3D face scanning with "Flying Triangulation"

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Based on our new measurement principle "Flying Triangulation", we demonstrate a handheld 3D scanner for objects with a size of a few hundred millimeters. A specific application is the 3D measurement of human heads. The sensor can be freely moved around the object without requiring any external tracking. The resulting 3D model is displayed in real time.

1 Introduction

Last year we introduced a new optical 3D measurement principle: "Flying Triangulation" [1]. It combines a single-shot sensor and sophisticated algorithms. Using this new principle, we developed a handheld 3D scanner for objects such as sculptures, archeological artifacts, or parts of the human body, especially for faces (see Fig. 1).

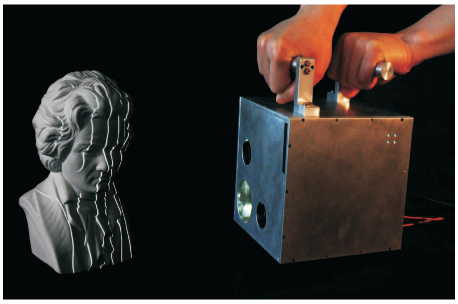

Fig. 1 *Prototype of the hand-held motion-robust sensor.*

Due to its single-shot property, neither the sensor nor the object have to stand still during the time of acquisition. Thus, complex objects can be measured quite comfortably. External tracking is not required for the registration. Our handheld sensor can be freely moved around the object and the resulting 3D model is displayed in real time.

2 Measurement principle

The idea of the measurement principle is depicted in Fig. 2. Our single-shot sensor is based on light sectioning, realized for two independent triangulation planes (see Fig. 3): Two orthogonal light patterns are alternately projected onto the object surface while the sensor is freely moved around the object.

From each line pattern observed by the camera, the height information can be calculated. By taking a series of (several hundred) 2D camera images, a large amount of sparse 3D views can be generated.

The sparse 3D views are successively aligned to each other by sophisticated registration algorithms [2] while the current registration result is displayed in real time. Successively, we obtain a dense 3D model.

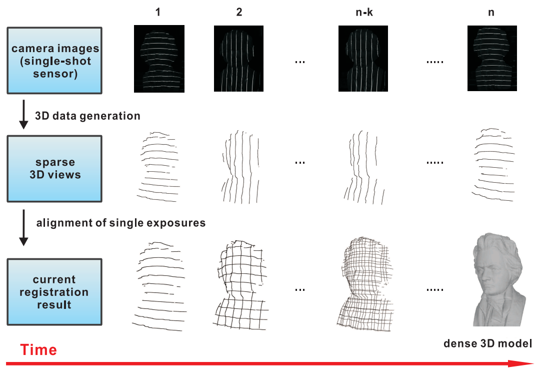

Fig. 2 *Principle of Flying Triangulation. Each exposure of the camera yields sparse 3D data which is automatically aligned to the already acquired 3D data. Successively, a dense 3D model of the object evolves.*

3 Single-shot sensor specifications

To yield a satisfying result of the measurement, several key requirements have to be fulfilled: To guarantee motion robustness, the sensor must have a short exposure time. The triangulation angle has to be chosen small enough to avoid shading effects [3]. The internal parameters of all system components have to be optimized to achieve the requested measurement uncertainty.

Our sensor consists of two projection light paths and one observation light path observation (see Fig. 3). Each projection unit employs a high-power LED, a specially designed line pattern, and an objective with low aperture. For observation, we use a FireWire CCD-camera with up to 30 frames per seconds. The light sources are synchronized with the camera.

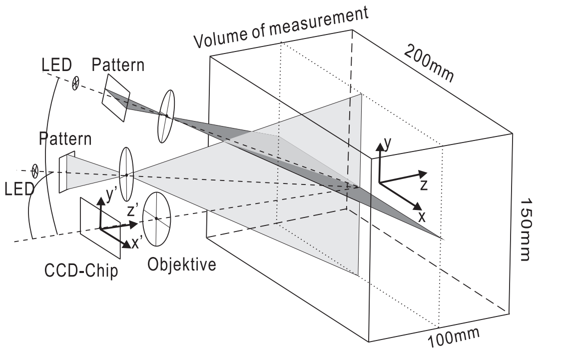

Fig. 3 *Scheme of the single-shot sensor.*

The whole sensor setup is stored in a handy housing measuring $150\,\mathrm{mm} \times 150\,\mathrm{mm} \times 180\,\mathrm{mm}$ (see Fig. 1). The main specifications of the sensor are listed in Tab. 1.

