Digital holographic recording of large scale objects for metrology and display

Thomas Meeser, Silke Huferath-von Lüpke, Thomas Kreis
Bremer Institut für angewandte Strahltechnik GmbH
Klagenfurter Straße 2, 28359 Bremen
Germany

1 Introduction

Holography [1] is a method to record and display the whole optical wavefields including intensity and phase. It is used in numerous applications, e.g. in metrology for interferometric measurement of shape, deformation, or refractive index distributions, as well as particle detection and analysis [2]. Another application is holographic 3D-displays, e.g. in arts or security issues. Holographic 3D-television is a topic of actual research and development [3].

The photographic emulsion of the early holography has been replaced by recording on CCD- or CMOS-targets. The captured digital holograms are stored in a computer, where the complex wavefields can be reconstructed numerically [4,5], or the hologram data are inscribed into a spatial light modulator, whereby the wavefield is reconstructed optically [6,7].

The main difference between holographic film and CCD-targets is the resolution. While silver halide holofilm can resolve up to 7000 line pairs/mm, common CCD-cams have a pixel pitch of e.g. $\Delta\xi$ = 3,45µm, which equates to a resolution of 144 line pairs/mm. The sampling theorem states, that a reliable reconstruction of the recorded hologram is possible, if the fringe period p in the hologram is sampled by more than two pixels.

$$p > 2\Delta\xi \tag{1}$$

The fringe period p at any point in the hologram is given by:

$$p = \frac{\lambda}{2 \cdot \sin(\theta / 2)}, \tag{2}$$

where λ is the wavelength and θ the angle between reference and object wave at the hologram point under consideration. In order to fulfil Eq. (1) for all points in the hologram and all points of the object, the angle θ must remain small. This can be obtained by recording objects of small size, but sometimes one needs to measure large objects. Another way for the detection of large objects is to place the object far from the recording target, but optical arrangements with distances of several meters are bulky and prone to amplify small vibrations.

A solution of these problems is the optical reduction of the angle θ. This is done by bringing the object wave from a small virtual image of the object to the target instead of the original reflected or scattered wave [8].

In the following we will describe optical systems which perform this reduction and we will present results produced by these systems.

2 Optical reduction

Without an optical reduction the optical arrangement for capturing a hologram will have the length d_{nolens} from the object to the CCD-Chip [2]:

$$d_{nolens}(h) > \frac{(h + N\Delta\xi)\cdot\Delta\xi}{\lambda}, \qquad (3)$$

where h is the height of the object and N the pixel number in one direction.

Using a single lens to decrease the optical field reduces the total length from object to CCD-Chip to $d_{onelens}$, based on Eq. (3) and imaging equations:

$$d_{onelens}(h) > \left(-\frac{f_1 \cdot h}{g_1 - f_1} + N\Delta\xi\right)\cdot\frac{\Delta\xi}{\lambda} + g_1 + \frac{f_1 \cdot g_1}{g_1 - f_1}, \qquad (4)$$

where g_1 is the object distance to lens L_1 and f_1 is its focal length.

The reduction of the angle can be further increased by repeating the imaging of the object. That means that the first virtual image I_1 (Fig. 1) is displayed by a second lens L_2. The distance from object to CCD-Chip now is $d_{twolenses}$.

$$d_{twolenses}(h) > \left(\frac{f_1 f_2 h}{\Delta L(g_1 - f_1) - f_1 g_1 - f_2(g_1 - f_1)} + N\Delta\xi\right)\frac{\Delta\xi}{\lambda} \qquad (5)$$

$$+ \Delta L - \frac{f_1 g_1}{g_1 - f_1} + \frac{f_2(\Delta L(g_1 - f_1) - f_1 g_1)}{\Delta L(g_1 - f_1) - f_1 g_1 - f_2(g_1 - f_1)},$$

