

Ulf Schnars • Werner Jueptner

Digital Holography

Digital Hologram Recording,
Numerical Reconstruction,
and Related Techniques

With 100 figures



Springer

Dr. Ulf Schnars
Im Grund 7
D-27628 Hagen
schnars@t-online.de

Prof. Dr. Werner Jueptner
Bremer Institut
für angewandte Strahltechnik (BIAS)
Klagenfurter Str. 2
D-28359 Bremen
jueptner@bias.de

ISBN 3-540-21934-x Springer Berlin Heidelberg New York

Library of Congress Control Number: 2004111072

This work is subject to copyright. All rights are reserved, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitations, broadcasting, reproduction on microfilm or in any other way, and storage in data banks. Duplication of this publication or parts thereof is permitted only under the provisions of the German copyright Law of September 9, 1965, in its current version, and permission for use must always be obtained from Springer-Verlag. Violations are liable to prosecution under the German Copyright Law.

Springer. Part of Springer Science+Business Media
springeronline.com

© Springer-Verlag Berlin Heidelberg 2005
Printed in Germany

The use of general descriptive names, registered names trademarks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

Typesetting: data delivered by authors
Cover design: medionet AG, Berlin
Printed on acid free paper 62/3020/M - 5 4 3 2 1 0

Contents

Preface	V
Contents	VII
1 Introduction	1
2 Fundamental Principles of Holography	5
2.1 Light Waves.....	5
2.2 Interference	8
2.3 Coherence	10
2.3.1 General	10
2.3.2 Temporal Coherence	10
2.3.3 Spatial Coherence.....	13
2.4 Diffraction.....	15
2.5 Speckles	18
2.6 Holography	21
2.6.1 Hologram Recording and Reconstruction	21
2.6.2 The Imaging Equations	23
2.7 Holographic Interferometry	26
2.7.1 Generation of Holographic Interferograms	26
2.7.2 Displacement Measurement by HI	29
2.7.3 Holographic Contouring.....	31
2.7.4 Refractive Index Measurement by HI	35
2.7.5 Phase Shifting HI.....	37
2.7.6 Phase Unwrapping.....	38
3 Digital Holography	41
3.1 General Principles.....	41
3.2 Numerical Reconstruction	44
3.2.1 Reconstruction by the Fresnel Approximation	44
3.2.2 Reconstruction by the Convolution Approach	52
3.2.3 Digital Fourier Holography	55
3.3 Separation of Virtual Image, Real Image and DC-term	56
3.3.1 Suppression of the DC term	56
3.3.2 Spatial Separation of Images	57

3.3.3 Phase Shifting Digital Holography.....	59
3.4 Recording of Digital Holograms.....	61
3.4.1 Charged-Coupled Devices.....	61
3.4.2 Spatial Frequency Requirements.....	64
3.4.3 CCD's for Digital Hologram Recording	65
3.4.4 Recording Set-ups	66
3.4.5 Stability Requirements	69
4 Digital Holographic Interferometry (DHI)	71
4.1 General Principles.....	71
4.2 Deformation Measurement	73
4.2.1 Quantitative Displacement Measurement.....	73
4.2.2 Mechanical Materials Properties	76
4.2.3 Thermal materials properties.....	82
4.2.4 Non-Destructive Testing	85
4.3 Shape Measurement.....	86
4.3.1 Two-Illumination-Point Method	86
4.3.2 Two- and Multi-Wavelength Method.....	88
4.3.3 Hierarchical Phase Unwrapping	90
4.4 Measurement of Refractive Index Variations	92
5 Digital Holographic Microscopy	95
5.1 Direct Method.....	95
5.2 Phase Shifting Digital Holographic Microscopy	98
6 Special Techniques and Applications	101
6.1 Applications using Short Coherence Length Light.....	101
6.1.1 Light-in-Flight Measurements.....	101
6.1.2 Short-Coherence Tomography	106
6.2 Particle Distribution Measurements.....	107
6.3 Endoscopic Digital Holography.....	111
6.4 Optical Reconstruction of Digital Holograms	114
6.5 Comparative Digital Holography.....	116
6.5.1 Fundamentals of Comparative Holography.....	116
6.5.2 Comparative Digital Holography	117
6.6 Encrypting of Information with Digital Holography	120
6.7 Synthetic Apertures	122
7 Speckle Metrology	125
7.1 Electronic Speckle Pattern Interferometry (ESPI).....	125
7.2 Digital Shearography	129
7.3 Digital Speckle Photography	133
7.4 Comparison of Conventional HI, ESPI and Digital HI.....	134
Appendices	141
A The Fourier Transform.....	141

A1 Definitions	141
A2 Properties	142
A3 The Discrete Fourier Transform	143
B Phase Transformation of a Spherical Lens	145
B1 Lens Transmission Function	145
B2 Correction of Aberrations	147
References	151
Index	161