Digitalna Holografija i Primjene

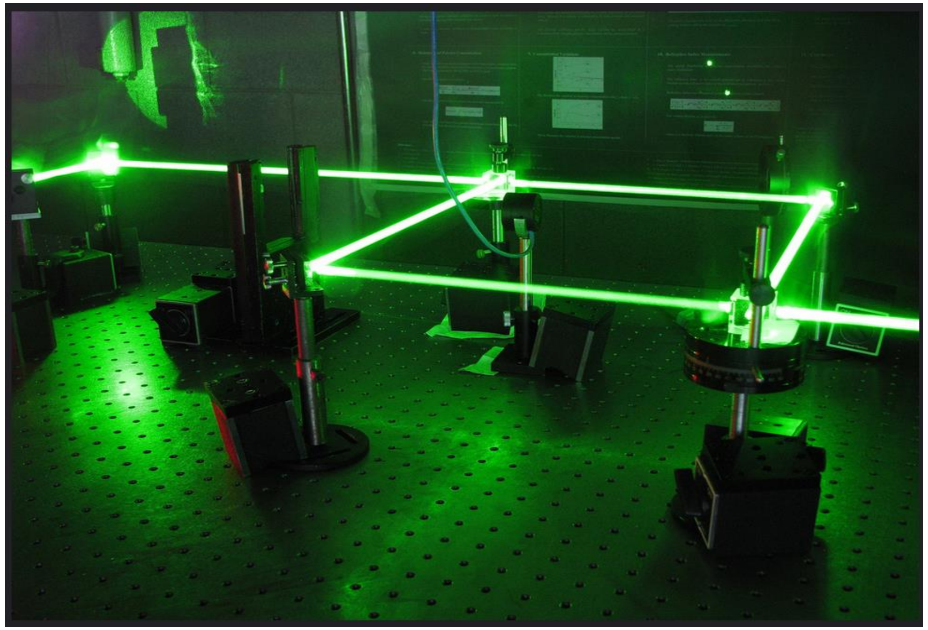
Hrvoje Skenderović
Institut za fiziku

5. PIF Radionica, IRB, 16.12.2014.

Holography

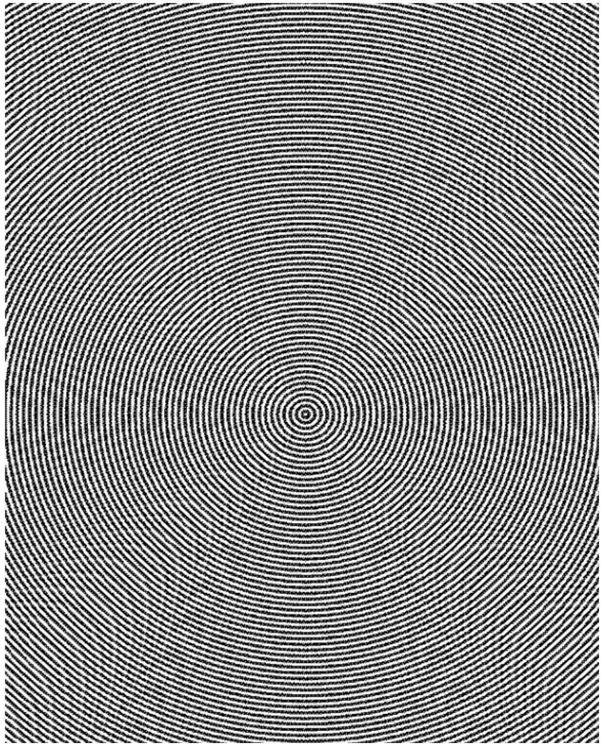
Dennis Gabor invented holography in 1948 as a method for recording and reconstructing amplitude and phase of a wave field, (Nobel Prize, 1971.). He created the word *holography* from the Greek words 'holos' meaning whole or entire and 'graphein‘ meaning to write.

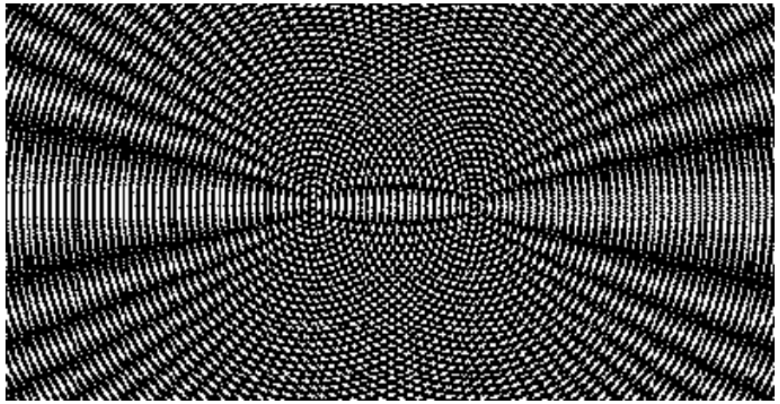
A holographically stored image or hologram is the photographically or otherwise recorded interference pattern between a wave field scattered from the object and a coherent background named reference wave. It is usually recorded on a flat surface, but contains the information about the entire three-dimensional wave field. This information is coded in form of interference stripes, usually not visible for the human eye due to the high spatial frequencies. The object wave can be reconstructed by illuminating the hologram with the reference wave again. An observer recognizes a three-dimensional image with all effects of perspective and depth of focus

