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Feature-based reverse modeling strategies

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Abstract

We presented two integrated solution schemes, sectional feature based strategy and surface feature based strategy, for modeling industrial components from point cloud to surfaces without using triangulation. For the sectional feature based strategy, slicing, curve feature recognition and constrained fitting are introduced. This strategy emphasizes the advanced feature architecture patterns from 2D to 3D in reverse engineering. The surface feature based strategy relies on differential geometric attributes estimation and diverse feature extraction techniques. The methods and algorithms such as attributes estimation based on 4D Shepard surface, symmetry plane extraction, quadric surface recognition and optimization, extruded and rotational surface extraction, and blend feature extraction with probability and statistic theory are proposed. The reliable three-dimensional feature fabricated the valid substratum of B-rep model faultlessly. All the algorithms are implemented in RE-SOFT, a reverse engineering software developed by Zhejiang University. The proposed strategies can be used to capture the original design intention accurately and to complete the reverse modeling process conveniently. Typical industrial components are used to illustrate the validation of our feature-based strategies.

Keywords: Reverse engineering; Feature recognition; Geometric constraints; Constrained fitting; Probability and statistics

1. Introduction

Design intention understanding and CAD model reconstruction from a physical object are important issues in product improvement, reproduction and quality control [1]. Reverse engineering, as the most popular methodology, converts low-level geometric information generally represented by point cloud positions and their differential geometric attributes to high-level information, such as design methods, functional principles, engineering constraints and aesthetical evaluations. As a tie to associate the low-level information and the advanced design intention, features are described as geometric shape, topological representation and their evolvement in reverse modeling process. With the introduction of feature-based representation, there exist mainly two approaches for model reconstruction: the boundary representation (B-rep) approach [2] and the feature template approach [3,4]. Theoretically, the B-rep approach can produce accurate and topologically consistent model, if all the major features can be recognized from points and some minor features are allowed to ignored to some extent. Although this method has great advantages in inherent feature semantics and topological information representation of the natural surfaces, it is not easy to integrate with complicated free-form surface features. Here the feature semantics are defined by a set of geometric primitives and constraints extracted from point cloud. The feature template approach handles specific geometric primitives, such as mannequin feature in garment design and manufacture feature in mechanical engineering, depending on the applications. Therefore, the feature template approach cannot be directly generalized to reverse design for general industrial products.

The state-of-art commercial reverse engineering systems such as CopyCAD, Geomagic series, Imageware and RE-SOFT have provided different reverse modeling solutions for conventional industrial products according to their devotional technique schemes [5]. However, the lack of feature representation usually results in inaccurate and inconsistent topological CAD model. Consequently, it is difficult to represent the original design intention and to modify the final model parameters in an effective way. From the function design point of view, the final reverse engineering model of turbine blade from point cloud without feature representation possibly cannot demonstrate the original hydrodynamic properties. We integrate the feature based solution strategies

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in the RE-SOFT system by feature semantics representation. Our strategies can deal with different feature types to recover the design information implied in physical prototypes.

Different strategy favors different surface types and feature parameters in the representation of the original design concept. There exist two basic solution strategies in reverse modeling process, strategy based on sectional curve feature and strategy based on surface feature. In the first solution strategy, the sectional curves represented by ordered points are constructed by slicing point cloud [6]. Then feature primitives such as line segments, circular arcs, B-spline curves and inherent constraints are recognized from the ordered points. The single primitive or primitives imposed on constraints are optimized to generate the parametric feature curves [7]. Finally, the surface features are modeled by sweeping or skinning method. In the other solution strategy, the differential geometric attributes of point cloud are estimated. Then surface feature primitives and geometric regularities such as quadrics, extruded and rotational surface, blend, symmetry, and array are extracted by using the point cloud and its differential geometric information [8–11]. The feature primitives imposed on engineering constraints are optimized globally to construct the final surface model. The basic solution strategies for reverse modeling in RE-SOFT are shown in Fig. 1, which are enclosed by rectangles, respectively. The strategies mentioned above often overlap each other in practical applications, as depicted by the dashed lines in Fig. 1.