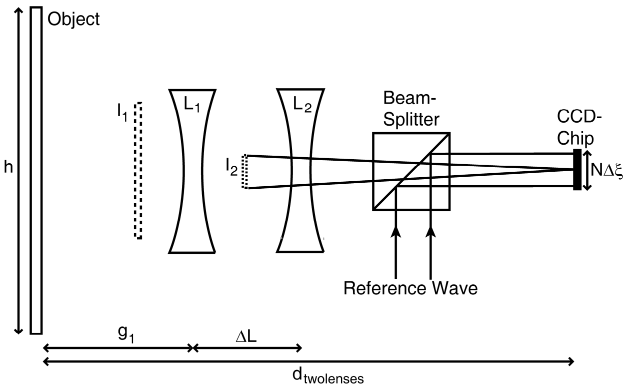

Fig. 1. Arrangement of the two lenses L_1 and L_2 considering the sampling theorem

with f_2 the focal length of lens L_2 and ΔL the distance between L_1 and L_2. This system can be enlarged to three or more lenses but the obtained reduction is small compared to that of the first two lenses.

Generally convex lenses do the same job [2], but the reduction is less than that of concave lenses.

3 Experimental results

A setup with two concave lenses has been successfully applied to an object of height 18cm (the Bremen Town Musicians). The capturing has been done by Fresnel holography as well as by lensless Fourier transform holography. With the two lens setup we obtained an object-CCD-Chip distance of about 18cm (f_1 = 75mm, f_2 = 50mm, N = 2452, λ = 532nm), see Fig. 2, while for a setup without lenses more than 1.2m would be necessary.

The resulting reconstructed intensity images shown in Fig. 3 demonstrate the feasibility of the presented method.

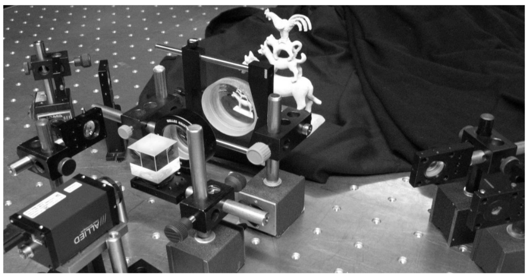

Fig. 2. Setup for capturing using two concave lenses for reducing the angle θ

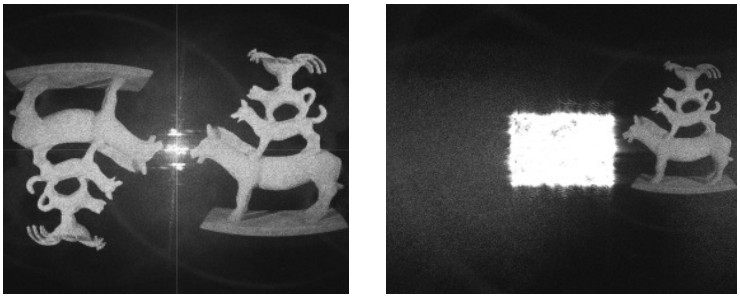

Fig. 3. Numerical reconstruction of an off-axis lensless Fourier transform hologram (left) and of an off-axis Fresnel hologram (right)

4 Acknowledgements

The authors thank J. Mundt for his support in the experiments. The research leading to these results has received funding from the European Community's Seventh Framework Programme FP7/2007-2013 under grant agreement n° 216105. This support is gratefully acknowledged.

5 References

1. Gabor, D, (1948) A New Microscopic Principle. Nature 161:777-778
2. Kreis, T, (2004) Handbook of Holographic Interferometry. WILEY-VCH Verlag GmbH & Co. KGaA
3. Onural, L, Gotchev, A, Ozaktas, H M, Stoykova, E, (2007) A Survey of Signal Processing Problems and Tools in Holographic Three-Dimensional Television. IEEE Transactions on Circuits and Systems for Video Technology 17:1631-1646
4. Yaroslavskii, L P, Merzlyakov, N S, (1980) Methods of Digital Holography. Consultants Bureau, New York
5. Schnars, U, (1994) Direct phase determination in hologram interferometry with use of digitally recorded holograms. Journal of the Optical Society of America A 11:2011-2015
6. Kreis, T, Aswendt, P, Höfling, R, (2001) Hologram reconstruction using a digital micromirror device. Optical Engineering 40:926-933
7. Agour, M, Kreis, T, (2009) Experimental Investigation of Holographic 3D-TV Approach. IEEE 3DTV Conference
8. Schnars, U, Kreis, T, Jüptner, W, (1996) Digital recording and numerical reconstruction of holograms: reduction of the spatial frequency spectrum. Optical Engineering 35:977-982