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3D shape reconstruction of teeth by shadow speckle correlation method

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Abstract

This paper presents a new method for 3D shape reconstruction in computer-aided dental prosthetics. A specklegram is projected onto the tooth to be measured. This shadow speckle image is recorded and then processed by a digital image correlation method, which enables the computation of 2D shapes based on the similar principle of shadow moiré method. By repeating the procedure for all the sides, i.e., one crown and several side surfaces, local 2D shapes can be measured precisely. Afterwards, these local 2D profiles are merged to form a 3D model, during which certain constraints such as the widths along perpendicular directions are introduced to guide the process. As the height information within an entire image field is recorded instantly, it has the potential to be employed in an intra-oral environment, which would make the patient feel more comfortable during the restoration process. In vitro experiments were carried out on gypsum teeth models and the results proved the effectiveness of the proposed method.

Keywords: Shadow speckle; Digital image correlation; Dental prosthetics; 3D shape reconstruction; Shape measurement

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1. Introduction

Traditional tooth restoration is usually a complicated process. Firstly, it requires taking an impression of the relevant teeth in maxilla and mandible so that a die can be made. Then the dentist will make teeth models and design a restoration crown, an inlay or an onlay. It is primarily an artistic work based on the experiences of the dentist. Even the most experienced dentist can hardly guarantee the same prosthetic result for the same patient. This situation has been improved significantly thanks to the applications of computer-aided design and manufacturing (CAD/CAM) techniques in the last two decades. The pioneering work was carried out by Duret [1] in the 1980s. Since then, researchers from both clinics and academy had been continuously working on developing innovative techniques for quantitative 3D model reconstruction and prostheses fabrication, aiming at both speeding up the dental restoration process and making it a more automated task. The first commercialized dental CAD/CAM system, CEREC, was launched on the market in 1987 [2]. Today, its improved systems have been widely used in dental clinics, making CEREC the most successful commercialized CAD/CAM dental prosthetic system in the world.

Normally, a computer-aided dental restoration system consists of three parts: (1) 3D model reconstruction for all the corresponding teeth; (2) computer-aided design to generate an appropriate prosthetic model of a crown, an inlay or an onlay numerically; and (3) computer-aided manufacturing of prostheses from the 3D model using typically the rapid prototyping (RP) techniques. Among them, an accurate measurement of 3D models of the teeth is the basis of the entire process. In view of the clinical requirements, the non-contact optical method is obviously the ideal approach for this technique. In the CEREC system [2–4], a probe was designed to take optical impression of the prepared tooth. However, it can only detect depth of cavity, not the complete 3D shape of the teeth. The other CAD/CAM systems [5–8] tended to rely on invitro shape measurement, mostly using a laser scanning technique to measure the shape of the model rather than the original tooth. This is because laser scanning is actually a point-wise method in principle, which allows only one height data point to be measured or recorded at a single instant. The use of a particular mechanical positioning setup, though, makes the point-wise scanning a rapid process of possibly within a fraction of a second, and it brings certain restrictions in the meantime that prohibits its direct application in an intra-oral environment.

The aim of this paper is to introduce an approach that can be potentially used in an intra-oral environment by a specially designed probe. Among all the non-contacting optical methods for contour measurement, the well-developed one is the shadow moiré method [9], which has been widely used for research and in industry. It has the capability of recording the contour information within the whole field of view of an object instantly, and the height data can be calculated subsequently by numbering the orders of the shadow moiré fringes. However, it has a major disadvantage that limits its application in dental prosthetics. When the shape of an object contains discontinuity, determining the fringe order of the recorded shadow