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Holographic surface imaging for archaeological applications

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Abstract

A new approach to precise 3D topometry for medical applications has been applied for the documentation of cultural heritage. The 3D imaging system works with pulsed holography. With a single pulse of a Nd:YLF laser, a surface is recorded with a holographic camera on photosensitive material. The short exposure time of 35 ns allows for high resolution 3D measurement without movement artefacts. The pulsed technique is robust against vibrations and the latest generation of cameras is portable and works at daylight. The holograms are digitized in a second self-contained unit where the projections of the optically reconstructed real image of the hologram are recorded. Numerical data processing leads to a 3D computer model of the surface with intrinsic gray scale texture. In addition, full-scale daylight copies of the master hologram give an impressive detailed 3D view of the recorded object. The technique is used for 3D imaging of the Windeby Child bog body.

A new method for surface measurement has been developed in Bonn at the *center of advanced european studies and research* (caesar) (Bongartz, 2002; Giel, 2003; Frey, 2005). The most important advantage of the new holographic method is a very short recording time resp. exposure time, taking only 35 ns (35 billionth part of a second), so the results are absolutely focused and show no movement artifacts.
The current main application of our method is medical science: complete documentation and planning of craniofacial surgery requires a three-dimensional view of the bone structure (obtained by computer tomography) as well as an accurate method to detect soft tissue. The latter is provided by the new holographic system.
Aside from medical applications, several inquiries concerning archaeological imaging were directed to our group because of the unique imaging properties of holography. Holography provides a high resolution optical reproduction of a recorded scene in three dimensions, which leads to a most genuine impression of the displayed object. Accordingly, a display hologram can be exhibited in place of the object itself. The presented technique offers the combination of display imaging and non-contact surveying from a single hologram.
Due to ongoing advancements in laser technology hologram recordings are now possible with a mobile holography camera which works at any ambient light condition. The recording procedure is introduced in the next section. The hologram may be copied as display hologram for exhibitions. Furthermore, a textured computer model is retrieved from the recording. These two aspects are presented in section 2. The proceeding closes with a summary in section 3.

Holography camera

A hologram stores phase and amplitude information of a light wave scattered by an object. This is done by superimposing the unfocused object wave and a coherent background wave, the reference wave. The two waves interfere, and the intensity of the interference pattern varies with the relative phase of the two waves. The interference pattern is recorded on a photographic emulsion. The object wave can be restored as virtual image from the hologram by illuminating it with the reference wave. A real image is formed if the hologram is illuminated with the phase conjugate reference wave.
The holographic principle was found by D. Gabor, who received a Nobel price for this discovery in 1971 (Gabor, 1948; Gabor, 1949). Further developments were contributed by Leith and Upatnieks who developed the concept of off-axis holography (Leith and Upatnieks, 1962; Leith and Upatnieks, 1963). For an in-depth presentation of the principles of optical holography the reader is referred to literature (Collier et al., 1971; Hariharan, 1984).
In practice, short laser pulses for holography facilitate a very robust recording set-up. Consequently a mobile holography

set-up has developed in cooperation with Geola Company (www.geola.de). The system is shown in figure 1. It is set up within 20 minutes and works at daylight, thus it allows for in-situ recordings of archaeological sites. The recording procedure does not require a calibration step. Scenes of interest that are recorded on a holographic plate or film are then available for analysis and digitization. Optical read-out may be repeated after years if necessary on the basis of new insights.
In addition to the mobile system we employ a stationary holography camera of the type Geola GP2J. The applications presented below were realized with the stationary system. It is therefore specified more detailed. The stationary holographic camera comprises a flash lamp pumped Nd:YLF laser oscillator with subsequent

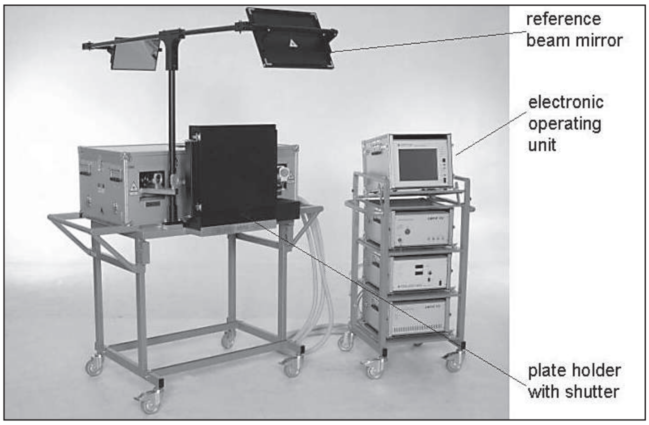

Fig. 1 - The mobile holographic camera for in-situ recordings of sites and scenes.

amplification and second harmonic generation. The resulting wavelength is 526.5 nm. The recording time is 35 ns. Careful mode selection leads to a coherence length of approximately 3 m. The maximum pulse energy is 2 J. The high energy output and the long coherence length allow for an uncritical positioning of objects in front of the camera (a distance of 60 cm is recommended) and for the recording of large objects and scenes of several cubic meters.
The laser beam is split into three beams: Two beams serve for even illumination of the object. They are expanded by concave lenses and diffusor plates at the output ports of the laser. The third beam is the reference beam. After positioning the object and fixing the hologram plate, the recording is carried out by a single push on a button. The hologram plates (VRPM emulsion by Slavich) undergo conventional chemical processing which is finished by a bleaching step. Further information about the system and the material can be found on the internet (http://www.geola.com).