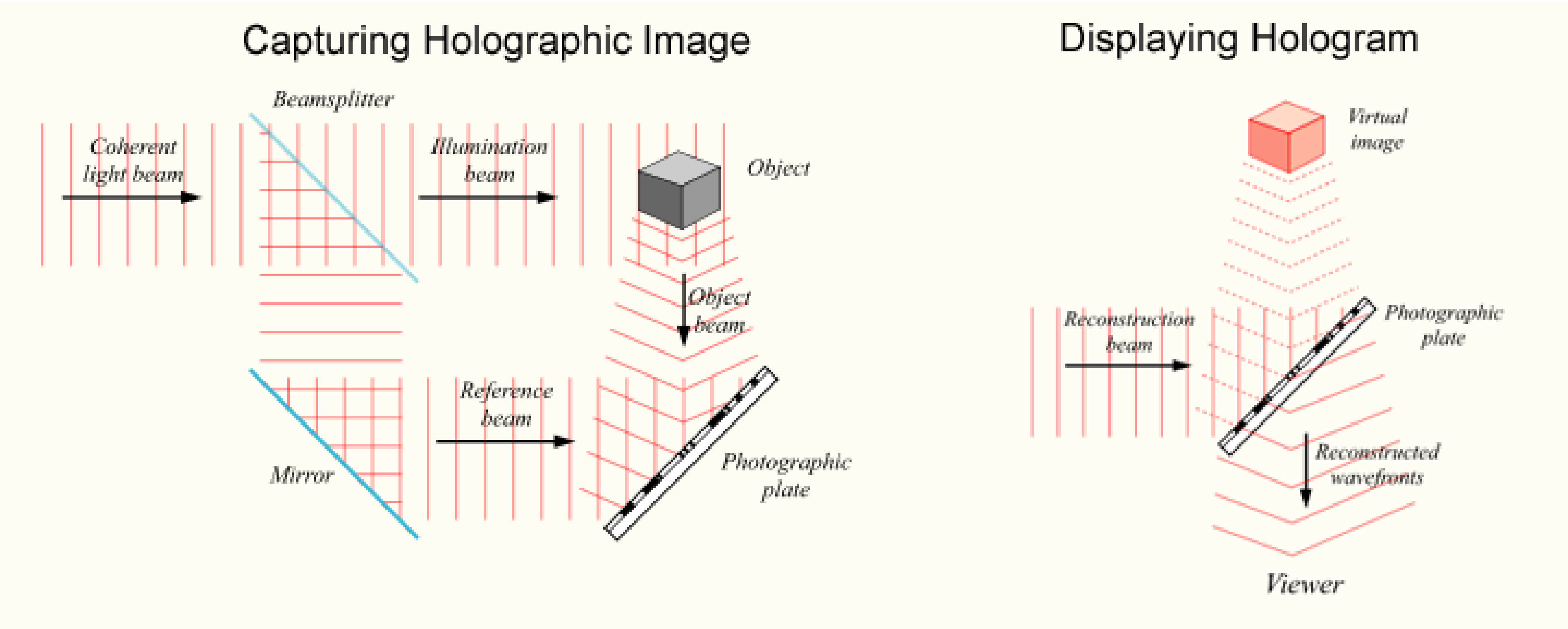


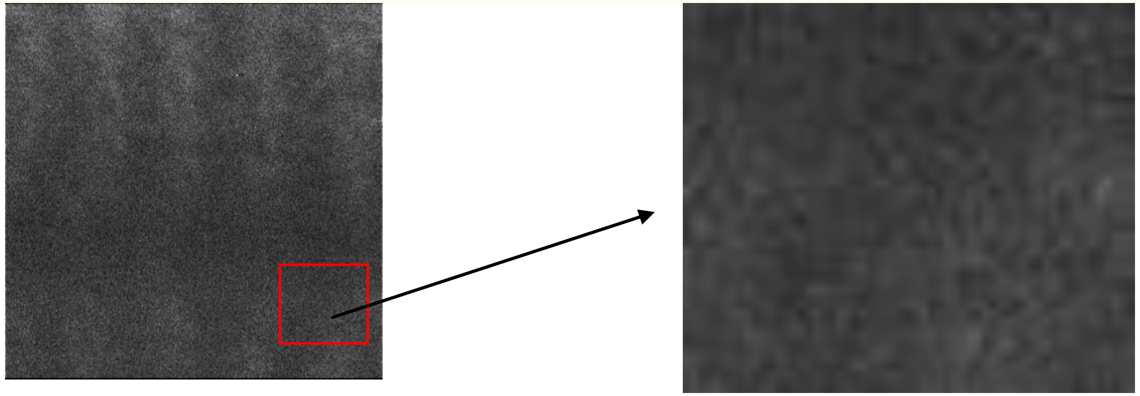
University Lund, Sweeden

- Basic Principles
- Holographic Interferometry
- Digital Holography

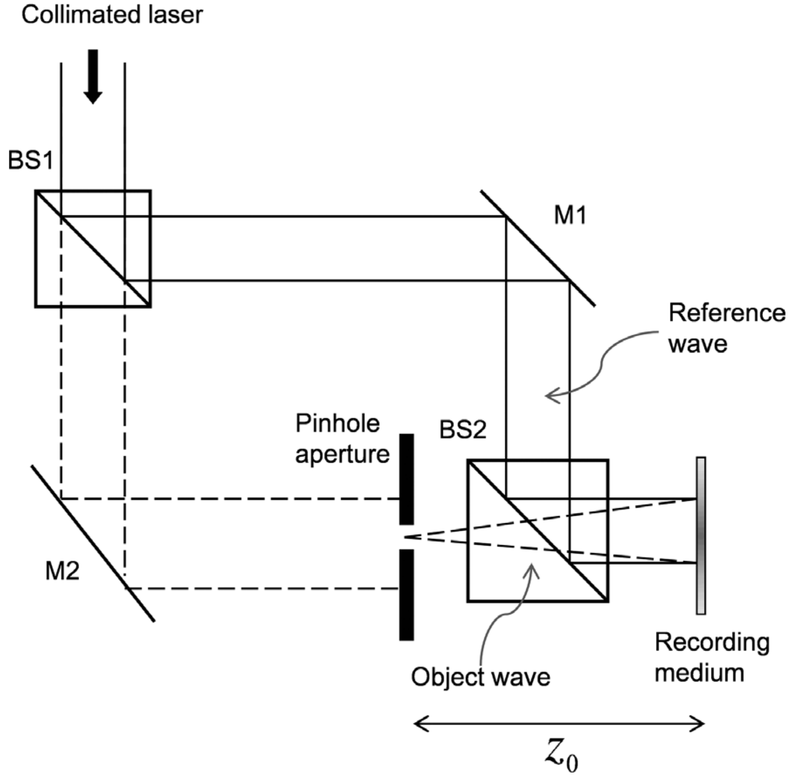





Capturing Holographic Image
Displaying Hologram
Beamsplitter
Coherent light beam
Illumination beam
Object
Object beam
Reference beam
Mirror
Photographic plate
Virtual image
Reconstruction beam
Photographic plate
Reconstructed wavefronts
Viewer



Holographic recording of a point source object:



$$I(x,y) = |\Psi_r + \Psi_o|^2 = \left| a \exp(-ik_0 z_0) + \exp(-ik_0 z_0) \frac{ik_0}{2\pi z_0} \exp\left[-\frac{ik_0}{2\pi z_0}(x+y)^2\right]\right|^2 =$$

$$= a^2 + \left(\frac{ik_0}{2\pi z_0}\right)^2 + a\frac{-ik_0}{2\pi z_0}\exp\left[\frac{ik_0}{2\pi z_0}(x+y)^2\right] + a\frac{ik_0}{2\pi z_0}\exp\left[-\frac{ik_0}{2\pi z_0}(x+y)^2\right]$$

To reconstruct the original light field from the hologram, I(x, y), we can simply illuminate the hologram with plane wave. Three light fields emerge from hologram:

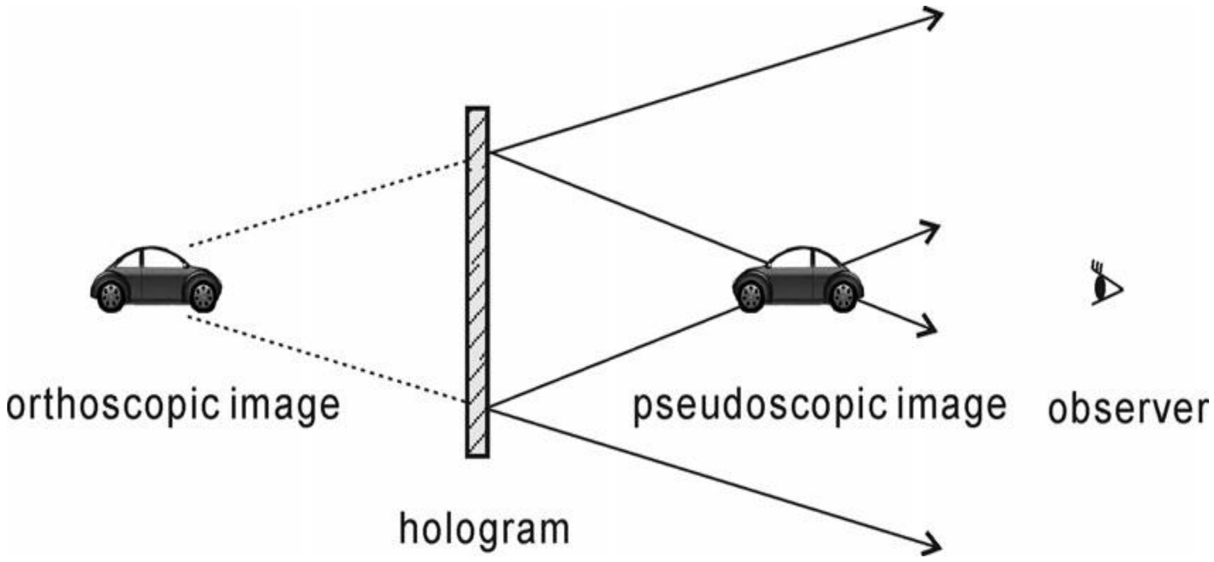
I. Plane wave which propagates without diffraction. Z*eroth-order* beam

