Computers in Industry 65 (2014) 598–609

Contents lists available at ScienceDirect

Computers in Industry

journal homepage: www.elsevier.com/locate/compind

Creation of user-defined freeform feature from surface models based on characteristic curves

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ARTICLE INFO

Article history:
Received 24 October 2012
Received in revised form 11 January 2014
Accepted 14 January 2014
Available online 18 February 2014

Keywords:
Freeform feature
User-defined freeform feature (UDFFF)
Characteristic curve
Feature recognition

ABSTRACT

This paper proposes a novel method for the creation of user-defined freeform feature (UDFFF) from existing surface model. The developed methodology has four major steps: selecting the region of interest (ROI), obtaining the characteristic curves from the surface model, reconstructing the ROI surface, and parameterizing the UDFFF. To quickly create UDFFF on the ROI, the representation of freeform feature based on characteristic curves is proposed. First, the characteristic curves of ROI are obtained automatically or by a small amount of human–computer interaction. In particular, user can directly and easily draw the curves on surface to satisfy the designer's requirements. Second, from the set of characteristic curves that is obtained, freeform surface is reconstructed by a suitable surface generation method, e.g., sweeping, revolving, skinning, and filling. Finally, parameterization of the freeform feature is configured, which primarily involves establishing parameters and building the mappings between feature parameters and shape data. Moreover, according to the degrees of freedom, two types of parameterization of freeform features may be described: one (low degrees of freedom) can be accurately described by the characteristic curves and the other (high degrees of freedom) can be approximated with these curves. The proposed UDFFF creation method has been tested with examples based on the surface models. Experience with our prototype system indicates that it allows untrained users to create UDFFFs from the surface models.

1. Introduction

Feature modelling has become a fundamental design paradigm for computer-aided design (CAD); features are defined as interfaces between shape models and applications [1–3]. Freeform surface features have been increasingly used in complex products. However, freeform surfaces are complex and diverse. In general, NURBS is a prevalent mathematical representation for both freeform surfaces and standard analytical surfaces in CAD. The shape of a NURBS surface is manipulated by control points, knot vectors, and a variety of other parameters; nevertheless because these parameters lack physical significance, they are not intuitive or convenient for users to manipulate. To overcome these drawbacks, a NURBS-based method to define freeform features in terms of intuitive and user-friendly parameters must be created. Feature-based or parametric modelling allows the designer to control a shape by assigning numerical values to parameters. These parameters have a procedural relationship with the data for a shape. This relationship is not visible to the user, but the shape can be manipulated through this relationship, thereby reducing the effort that is required to perform the manipulation of a shape of interest.

In addition, in the process of surface model design, the creation of freeform surface is not only time-consuming and tedious, but also requires knowledge about the underlying curve and surface representations. It is difficult for inexperienced users to completely generate the control structure for an intended shape. Freeform feature-based design is currently a hot research topic [4,5]. Certain researchers have focused on freeform surface features to support product modelling [6] and freeform feature recognition [7,8]. Sunil and Pande use curvature, orientation and connectivity of the shape to identify freeform features in STL models [7]; while Gupta and Gurumoorthy put forward an algorithm for identifying and representing the ROI based on the taxonomy of freeform features [8]. However, at the present time, a number of issues with respect to freeform surface features remain unresolved, particularly, the creation of UDFFF [9,10]. The existing methods of creating UDFFF are very difficult and complex, for all the geometric elements need to be constructed from scratch [11,12]. Generally, these methods

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http://dx.doi.org/10.1016/j.compind.2014.01.011

need to draw new geometric elements based on the reference plane, especially, to draw and edit 3D curve based on multi reference planes, so that the work is not only repeated and boring, but also inconvenient and difficult to carry out.

In consideration of the existing surface models, there are certain regions that are significant and useful in CAD. The creation of UDFFF on these regions can improve design efficiency, which not only allows the designer to be inspired by existing shapes but also permits these shapes to be quickly introduced into the user's own designs [13]. In the process of the creation of UDFFF, surface (re)construction is a most important problem. The reconstruction problem has been researched extensively and many techniques have been developed in the past two decades [14,15]. Most of the surface reconstruction algorithms focused primarily on the generation of smooth triangulated surface from scanned 3D points and on the improved reconstruction result with clear sharp feature. But, by far, no methods were proposed to reconstruct ROI from existing surface models and then to create the UDFFF on the ROI.

