

PROCEEDINGS OF SPIE

# Optical Measurement Systems for Industrial Inspection XI

Peter Lehmann  
Wolfgang Osten  
Armando Albertazzi Gonçalves Jr.  
Editors

24–27 June 2019  
Munich, Germany

Sponsored by  
SPIE

Cooperating Organisations  
European Optical Society  
German Scientific Laser Society (Wissenschaftliche Gesellschaft  
Lasertechnik e.V.)

Published by  
SPIE

Volume 11056  
Part One of Two Parts

Proceedings of SPIE 0277-786X, V. 11056

SPIE is an international society advancing an interdisciplinary approach to the science and application of light.

The papers in this volume were part of the technical conference cited on the cover and title page. Papers were selected and subject to review by the editors and conference program committee. Some conference presentations may not be available for publication. Additional papers and presentation recordings may be available online in the SPIE Digital Library at [SPIDigitalLibrary.org](http://SPIDigitalLibrary.org).

The papers reflect the work and thoughts of the authors and are published herein as submitted. The publisher is not responsible for the validity of the information or for any outcomes resulting from reliance thereon.

Please use the following format to cite material from these proceedings:

Author(s), "Title of Paper," in *Optical Measurement Systems for Industrial Inspection XI*, edited by Peter Lehmann, Wolfgang Osten, Armando Albertazzi Gonçalves Jr., Proceedings of SPIE Vol. 11056 (SPIE, Bellingham, WA, 2019) Seven-digit Article CID Number.

ISSN: 0277-786X

ISSN: 1996-756X (electronic)

ISBN: 9781510627918

ISBN: 9781510627925 (electronic)

Published by

SPIE

P.O. Box 10, Bellingham, Washington 98227-0010 USA

Telephone +1 360 676 3290 (Pacific Time) · Fax +1 360 647 1445

[SPIE.org](http://SPIE.org)

Copyright © 2019, Society of Photo-Optical Instrumentation Engineers.

Copying of material in this book for internal or personal use, or for the internal or personal use of specific clients, beyond the fair use provisions granted by the U.S. Copyright Law is authorized by SPIE subject to payment of copying fees. The Transactional Reporting Service base fee for this volume is \$21.00 per article (or portion thereof), which should be paid directly to the Copyright Clearance Center (CCC), 222 Rosewood Drive, Danvers, MA 01923. Payment may also be made electronically through CCC Online at [copyright.com](http://copyright.com). Other copying for republication, resale, advertising or promotion, or any form of systematic or multiple reproduction of any material in this book is prohibited except with permission in writing from the publisher. The CCC fee code is 0277-786X/19/\$21.00.

Printed in the United States of America by Curran Associates, Inc., under license from SPIE.

Publication of record for individual papers is online in the SPIE Digital Library.

**SPIE. DIGITAL  
LIBRARY**

[SPIDigitalLibrary.org](http://SPIDigitalLibrary.org)

---

Paper Numbering: *Proceedings of SPIE* follow an e-First publication model. A unique citation identifier (CID) number is assigned to each article at the time of publication. Utilization of CIDs allows articles to be fully citable as soon as they are published online, and connects the same identifier to all online and print versions of the publication. SPIE uses a seven-digit CID article numbering system structured as follows:

- The first five digits correspond to the SPIE volume number.
- The last two digits indicate publication order within the volume using a Base 36 numbering system employing both numerals and letters. These two-number sets start with 00, 01, 02, 03, 04, 05, 06, 07, 08, 09, 0A, 0B ... 0Z, followed by 10-1Z, 20-2Z, etc. The CID Number appears on each page of the manuscript.