II. Real point source at z=z_0 (pseudoscopic)

$$\frac{-ik_0}{2\pi z_0}\frac{ik_0}{2\pi z}\exp\left[\frac{ik_0}{2\pi(z_0-z)}(x+y)^2\right]$$

III. Virtual point source at z=-z_0 (orthoscopic)

$$\frac{-ik_0}{2\pi z_0}\frac{-ik_0}{2\pi z}\exp\left[-\frac{ik_0}{2\pi(z_0+z)}(x+y)^2\right]$$

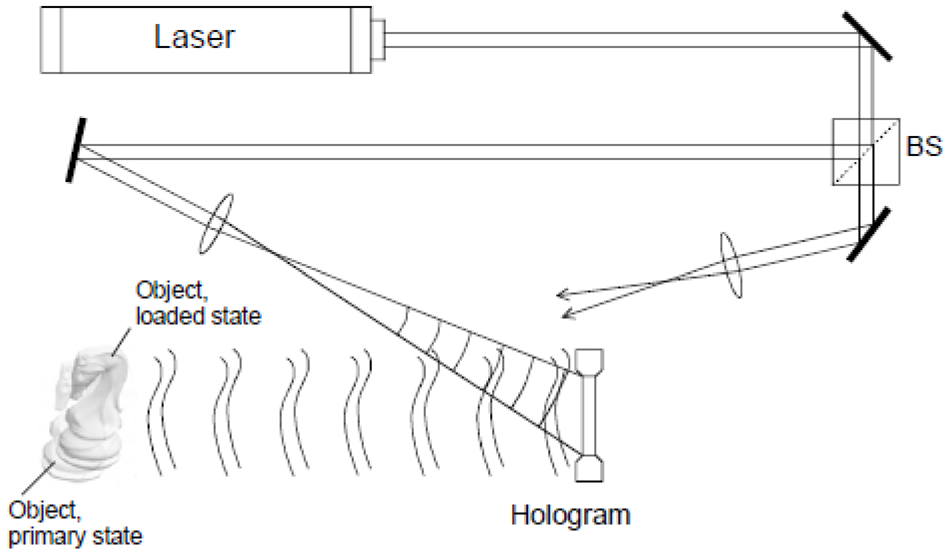


Application of holography in:

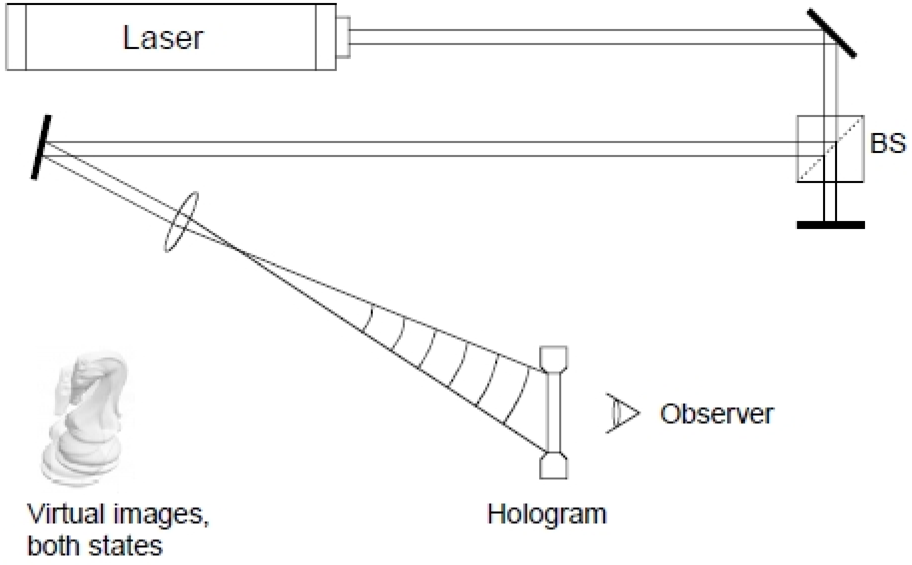
1. **microscopy**
2. **3D imaging**
3. **metrology**
4. **display technology**
5. **material processing**
6. **data storage**
7. **information processing**

Holographic Interferometry

Holographic Interferometry is a method to measure optical path length variations, which are caused by deformations of opaque bodies or refractive index variations in transparent media, e.g. fluids or gases. It is a non-contact, non-destructive method with very high sensitivity. Optical path changes up to one hundredth of a wavelength are resolvable.



Recording



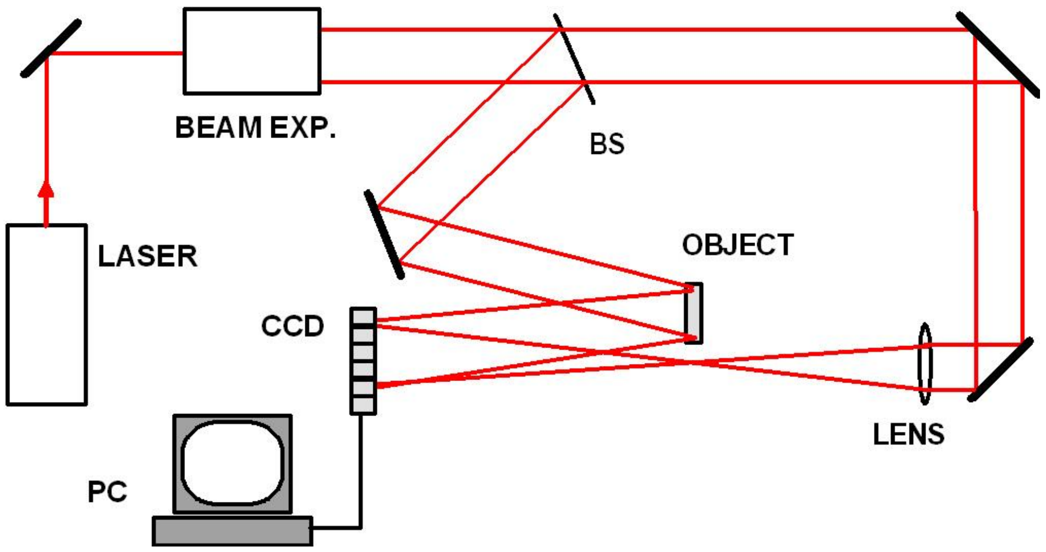
Reconstruction

Path length variations:

1. **Static**
2. **Dynamic**
3. **Periodic**

Digital holography

In digital holography, the recording schemes are the same, but the recording material is replaced by an electronic device, such as a charge-coupled device (CCD). Optical interference fringes acquired by the CCD are digitized into a two-dimensional digital signal and then processed using digital image processing to reconstruct the object.



