## PROCEEDINGS OF SPIE

# Optical Measurement Systems for Industrial Inspection XII

Peter Lehmann Wolfgang Osten Armando Albertazzi Gonçalves Jr. Editors

21–25 June 2021 Online Only, Germany

Sponsored by SPIE

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

Published by SPIE

**Volume 11782** 

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 SPIEDigitalLibrary.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 XII*, edited by Peter Lehmann, Wolfgang Osten, Armando Albertazzi Gonçalves Jr., Proc. of SPIE 11782, Seven-digit Article CID Number (DD/MM/YYYY); (DOI URL).

ISSN: 0277-786X

ISSN: 1996-756X (electronic)

ISBN: 9781510643987

ISBN: 9781510643994 (electronic)

Published by

SPIE

P.O. Box 10, Bellingham, Washington 98227-0010 USA Telephone +1 360 676 3290 (Pacific Time)

SPIE.org

Copyright © 2021 Society of Photo-Optical Instrumentation Engineers (SPIE).

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 fees. To obtain permission to use and share articles in this volume, visit Copyright Clearance Center at 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.

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.



**Paper Numbering:** A unique citation identifier (CID) number is assigned to each article in the Proceedings of SPIE 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

ix	Introduction
	SPECIAL FOCUS: KEYNOTE SESSION II
11782 03	Tomography imaging based on three-color digital holography [11782-14]
	IN-PROCESS AND IN-SITU MEASUREMENT
11782 05	Speckle photographic in-process measurement of three-dimensional deformations in running manufacturing processes [11782-1]
11782 06	Intelligent quality monitoring for additive manufactured surfaces by machine learning and light scattering [11782-2]
	HIGH-SPEED TECHNOLOGIES
11782 09	Digital holography as a tool for high-speed high-precision 3D-measurements for industrial applications [11782-5]
11782 0A	High-speed electronic speckle pattern interferometry for analysis of thermo-mechanical behavior of electronic components [11782-6]
11782 OB	Critical imaging parameters in time resolved digital image correlation (TRDIC): effect of optical blur during drop test on composite structures [11782-7]
	DISPLACEMENT, DEFORMATION, AND VIBRATION MEASUREMENT
11782 OD	Speckle pattern modulation for high-resolution displacement measurements [11782-9]
11782 OE	Analyzing real-time capability of raw laser-Doppler vibrometer signal combination for signal diversity [11782-10]
11782 0G	Speckle simulation tool for the design of laser-based displacement sensors [11782-13]

#### DIGITAL HOLOGRAPHY

	DIGITAL HOLOGRAFITI
11782 OH	Low-coherence digital holography for long-range object profilometer using double multi-reflection reference mirrors [11782-15]
11782 OI	In-situ laser beam melting investigation with multi-wavelength digital holography [11782-16]
11782 OJ	Holographic fingerprint as a morphological marker to identify micro-plastics [11782-17]
11782 OK	Volume phase holographic grating based digital holographic interferometer for measurement of temperature distribution and temperature fluctuations in diffusion flames [11782-18]
	MEASUREMENT UNCERTAINTY AND MATERIAL MEASURES IN 3D MICROSCOPY
11782 OM	Towards a continuous frequency band chirp material measure for surface topography measuring instrument calibration [11782-20]
11782 ON	Metrological characteristics of material measures depending on manufacturing parameters in direct laser writing and external stress factors [11782-21]
	3D MICROSCOPY
11782 00	Fast and robust diffraction based overlay metrology using dark-field digital holographic microscopy [11782-22]
11782 OP	Compensating aberration induced error in differential confocal microscopy [11782-23]
11782 0Q	Metrological characterization of different methods for recovering the optically sectioned image by means of structured light [11782-24]
11782 OR	Analysis of resolution enhancement through microsphere-assisted interferometry in the 3D spatial frequency domain [11782-25]
11782 OT	Spatial-frequency domain representation of interferogram formation in coherence scanning interferometry [11782-27]
	NONDESTRUCTIVE TESTING
11782 OU	Angstrom-accuracy multilayer thickness determination using optical metrology and machine learning [11782-28]
11782 OV	Spatially modulated thermal excitations for shearography non-destructive inspection of thick composites [11782-29]

