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Reverse engineering of a symmetric object

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Abstract

This paper presents a procedure to find an approximate symmetry plane from a point cloud for the reverse engineering of a symmetric object. Even if, the point cloud acquired from a symmetric object does not have exact symmetry planes in the mathematical sense, the data usually carries adequate symmetric information for reverse engineering. To generate a CAD model satisfying the original aesthetic and functional design, it is essential to extract approximate symmetry planes. This paper proposes a new procedure to extract a symmetry plane, and it includes a registration step, aligning three-dimensional models. To improve the computational efficiency of the proposed procedure, the registration step has been modified by using the inherent attributes of the problem: (1) the measured point data may include noise and (2) the point cloud might be partially asymmetric. The proposed procedure has been implemented and proven to be efficient enough to handle very heavy data sets including millions of entities (points and triangles).

Keywords: Symmetry plane; Reverse engineering; Segmentation; Registration; Approximate symmetry plane

1. Introduction

While conventional engineering creates a CAD model based on the functional specifications of a new product, reverse engineering uses a manufactured part to produce a CAD model (Ke et al., 2006; Lee & Woo, 2000; Varady, Martin, & Cox, 1997; Xinmin, Zhongqin, Tian, & Ziping, 2001). The existence of a CAD model provides enormous gains in improving the quality and efficiency of an analysis, because we can exploit the advantages of the extensive use of CAD/CAM technologies. Reverse engineering typically starts with measuring a physical object to reconstruct a CAD model for applications like redesign, reproduction and quality control. The flowchart shown in Fig. 1 characterizes the typical procedure of reverse engineering, which consists of five steps: (1) data acquisition, (2) preprocessing (noise filtering and merging), (3) triangulation, (4) feature extraction, and (5) segmentation and surface fitting. The most critical step of reverse engineering is the segmentation

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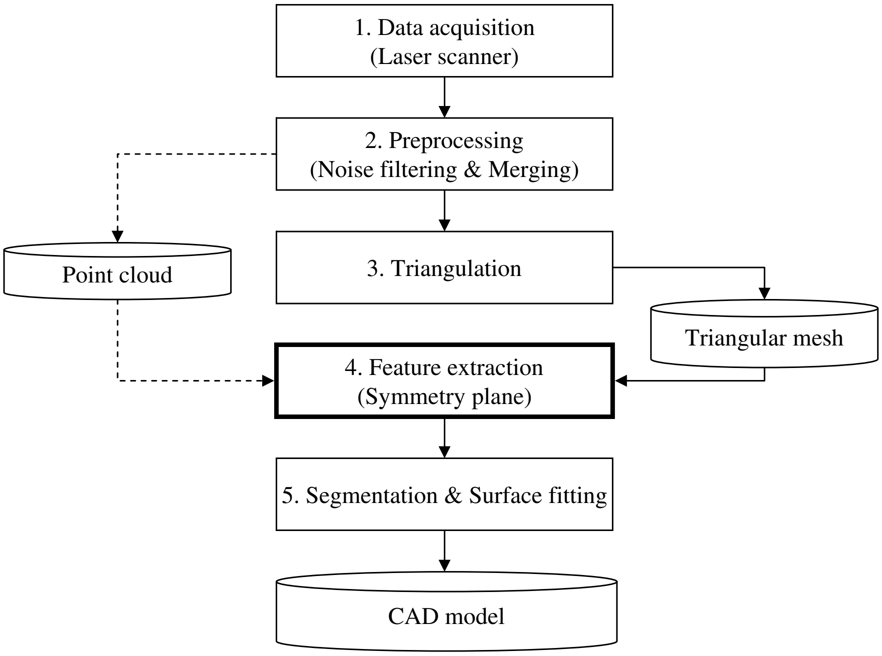

Fig. 1. Typical flow of reverse engineering.

process of the fifth step. The segmentation process splits a triangular mesh into sub-meshes to which an appropriate single surface can be fitted, and it seriously affects the quality of the resulting CAD model. To improve the quality of segmentation, it is essential to make use of the features (sharp edges and symmetry planes) extracted in the fourth step. Among various features, a symmetry plane is a very important feature for the segmentation process (Langbein, Marshall, & Martin, 2004; Momi et al., 2006; Tate & Jared, 2003), because the symmetric property is the most general feature of industrial products. This paper mainly focuses on how to find an approximate symmetry plane from a triangular mesh that is generated by processing a point cloud.

The concept of symmetry has been of major interest in many fields of research over many years. Especially, the problem of determining exact symmetry of a solid model has been well studied for several decades (Jiang & Bunke, 1992; Sugihara, 1984; Wolter, Woo, & Volz, 1985). Previous results showed that polyhedral symmetry can be determined in three dimensions in $O(n \log n)$ time (where n is the number of vertices) by the use of symbolic sorting algorithms. However, the algorithms for determining exact symmetry can not be applied to approximate cases, because they require the ability to tell locally whether one point can be mapped to another, which is not true for a point cloud with various noises.

Although, a point cloud acquired from a symmetric object does not have exact symmetry planes in the mathematical sense, the data usually carries adequate symmetric information for reverse engineering. To generate a CAD model satisfying the original aesthetic and functional design, it is essential to extract approximate symmetry planes. There have been various previous results in determining the approximate symmetry planes. Fukushima and Kikuchi (2006) proposed an artificial neural network that extracts symmetry axes from visual patterns. One of the attributes of this method is the use of blur for extracting a symmetry axis to reduce the computational cost. Tuzikov, Colliot, and Bloch (2003) proposed an algorithm to detect the best symmetry plane in 3D magnetic resonance (MR) brain images. The symmetry plane is initialized by a plane obtained from principal inertia axes and is optimized by using the downhill simplex method. Although the algorithm is stable with respect to noise and intensity nonuniformity, it is sensitive to the position of the initial plane in the optimization procedure. Mills, Langbeing, Marshall, and Martin (2001) proposed an algorithm for finding symmetry planes consisting of two steps. The first step of the algorithm replaces certain groups of points by their centroid, and the second step finds the approximate symmetries of the collection of points remaining after this grouping. Ke et al. (2006) proposed an algorithm to extract a symmetry plane from a point cloud.