# Contents

xiii	Authors
xix	Conference Committee
xxiii	Introduction

## Part One

### SESSION 1 INTERFEROMETRY I

---

11056 03	Bessel fringes modulation determination by directional spatial carrier phase shifting [11056-2]
11056 04	Analysis of measurement error caused by swing motion for determining the physical thickness and group refractive index of a large glass panel [11056-4]
11056 05	Comparison of algorithms determining sign of Bessel function in time averaging interferometry [11056-3]

### SESSION 2 DIGITAL HOLOGRAPHY

---

11056 06	Digital holographic imaging for optical inspection in learning-based pattern classification [11056-5]
11056 07	High-NA lensless coherent imager as a building block for a synthetic aperture interferometry array [11056-6]

### SESSION 3 INTERFEROMETRY II

---

11056 0A	Topography measurement of glass disk substrates with sub-nanometer resolution [11056-9]
11056 0B	Three-dimensional shape measurement of fine structure by detecting phase distribution of only zeroth order diffraction beam based on speckle interferometry [11056-10]
11056 0C	Two-dimensional remote interferometric stage encoder through a single access port using range-resolved interferometry [11056-11]

- 11056 0D Absolute distance measurement of optical path length of non-contact three-dimensional nanoprofiler based on normal vector tracing method by tandem white-light interferometer [11056-12]
- 11056 0E Differential displacement measurements along a single beam using range-resolved interferometry [11056-13]
- 11056 0F Demodulation for sinusoidal frequency/phase modulation interferometer using artificial harmonic series signal and phase-locked loop [11056-14]

---

SESSION 4 SPECKLE AND SHEARING INTERFEROMETRY

---

- 11056 0G Thermography-inspired processing strategy applied on shearography towards nondestructive inspection of composites [11056-15]
- 11056 0H A robust integration algorithm for out-of-plane displacement field measurements applied to multiple images of shearography [11056-16]
- 11056 0I Shearography inspection of monolithic CFRP composites: finite element modeling approach for assessing an adequate strategy of artificial defects representing delamination [11056-17]
- 11056 0J EXTREME shearography: high-speed shearography instrument for in-plane surface strain measurements during an impact event [11056-18]
- 11056 0K Absolute angle measurement using dual-wavelength laser speckle for robotic manufacturing [11056-19]

---

SESSION 5 TOPOGRAPHY SENSORS AND MEASURING SYSTEMS

---

- 11056 0L Scale spanning subnanometer metrology up to ten decades (Invited Paper) [11056-20]
- 11056 0M Concept for a highly miniaturized endoscopic point distance sensor [11056-21]
- 11056 0N Evaluation of the optical performance of a novel high-speed focal-distance-modulated fibre-coupled confocal sensor [11056-22]

---

SESSION 6 RESOLUTION ENHANCEMENT TECHNIQUES

---

- 11056 0Q Light-sample interaction in microsphere enhanced 2D super-resolution imaging [11056-25]
- 11056 0R Microsphere-assisted imaging of sub-diffraction-limited features [11056-26]
- 11056 0S Label-free 3D super-resolution nanoscope [11056-27]

---

SESSION 7 HIGH-SPEED TECHNIQUES

---

- 11056 0T Double pulse LED illumination for phase detection in RGB-interferometry [11056-28]
- 11056 0U Full-field, high-frequency, heterodyne interferometry for dynamic metrology based on phase detection using a modified time-of-flight camera [11056-29]
- 11056 0V GPU-based digital image correlation system for real-time strain-controlled fatigue and strain field measurement [11056-30]

---

SESSION 8 3D MICROSCOPY

---

- 11056 0W Active illumination focus variation [11056-31]
- 11056 0X Optical measurement of ground cylinder lead angle [11056-32]
- 11056 0Y User-oriented evaluation of the metrological characteristics of areal surface topography measuring instruments [11056-33]
- 11056 0Z Correction of surface error occurring in microlenses characterization performed by optical profilers [11056-34]
- 11056 10 The use of parabolic mirrors in combined low-coherence and confocal refractive index measurement [11056-35]
- 11056 11 Novel chromatic confocal differential interference contrast prototype [11056-36]

---

SESSION 9 STRUCTURED ILLUMINATION TECHNIQUES I

---

- 11056 13 Hybrid telecentric triangulation sensor system with real-time field-dependent deconvolution [11056-38]
- 11056 14 Structured light sensor with telecentric stereo camera pair for measurements through vacuum windows [11056-39]
- 11056 15 3D shape from thermal patterns: investigation of projection parameters in simulation and experiment [11056-40]

