

# Facial topometry using pulsed holography

S. Hirsch<sup>a,b</sup>, S. Frey<sup>a</sup>, A. Thelen<sup>a</sup>, N. Ladrière<sup>a</sup>, P. Hering<sup>a,c</sup>

<sup>a</sup> *Stiftung caesar, Ludwig-Erhard-Allee 2, 53175 Bonn*

<sup>b</sup> *HFZ, Universitätsspital Basel, Schanzenstrasse 46, 4031 Basel*

<sup>c</sup> *Institut für Lasermedizin, Universität Düsseldorf, Universitätsstraße 1, 40225 Düsseldorf*

## 1. Introduction

Planning, simulation and documentation of interventions in maxillofacial surgery require high resolution soft tissue information of the human face. Topometric data may be gained with various methods (CT, optical, contact), and these all have their advantages and drawbacks. We developed a topometry system using pulsed holography to capture the surface of objects.

In topometry it is necessary to avoid movement of the object during measurement. For static objects this is hardly of influence, however, movement artefacts are the primary cause of errors in measurements of living or moving objects. In this case either the recording time needs to be sufficiently short, or the object needs to be immobilized as much as possible. Most current topometric techniques feature overall capture times ranging around or just below one second. Although their nominal accuracy, which is defined on static objects, might be good, the surface quality is often questionable. Therefore, great efforts are being made to speed up the measurement.

Our system avoids movement artefacts systematically, and is therefore able to perform surface measurement even on moving objects. We record the object information holographically with a single pulse of 20 ns duration. This approach virtually freezes all movements [1,2], and allows us to digitize even uncooperative patients, e.g. babies, with high precision.

## 2. Mobile holographic camera

During our development of holographic topometry we used a standard GP-2J holographic camera from GEOLA with a Nd:YLF laser (526.5 nm). There we saw the demand for a flexible and mobile recording system. In cooperation with GEOLA uab (Lithuania) we designed a mobile holographic camera (see Fig. 1, left) with an overhead beam scheme. The system is currently located at the Universitätsspital Basel in the High Tec Forschungszentrum (Prof. H.F. Zeilhofer), where we are performing clinical studies in the field of maxillofacial surgery. The system is also used to conduct measurement projects for data retrieval outside our laboratory.

The heart of the camera is a pulsed Nd:YAG laser with a maximum energy output of 1.4 J at 532 nm wavelength,

using a master-oscillator arrangement and second harmonic generation. The pulse duration is 20 ns with a coherence length of approximately 6 m. Due to its modular and compact construction, the camera is portable and can be set up in the field within 20 min. The camera also contains the option to engage structured illumination. This feature allows the digitization of objects that lack sufficient structure on the reflecting surface.

The recording procedure is usually performed with the patient in an upright sitting position. We use diffuser plates on the two illumination ports, which ensures a homogeneous illumination and which makes the hologram capture eyesafe, so there is no exposure to harmful radiation (see Fig. 1, right). The camera features a mechanical shutter system, and light safe cassettes for handling the holograms. Thus, we may work and record in daylight conditions.

## 3. Holographic topometry

With our system, the capture of the face and the reconstruction of the textured surface are performed in two separate steps.

The portrait hologram of the patient is recorded with a single 20 ns laser pulse of about 1 J energy. We use standard holographic plates or film VRP-M from Slavich as recording material. For chemical processing of the exposed film we adapted an automated film processor [3] to the special needs of holograms. The fundamentals of hologram recording are assumed to be known and will thus not be illustrated at this point.

The second step is the optical reconstruction of the hologram (see Fig. 2). The hologram is illuminated with the conjugate reference beam, thus forming the real image. As we have no frequency shift between the recording laser and the reconstruction laser, the real image has exactly the same dimensions as the real object, showing next to no aberrations. The real image is then scanned axially in 2d-projections of equal distance. With a lateral resolution of 200  $\mu\text{m}$ , the inter slice distance seems to be reasonable between 100  $\mu\text{m}$  and 1 mm. The procedure is referred to as hologram tomography; a typical image stack contains 256–512 slices representing the full volume of the face.

In the volumetric image stack, each slice contains information of the focused regions and blurred information of all neighboring regions (Fig. 3) as described by the point spread function (PSF) of each point. The PSF is not static

---

E-mail address: [hering@uni-duesseldorf.de](mailto:hering@uni-duesseldorf.de) (P. Hering).



Fig. 1. Left: Mobile holographic camera HSF-mini, developed in cooperation with GEOLA uab (Lithuania). Right: The camera from the viewpoint of the patient. The two illumination ports with the diffuser plates are on the left and right, and the mechanical shutter system that covers the holographic plate is in the center.

