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Reverse engineering with a structured light system ☆

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ABSTRACT

This paper proposes a scanning procedure using an structured light system (SLS). To respond to the increasing needs of reverse engineering, it becomes very important to achieve high efficiency of measuring procedure. As an SLS can measure only the visible area from a specific direction, it is necessary to scan multiple times to obtain a complete model. However, it is more desirable to minimize the number of scanning directions to save the measuring time and the amount of required memory. The proposed procedure identifies missing areas from multiple range images (scanning data), and attempts to locate additional scanning orientations to fill the missing areas. The core part of the proposed procedure is the identification of missing areas from multiple range images. Since the identification of missing areas may be called repeatedly during the scanning procedure, it is very important to improve the efficiency. To satisfy the requirement, this paper proposes a new method for identifying missing areas using a graphic hardware. Once missing areas are identified, the proposed procedure computes additional scanning orientations by using the visibility information of missing areas. As the proposed procedure is based on well-known 2D geometric algorithms, it is very efficient.

1. Introduction

One of the main issues of 'reverse engineering (RE)' is to obtain a geometric model (CAD model) from a physical object whose geometrical information is partially or completely unavailable in digital form (Lee & Park, 2000; Son, Park, & Lee, 2002). The reverse engineering process involves measuring an object and then reconstructing it as a 3D geometric model. The physical part can be measured using 3D scanning technologies. The measured data is usually represented as a point cloud (a set of 3D points) which does not include topological information. The measuring techniques can be categorized into contact type (Spyridi & Requicha, 1990) and non-contact type (Son et al., 2002; Lee & Park, 2000). Coordinate measuring machines (CMMs) are commonly used in contact digitizing, and optical methods (stereovision systems, structured light systems) are mostly used in contact digitizing. While CMMs provide relatively accurate measuring results, they are not suitable for measuring a large number of points because they are too slow compared to optical methods. Because of the reason, optical methods have been considered to be more suitable for the purpose of reverse engineering, which requires of measuring a large number of points (e.g. millions of points).

There has been much interest in developing techniques of non-contact measurement of 3D objects. The mapping of 3D objects and reconstructing them in a CAD system is a subject of optical measurement and geometrical modeling, and it is becoming an increasingly important topic in computer vision, with applications in fields such as reverse engineering, inspection of geometrical properties of mechanical components, object recognition, guidance for robotic vision, medical applications, and virtual environment construction. For the non-contact measurement based on vision cameras, there have been two alternative techniques: stereovision and structured light system (SLS). Structured light system (Khardekar, Burton, & McMains, 2006; Priyadarshi & Gupta, 2004) avoids the so-called correspondence problem of passive stereo vision, and getting more popular in industry inspections due to fast measuring speed, very simple optical arrangement, non-contact, moderate accuracy, low cost, and robust nature in the presence of ambient light source in situation.

To response the increasing needs of RE, it becomes very important to achieve high efficiency (productivity) of measuring procedure. This paper focuses on the optimization of a scanning procedure with an SLS. As shown in Fig. 1, an SLS consists of a projector and a camera; the angle between them is known as an optical triangulation angle. As the optical triangulation angle does not change during scanning, the camera orientation and the projector orientation are restricted by the scanning orientation. Three-dimensional range data are spatial coordinates for surface points of an object and they are useful for 3D object matching, object rec-

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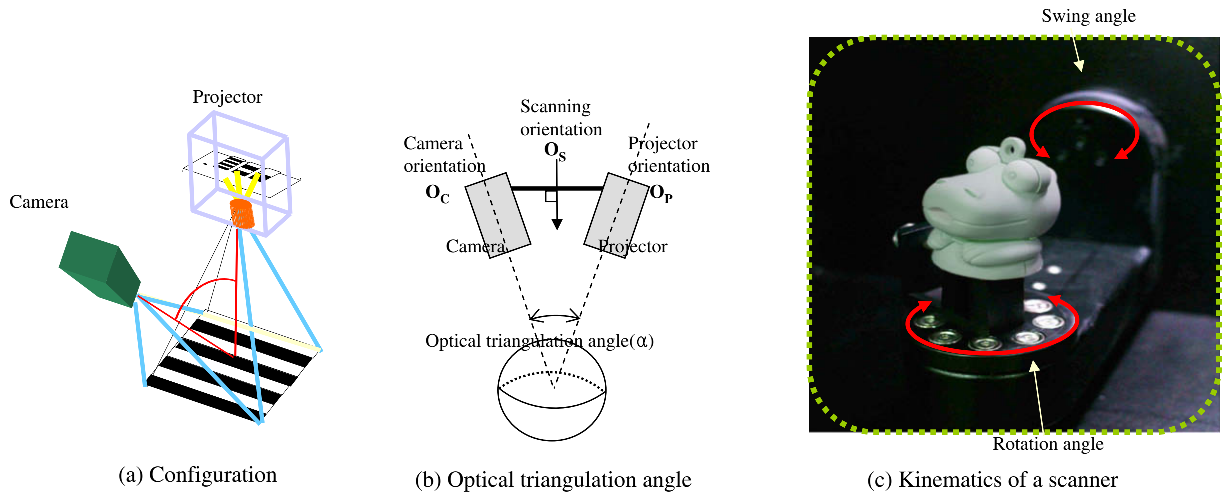

Fig. 1. SLS mechanism.

ognition, and dimensional measurement. An SLS is a general method of acquiring surface range data from a scene. For such systems, an object is illuminated from a structured light source and this scene is imaged by a camera. Examples of the output from an SLS are shown in Fig. 2.

Fig. 2 shows examples of range images acquired from different directions. As an SLS can measure only the visible (accessible) area from a specific direction, it is necessary to scan multiple times to obtain a complete model. However, it is more desirable to minimize the number of scanning directions to save the measuring time and the amount of required memory. Although, the scanning technology of an SLS has received a considerable recognition in industry, no systematic methodologies exist for the automation of SLS-based scanning tasks. Much of the work has been done manually through the intuition of skilled workers. Manual scanning requires highly skilled workers as well as much time and effort. For the automated scanning of an SLS, it is necessary to consider the visibility of a given object from a specific direction. As the visibility problem has various applications, including NC machining (Balasubramaniam et al., 2002; Chen & Woo, 1992; Choi & Jerard, 1998; Kang & Suh, 1997), mold partitioning (Khardekar et al., 2006; Huang, Gupta, & Stoppel, 2003; Priyadarshi & Gupta, 2004), the use of a coordinate measuring machine (CMM) (Spyridi & Requicha, 1990), and laser scanning (Lee & Park, 2000; Son et al., 2002), it has long been studied by many researchers. The related research activities are briefly described below. Woo (1994) presented the concept of using convex visibility maps that partition the Gaussian sphere, describing their application to different classes of visibility problems in manufacturing. The main focus of his paper was the development of a method that reduces the number of setups required for machining by clustering overlapping visibility maps for different surfaces to be machined. Kang and Suh (1997) proposed a method of calculating the setup orientations for five-axis machining that is implemented by numerical simula-

Fig. 2. Range images acquired from different directions.