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A reverse engineering system for rapid manufacturing of complex objects

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Abstract

This paper presents a reverse engineering system for rapid modeling and manufacturing of products with complex surfaces. The system consists of three main components: a 3D optical digitizing system, a surface reconstruction software and a rapid prototyping machine. The unique features of the 3D optical digitizing system include the use of white-light source, and cost-effective and quick image acquisition. The surface reconstruction process consists of three major steps: (1) range view registration by an iterative closed-form solution, (2) range surface integration by reconstructing an implicit function to update the volumetric grid, and (3) iso-surface extraction by the Marching Cubes algorithm. The modeling software exports models in STL format, which are used as input to an FDM 2000 machine to manufacture products. The examples are included to illustrate the systems and the methods.

Keywords: Reverse engineering; Optical digitizers; Surface reconstruction; Rapid prototyping

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1. Introduction

Growing global competition requires manufacturers to deliver more competitive products with better quality and lower prices. One of the most important and challenging tasks faced by manufacturing industry is substantial reduction of product development time. The traditional methods for making patterns and moulds with complex surfaces are inefficient and error-prone. For example, in medical applications such as orthotics and prosthetics, because precise production and fitting of such shapes are needed to satisfy medical standards and treatment requirements, and also because of product complexity with free-form surfaces, it is quite often that many modifications are needed. Therefore, reverse engineering and rapid prototyping of objects with complex surfaces have received significant attention from both research and industrial communities [1].

Reverse engineering is the process of engineering backward to build a CAD model geometrically identical to an existing product. Subsequently, CAD models are used for manufacturing or other applications. An example application is where CAD models are unavailable, unusable, or insufficient for existing parts that must be duplicated or modified. There are many practical applications ranging from tool and die making to biomedical device design and manufacturing.

Fig. 1 shows the reverse engineering system for rapid manufacturing of complex objects. An object is digitized by the 3D object digitizer and data is then fed into surface reconstruction software, which outputs a smooth surface model. The model is manufactured by a rapid prototyping machine. Two of the key technologies in this reverse engineering system are the 3D optical digitizer and the surface reconstruction algorithms.

Object digitizers can be classified into two broad categories: contact and non-contact. Among non-contact optical digitizers, laser triangulation is the most commonly used technology. Drawbacks of laser triangulation scanner include high cost and slow data acquisition.

New scanning technologies are emerging that have potential to further enhance the quality of 3D object scans. One such development is non-contact scanning systems employing white light rather than a single laser tracking line. This system generates dense volumetric

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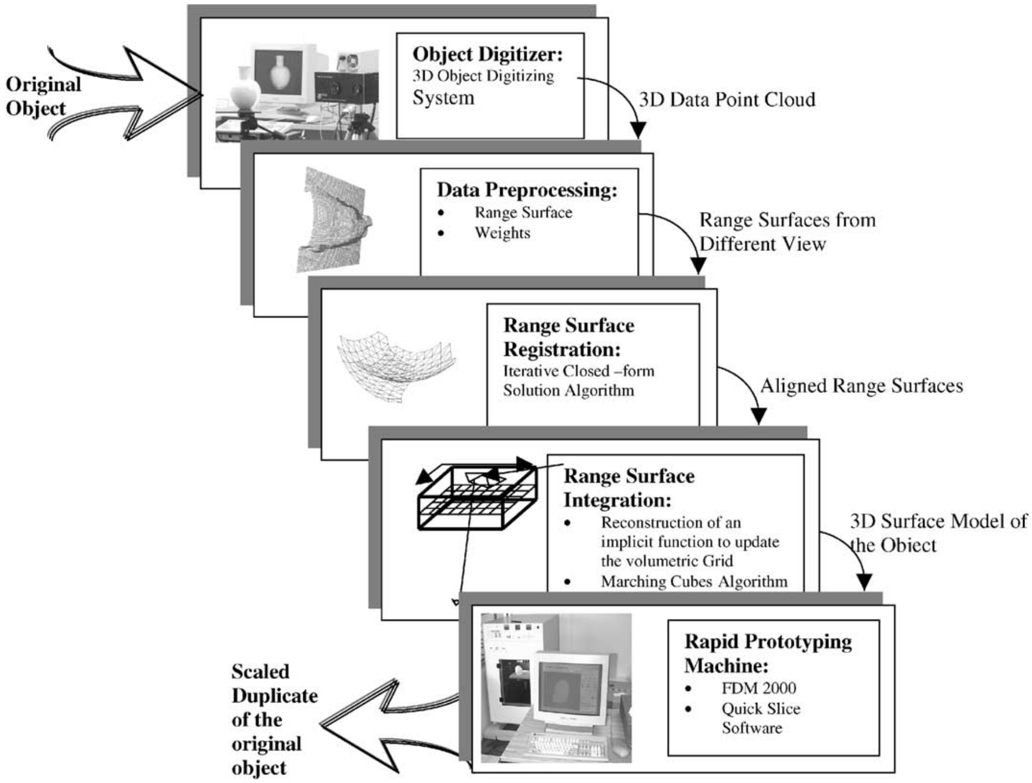

Fig. 1. Schematic diagram of the reverse engineering system.

scans. Detailed scans can be generated quickly, and the wide scanning volume reduces the importance of the angle at which the tracking light hits the target object [2].

Post-scanning data processing is an important step for any successful application of these scanning systems. The objective of post-scanning data processing is to reconstruct surface models from 3D point clouds. Strategies for surface reconstruction have proceeded in two main directions: reconstruction from unorganized points and reconstruction that exploits the underlying structure of the acquired data. The latter is called surface reconstruction using structured data. These two strategies can be further divided according to whether they operate by reconstructing parametric surfaces or by reconstructing implicit surfaces. The algorithm employed here falls into structured data reconstruction using implicit function methods that use samples of a continuous function to combine structured data. Previous relevant work includes [3–6]. These methods mainly apply to laser scanning technologies. In this paper, the existing algorithms were adapted for building of 3D models from point clouds generated by the 3D optical digitizing system.

To create a single model from multiple range images, two fundamental issues must be addressed: registration and integration. Registration refers to computing a rigid transformation that brings the points of one range image into alignment with the overlapping portion of another range image. Integration is the process of creating a single surface obtained from the multiple range images [6].

For a real world 3D object, no single range image suffices to describe the entire object surface. Multiple views must be digitized in order to obtain the complete geometric information of the object. In order to extract a 3D model from multi-view range images, the range images must be aligned in one global coordinate system. One of such methods that can achieve this is to capture the range images using a digitizer mounted on a precision motion device such as a coordinate measuring machine (CMM). This method is costly and inconvenient for many real world applications.

An alternative solution is to use a registration algorithm to align the range images. Two main approaches are used for the registration: (1) match "created" features of the images, such as the method that was presented in [7]; or (2) minimize the distance between all points on the overlapped surface represented by the two images. Examples of the latter approach include [6,8–10]. The minimal distance method was used in this work.

After registration is completed, the final surface can be extracted directly from range surfaces by the following two methods: (1) geometric details of all scans are averaged and the vertex positions of range surface