Problems:

Spatial frequency : $$\nu \leq \frac{1}{2\Delta x}$$

Angle: $$\vartheta_{MAX} = \sin^{-1}\left(\frac{\lambda \nu}{2}\right)$$

Materials:

Agfa 8E75 – 5000 lin/mm $\rightarrow \vartheta_{MAX} = 180^{o}$

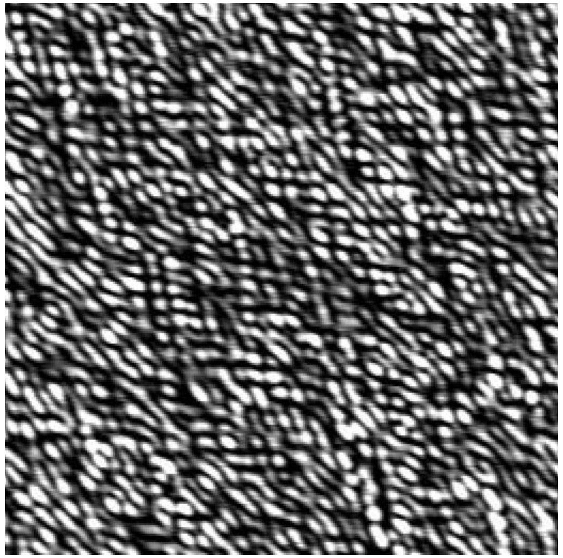
Thermoplastic film – 1000 lin/mm $\rightarrow \vartheta_{MAX} = 40^{o}$

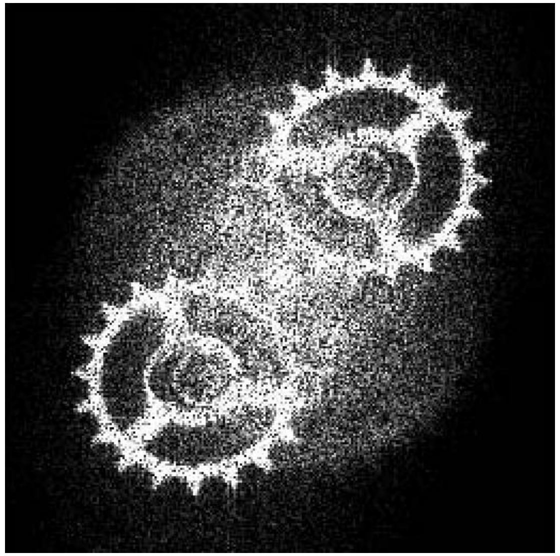
CCD pixel – 5 um $\rightarrow \vartheta_{MAX} = 8^{o}$, loss in 3D efficency

Advantages:

Fast data acquisition
Direct data manipulation…

Easy data manipulation - Subtraction digital holography

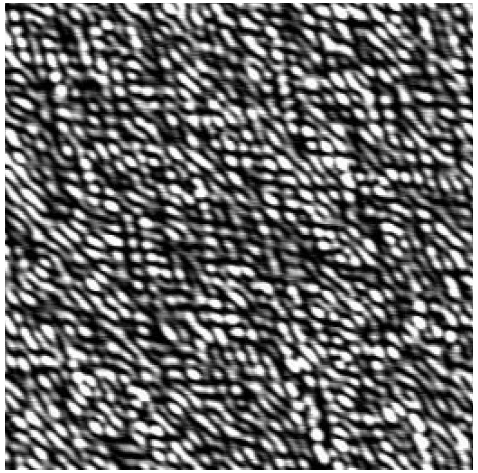




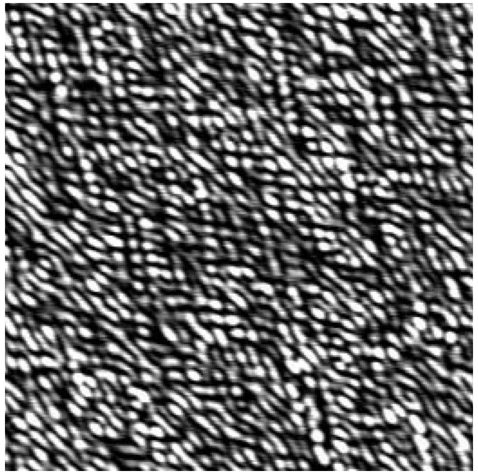
Large zeroth-order noise

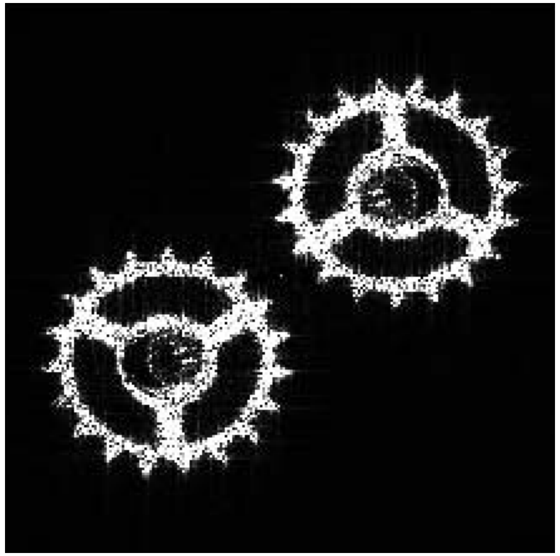
[Demoli N, Mestrovic J, Sovic I (2003) Subtraction digital holography. Appl Opt 42(5):798-804]