Surface measurement and display imaging of archaeological objects

Scenes that are recorded on a hologram may be restored optically as real image. They are then accessible for precise measurements. The holographic real image yields a one to one copy of the original scene. The real image reconstructed by a standard hologram (30 ¥ 40 cm illuminated area, 60 cm object distance, wavelength 526.5 nm) made with our holographic camera features an optical resolution in the range of 10 µm. To retrieve a computer model of the recorded scene a digitization step is necessary. To this aim digital sectional images of the real image are recorded. Examples of sectional images are shown in figure 2. The object on the hologram is the skull

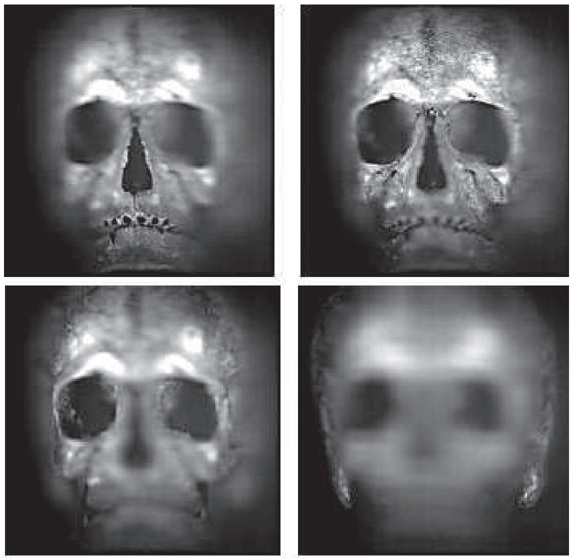

Fig. 2 - Optical sectional images of the real holographic image of a bog body skull (see text for details).

of the Windeby child bog body from the *Archäologisches Landesmuseum, Stiftung Schleswig-Holsteinische Landesmuseen Schloss Gottorf, Germany*.
A few hundred of such projections are recorded with a digital light sensor. Digital image processing yields a surface model that may be edited and visualized with common 3d software (Thelen et al., 2005). The pixel matching texture information is taken from the hologram without a registration step. Figure 3 shows a screenshot of the resulting digital computer model of the skull of the Windeby child bog body.

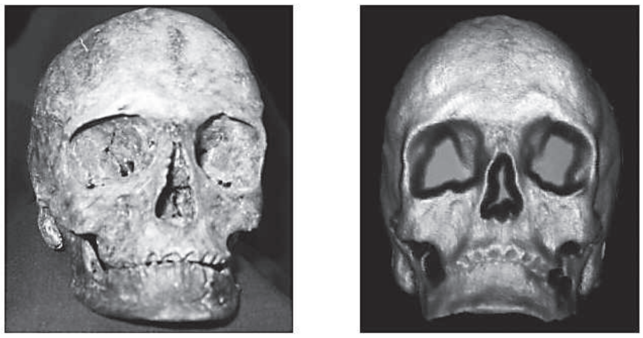

Fig. 3- Part (a) shows a photograph of the skull of the Windeby child bog body; part (b) shows a screenshot of the digital surface model of the skull which is retrieved from a hologram.

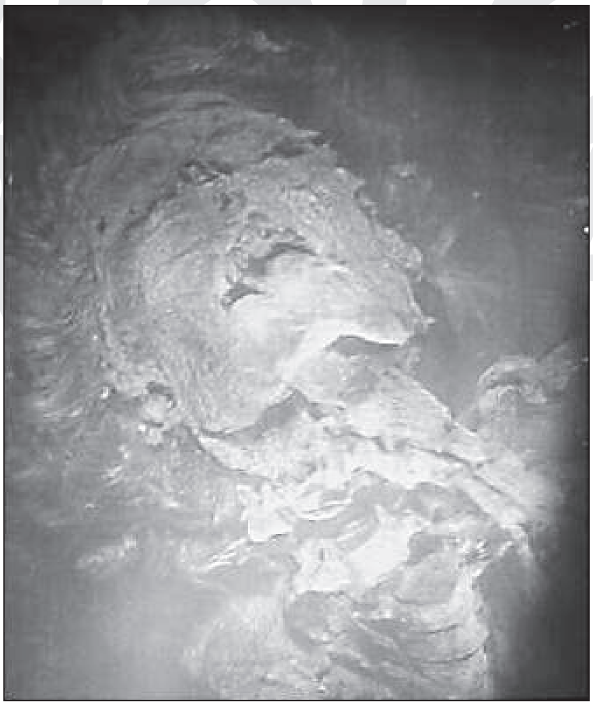

Fig. 4: Photograph of a display hologram of the bog body of Husbäke. The hologram is illuminated with a halogen lamp.

For surface measurements as described above the hologram is illuminated with laser light. This is the best way to read out a hologram concerning brightness, contrast, resolution and depth of field. To make the three-dimensional recordings accessible to a broader public, alternative holography techniques have been developed that work with white light (Denisyuk, 1963). We employ a method named image plane holography, or full aperture transfer holography (Rotz and Friesem, 1966; Brandt, 1969). The resulting holograms may be read out with white light, with the only drawback of a limited depth of field due to color blur.

To give an example, figure 4 shows a photograph of a display hologram of the bog body of Husbäke from the *Landesmuseum für Natur und Mensch in Oldenburg, Germany*, that was brought to our laboratory by Prof. Fansa and his co-workers in 2002 (Frey et al., 2003; Nature news in brief, 2002; Science news section, 2002).

Summary

Three-dimensional optical imaging of archaeological objects is performed using pulsed holography. The recording procedure is simple and flexible. New laser technology allows for recordings outside the lab and may be employed at archaeological sites, for instance. Display holograms that are read out with white light and serve as exhibits, if the original finding is to delicate to be presented to a broader public. Furthermore, a new method is presented that results in a textured 3d computer models of the recorded object. This is illustrated by imaging the skull of the Windeby child bog body.

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