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Next viewing directions for the scanning of dental impressions☆

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HIGHLIGHTS

- Dental impression scanning with the minimum number of scanning operations.
- Graphics board utilization to accelerate the evaluation of visibility.
- Missing area identification from range images.
- Next viewing directions from the visibility of missing areas.
- Proposed procedure is more than twice faster compared to conventional method.

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ABSTRACT

This paper proposes a scanning procedure for a structured light system (SLS) to measure dental impressions. Although increasing the number of scanning orientations may improve the quality of a scanned model, it is desirable to minimize the number of scanning operations to time and data storage. We attempt to reduce the number of scanning operations to the least number that will still acquire a complete model. The proposed procedure must resolve two sub-problems: (1) identification of missing areas from given range images, and (2) determination of the next viewing directions to fill those missing areas. If we consider range images as triangular meshes, the sub-problems can be solved by using well-known geometric algorithms. The triangular meshes, however, may consist of tens of millions of triangles, which require an unacceptably long time to compute. To cope with this problem, we propose two key ideas: (1) utilizing an inherent attribute of a range image, the map structure; (2) utilizing a graphics board to accelerate the evaluation of visibility. Our demonstration proves that the proposed approach improves the quality of scanned models and reduces the number of scanning operations.

1. Introduction

Nowadays, all-ceramic restorations for missing tooth structures are becoming popular because of their translucency, which minimizes gingival shadowing and maximizes the appearance of health [1]. Because all-ceramic restorations require different manufacturing processes relative to those used with traditional metal restorations, many researchers have attempted to develop new manufacturing processes involving CAD/CAM (computer-aided design/manufacturing) technologies [2]. These CAD/CAM-based manufacturing procedures involve the machining of ceramics that are partially sintered. After machining, the ceramic restorations are fired again to form a hard ceramic. The ceramic materials include glass-boned porcelain and phase-stabilized zirconia.

Fig. 1 shows the manufacturing procedure for all-ceramic restorations. The process consists of four steps: (1) preparation of a dental impression, which is usually carried out by dentists; (2) scanning the dental impression to create a proper CAD model (i.e., a triangular mesh model); (3) machining all-ceramic materials to create the restoration; (4) sintering the machined restoration to form a hard ceramic. Because the final product of the manufacturing procedure is intended to replace a person's missing tooth structure, the required accuracy (50 μm) should be ensured throughout all steps of manufacturing.

This paper focuses primarily on the second of the four steps shown in Fig. 1 (scanning a dental impression), because it is crucial for the accuracy of restoration. For scanning dental impressions, it is necessary to use optical measurements based on machine vi-