Easy data manipulation - Subtraction digital holography



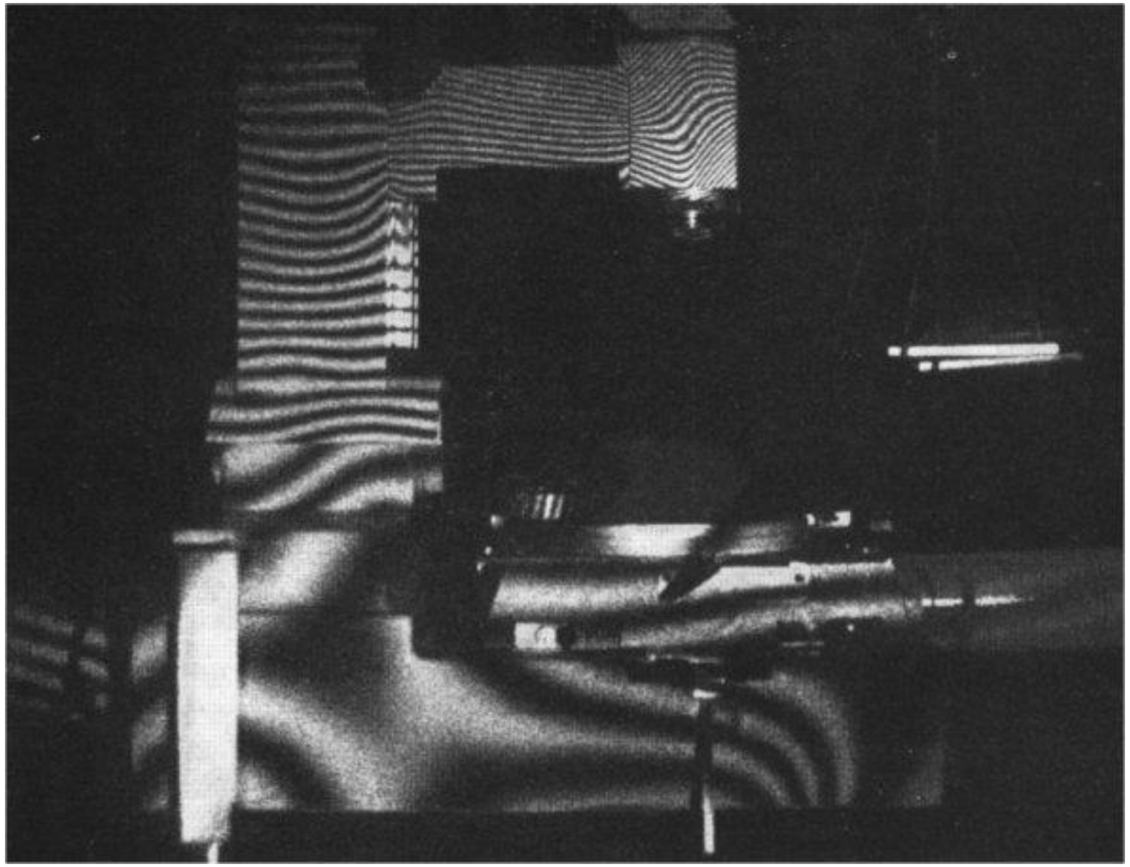
Subtraction



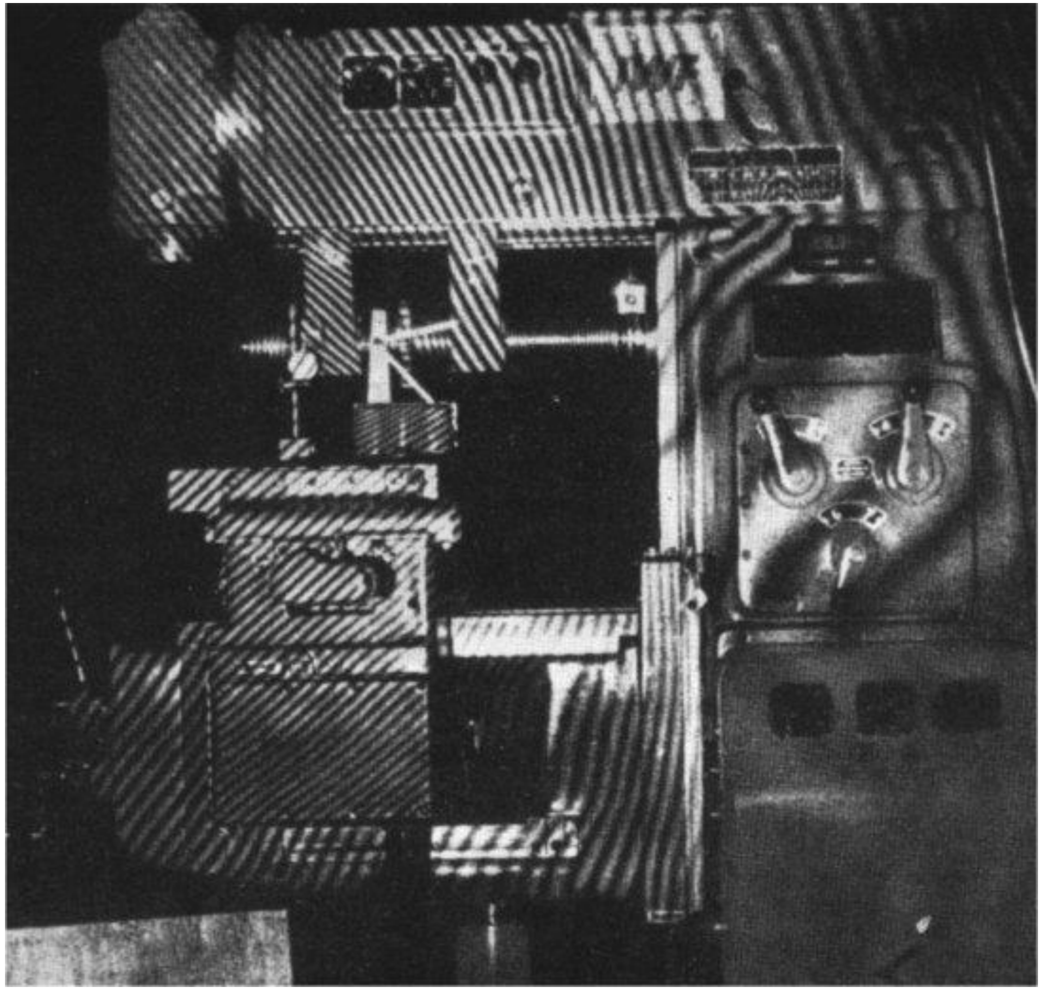


Large zeroth-order noise

[Demoli N, Mestrovic J, Sovic I (2003) Subtraction digital holography. Appl Opt 42(5):798-804]