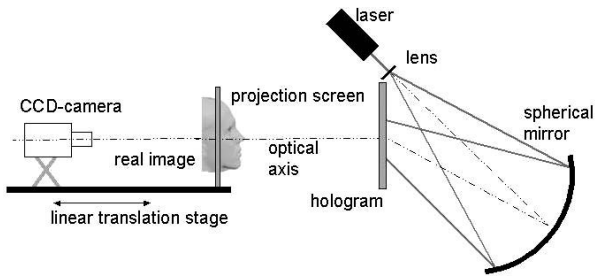


Fig. 2. Optical reconstruction of the hologram and digitization of a set of two-dimensional projections of the real image.

over the volume, so the volume cannot be deconvoluted effectively. As a result, we face the task of discriminating between focused and unfocused regions.

This is achieved by defining a focus measure operator  $F_{xy}(z)$ , whose values are compared for different  $z$ -positions. Such a comparison causes a curve like that shown. The slice position, which is maximal towards this focus measure operator, leads to the desired  $z$  coordinate corresponding to the lateral position  $(x, y)$  and therefore to the topometry of the recorded object [4]. By determining the appropriate depth

value for each point a height map for the complete face is established (depth-from-focus approach).

When the focus of the surface is identified, one can extract the surface coordinate as well as the brightness information of this point [5]. So, along with the surface one obtains a grayscale representation of the surface texture. The combination of this information yields textured 3d models with fine details (see Fig. 4). Here the texture is dyed to give a more natural look, actually it is the reflection of a green light source. The accuracy of the surface gained by our method is about 0.4 mm [1].

#### 4. Applications

The main motivations of our topometry method derive from the medical field [9]. For maxillofacial surgery it is one of our goals to capture the face of baby patients. Facial data are of crucial importance to the surgeon for planning and documentation of cleft lip interventions. These cases are impossible to capture for other systems, especially if the young patients are awake. The results of these applications will be presented.

When using CT data of the skull in addition to the soft tissue information of the hologram it is possible to achieve a



Fig. 3. In the projections of the real image, each slice displays focused and unfocused regions. The evaluation of the focus measure operator  $F_{xy}(z)$  for a specific lateral coordinate  $(x, y)$  along the  $z$ -axis is shown. The  $z$  value, for which  $F_{xy}(z)$  is maximal, delivers the third coordinate of the focus point.



Fig. 4. The textured 3d model is a combination of the surface with the inherent grayscale texture of the hologram.

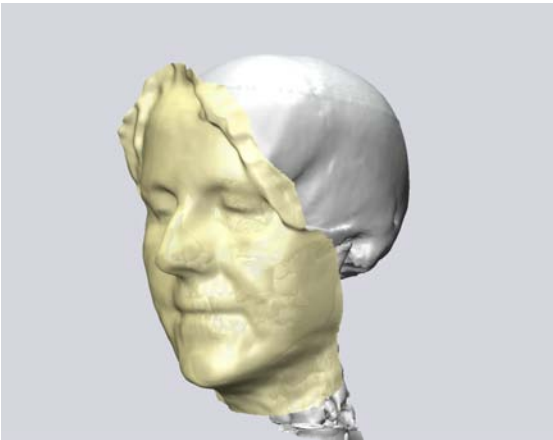


Fig. 5. Resulting three-dimensional model as a combination of CT data with holographic surface data. The texture information is not shown in this figure.

very accurate representation of the patient's face along with the face texture. CT can give a good volume representation of the head; the current minimal slice thickness of a CT is 0.4 mm. Through appropriate threshold it is possible to obtain bone information for the head and the facial surface. By registering the holographically attained surface to the facial surface from the CT scan, the surface of the holographic method is perfectly aligned with the CT surface (Fig. 5). The result is a multimodal data set of skin and bones, equipped with a perfectly matched surface texture.

It is standard practice to expose the patient to a minimal radiation dose. As a consequence, a patient will be scanned with a larger slice distance and only a confined volume will be recorded. Especially in these cases a good surface scan is of high value, a task which cannot be completed with the CT data alone. Obviously our 3d shells can be used to quantify the difference in volume between the individual models, as with any other topometric data. Fig. 6 gives an example of a comparison of the same person before and after



Fig. 6. A patient before and after aesthetic surgery [8].

aesthetic surgery. The difference map in Fig. 7 clearly marks the differences in the volume as a result of the cosmetic corrections [8].

One unique feature of our method is the intrinsic texture which matches perfectly to the topometric information. The resolution is theoretically limited due to diffraction (approximately 1  $\mu\text{m}$ ) and to speckle size (approximately 5  $\mu\text{m}$ ), however, we found that in practice the attainable resolution is much higher (approximately 40  $\mu\text{m}$ ). The advantage of a perfectly fitting texture allows features to be tracked on the surface when comparing different captures. Thus, not only can we quantify the difference in volume, but also have the tools to precisely determine the soft tissue shift [7].

