encounters frequent design changes in development cycle and the initial design data become obsolete; and (3) when spare parts for a product are needed but its engineering drawing is lost or unavailable [1–3]. The typical process of reverse engineering begins with collecting point data from the surface of physical object. For obtaining the part's surface data, either contact or non-contact type measuring devices can be used. The initial point data captured by a measuring device generally require pre-processing operation such as noise filtering, smoothing, merging and data ordering in order to be useable in subsequent operations [1]. Using the preprocessed point data, a surface model can be generated either by a curve-net-based method or by a polygon-based modeling method. The curve-net-based method is more commonly used when generating a surface model from the scan data. The polygon-based modeling method is fast and efficient in fitting surfaces; however, it generates less accurate surface models than those of the curve-net-based method and it is also difficult to modify the final models [4]. To facilitate surface modeling tasks, the point cloud should be arranged well and segmentation.

Rapid prototyping refers to a class of layer-based manufacturing technologies. In contrast to traditional material removal processes, these techniques build a part by gradually adding materials layer-by-layer. The process is fully automatic and it offers many advantages over traditional manufacturing processes. It allows us to fabricate features that are difficult or impossible to fabricate by machining operation. Different fabrication methods exist for RP, but nearly all use the same geometric input format, called STL format, which consists of a list of triangular facet data. The STL has its advantages due to its simple structure and ease of use, but it has serious drawbacks. It requires a large amount of memory as the accuracy of a part increases and also takes a significant amount of repair time when it has flaws such as gaps, overlaps, and mixed normal vectors. In order to bridge RE and

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RP, efficient point cloud handing methods have to be developed first. Second, an accurate geometry input format for RP machines needs to be prepared. Lee and Woo [5] proposed a procedure that allows fabricating RP parts directly from reverse engineering geometric data. The new procedure proposes not to develop surface models for RP fabrication but rather suggests the use of contour data model created from the scanned data. However, the direct integration of RE and RP has an inherent disadvantages. Some useful information for example curvature, normal and geometric shape which, are necessary for adaptive slicing in RP, cannot be obtained directly from scattered points.

Adaptive slicing involves slicing the CAD model with varying layer thicknesses. The user can specially a maximum allowable cusp height for the object and also a deposition requirement. In order to achieve the user specification, surfaces of high curvature are sliced with thinner layer thicknesses and surface of low curvature are sliced with thicker layer thicknesses. Adaptive slicing has two advantages over uniform slicing. First, the surface quality of the manufactured part is better due to a less pronounced staircase effect. Variations in cusp height are minimized, giving the manufactured objected a smooth finish. The second advantage of adaptive slicing is a reduction in the build time. For δ^*, a user specified cusp height, adaptive slicing leads to the fastest manufacturing. Assume that $[\lambda_{\min}, \gamma_{\max}]$ is the range of layer thicknesses computing corresponding to δ^*. If the object is manufactured by uniform slicing using layer thickness $\lambda_{\min}$, the maximum cusp height for the object as a whole, will remain with δ^*. However, it is clear that the number of the slices for this model would be much larger than the adaptively sliced model. Also, even though the maximum cusp height would be δ^*, there would be a significant variation in the cusp height layers [6]. Mani et al. [7] presented a method for region-based adaptive slicing, which developed the adaptive slicing method further. The method allows the user to specify distinct cusp height values for different surface of the CAD model. From the above description, we can see that adaptive slicing and region-based adaptive slicing are all based on CAD representation. However, it is reported that the surface modeling task accounts for 90–95% of the reverse engineering compared to 5–10% of that for the digitized task. On the other hand, aforementioned, the CAD model is necessary for adaptive slicing in RP. It put us in a difficult dilemma. To resolve this question, a novel strategy is proposed in this paper based on the properties of NURBS or B-spline. An accurate slicing procedure for layered manufacturing is described in the following sections in that adaptive slicing is the key advantage of the proposed integration of RE and RP and in industry layered manufacturing technologies are often referred to as RP technologies.

The paper is organized as follows. Section 2 described the slicing procedure for layered manufacturing and the properties of NURBS and B-spline. Section 3 is devoted to propose a novel strategy for integration of RE and RP. In Section 4 the procedure for integration of RE and RP is presented. Finally, the proposed method is applied to two sample objects and the results are discussed in Section 5.

2. Adaptive slicing and NURBS

2.1. Adaptive slicing

The adaptive layer thicknesses for the adaptive layer thickness (ALT) region in a zone are determined based on the geometry, the surface finish requirements for the critical surface and the deposition requirement as specified by the user. Later thickness generation starts from the bottom zone to the top zone. Within a zone, layer thickness determination proceeds from bottom to top of the zone. The z height of the bottom and the top of the zone are referred to as bot-z and top-z, respectively. The procedure we use for determining the layer thickness is described in ref. [8]. We summarize the method below. The slice obtained by slicing the model at bot-z comprises the various curve segments corresponding to the various surfaces that bound the zone. Let curve C represent the curve segment off a surface S that bounds the model. In Fig. 1 let P be a point on the curve C. the vertical normal curvature of the surface S at the point P is determined. The normal section of the surface at the point P is locally approximated as a circle with the radius given by the reciprocal of the absolute value of the vertical curvature at point P. Using this circular approximation at P, the optimal layer thickness at point P is found based on the deposition requirement (excess or deficient) and the cusp height requirement (δ_i) on that surface. An optimization procedure computes the layer thickness d in Fig. 1 (see [8] for details).

2.2. NURBS and B-spline curves or surfaces and their properties

NURBS curves and surfaces are widely used in free-form surfaces modeling due to their interesting properties such as the ability to handle large surface patches, local controllability and the ability to represent analytical features as well. A NURBS curve is defined by following equation [24]:

$$S(u) = \frac{\sum_{i=1}^{n} B_i(u)\omega_i c_i}{\sum_{i=1}^{n} B_i(u)\omega_i} = \sum_{i=1}^{n} R_i(u) c_i \tag{1}$$

where c_i are control points, $B_i(u)$ are normalized B-spline functions, ω_i are the weights of control points. When $\omega_i = 1 (i = 0, 1, \ldots, n)$ the Eq. (1) will be B-spline curve.

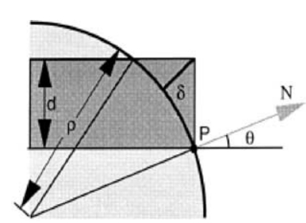

Fig. 1. Normal vertical section.