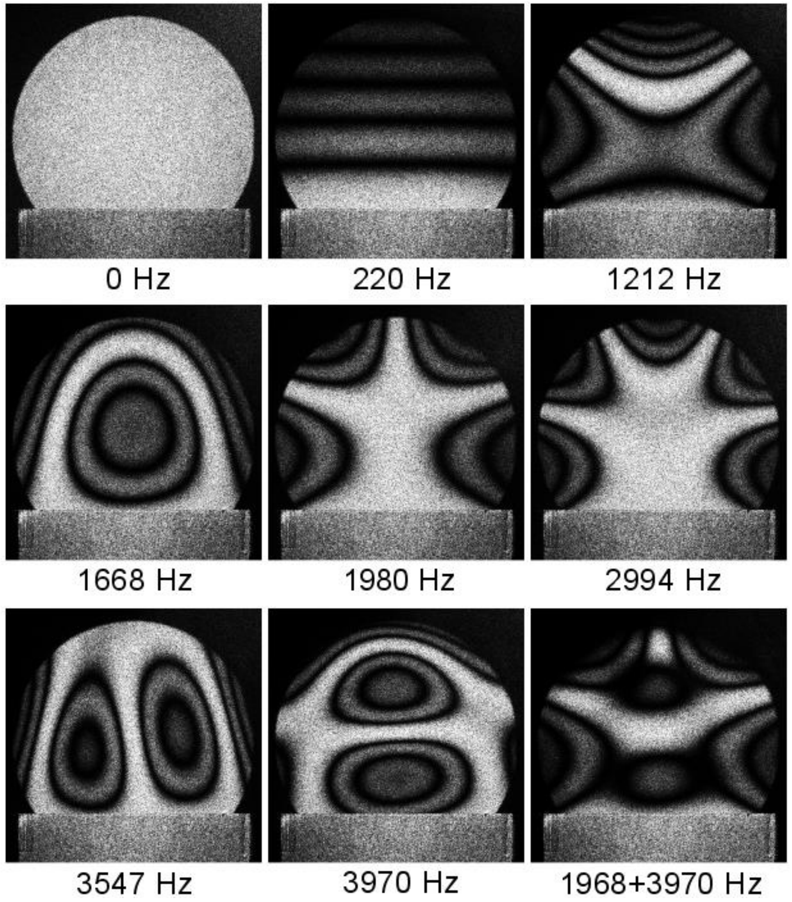


Static load on microscope, Schreiber



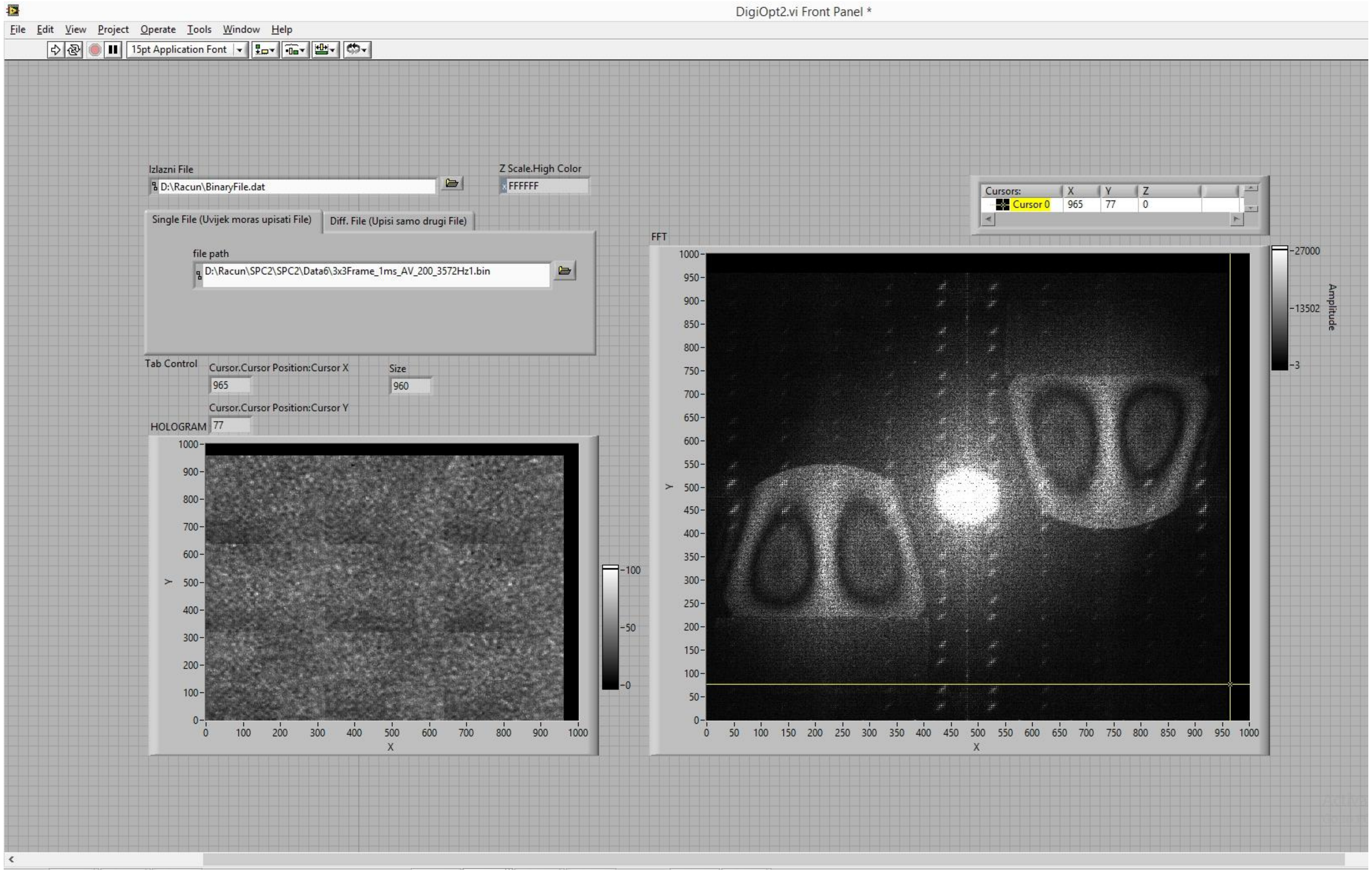
Static load on a machine, Abramson

Time Averaged Digital Holography – vibrating membrane

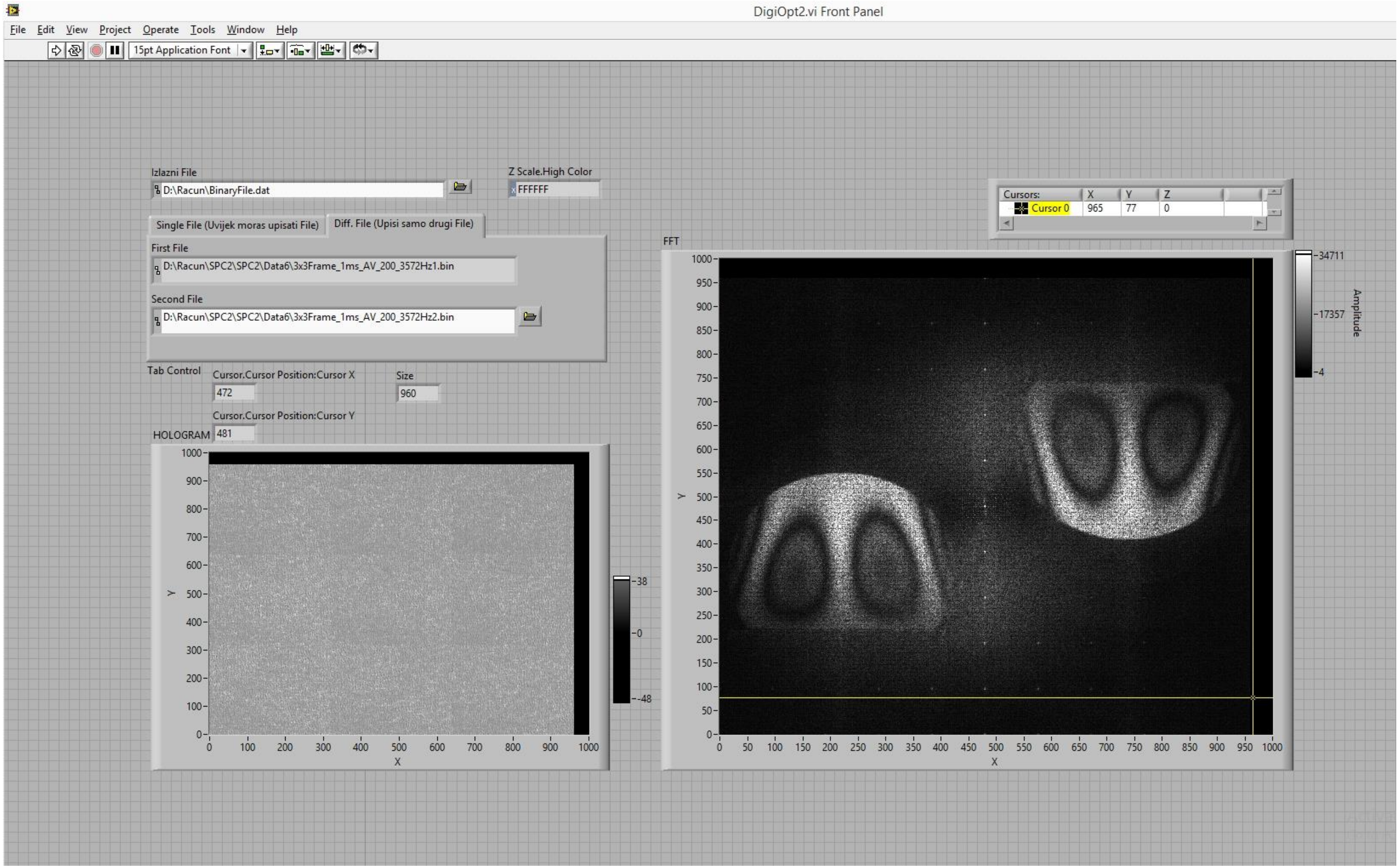


[Demoli N (2006) Real-time monitoring of vibrating fringe patterns... Opt Express 14(6): 2117-21223]