Since there are many meaningful regions in plenty of existing surface models, these regions are not defined as features so that it is difficult to reuse them. The research work reported in this paper is motivated by above observation. Combined with the thought of feature, the main contribution of this paper lies in the development of a novel method for defining the ROI from existing surface model as UDFFF. Our proposed method can support user to customize freeform feature. To reuse ROI easily, an approach of reconstructing surface based on characteristic curves is fundamental. There are four main steps to accomplish from surface in CAD model to freeform surface feature. First, the ROI is chosen. Second, the characteristic curves are obtained from surface model. Third, the surface of the ROI is reconstructed. Finally, the freeform feature is parameterized and the mappings are established between the parameters and shape data.

The paper is organized as follows. In Section 2, the relevant literature is discussed. Section 3 presents an approach that uses characteristic curves for the representation of freeform features. Section 4 provides an overview of the proposed research on freeform features. Section 5 elaborates the method for creating a UDFFF on the ROI. In Section 6, the approach is implemented, and examples are addressed. Section 7 concludes with a summary of the content of this study and proposes future research directions.

2. Related works

Features can generally be divided into regular features and freeform features [16]. Regular features, which are generally created from a quadric surface, can be strictly defined in terms of several parameters, e.g., length, width, and height. However, freeform features are complicated and may be surface- or volume-based. So it is hard to define their shape by several parameters. To improve the work of UDFFF and its related works, such as reuse and reconstruction, parameterization and user-defined feature on surface, a number of relevant studies have been performed, as discussed in the following subsections.

2.1. Surface reuse and reconstruction

Design reuse is very important in engineering applications for many common subparts of different CAD models are likely to be reusable [17,18]. The creation of UDFFF from the ROI is the most useful way in order to reuse the surface. It is estimated that approximately 80% of designs are variant and/or adaptive designs [19]. The most important factor for ensuring that variant design and adaptive design are effective and efficient is design reuse. In the past several years, various types of solutions have been proposed to define different types of feature-reusing operations [20]. Biermann et al. [21] utilize a subdivision formulation of surfaces to define feature creation and placement actions along a user-defined curve path. Gao and co-workers [22] propose an approach to reuse freeform features with NURBS representations based on the Poisson equation.

Moreover, considerable research has been invested into the field of surface reconstruction. With respect to underlying surface representations, the existing approaches on surface reconstruction fall into three categories of polygonal meshes, splines and zero-set surfaces; spline-based surfaces are well suited for further processing in CAD/CAM. Qin and co-worker [23] present a novel modelling technique for reconstructing a triangular B-spline surface from a set of scanned 3D points. Ke and co-workers [24] propose a deformation-based freeform feature reconstruction in the context of reverse engineering. Chen and co-workers [25] present a new surface reconstruction framework that uses the implicit PHT-spline method for shape representation to reconstruct surface models from large sets of points. Azariadis and Sapidis [26] proposed a new method for parameterizing and constructing 3D point-cloud using a quadtree structure and a novel grid-based surface-fitting technique.

In this paper, feature is regarded as an ideal object for reuse. Thus, the ROI becomes freeform feature in the features library of the designer that is reusable for different target surface models.

2.2. Feature representation and parameterization

Feature representation and parameterization is a very beneficial way to reuse surface. With respect to the parameterization of freeform feature, Vergeest et al. [27] propose a formal approach for depicting freeform feature, giving examples of ridge and hole features. Song et al. [28] suggest a parameter-driven deformation approach for defining a surface in terms of intrinsic parameters. Nyirenda and Bronsvoort [29] propose numeric and curve parameters to define freeform features. Numeric parameters specify the usual properties, e.g., length, width, and height, whereas curve parameters can be added to feature models and modify the local shapes in styling design. Pernot et al. [16,30] offer an approach for parameterizing freeform feature templates to represent a surface; this approach requires a highly iterative process between the surface deformation and the feature template. Park and Lee [31] suggest a parametric method for freeform mesh models that uses control freeform mesh. This method involves constructing a control mesh that surrounds an object model and then imposing constraints on this mesh. Thus, this approach is useful for existing models, allowing users to reduce the time and effort that they spend in converting mesh models to parametric surface models. Langerak and Vergeest [32] suggest one possible approach for user-driven feature definition. Freeform feature is a parametric description of a shape. Complex mappings must be constructed between control points and parameters because parametric influence is defined through the NURBS control points.

The methods mentioned above are useful and meaningful for representing and parameterizing freeform features. However, both the parameterization and the mapping directly between the feature parameters and shape data are still very difficult.

2.3. User-defined feature

Some systems can only offer standard features, such as pockets and ribs for regular features, as well as ridges and bumps for freeform features. Other systems can also offer some non-standard features, such as lifted hole belonging to protrusions for regular features, and variable section sweep belonging to sweeps for freeform features. However, in these systems, the vertices and edges on surface cannot be directly edited by user; moreover,