"Flying Triangulation" - a new optical 3D sensor enabling the acquisition of surfaces by freehand motion

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There is a high demand for handheld motion-robust optical 3D sensors. They simplify the measurement of complex surfaces by being freely movable around the object. Further, they enable acquisitions where a motion of the object relative to the sensor is unavoidable. Existing sensors lack to have both properties simultaneously. We present a new measurement principle that enables such tasks.

1 Introduction

In order to obtain complete 3D surface information of an object it is often necessary to acquire many partial 3D views. For this purpose, the sensor has to be moved (e.g. for the acquisition of sculptures or rooms). Further, in many cases a motion of the object relative to the sensor is unintended but inevitable (e.g. for medical applications such as intraoral measurements of teeth). Nearly all existing optical 3D sensors either lack an easy handling or require a standstill during the acquisition of a single partial 3D view, since usually multiple camera shots have to be taken for this purpose. This makes such measurements elaborate or even impossible.

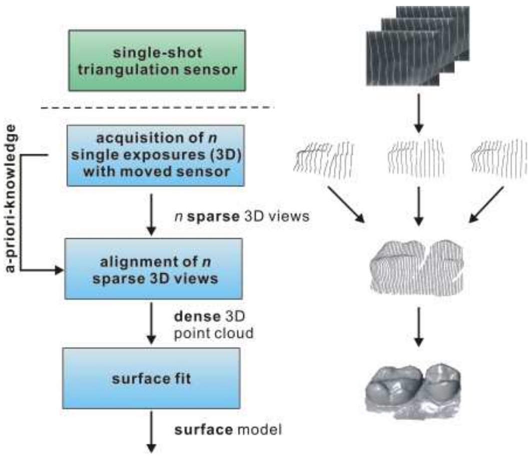

Fig. 1 *The work flow of "Flying Triangulation": A single-shot sensor generates a 'movie' of 3D views. These are aligned to yield a complete 3D surface model.*

We demonstrate an optical 3D measurement system that overcomes the mentioned difficulties. It combines a simple (single-shot) sensor and sophisticated algorithms (Fig. 1). A series of sparse 3D views is acquired while the handheld sensor moves freely around the object. In order to get a dense 3D surface model the views are aligned by specially developed algorithms. In this paper we will present this new 3D sensor and show a measurement example.

2 Measurement principle

The new measurement system is called "Flying Triangulation". It employs a single-shot sensor which enables a motion-robust acquisition while being freely moved around the object. However, in order to avoid an elaborate repositioning and a standstill of the sensor we have to pay a price: We obtain only "sparse" 3D data, instead of dense surface information, in each single measurement.

The concept of the sensor is as follows (see Fig. 1): The single-shot sensor is based on the well-known principle of active triangulation. Here, a light pattern is projected onto the surface. The height information is obtained from the distortion of the pattern observed by the camera. A series (a 'movie') of 2D images is taken and from each single image sparse 3D data can be generated.

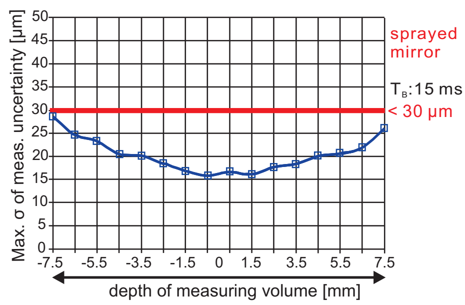

Fig. 2 *The realized measurement uncertainty is below 30 µm within the entire depth of the measuring volume of 15 mm [1].*

In order to obtain a complete 3D point cloud of the surface, the single 3D views need to be aligned. Common registration methods are based on detecting corresponding surface features and aligning them onto each other. However, sparse 3D data does not provide surface information - only pointwise information is available. Therefore, a new registration method especially tailored for sparse 3D data had to be developed. A more detailed description of the method can be found in [2].