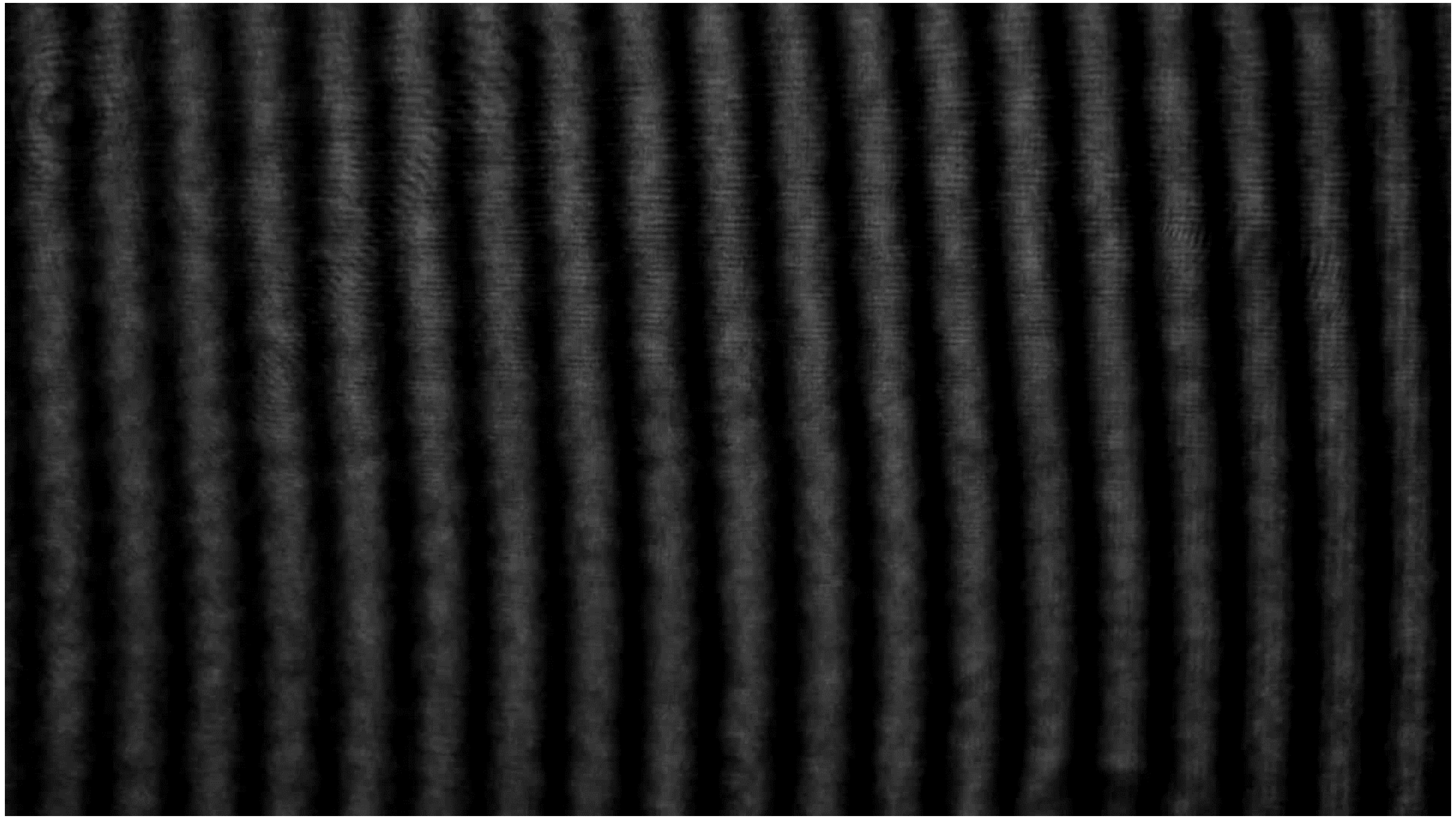
Subtraction digital holography with time averaging



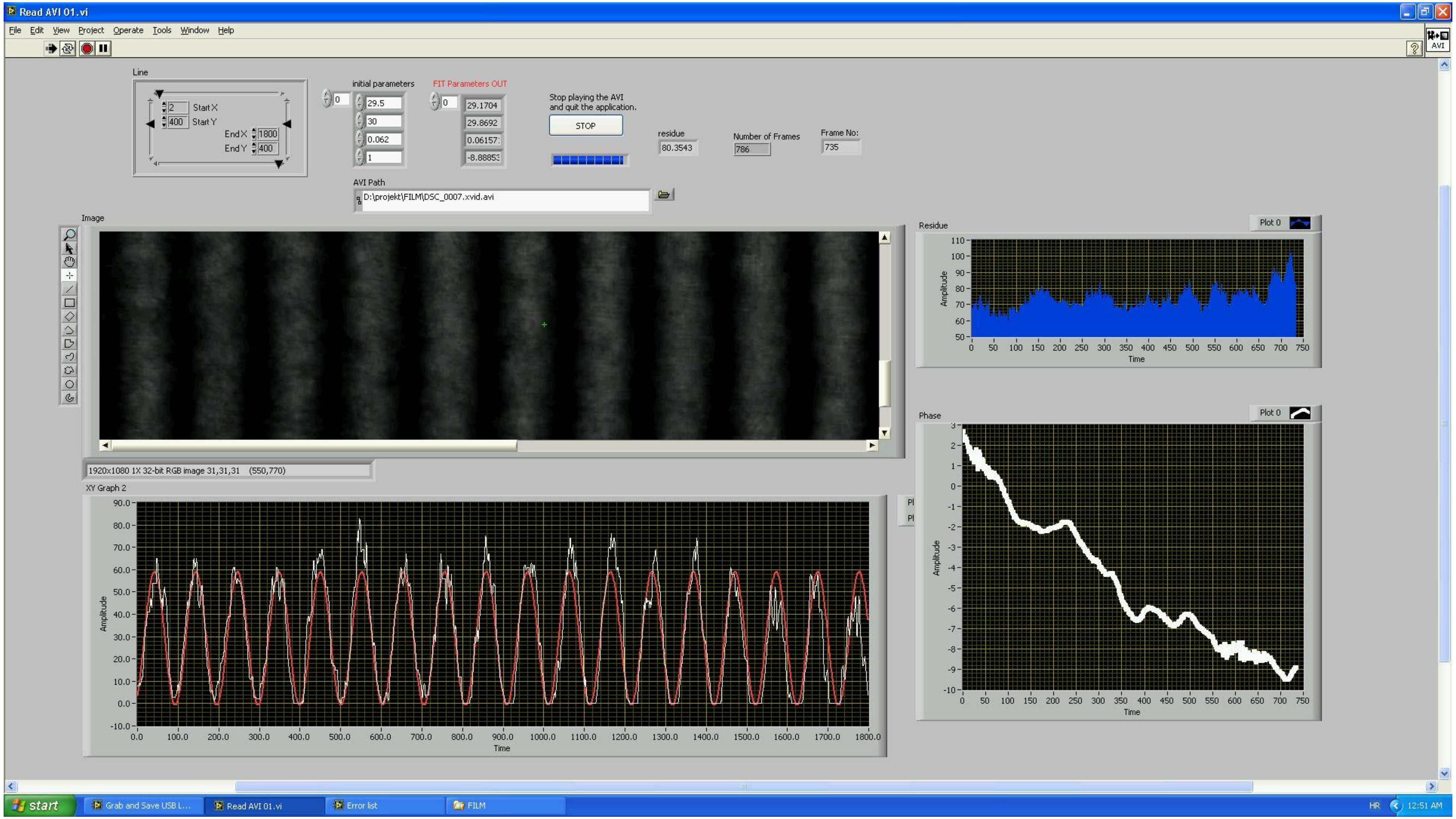
Subtraction digital holography with time averaging



Dynamic change of object – moving fringes



Dynamic change of object – moving fringes



Digital holography at light levels below noise using a photon-counting approach

Nazif Demoli,[1,*] Hrvoje Skenderović,[1] and Mario Stipčević[2]