Framerate	30 fps
Measurement volume	$150 \times 200 \times 100\,\mathrm{mm}^3$
Lateral resolution	$\mathrm{d}x = 200$ µm
Measurement uncertainty	$\delta z \leq 150$ µm

Tab. 1 *Specifications of the single-shot sensor.*

4 Results and discussion

Objects under test were a bust of Beethoven and a human head. Both objects were captured with the presented hand-guided Flying Triangulation sensor. In Fig. 4 the shaded 3D model of the measured bust is depicted and Fig. 5 shows the resulting point cloud of a human face.

Fig. 4 *Shaded 3D model of a bust measured "on the fly" with our Flying Triangulation sensor. Right corner: Image of the bust. For a movie of the measurement sequence see [4].*

The result of the measurement progress is displayed in real time. As displayed in Tab. 1, the measurement uncertainty is below $150\,\mu\mathrm{m}$ within the entire measurement volume.

Flying Triangulation has several key advantages compared to the so-called fringe projection principle, which is commonly employed for similar measurement tasks: The 3D data can be calculated directly from one single camera image, while fringe projection needs at least 3 images. Furthermore, the single-shot sensor consists only of non-expensive components: There is no need for spatial light modulators (SLM) or other expensive optical components.

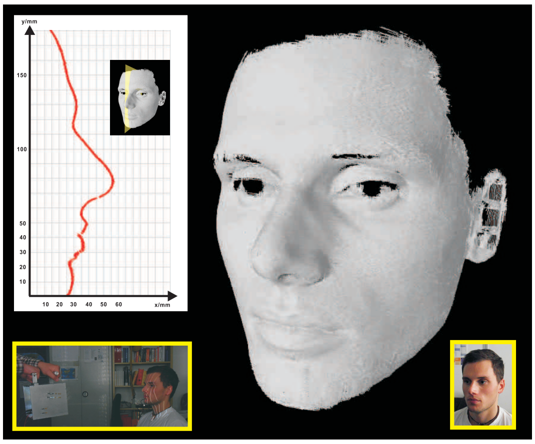

Fig. 5 *3D point cloud of a human face measured with our Flying Triangulation sensor. Left top: Cross section of measured 3D face point cloud. Left bottom: Picture of the measurement process. Right bottom: Picture of the measured face.*

The newly developed sensor can be employed for various applications: 3D measurement of faces and other parts of the human body, restoration of artworks or documentation in archeology and crime scenes. Industrial applications in reverse engineering or rapid prototyping are also conceivable.

Future versions of the single-shot sensor are intended to measure at other scales. This leads to a multiplicity of new applications. The universal sensor principle Flying Triangulation permits measuring on small scales like intraoral teeth scanning [3] as well as measuring on large scales such as acquisitions of the interior of rooms.

References

[1] S. Ettl, O. Arold, P. Vogt, O. Hybl, Z. Yang, W. Xie, and G. Häusler, ""Flying Triangulation": A motion-robust optical 3D sensor principle," in *Proceedings of Fringe 2009*, W. Osten and M. Kujawinskaja, eds., pp. 768–771 (2009).

[2] O. Arold, Z. Yang, S. Ettl, and G. Häusler, "A new registration method to robustly align a series of sparse 3D data," DGaO-Proceedings, 110, P20 (2009).

[3] Z. Yang, W. Xie, O. Arold, O. Hybl, P. Vogt, K. Bobey, S. Ettl, and G. Häusler, ""Flying Triangulation" - a new optical 3D sensor enabling the acquisition of surfaces by freehand motion," DGaO-Proceedings, 110, P19 (2009).

[4] *Movie of the measuring sequence of the bust*, http://www.optik.uni-erlangen.de/osmin/upload/flytri/videos/Messung.wmv.