As shown, it is possible to generate digital models of the face/skin, however, it is not limited to this application. We successfully measured various technical objects and digitized surfaces of forensic and archaeological objects. For these applications the capture procedure is obviously not time critical. In Fig. 8, the skull cap of a Neanderthal man was

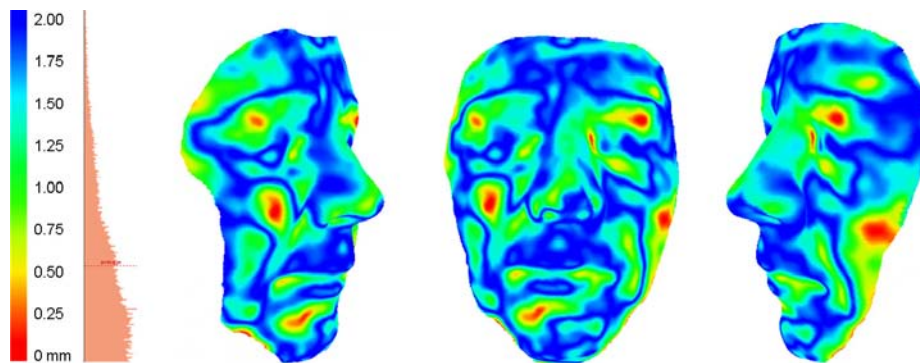


Fig. 7. The images show a color coded difference map between the two surfaces of Fig. 6 [8].



Fig. 8. Digital model of a Neanderthal man's skull cap [7].

recorded from numerous perspectives and combined to a perfect virtual model [7] representing the inside and the outside of the bone.

## 5. Conclusion

With our holographic measurement technique we are able to capture people and digitize the real image in a following step with high precision. The extremely short exposure time of 20 ns systematically avoids any movement artefacts and makes it possible to digitize even moving objects. Due to the large measurement volume, the method can be applied to extended areas. Although we are primarily focusing on medical application, we successfully used our method for various metrological tasks.

In a current effort we are exploring the potential and limitations of complete digital processing of the hologram. It is possible to capture the hologram with a light sensitive array and perform a digital reconstruction of the real image [6]. Due to technical limitations of the current capture hardware, the resolution of the image sensors (approximately 2–10  $\mu\text{m}$ ) is still more than a magnitude away from the resolution of holographic film. However, this approach already shows promising results for small object angles.

## Acknowledgments

This work is supported by CO-ME (Computer Aided and Image Guided Medical Interventions) project funded by Swiss National Research Foundation.

## References

- [1] J. Bongartz, Hochauflösende dreidimensionale Gesichtsprüfvermessung mit kurzgepulster Holographie, Ph.D. Dissertation, Mathematisch naturwissenschaftliche Fakultät der Heinrich-Heine-Universität Düsseldorf, 2002. <http://diss.uni-duesseldorf.de/ebib/diss/file?dissid=192>.
- [2] D. Giel, Hologram tomography for surface topometry, Ph.D. Dissertation, Mathematisch naturwissenschaftliche Fakultät der Heinrich-Heine-Universität Düsseldorf, 2002. <http://diss.uni-duesseldorf.de/ebib/diss/file?dissid=598>.
- [3] N. Ladrrière, Optische und chemische Aspekte der hochauflösenden, automatischen Hologrammentwicklung, M.S. Thesis, Fachhochschule Köln, 2004.
- [4] A. Thelen, J. Bongartz, D. Giel, S. Frey, P. Hering, Iterative focus detection in hologram tomography, *JOSA A* **22** (2005) 1176–1180.
- [5] S. Frey, Three-dimensional facial measurement by portrait holography and texture-based focus detection, Ph.D. Dissertation, Mathematisch naturwissenschaftliche Fakultät der Heinrich-Heine-Universität Düsseldorf, 2005. <http://www.uni-duesseldorf.de/home/etexte/diss/show?dissid=1166>.
- [6] W. Jüptner, U. Schnars, Direct recording of holograms by a CCD target and numerical reconstruction, *Applied Optics* **33** (2) (1994) 179–181.
- [7] A. Thelen, Optimized surface extraction from holographic data, Ph.D. Dissertation, Mathematisch naturwissenschaftliche Fakultät der Heinrich-Heine-Universität Düsseldorf, 2006.
- [8] C.U. Fritzscheier, H.G. Bull, A. Thelen, J. Bongartz, P. Hering, S. Frey, S. Hirsch, N. Ladrrière, Hologramm-Tomographie als Qualitätskontrolle bei ästhetischen Gesichtsoptionen, *Magazine for Aesthetic Surgery* **3** (2005) 14–25.
- [9] A. Thelen, S. Frey, S. Hirsch, N. Ladrrière, P. Hering, Ultrafast holographic topometry of the face for medical applications, *Medical Laser Application* **21** (2006) 9–14.