Digital Holography

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Digital Hologram Recording, Numerical Reconstruction, and Related Techniques

With 100 figures

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Preface

Sag' ich zum Augenblicke
verweile doch, Du bist so schön
J.W. v. Goethe, „Faust"

An old dream of mankind and a sign of culture is the conservation of moments by taking an image of the world around. Pictures accompany the development of mankind. However, a picture is the two-dimensional projection of the three-dimensional world. The perspective – recognized in Europe in the Middle Ages – was a first approach to overcome the difficulties of imaging close to reality. It took up to the twentieth century to develop a real three-dimensional imaging: Gabor invented in 1948 holography. Yet still one thing was missing: the phase of the object wave could be reconstructed optically but not be measured directly. The last huge step to the complete access of the object wave was Digital Holography. By Digital Holography the intensity and the phase of electromagnetical wave fields can be measured, stored, transmitted, applied to simulations and manipulated in the computer: An exciting new tool for the handling of light.

We started our work in the field of Digital Holography in 1990. Our motivation mainly came from Holographic Interferometry, a method used with success for precise measurement of deformation and shape of opaque bodies or refractive index variations within transparent media. A major drawback of classical HI using photographic plates was the costly process of film development. Even thermoplastic films used as recording medium did not solve the hologram development problem successfully. On the other hand the Electronic Speckle Pattern Interferometry (ESPI) and it derivate digital shearography reached a degree mature for applications in industry. Yet, with these speckle techniques the recorded images are only correlated and not reconstructed as for HI. Characteristic features of holography like the possibility to refocus on other object planes in the reconstruction process are not possible with speckle metrology.

Our idea was to transfer all methods of classical HI using photographic plates to Digital Holography. Surprisingly we discovered, that Digital Holography offers more possibilities than classical HI: The wavefronts can be manipulated in the numerical reconstruction process, enabling operations not possible in optical holography. Especially the interference phase can be calculated directly from the holograms, without evaluation of an interference pattern.

The efficiency of Digital Holography depends strongly on the resolution of the electronic target used to record the holograms. When we made our first experiments in the nineties of the last century Charged Coupled Devices begun to re-

place analogue sensors in cameras. The resolution of commercially available cameras was quite low, about some hundred pixels per line, and the output signal of cameras already equipped with CCD's was still analogue. In those days digital sampling of camera images and running of routines for numerical hologram reconstruction was only possible on special digital image processing hardware and not, as today, on ordinary PC's. The reconstruction of a hologram digitized with 512 × 512 pixels took about half an hour in 1991 on a Digital Image Processing unit developed at BIAS especially for optical metrology purposes. Nevertheless we made our first experiments with this type of cameras. Today numerical reconstruction of holograms with 1 million pixel is possible nearly in real time on state of the art PC's.

Then fully digital CCD cameras with 1 million pixels and smaller pixels than those of the previous camera generation emerged on the market. These cameras showed better performance and first applications in optical metrology became possible. Today digital CCD cameras with 4 million pixels are standard.

The tremendous development in opto-electronics and in data processing pushed Digital Holography to new perspectives: It is applied with success in optical deformation and strain analysis, shape measurement, microscopy and for investigations of flows in liquids and gases. In this book we make the trial to describe the principles of this method and to report on the various applications. We took pains to prepare the manuscript carefully and to avoid mistakes. However, we are not perfect. Comments, suggestions for improvements or corrections are therefore welcome and will be considered in potential further editions.

Some pictures in this book originate from common publications with other co-authors. All of our co-workers, especially W. Osten, Th. Kreis, D. Holstein, S. Seebacher, H.-J. Hartmann and V. Kebbel are gratefully acknowledged.

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