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A High Quality Lithograph with Integrated Environment for Computer Generated Holograms

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A HIGH QUALITY LITHOGRAPH WITH INTEGRATED ENVIRONMENT FOR COMPUTER GENERATED HOLOGRAMS

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Abstract

This paper describes a complete development environment for the production of digital holograms, including simulation software and a lithographic system. The software allows to compute phase and amplitude holograms of Kinoform, Fresnel and Fourier type. The lithograph has a resolution of 0.4 µm and provides 1,000 grey values using As_2S_3 as a holographic film.

Introduction

The goal of our investigations is the construction of an optical neural network computer. Here the basic and most costly operation in computing time is a matrix multiplication. This operation will be realized optically using computer generated holograms (CGH). Only CGHs provide an optical imaging sufficiently good to realize the synaptic connection between the neurons. In the case of neural networks with a large number of neurons, high-quality holograms are required. For their production three conditions have to be met.

First, digitalization algorithms are required which both provide an sufficient reproduction quality and are efficient enough to calculate large CGHs. In respect to the complexity of the task a user-friendly test environment must be available. These are provided by the program package DIGIHOL developed by us.

Second, the computed holograms have to be exposed with high resolution (<1µm), a greyscale resolution of more than 100 values, possibility as a phase holograms with good reconstruction quality. We constructed a greyscale lithograph which fulfills these requirements.

Third, a proper holographic material is required. At this time we use the semiconductor glass As_2S_3 as holographic film.

Computer Generated Holograms

An extensive, user-friendly simulation program DIGIHOL was developed to calculate computer generated holograms and to simulate their optical imaging. Different coding forms are available, such as Kinoform, Fresnel and Fourier holograms. The calculated reconstruction allows to detect in advance nearly all optical aberrations: Scattering light effects, distortion, reduced grey scale, non-linear effects of exposure, distortion, and many others. A phase optimization for the reference beam was developed to improve the quality of holograms. The integration of the DIGIHOL program into the pattern recognition program IMAGE 1) provides a complete and accurate visualization of all the calculated data. The different types of holograms we make available for calculation are shown in table I. For tests and inspections of calculated results some functions were added, for example to show the difference or correlation between two results, or the reconstructed hologram and the original. CGHs with different reference beam profiles can be calculated as zero phase, random phase, and a lens phase.

Type	binary	greyscale	amplitude hologram	phase hologram	different reference beam
Kinoform	•	•	•	•	•
Fresnel	•	•	•	•	•
Fourier	•	•	•	•	•

Table I: Possible types of CGHs which were implemented in DIGIHOL

A new method was developed to code grey scale holograms in binary form. The results show a good signal to noise ratio and a high diffraction efficiency in comparison to other methods. The binarization is performed gradually and randomized; by using an iterative algorithm the quantization error is distributed.

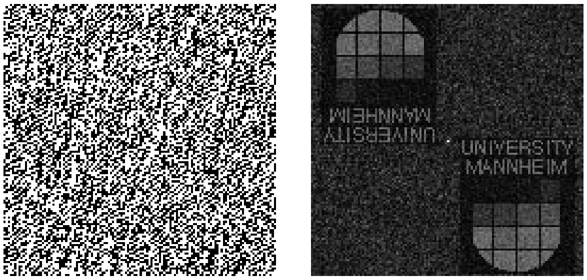

Fig. 1: Example for a binarized grey scale hologram based on gradual and randomized binarization with distributed quantization.

The size of holograms which can be calculated depends to the available RAM size and time. Normally we calculate holograms up to 2000×2000 points. As an example a 1000×1000 hologram needs nine minutes on a Macintosh Quadra 700 with 20 MB RAM. Its flexibility and user-friendly surface makes DIGIHOL easy to handle.