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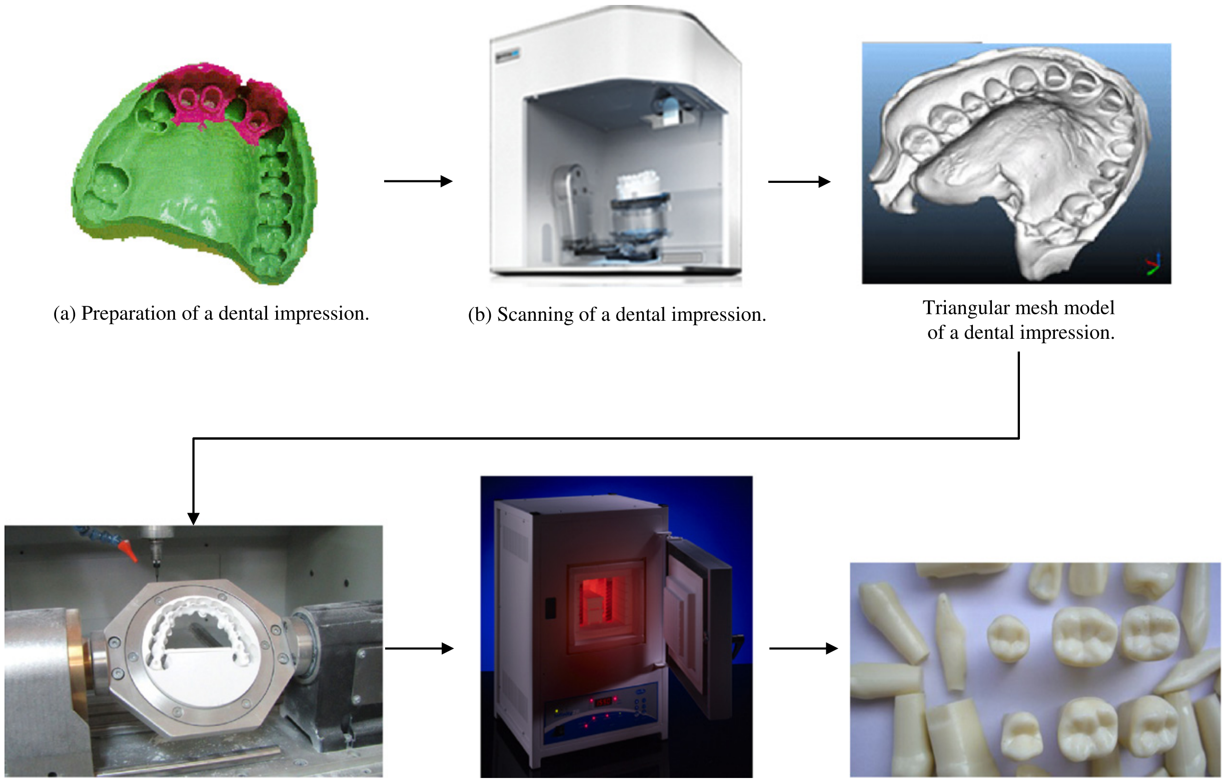
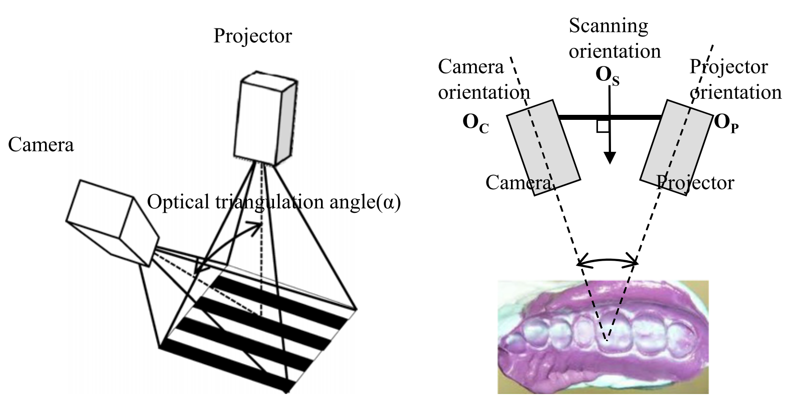


(a) Preparation of a dental impression. (b) Scanning of a dental impression. Triangular mesh model of a dental impression.

(c) Machining all-ceramic materials. (d) Sintering the machined restoration. Final product.

Fig. 1. Manufacturing procedure for all-ceramic restorations.



(a) Optical triangulation angle. (b) Scanning orientation.

Fig. 2. Configuration of a structured light system.

sion cameras. Structured light systems (SLS) are currently popular for use in dental CAD/CAM due to their fast measuring speed, simple optical arrangement, non-contact arrangement, moderate accuracy, low cost, and ability to function under varying ambient light conditions. Three-dimensional range images consist of spatial coordinates for the surface points of an object [3]. They are useful for 3D object matching, object recognition, and dimensional measurement. An SLS provides a general method for acquiring the surface range data from a scene.

Fig. 2 shows the typical configuration of an SLS that consists of a projector and a camera. In an SLS, an object is illuminated from a structured light source (i.e., a projector) and the scene is captured by a camera. The angle between the projector and the camera is known as an optical triangulation angle. Because the optical triangulation angle does not change during scanning, the camera and projector orientations are restricted by the scanning orientation. An SLS can measure only the area visible from a specific scanning orientation; however, the geometry of a dental impression is usually complicated. Therefore, a typical SLS has mobile axes (a swing axis and a rotation axis) to enable multiple scan operations from different directions.

As shown in Fig. 3, we may improve the quality of a scanned model by increasing the number of scanning orientations. Using many scanning operations, however, requires an excessive amount of scanning time and computer memory. As long as a complete model can be acquired, it is desirable to minimize the number of scanning operations in order to save time and memory. Scanning of a dental impression is currently performed in three steps: (1) multiple range images are acquired with initial scanning orientations; 40–60 orientations are used, depending on the complexity of the impression (Fig. 4-(a)), (2) a human operator conducts manual scanning operations to fill missing areas (Fig. 4-(b)); (3) all range