Our reverse engineering system directly uses point cloud as the substructure of geometric operations, rather than triangular meshes. The main algorithms and methods integrated in our strategies are described in the following:

- Besides analytical geometries, free-form curves and surfaces are involved in our constrained fitting procedure.
- Instead of thousands of local surface patches, a global 4D shepard surface is used to estimate differential geometric attributes.
- Based on the data registration technique, a symmetric plane extraction algorithm is applied.
- By using principle direction Gaussian image (PDGI) of point cloud, an extraction method for extruded and rotational surfaces is approached.
- A heuristic method for blend extraction, covering constant radius and variant radius, is discussed.
- To correct the extracted parameters, statistic theory and method is used.

This paper is organized as follows. In Section 2, we describe the sectional feature based reverse modeling strategy and introduce slicing, curve feature recognition and constrained fitting. In Section 3, we discuss the surface feature based reverse modeling strategy and introduce some novel or improved methods and algorithms: differential geometric attributes estimation, symmetry plane extraction, quadric surface recognition and optimization, extruded and rotational surface extraction, and probability and statistic theory based blend feature extraction. In Section 4, typical industrial components are used to illustrate the validation of our feature-based strategies. In Section 5, we conclude the paper and point out future work.

For convenience, we put the following assumptions on the point cloud $P=\{p_0,\ldots,p_{n-1}\}$. We assume that the point cloud is ρ-dense [35], which means any sphere with radius $\rho>0$ and center at $p_i\in P$ contains at least one point other than p_i in P. We also assume that the data is non-degenerate, i.e. overlapping or very close points are absent. To accelerate the data search in point cloud, we use a 3D grid structure. The axis-aligned bounding box of the point cloud is subdivided into grids such that each grid is parallel to a coordinate axis. We denote the size of the grid G_{i_x,i_y,i_z} as $s_x\times s_y\times s_x$, where $i_x=0,\ldots,n_x-1$, $i_y=0,\ldots,n_y-1$, $i_z=0,\ldots,n_z-1$ are the grid indices. The edge length of the grid G_{i_x,i_y,i_z} is associated with a quantity $c_g\rho$, where the coefficient c_g equals 4, 5 or 6 in our application. Points in the point cloud are entered into sets corresponding to the grid to which they belong, and these sets are accessed through the grid indices. If a grid contains at least one point, it is called valid, otherwise invalid.

2. Sectional feature based strategy—from 2D to 3D

The design process of modern industrial product commonly follows the basic principle from simplicity to complexity,

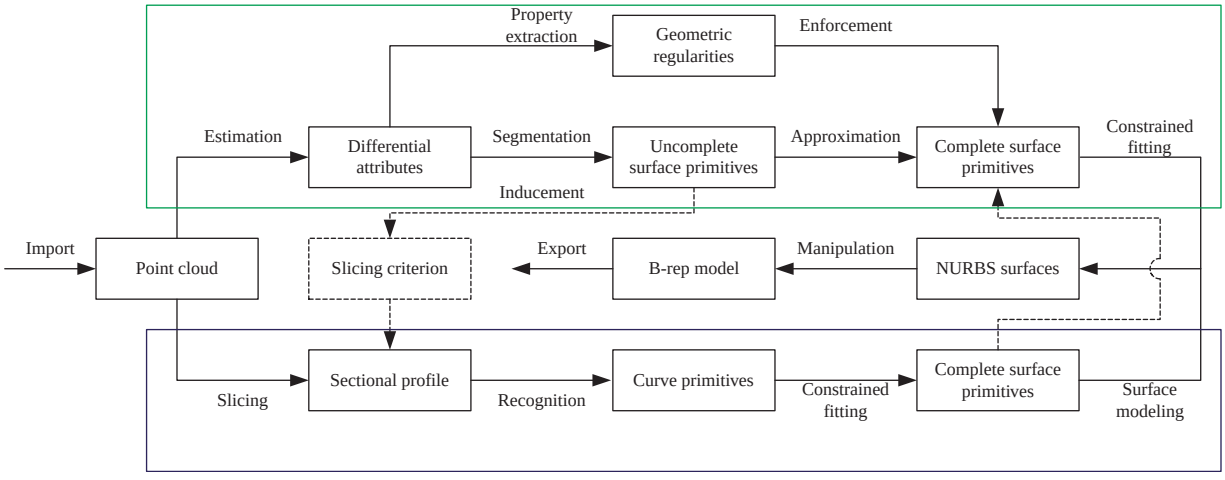

Fig. 1. Reverse modeling strategies in RE-SOFT.