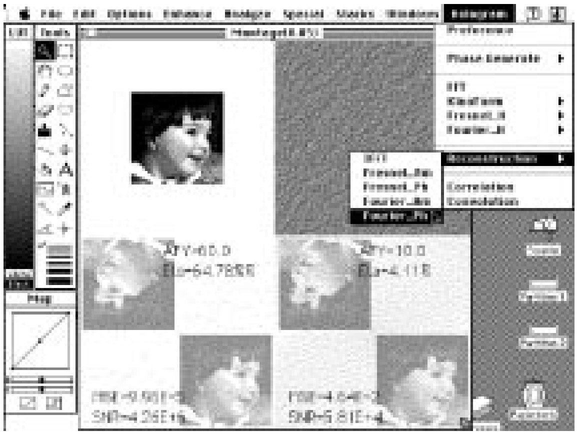

Fig. 2 shows a typical screen shot of the user surface of DIGIHOL, implemented on a Macintosh computer. The value of the chosen output amplification of the reconstructed hologram (AFY), the diffraction efficiency (Eta), the Mean-Square-Error (MSE), and the Signal-to-Noise-Ratio (SNR) can be calculated to compare the results of different tests.

Lithographic system

The construction of the lithographic system is based on a scanning sample, and a fixed air-cooled Ar^+ laser using the visible laser line (488nm), see fig. 3. The holographic film sample is driven by a commercial DC motor x-y actuator from Physical Instruments. The location of the micropositioners is controlled to a resolution of 100nm. After intensive research on the focusing system we replaced the microscope lens by a commercial CD player module. An auto focus regulator using the method of "knife edge" enables a Z-stabilisation of less than 0.1µm. Different film parameters are accounted for by a built-in automatic exposure time unit based on a confocal laser microscope with a He-Ne laser to ensure proper exposure intensity. For every holographic sample a predefined installation pattern with different intensities is written by the lithograph and read out by the confocal laser microscope, see fig. 4. The analysis of the film sensivity is done by the computer. On a sample of size 2×2 cm^2 up to 100 holograms can be written. The automatic exposure control is a very important feature for holograms with analogue values for optimizing the diffraction efficiency. The confocal laser microscope can also be used for the inspection of exposured structures, as shown in fig. 5.

The complete system is controlled by a Macintosh Quadra 700 computer. The software driver of the lithograph is implemented in the program DIGIHOL. From the user's point of view the lithograph can be used similar to a laser printer.

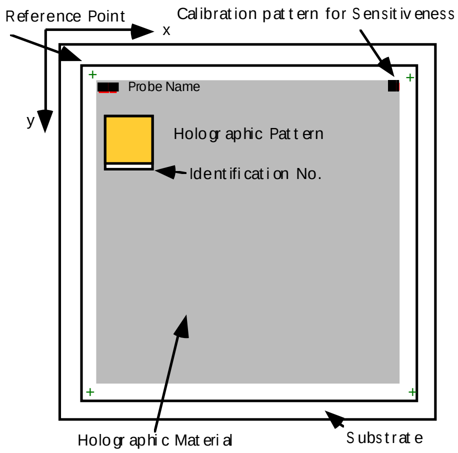

Fig. 4: Predefined installation pattern on a holographic sample. The positions of all holograms are stored in a database with all important descriptions for a later identification.

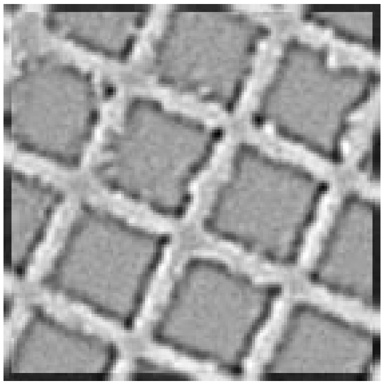

Fig. 5: Example of a 5µm grid recorded by a confocal laser microscope

<u>Parameters of the lithographic system:</u>

Writing area:	200×200 mm^2
Positioning error:	< 0.5µm
Spot size:	0.4µm
Autofocus error:	0.1µm
Dynamic of exposure:	1000
Laser intensity at spot:	1.7 MW
Data format for printing:	TIFF, PICT, RAW
Speed of writing:[2]	5000 points/sec

Holographic material

We used the semiconductor glass As_2S_3 as the holographic material. It allows an effective phase change and thus a high diffraction efficiency, combined with a high resolution (10,000 l/mm). The As_2S_3 film we used for synthetic holograms has a thickness of 2µm. Test pattern holograms show excellent results with high diffraction efficiencies 2).