---

SESSION 10 STRUCTURED ILLUMINATION TECHNIQUES II

---

- 11056 16 Automatic camera calibration and sensor registration of a multi-sensor fringe measurement system using hexapod positioning [11056-41]
- 11056 17 Extrinsic calibration of a 3D sensor based on an array projector and a single camera [11056-42]

- 11056 18      3D multispectral imaging system for contamination detection [11056-43]
- 11056 19      Full-field deflectometry for optical characterization of high-precision mirrors [11056-44]

SESSION 11      LIGHT SCATTERING TECHNIQUES

---

- 11056 1A      Heterodyne detection system for nanoparticle detection using coherent Fourier scatterometry [11056-45]
- 11056 1B      Determination of optical fiber layer parameters by inverse evaluation of lateral scattering patterns [11056-46]
- 11056 1C      High-resolution Czerny-Turner scatterometer for BRDF measurements [11056-47]
- 11056 1D      Recent development in BTDF/BRDF metrology on large-scale lambertian-like diffusers, application to on-board calibration units in space instrumentation [11056-48]

SESSION 12      MEASUREMENT OF OPTICAL COMPONENTS I: ASPHERE AND FREEFORM MEASUREMENT. JOINT SESSION WITH EOS

---

- 11056 1F      Grazing incidence interferometry for testing rough asperics [11056-50]
- 11056 1G      Tilted wave interferometer in common path configuration: challenges and realization [11056-51]
- 11056 1H      Measurement of mid-spatial frequency errors on freeform optics using deflectometry [11056-52]

SESSION 13      MEASUREMENT OF OPTICAL COMPONENTS II

---

- 11056 1N      Precise measurement of known and unknown freeform surfaces using Experimental Ray Tracing [11056-55]
- 11056 1O      Interferometric measurement of local radii of curvature for aspheric surface using a PDI [11056-56]

SESSION 14      HYPERSPECTRAL IMAGING AND SPECTROSCOPIC TECHNIQUES

---

- 11056 1P      Setup and evaluation of a static imaging Fourier transform spectrometer for the mid-infrared spectral range [11056-57]
- 11056 1Q      An approach to combined multispectral reflectorless distance measurement and material probing [11056-58]

- 11056 1R      Precise thickness measurement and comparison of step-shaped microfluidic channel mold using optical interferometry [11056-59]
- 11056 1S      Hyperspectral imaging microscopy for thickness measurement and surface characterization of layered MoS<sub>2</sub> [11056-60]
- 11056 1T      Realization of a LIBS-based, temporally and spatially resolved welding control [11056-61]
- 11056 1U      Rotational Raman spectroscopy for in situ temperature and composition determination in reactive flows [11056-62]

SESSION 15      IN-PROCESS AND IN-SITU MEASUREMENTS

---

- 11056 1V      Automated pump-probe microscope to observe laser ablation on a picosecond scale [11056-63]
- 11056 1X      Fluorescence laser scanner for in-line inspection of functional coatings in metal processing industries [11056-65]
- 11056 1Y      Automated inline visual inspection and 3D measuring in electrode manufacturing [11056-66]
- 11056 1Z      Innovative system for automated measurement of the distribution of the length of natural fibres [11056-67]
- 11056 20      Imaging detection and classification of particulate contamination on structured surfaces [11056-68]

SESSION 16      NONDESTRUCTIVE TESTING AND FAULT DETECTION

---

- 11056 21      Diameter quantification of through holes in pipelines hidden by protective layers of composite materials using instantaneous shearography simultaneously in three shearing directions [11056-70]
- 11056 22      Photoacoustic inspection of CFRP using an optical microphone [11056-71]
- 11056 23      Development of a convolutional autoencoder using deep neuronal networks for defect detection and generating ideal references for cutting edges [11056-72]
- 11056 24      An automatic visual inspection system to scan outer lenses of automotive rear lamps [11056-74]

