A 3D sensor for intraoral metrology

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We introduce a miniaturized optical 3D sensor. One of its potentials is the intraoral measurement of teeth. In the presence of unavoidable relative motion between the sensor and the patient dental applications require a measuring uncertainty of less than 30 µm and a depth of field of 15 mm. Both requirements contradict each other. We solve this by a novel principle "Flying Triangulation".

1 Introduction

There are plenty of 3D measurement principles for the quality control, reverse engineering, and virtual reality which allow the sensor to acquire full-field surface 3D information from one perspective [1]. The typical methods are e.g. phase-measuring triangulation with fringe projection, laser confocal sampling and interferometry. Due to the fact that these methods always need to acquire multiple images to obtain one single 3D view the sensor has to stand still during the acquisition. This restriction makes the measurement of a complex object (e.g. sculpture and tooth) elaborate and time consuming. A movable 3D sensor is in need to solve this problem.

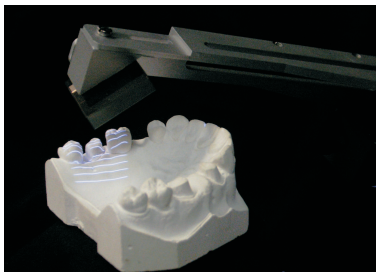

Fig. 1 *Prototype of a miniaturized single-shot intraoral 3D sensor based on the "Flying Triangulation" principle.*

We employ the novel measurement principle called "Flying Triangulation" [2], which combines a 'simple' single-shot sensor and sophisticated registration algorithms [3]. This allows us to freely move the 3D sensor around the object (see Fig. 1). One of its potentials is the intraoral measurement of teeth with a miniaturized sensor.

An intraoral measurement mainly aims at obtaining digital 3D information of the teeth from which the crown can be easily tailored by software and then fabricated by a machine. In dental applications the gap between the fixed crown and the prepared teeth stump is not allowed to exceed 120 µm, otherwise bacteria can penetrate the gap which may lead to caries. Thus, the required measurement uncertainty should be below 30 µm (one standard deviation) for a single 3D view within a depth of field of at least 15 mm. To meet both demands the miniaturized sensor needs to be built at its physical limits. We achieve the required specifications by optimizing the physical and technical parameters, as well as the projected light pattern.

2 Single-shot sensor

Considering the concept of the sensor based on active triangulation there are three challenges to overcome for the planned measurement task. First, the sensor must have a short exposure time to avoid blurring of the captured pattern. Second, the sensor parameters should be optimized to meet the requested measurement uncertainty within a certain depth of field. Third, the projector and the camera should be synchronized precisely.

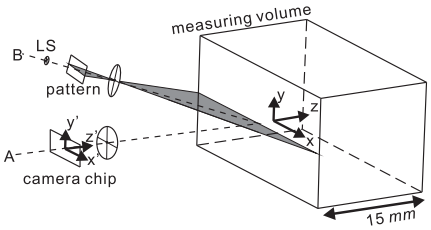

Fig. 2 *Setup of the single-shot sensor [4].*

We realized an exposure time of 15 ms by employing both a slide projector with a high-power light source (see Fig. 2) and an electric amplification which enables a frame rate of 30 fps. By means of the right choice of illumination and an optimization of camera and projector apertures the required measurement uncertainty of 30 µm (for a single 3D view) is achieved in the entire measuring volume (see Fig. 3). Pulse trains are generated by a timer card to garantee the correct working timing of the projection and observation components.