Measurements and results

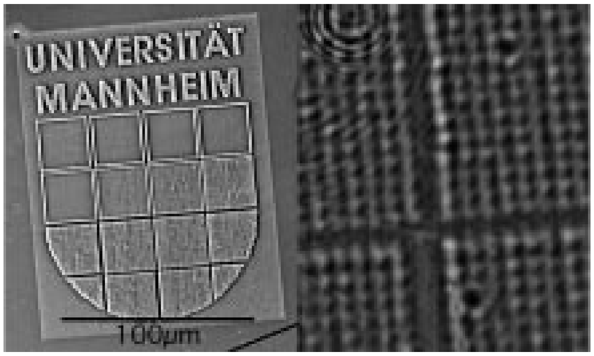

Fig. 6: As a demonstration of the accuracy of the lithographic system, the emblem of the University of Mannheim was plotted with a pixel distance of 1µm and a grey level range of three orders of magnitude.

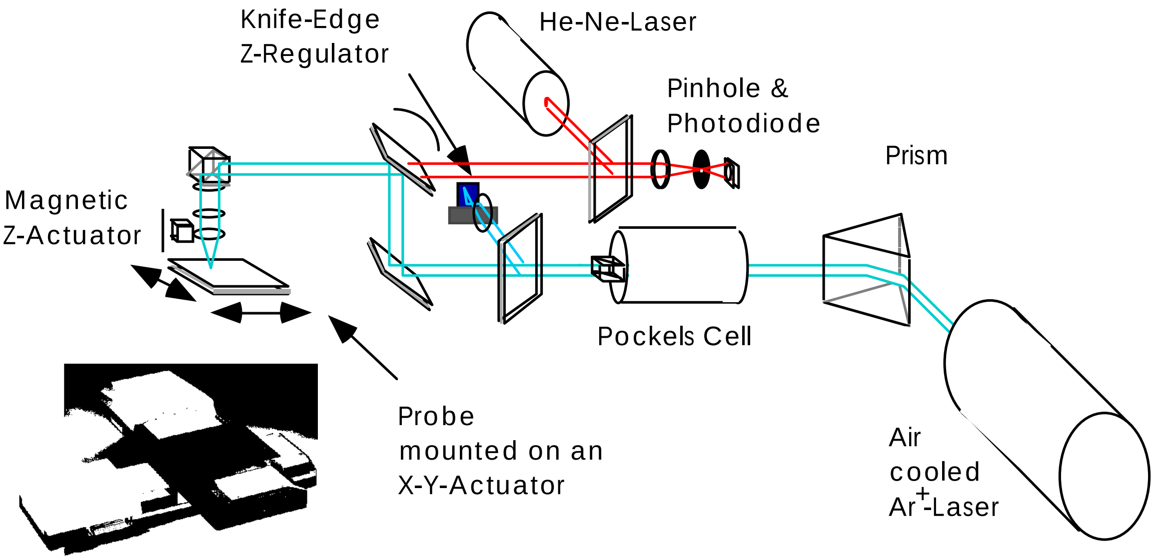

Fig. 3: Schematic set-up of the lithograph

At the right side a magnification were one can see the single points.

The spot size was measured with a confocal laser microscope from *Leika Instruments* and a atomic force microscope from the Physical Institute of the University of Heidelberg. The greyscale resolution was measured by writing grids with different intensities. The change of refractive index was indirectly measured by the diffraction efficiency. The measurement of the absolute phase shift at nano scale structures is very complicated. We are trying to reduce the error of absolute phase shift from ±10% to less than 1%.

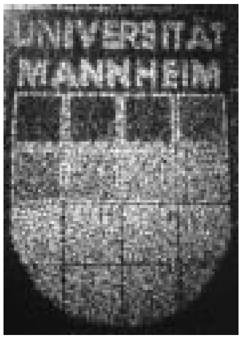

Fig. 7: Reconstruction of a hologram of size 256×256 μm^2.

An example for the projection of a mini hologram with a size of only 0.25×0.25mm is given in Fig. 7. The diffraction efficiency is only 7% less than the calculated efficiency.
A second miniaturized version of this lithograph is planned for the future. It will have a higher writing speed and a pizzabox size including all electronics and lasers.

Acknowledgements

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References

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