[1]*Institute of Physics, Bijenička cesta 46, HR-10000 Zagreb, Croatia*

[2]*Ruđer Bošković Institute, Bijenička cesta 54, HR-10000 Zagreb, Croatia*

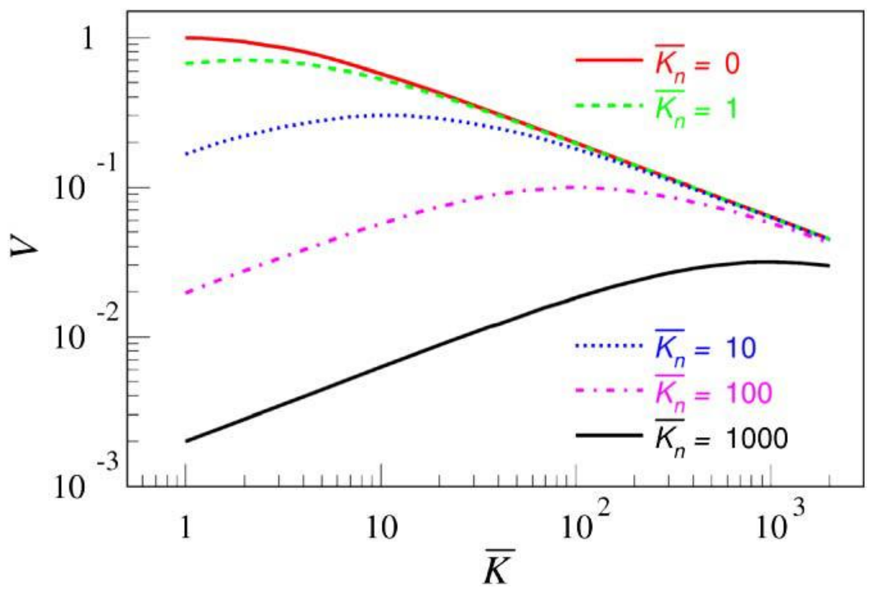
**Corresponding author: demoli@ifs.hr*

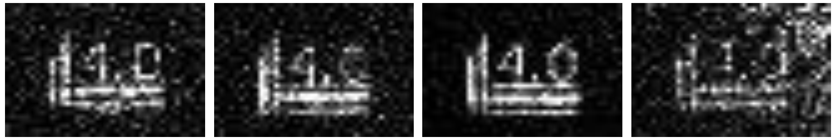
Received June 9, 2014; revised July 21, 2014; accepted July 21, 2014; posted July 22, 2014 (Doc. ID 213778); published August 19, 2014

Recording of digital holograms of a weak signal [0.44 counts per second (cps)] hidden below the detector's noise (21 cps) is investigated by employing the high dynamic range of a photon-counting detector. Recording conditions are discussed in terms of the most important holographic measures, namely, the fringe visibility (or contrast) and signal-to-noise ratio (SNR), and in relation to the main holographic parameters. Theoretically evaluated curves are tested by recording holograms for a wide range of the parameter values. We found that (i) the optimum set of holographic parameters can be determined for a harsh signal conditions, (ii) increasing the visibility does not necessarily improve the more important SNR, and (iii) in cases of nearly constant visibility, the SNR clearly reveals differences in the quality of holographic recordings.

OCIS codes: (090.0090) Holography; (090.1995) Digital holography; (030.5260) Photon counting; (100.2650) Fringe analysis.

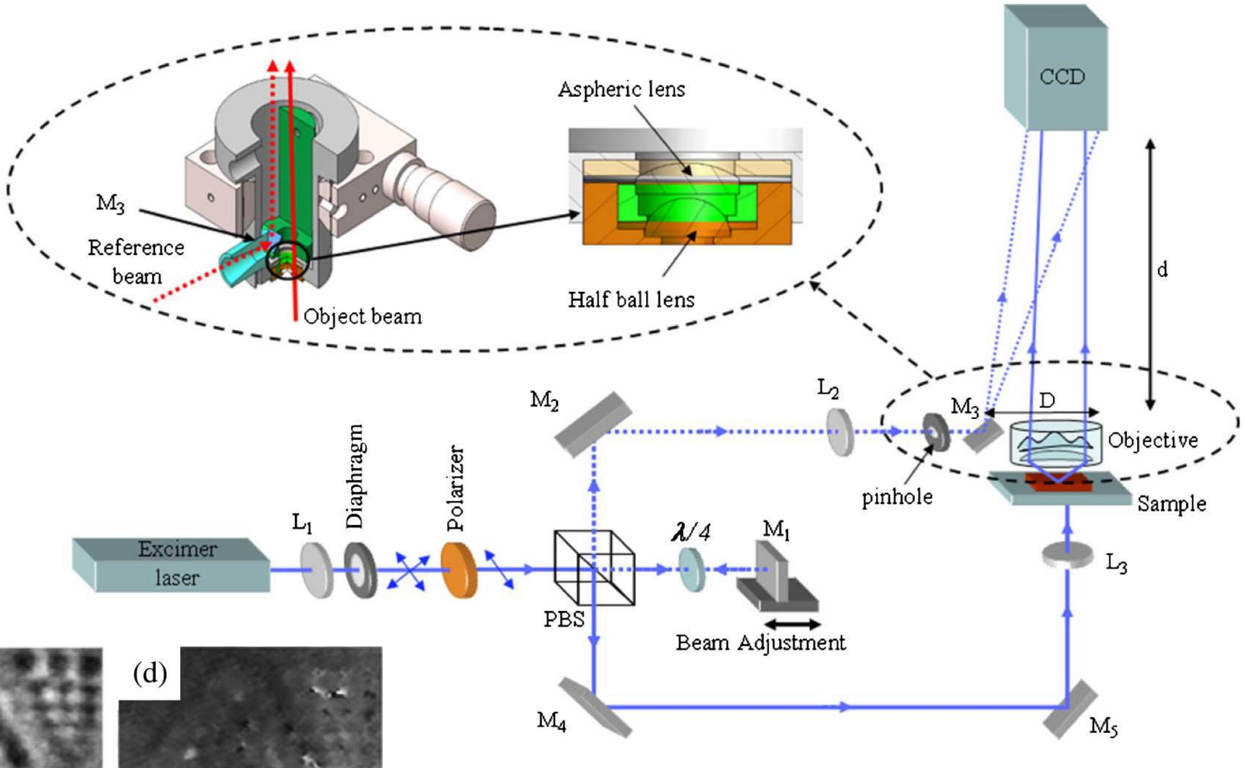
http://dx.doi.org/10.1364/OL.39.005010

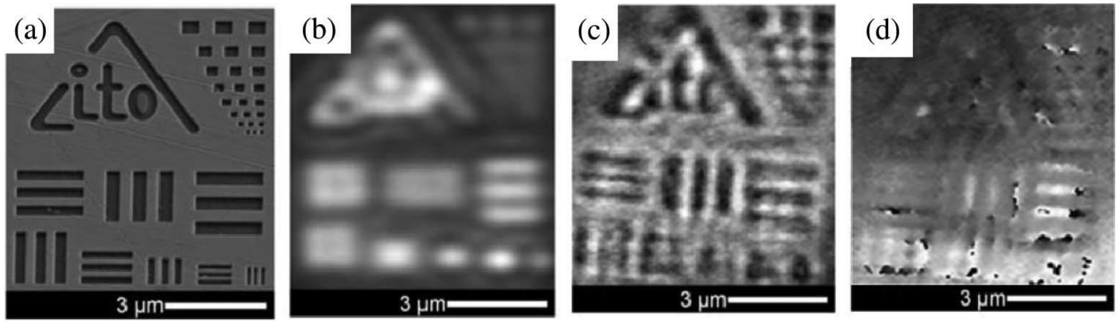




K=1 K=4 K=10 K=100

Holographic Microscopy





(a) Scanning electron microscope image of the nanostructured template. (b) Image taken by a conventional optical microscope with NA 0.75, 100× objective. (c),(d) Reconstructed synthesized (c) amplitude and (d) phase of the object

[W. Osten et al, Applied Optics, 2014]

Outlook:

1. **Holographic microscope**
2. **Direct laser writing of computer generated holograms**
3. **…**

Thanks to:
Dr. Demoli
Dr. Stipčević

Hvala na pažnji