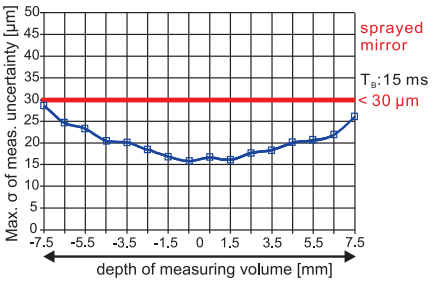

Fig. 3 *The realized height uncertainty is below 30 µm within the entire depth of the measuring volume [4].*

3 Structured light pattern

The correct evaluation of the distorted pattern to obtain the 3D information is always a big challenge, especially in the application of intraoral metrology, due to the depth of teeth and the complexity of teeth surface. Fig. 4 shows examples of observed light lines which were projected respectively onto a thick cuboid and a dental cast. Fig. 5 denotes the height reconstruction errors (the outliers marked by a red ellipse) resulted from the deep gap between enamel and gingiva [4].

Fig. 4 *Examples of indexing difficulty that light lines were projected on a thick cuboid (left) and a dental cast (right, segmentation of an observed light pattern).*

A solution is to apply a light pattern with a certain structure that is projected by a light source onto the measuring surface. Thus, a set of corresponding pixels on observed images can be easily distinguished, located, and matched by a-priori knowledge of the structure and a decoding strategy.

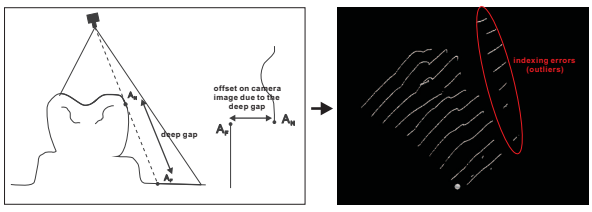

Fig. 5 *An example of height reconstruction errors for the application of teeth measurement [4].*

Many existing approaches try to encode the structured light pattern with a lot of light lines in order to achieve accurate results but most of them require color light or suffer from complicated image processing. We propose a new structured light pattern with an elaborate decoding and indexing method that demands only grayscale information to solve the above difficulties.

By spatial intensity modulation of light lines, observed fringe segmentation (see Fig. 4 right), and index decoding we can distinguish a large number of light lines. Therefore, our structured light pattern can yield much more information in a single 3D view than uncoded patterns but simultaneously assures a unique identification of the pattern in the camera image. That is, by enriching the information of each sparse 3D view we can achieve a high robustness of our registration algorithms with accurate 3D surface information.

4 Measurement result

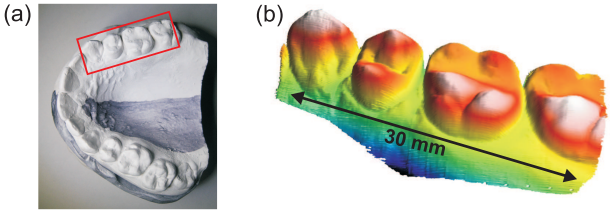

Fig. 6 *(a) Object under test: a dental cast. (b) 3D surface model reconstructed from 500 sparse 3D views using surface fit in software "MountainsMap" (3 million points, acquired within 17 seconds).*

Object under test was a dental cast (see Fig. 6(a)). The sensor was moved around the teeth and 3D data was acquired. Employing the method described in [3] the complete point cloud was formed by aligning the single partial-field 3D views to each other, without knowledge of the sensor movement (see Fig. 6(b)).

References

[1] M. Knauer, C., C. Richter, and G. Häusler, “3D sensor zoo - Species and natural habitats,” Laser Technik Journal **3(1)**(33-37) (2006).

[2] S. Ettl, O. Arold, P. Vogt, O. Hybl, Z. Yang, W. Xie, and G. Häusler, “Flying Triangulation- a new optical 3D sensor enabling the acquisition of surfaces by free-hand motion,” DGaO-Proceedings **A13** (2009).

[3] O. Arold, Z. Yang, S. Ettl, and G. Häusler, “A new registration method to robustly align a series of sparse 3D data,” DGaO-Proceedings **P20** (2009).

[4] Z. Yang, “Ein miniaturisierter bewegungsunempfindlicher 3D-Sensor,” Master’s thesis, Hochschule für angewandte Wissenschaft und Kunst, Hildesheim/Holzminden/Göttingen (to be published).