Finally, in order to view the obtained 3D surface on a PC a surface model is required. For this purpose, a surface fit has to be performed which then yields the desired result.

3 Hardware and software challenges

There are three main challenges for a handheld motion-robust optical 3D sensor. First, the sensor should be freely movable during a single measurement. Second, the height measurement uncertainty should be minimized to meet the demands of the application, for example below 30 µm for an intraoral measurement of teeth (see Fig. 2). And third, the sensor should be handheld in order to ensure an ease of acquisition.

The registration of the resulting 3D data also implies several challenges: First, the sparse 3D data should be aligned robustly. Second, the resulting propagation error needs to be minimized. And last, the registration should be performed in real time. How we overcame these challenges and further details about the sensor specifications can be found in [1, 2].

4 Measurement example

A measurement was performed with the sensor shown in Fig. 3. The object under test was a dental cast (Fig. 4(a)).

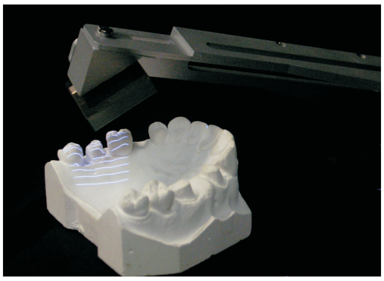

Fig. 3 *Prototype of miniaturized single-shot intraoral 3D sensor based on the 'Flying Triangulation' principle.*

The sensor was moved freely along the teeth while acquiring 500 images in 17 seconds yielding about 3.6 million points. The sparse 3D views (Fig. 5, left) were automatically aligned by applying the method described in [2].

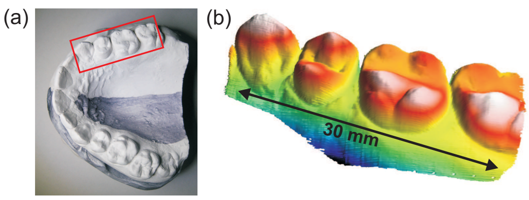

Fig. 4 *(a) Object under test: a dental cast and measured area (red). (b) 3D surface model reconstructed from about 3.6 million 3D points.*

The resulting complete and dense 3D model of the measured teeth is depicted in the right of Fig. 5. For visualization purposes the surface was fitted using the software MountainsMap. The outcome is depicted in Fig. 4 (b).

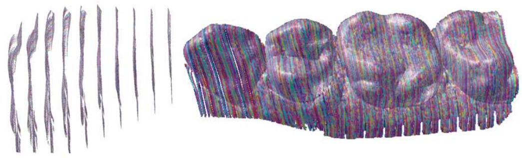

Fig. 5 *Left: Several unregistered 3D views in the sensor coordinate system. Right: Complete and dense 3D model after automatic registration.*

During an acquisition, the sensor should deliver immediate feedback for the operator about missing parts of the object. However, the real-time demand is not yet achieved for the 3D data generation from the single 2D images. But for the 2D image acquisition and for the registration the real-time demand are reached already (see Tab. 1 for details).

Acquisition	15 ms
3D data generation	1.5 s
Coarse registration	10 ms
Fine registration	30 ms

Tab. 1 *Time demands for a single 3D view, obtained at a common PC (Quadcore 2.83 Ghz, 8 GB RAM).*

5 Conclusion and outlook

We introduced a new measurement principle called "Flying Triangulation". It is robust against motion and the sensor can be hand guided. This enables a flexible measurement of rough surfaces 'on the fly'. We further demonstrated that the sensor has been optimized to allow a free motion during a single measurement with minimized measurement uncertainty. The next steps are to speed up the algorithms, especially the 3D data generation [3], to meet the real-time demand and to develop a sensor for larger objects, such as sculptures or faces.

References

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

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

[3] Z. Yang, W. Xie, O. Arold, P. Vogt, K. Bobey, S. Ettl, and G. Häusler, "A 3D-Sensor for intraoral metrology," DGaO Proc. **P19** (2009).