### INTERFEROMETRIC TECHNIQUES 11782 0X Advanced technology for the fabrication of optical microstructures and their interferometric characterization [11782-31] 11782 OY Adaptation of classical interferometry for measuring expansion coefficients of thin materials [11782-32] MEASUREMENT/CHARACTERIZATION OF OPTICAL COMPONENTS AND SYSTEMS 11782 11 Time resolved characterization of stray light [11782-37] NOVEL SENSOR AND SENSOR CHARACTERIZATION I 11782 12 Light scattering by gold nanoparticles cured in optical adhesive at optical fibre interfaces [11782-38] 11782 13 Measurement accuracy and practical assessment of the lidar camera Intel RealSense L515 [11782-39] 11782 14 Ensemble cross-correlation for image retrieval from the intensity signal recorded by a single **pixel** [11782-40] **NOVEL SENSOR AND SENSOR CHARACTERIZATION II** 11782 15 On the development of a flexible borescope fringe projection system [11782-41] 11782 16 Roundness measurement with deflectometry: principles and first results [11782-42] 11782 18 Robust and sub-pixel accurate wavelet-based segmentation of laser lines formed by lenticular lenses [11782-44] 11782 19 On inherent spatio-spectral image distortion in AOTF-based imagers [11782-45] 11782 1A Recovering defect distributions from reduced-area bright-field wafer inspections [11782-91] FRINGE PROJECTION, STRUCTURED LIGHT, TRIANGULATION, AND PHOTOGRAMMETRY Three-dimensional measurement using a shape from focus method applied on a context of 11782 1B

Evaluating and propagating uncertainty in digital fringe projection systems [11782-47]

structured light profilometry [11782-46]

11782 1C

11782 1D	Impact of multireflections on measurement accuracy in the endoscopic 3D reconstruction of gearing geometries $[11782\text{-}48]$
11782 1G	Accuracy assessment of optical 3D measurements in hydrodynamic tunnel [11782-51]
	POSTER SESSION: INTERFEROMETRIC TECHNIQUES
11782 1H	Uncertainty evaluation of a 300-mm-aperture vertical Fizeau interferometer [11782-52]
11782 11	Remote sensing catadioptric telescope corrector lens design for facilitating measurement of center thickness and air gaps of inner lenses using low-coherence interferometry [11782-53]
11782 1J	Fizeau interferometer with double interference cavity for suppressing errors from vibration and air turbulence [11782-54]
11782 1K	Two-step iterative algorithm immune to tilt shifts for phase extraction [11782-55]
11782 1M	Optical parameter measurement of parallel plates based on weighted multi-step phase-shifting algorithm $[11782-60]$
11782 1N	Measure PI film topography by laser confocal microscope [11782-92]
	DOCTED SESSION DIGITAL HOLOGRAPHY
	POSTER SESSION: DIGITAL HOLOGRAPHY
11782 1P	Microscopic height measurements on moving objects with digital holography [11782-61]
11782 1Q	Combined data from digital and classical holographic recording provides insight on early stages of strain soliton formation [11782-62]
11782 1R	Digital holographic measurement system for use on multi-axis systems [11782-63]
	POSTER SESSION: LIGHT SCATTERING AND SPECKLE TECHNIQUES
11782 1\$	Surface roughness measurement using the generalized Harvey-Shack scattering theory and the K-correlation model [11782-64]
11782 1T	Electro-optical measuring system for investigating the reflection-supressing properties of novel nanosurfaces [11782-65]
11782 1U	Recognition of small areas of activity by the pointwise intensity-based dynamic speckle analysis [11782-66]

	POSTER SESSION: 3D IMAGING AND SHAPE MEASUREMENT
11782 1W	A parallel memory efficient outlier detection algorithm for large unstructured point clouds [11782-68]
11782 1Y	Algorithm for the automated analysis of the shape of objects located on the cutting table of industrial robotic systems $[11782-70]$
	POSTER SESSION: DEFORMATION MEASUREMENT AND NONDESTRUCTIVE TESTING
11782 21	Optical flow tracking of the intensity barycenter position in a frame sequence recorded during a tensile test to establish the XY-plane deformation map of a flat 3D printed sample [11782-73]
11782 25	Optic-electronic autocollimation system for measuring line and angular deformation [11782-77]
	POSTER SESSION: SPECTROSCOPIC TECHNIQUES
11782 2B	Large spot size diffuse reflectance FT-NIR spectral sensor for inhomogeneous samples [11782-84]
	POSTER SESSION: ADVANCED OPTICAL SENSING
11782 2E	Self-learning-based detection via multiple microresonator imaging [11782-87]
11782 2H	Implementation of multi-task learning neural network architectures for robust industrial optical sensing [11782-90]