Part Two

- 11056 25      Development of an experimental setup and a study for the comparison between optical properties and the subjective perception of a quality of a display surface [11056-69]

POSTER SESSION

---

- 11056 27 Wavelength-switchable Fizeau interferometry and its applications [11056-75]
- 11056 28 Light field three-dimensional measurement [11056-76]
- 11056 29 Measurement of wavefront curvature using computer-generated Fourier holograms [11056-77]
- 11056 2B Surface roughness measurement accuracy analysis of grinded silicon wafer by white light scanning interferometry (WLSI) [11056-80]
- 11056 2C Non-destructive and real-time optical inspection for lens size using swept source optical coherence tomography [11056-81]
- 11056 2D Optical form measurement system using a line-scan interferometer and distance measuring interferometers for run-out compensation of the rotational object stage [11056-83]
- 11056 2E Dynamic speckle inspection with raw data compression [11056-84]
- 11056 2F Study of the errors of stereoscopic optical-electronic system for railroad track position [11056-85]
- 11056 2G Motionless and fast measurement technique for obtaining the spectral diffraction efficiencies of a grating [11056-86]
- 11056 2H Influence of test bench parameters on determination of CMOS -cameras feature [11056-87]
- 11056 2I Near real-time digital holographic imaging on conventional central processing unit [11056-88]
- 11056 2J Optic-electronic multi-matrix system for measuring the positions of the reflecting panels on the main mirror of the large radio-telescope [11056-89]
- 11056 2K Design and fabrication of opto-mechanical micro polymeric cantilever based optical fiber sensor [11056-90]
- 11056 2M Bright high harmonic generation around 30 nm and 10 nm for seeding full coherent XFEL [11056-92]
- 11056 2N Impact damage characterization in CFRP plates using PCA and MEEMD decomposition methods in optical lock-in thermography phase images [11056-93]
- 11056 2O Turning a machine vision camera into a high precision position and angle encoder: nanoGPS-OxyO [11056-94]
- 11056 2Q Nonlinear noise analysis in a long-haul fiber-optic sensing system [11056-96]
- 11056 2R Wafer-level inspection platform on high-volume photonic integrated circuits for drastic reduction of testing time [11056-97]



- 11056 2S Ultra-large dynamic signal detection method based on combined 3x3 optical fiber interferometer [11056-98]
- 11056 2T Comparative analysis of feedback methods in reconstruction algorithms for multiple-scattering holographic tomography [11056-99]
- 11056 2U A conceptual study of infrared and visible-light image fusion methods for three-dimensional object reconstruction [11056-100]
- 11056 2V Study of the non-uniformity of sensitivity distributed over photomultiplier active area influence on the operation of the photometric module for separate x-ray luminous diamond [11056-101]
- 11056 2W Optimization of a geometrical calibration procedure for stereoscopic endoscopy systems [11056-102]
- 11056 2X Optic-electronic system for measurement the position of Millimetron's space telescope segments of main mirror [11056-103]
- 11056 2Y Measurement and calculation of solid-state matrix photomultiplier's polarization parameters [11056-104]
- 11056 2Z Optical laser reflection borometry [11056-105]
- 11056 30 Characterization the effect of acetone gas concentration on polymeric tapered optical fiber sensor [11056-107]
- 11056 31 Spectrally-resolved white-light phase-shifted interferometry for 3D measurements of multilayer films [11056-108]
- 11056 32 Optical methods of on-line diagnostics of processes of the Nickel alloy powder consolidation in the layer-by-layer laser melting technology [11056-109]
- 11056 33 Optical method of on-line temperature monitoring on the melt surface in laser metal deposition technology [11056-110]
- 11056 35 Camera calibration method of optical system for large field measurement of hot forgings in heavy industry [11056-112]
- 11056 36 Original methods of aberration correction in optical systems of autocollimators [11056-113]
- 11056 37 Micro- and nanofabrication technologies using the nanopositioning and nanomeasuring machines [11056-114]
- 11056 38 Removal of monotonically increasing or decreasing phase ambiguity in retrieved phase by Riesz transform method in digital interferometric techniques [11056-115]
- 11056 39 Optoelectronic autocollimator as a tool for monitoring load-carrying structure [11056-117]
- 11056 3A Automatic control system of combustion processes based on the methods of contactless optical spectroscopy [11056-118]

