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Solid reconstruction using recognition of quadric surfaces from orthographic views

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Abstract

The reconstruction of 3D objects from 2D orthographic views is crucial for maintaining and further developing existing product designs. A B-rep oriented method for reconstructing curved objects from three orthographic views is presented by employing a hybrid wire-frame in place of an intermediate wire-frame. The Link-Relation Graph (LRG) is introduced as a multi-graph representation of orthographic views, and quadric surface features (QSFs) are defined by special basic patterns of LRG as well as aggregation rules. By hint-based pattern matching in the LRGs of three orthographic views in an order of priority, the corresponding QSFs are recognized, and the geometry and topology of quadric surfaces are recovered simultaneously. This method can handle objects with interacting quadric surfaces and avoids the combinatorial search for tracing all the quadric surfaces in an intermediate wire-frame by the existing methods. Several examples are provided.

Keywords: Solid reconstruction; Wire-frame; Quadric surface; Feature recognition; Orthographic projection

1. Introduction

Engineering drawings have been employed as a standard language for describing mechanical designs since the 19th century [1] and still plays an essential role in engineering practice today. Most existing products are represented by means of engineering drawings. But nowadays, solid modelers have become popular mechanical CAD tools, and solid models are necessary for some computer-aided product development techniques, such as finite-element analysis, process planning, numerically controlled machining, and emulation display. Unfortunately, the information embedded in 2D drawings cannot be directly used in 3D CAD systems. Consequently, the automatic conversion of engineering drawings to solid objects is critical to the maintenance of considerable legacy designs and the upgrade of existing products based on their designs.

A body of work related to the reconstruction of solid models from three orthographic views has existed since the 1970s. In terms of solid representations, existing reconstruction schemes can be basically classified into two major categories: B-rep oriented approach and CSG oriented approach [2,3]. The B-rep oriented approach has one important advantage over the CSG oriented approach, which is reflected in the complexity of the object domain that can be reconstructed. The former can handle more complicated polyhedra and so far has extended the object domain into quadric solid models without restrictions on the axes of curved surfaces. The latter, however, is generally applicable only to mechanical parts of uniform thickness or axis-aligned volumes of revolution, because it typically uses either pre-defined primitives or identifies entities that can be extruded or rotated. The B-rep oriented approach does provide a practical way for automatically reconstructing mechanical parts from their orthographic views. However, two limitations of existing B-rep oriented algorithms are as follows.

1. The object domain is still restricted since intricate cases of objects with interacting quadric surfaces have not been settled due to the complexity of intersections between quadric surfaces.
2. Long processing time is involved in searching for all the valid surfaces, especially quadric surfaces, in an

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intermediate wire-frame with the possibility of backtracking and heuristics due to the ambiguity of the wire-frame.

We consider here the natural quadrics, i.e. the sphere, cylinder, cone, and plane, since they are by far the most commonly occurring quadric surfaces used in modeling mechanical parts. The purpose of this paper is to extend the capability and improve the efficiency of the B-rep oriented approach. A novel method is proposed to directly recognize interacting quadric surfaces as well as isolated ones by hint-based pattern matching based on a multi-graph representation of orthographic views. A *hybrid wire-frame*, which consists of the geometry and topology of quadric surfaces besides vertices and edges, is constructed instead of a conventional wire-frame. This method is able to effectively handle objects with interacting quadric surfaces. And it requires considerably less searching time to extract surfaces by avoiding the combinatorial search that could grow exponentially in complexity.

The rest of the paper is organized as follows. The next section reviews related work focussing on the B-rep oriented approach. Some definitions involved in this paper are then introduced in Section 3. An overview of our B-rep oriented algorithm is presented in Section 4 followed by the details of hint-based feature recognition described in Section 5. Section 6 reports some experimental results of implementation. And in Section 7, a conclusion is presented with a discussion on further development.

2. Related work

2.1. CSG oriented approach

The CSG oriented approach assumes that each object can be built from certain primitives in a hierarchical manner. It tries to construct primitives based on projective entities in orthographic views, and then assemble constructed primitives to form the final solid model using a CSG tree. According to primitive construction, the approach can be categorized into two subclasses. The first one, known as the pattern-guided method, interprets the views based on pattern recognition where the patterns being searched for are projections of pre-defined solid primitives [4,5]. Aldefeld's method [5] is restricted to objects of uniform thickness. The other subclass, known as the volume-cut method, selects 2D loops as bases and uses extrusion (e.g. [6–8]) or rotation (e.g. [9–11]) to construct 3D primitives. The two-stage extrusion method proposed by Shum et al. [8] can handle objects with 2.5D elements. Soni's method [9] can construct axis-aligned volumes of revolution that are limited to isolated cases. Lee et al. [10] proposed a hint-based method to generate interacting axis-aligned volumes of revolution. Dimri et al. [11] adjusted the identification of loops for handling sectional views.

2.2. B-rep oriented approach

The B-rep oriented approach was first proposed by Idesawa [12] and was formalized by Markowsky and Wesley [13,14]. This approach is based on the idea of constructing an intermediate wire-frame and typically involves the following four steps.

(1) Transform 2D junctions to 3D vertices.
(2) Generate 3D edges from 3D vertices.
(3) Construct 3D faces from 3D edges.
(4) Form 3D objects from 3D faces.

Earlier efforts by this approach mainly focused on generating polyhedral objects from their orthographic views (e.g. [13–17]). Since quadric surfaces play an essential role in the description of manufactured mechanical parts, most later research focuses on the reconstruction of quadric solid models (e.g. [18–23,25–27]) and has extended the object domain that can be handled.

The automatic conversion of orthographic views to 3D curvilinear wire-frames is the pivotal stage of the B-rep oriented approach. Shin et al. [22] established types of vertices and generated different types of edges according to the types of their endpoints by introducing auxiliary vertices and edges. The method requires a large amount of time to preprocess input data in order to ascertain all the types of 2D elements in the views. Furthermore, it may fail to correctly reveal match projections when there is more than one 2D element between two junctions in a view. Kuo [23] used five points on projective conics to match projections in different views and therefore handled the case of failure by Shin's method. However, the recovery of conics involves four complex steps and is a time-consuming process. Shin's and Kuo's methods can deal with quadric surfaces with the restriction that the axes of curved surfaces must be parallel to the directions of projection. Zhang et al. [24] extended Kuo's method to handle the cases that no more definite conic types are available from the views, by employing the five-point method to first obtain the types of projective curves. However, the method may fail to correctly determine the corresponding relationship between the three projective conics of a 3D conic, since the points arbitrarily chosen on the unknown type 2D curves do not always satisfy the matching relations. Liu et al. [25] proposed a method based on conjugate diameters to generate conic edges. By combining the geometric properties of conics with affine properties, the method removed restrictions placed on the axes of conics by other methods. Unfortunately, it is a complex procedure to employ distinct retrieval techniques of geometric parameters for different types of conics, which involves large amounts of intersecting detection and affine transform. The authors proposed an efficient method for reconstructing 3D wire-frame models of curved objects from three orthographic views in previous work [26]. By depth-first tracing the decision trees constructed according to the projective properties of spatial edges, the method reduces the search space for identifying all the projective matches in three orthographic views. Furthermore, by employing the rational Bézier form of conics, the method simplifies the procedure for generating various types of spatial conics in arbitrary positions.

Almost all of the existing B-rep oriented algorithms use input drawings that are restricted to line segments and conic sections, and therefore cannot handle intersections of quadric surfaces, where higher order curves may arise. By employing pattern recognition, only Gu et al. [27] discussed handling higher order curves resulted from two intersecting cylindrical