- 11056 3B High-accuracy piston error measurement with a large capture range based on coherent diffraction [11056-119]
- 11056 3D Adaptive optics test bench for predictive wavefront correction [11056-121]
- 11056 3F Reliability results of a fully automated robust x-y stage measurement unit for precise light distribution measurement [11056-123]
- 11056 3G Noise reduction of digital holography using speckle correlation properties in longitudinal direction [11056-124]
- 11056 3H Characterization of thermal absorption and nonlinear absorption in KDP/DKDP crystals with different orientations [11056-125]
- 11056 3I High resolution topography sensors in a multisensor measuring setup [11056-126]
- 11056 3J Measurement of the refractive index of a transparent film using interferometry [11056-127]
- 11056 3K Multi degree-of-freedom position sensing by combination of laser speckle correlation and range-resolved interferometry [11056-128]
- 11056 3L Measuring method and standard system for retroreflective traffic marking's photometric characteristic [11056-129]
- 11056 3M Automatic and accurate full-view registration method for 3D scanning system [11056-130]
- 11056 3N 3D shape measurement in the presence of interreflections by light stripe triangulation with additional geometric constraints [11056-131]
- 11056 3O Analysis of sub-pixel laser spot detection in laser triangulation systems [11056-132]
- 11056 3P Digital holographic microscopy for thickness characterization using synthesized partially coherent holograms [11056-133]
- 11056 3Q Nonlocal means variants filtering methods for speckle noise reduction in digital speckle pattern interferometric fringes [11056-134]
- 11056 3R Polarization analysis of the object wave using FMCW-digital holography [11056-135]
- 11056 3S A hybrid method for velocity field of fluid flow estimation based on optical flow [11056-136]
- 11056 3T Interferometer for large convex optical aspheric surfaces testing [11056-137]
- 11056 3U A demodulation method with high stability for interferometric type vector fiber hydrophone [11056-138]
- 11056 3V Determination of paraxial focal length of lens using Strehl definition measurement [11056-139]

- 11056 3W Contactless optical spectroscopy methods in the tasks of monitoring physical and technological processes in extreme conditions [11056-140]
- 11056 3X Experimental light scattering by optical fibers: system design and testing [11056-141]
- 11056 3Z Direct monochromatic optic control system of the thickness of thin-film interference coatings applied in vacuum [11056-143]
- 11056 40 Development of absolute angular encoder design on coordinate photodetectors [11056-144]
- 11056 41 Adaptive windowed Fourier transform filtering method for speckle fringe patterns [11056-145]
- 11056 42 Coordinate mapping of the primary mirror vertex in a space telescope by using a CGH and theodolites [11056-146]
- 11056 43 A new method for measuring target reflectivity [11056-147]
- 11056 44 Highly repetitive low-coherence interferometry with time-stretch technique [11056-148]
- 11056 45 Contrast determination in phase-shifting algorithms for interferograms with arbitrary steps and additive noise [11056-149]
- 11056 46 Two-shot fringe pattern phase demodulation using the extreme value of interference with Hilbert-Huang per-filtering [11056-151]
- 11056 47 High resolution measurement of freeform wavefront by using self-imaging based sensor [11056-152]
- 11056 48 Development of an illumination module for stroboscopic phase-shift interferometry on MEMS devices [11056-153]
- 11056 49 Sensitivity of an image-plane digital holography interferometer for the measurement of pile-up [11056-154]
- 11056 4A Measurement system of characteristics of compensation devices by the autocollimation method [11056-155]
- 11056 4B Freeform optics alignment strategy and its effect on development of precision freeform optics [11056-156]
- 11056 4C Application of immersion method for measuring freeform surfaces [11056-160]